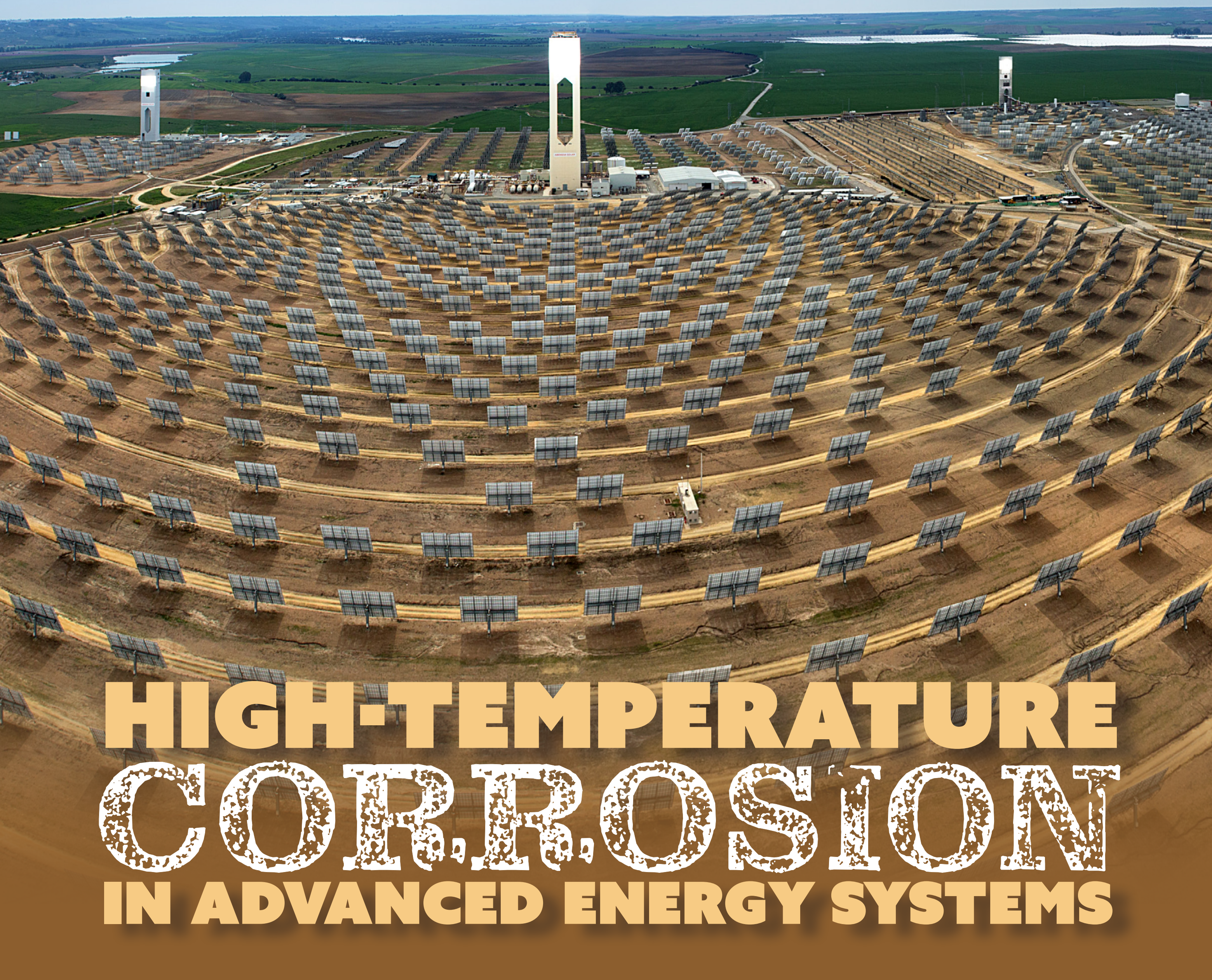
FULL ISSUE (PDF)

High-Temperature Corrosion in Advanced Energy Systems (Summer 2021)

To cite this article: 2021 *Electrochem. Soc. Interface* **30** 1

The Electrochemical Society
INTERFACE™

VOL. 30, NO. 2, Summer 2021



HIGH-TEMPERATURE CORROSION IN ADVANCED ENERGY SYSTEMS

8 Meet the New Society Officers

14 239th ECS Meeting Highlights

10 Up Close with the 2021 Queen Elizabeth Prize for Engineering Recipients

34 A Positive Spin on Corrosion Measurements

The New Normal?

Hopefully, by the time you read this, the world will have turned the corner on the COVID-19 pandemic in reality instead of in press conferences, with the vaccines becoming more and more available, and vaccine hesitancy becoming less and less common. Looking back, I can see how much has changed. Some things will come back, and they will be great, with hugs and handshakes between friends and loved ones being one of my favorites. Masks are a pain in the rear, particularly for those who wear glasses, but having to greet from a distance is something that I will miss even less. Social gatherings will be back, including at in-person conferences (a word from our sponsor: maybe the 240th ECS Meeting in Orlando, October 10-14). I realize more than ever that these meetings are the only time that I see some people, especially those outside my specialty. Catching up over a meal and an adult beverage or two is the best way to spend evenings at the meetings.

Some changes will remain in some form or another. I will never be able to cancel class again; students will expect a pre-recorded version posted online. I expect more routine meetings to be hybrid, making scheduling more straightforward for people with complicated schedules. Although my Zoom skills have a long way to go, I can see how it fills gaps when the intersections of schedules available for in-person meetings is the null set. I expect more conferences will also be hybrid to some extent; the increased access to those who cannot travel, including many students, will be a significant driver to figure out how to make that work financially. As I said in a previous column[1], video conferencing can't fully replace in-person meetings, but it beats not being there at all.

I will be most interested in seeing how much we each return to going into work each day. Although I know a few sick, sick people who enjoy commuting, most of us complain bitterly, even about a piddling 15-minute commute. Technology is at the point where many (although by no means all or even most) found that working at home can be done (this applies only to households with no young children, obviously). The temptation for some companies to reduce their physical footprint will be an irresistible siren song. For many workers, the savings of time and money in commuting will draw more to work at home. The planet will chime in that less commuting means less CO_2 being emitted, so it will vote in favor.

However, I submit that we have to be careful not to put aside the importance of social interactions at work. I have found Zooming with people I know very well is more or less fine, but when I am talking with those I have never met or don't know well, the computer monitor is an almost impenetrable barrier to making connections. These connections not only make work more pleasant, but they are also what we rely on when tensions arise. How organizations handle the returns could shake up those *Best Place to Work* lists. It seems that flexibility connected to accountability is far easier said than done, but those organizations who figure out will be ahead.

The pandemic has also put the value proposition of in-person learning on stronger ground. Those who claim that MOOC (Massive Open Online Courses) and online universities are the way of the future and residential colleges will all go the way of the dinosaurs will be deeply disappointed. Students cannot fully enjoy watching their grumpy professor struggle with technology remotely. That flailing is the kind of authentic entertainment students cannot get on Netflix. I suspect college's social aspects may have a minor influence on the students' desire to return to campus. With remote learning, it is impossible for an instructor to see for themselves which students are getting it, which are struggling, but want to understand it, and which are on Instagram. Empathy is much easier to give when the person is sitting across from you than through a computer screen (not that I am very empathetic, but I know people who are). Many knew the criticality of in-person education in their bones, but the past year should have provided all the evidence needed for any doubters. Here's hoping that we get together in Orlando. Get your Mickey Mouse ears ready. Until next time, be safe and happy.

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[1]The Electrochemical Society *Interface*, Vol. 28, No. 4.

The Electrochemical Society
INTERFACE

Published by:
The Electrochemical Society (ECS)
65 South Main Street
Pennington, NJ 08534-2839, USA
Tel 609.737.1902, Fax 609.737.2743
www.electrochem.org

Canada Post:
Publications Mail Agreement #40612608
Canada Returns to be sent to:
Pitney Bowes International, P.O. Box 25542, London, ON N6C 6B2

ISSN : Print: 1064-8208 Online: 1944-8783

The Electrochemical Society *Interface* is published quarterly by The Electrochemical Society (ECS), at 65 South Main Street, Pennington, NJ 08534-2839 USA. Subscription to members is part of membership service; subscription to nonmembers is available; see the ECS website. Single copies $10.00 to members; $19.00 to nonmembers.

Periodicals postage paid at Pennington, New Jersey, and at additional mailing offices. POSTMASTER: Send address changes to The Electrochemical Society, 65 South Main Street, Pennington, NJ 08534-2839.

The Electrochemical Society is an educational, nonprofit 501(c)(3) organization with more than 8,500 scientists and engineers in over 75 countries worldwide who hold individual membership. Founded in 1902, the Society has a long tradition in advancing the theory and practice of electrochemical and solid state science by dissemination of information through its publications and international meetings.

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The Electrochemical Society
INTERFACE™

Vol. 30, No. 2
Summer 2021

ECS

55 **High-Temperature Corrosion in Advanced Energy Systems**
by Dev Chidambaram

57 **Corrosion in Advanced Nuclear Reactors**
by Gary S. Was and Todd R. Allen

63 **Corrosion in Molten Salts for Solar Thermal Power**
by Kodi Summers and Dev Chidambaram

67 **High-Temperature Compatibility of Structural Alloys with Supercritical and Subcritical CO_2**
by Bruce A. Pint

73 **Corrosion by Hot CO_2 Gases**
by David J. Young and Jianqiang Zhang

79 **Perseverance Rover Lands on Mars**
by E. Jennings Taylor and Gregory S. Jackson

3 From the Editor: The New Normal?

7 From the President: The Return to "Normal" Must Be a Call to Action

8 Meet the New 2021 Society Officers

10 Nakamura, Craford, and Dupuis on the 2021 QEPrize for Engineering

12 Journal Patent Citations

14 239th ECS Meeting with IMCS 18 Digital Meeting Highlights

18 Society News

34 The Chalkboard: A Positive Spin on Corrosion Measurements: The Rotating Ring-Disk Electrode

38 People News

47 Looking at Patent Law

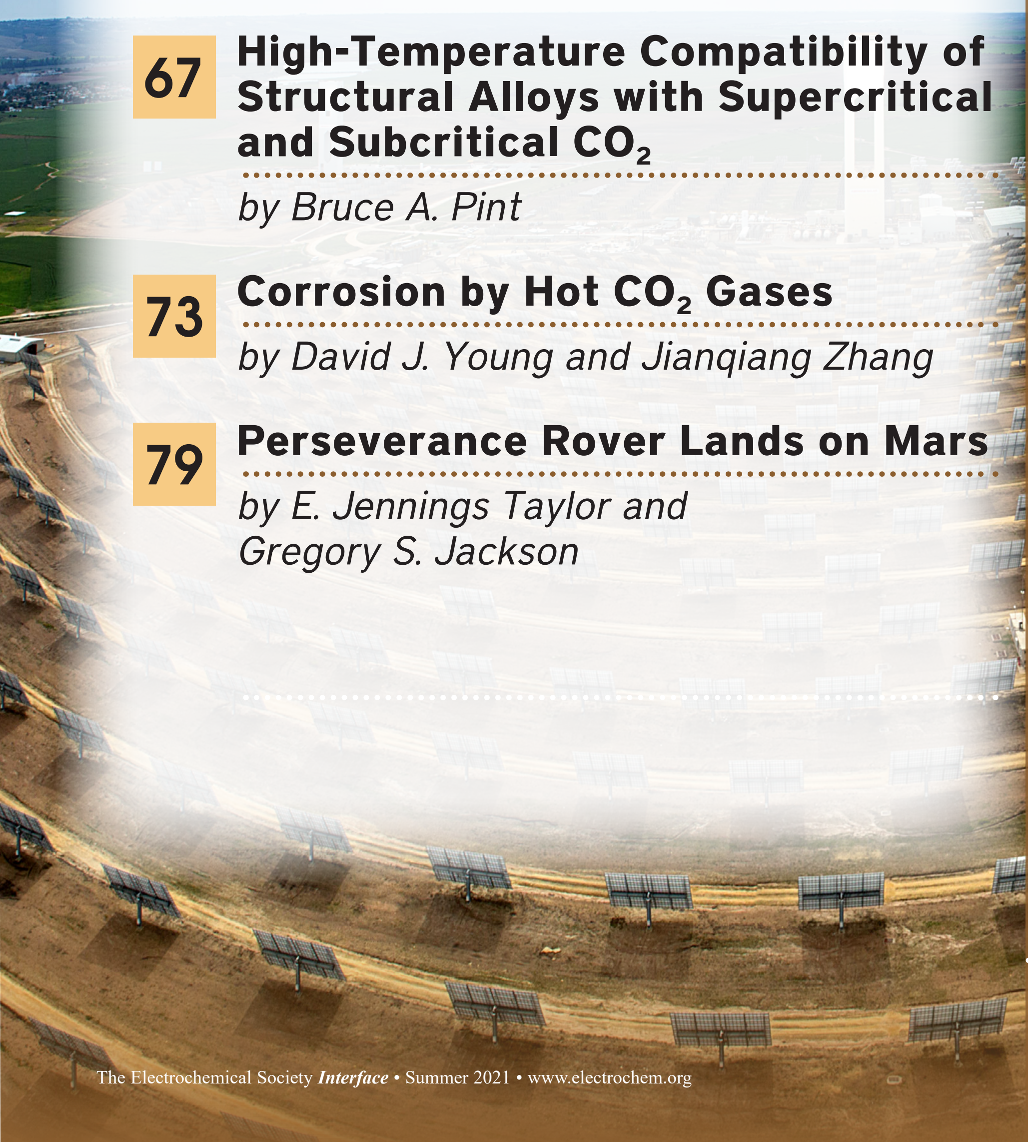
53 Tech Highlights

81 Section News

84 Awards Program

86 New Members

89 Student News



On the Cover: The Solucar solar platform built by Abengoa. Sunlight is focused onto a central tower where a salt mixture, often heated to >550°C, acts as the heat transfer medium.

Cover design by Dinia Agrawala.

The Return to "Normal" Must Be a Call to Action

2020 is a year that will live in infamy. The global pandemic has disrupted the lives and livelihood of almost everyone on the planet, and worse yet, killed millions. Thanks to science, death rates have dropped, and vaccines have been found that will slow and hopefully end the spread of this horrible disease. Life will return to "normal;" but what will that new "normal" be? I look forward to finally seeing my colleagues in person, in Orlando, at the 240th ECS Meeting this fall, but assume that in this new "normal" there will be a virtual component and some level of "distancing."

COVID-19's only positive impact was the reduction of air pollution and the emission of greenhouse gases (GHGs) as businesses went on extended shutdowns and we worked more from home. Unfortunately, as we come out of this pandemic, the resultant increase in economic activity will invariably result in greater GHG and other pollutant emissions. Under current business-as-usual policies, this a recipe for global disaster.

We live in a rapidly changing world with major societal issues, such as the availability of affordable and sustainable energy, clean water and air, food, and in this last year especially, health. The solutions to these issues are at the nexus of science and technology. Unfortunately, politicians don't always listen to scientists and engineers. More and more policies appear to be influenced by people with low regard for science and even conspiracy theorists.

The ECS community—made up of our members, volunteers, supporters, and staff—is uniquely positioned to use its voice and expertise to ensure that the contributions science makes to society are understood and valued, that policy decisions are grounded in scientific fact, and that our government funds scientific research. For more information on what you can do, visit Advocating for Science.

Wearing a mask and social distancing under the current pandemic, while an inconvenience, should be a societal norm and not a political issue. Vaccines are our best hope to move past this pandemic—not a conspiracy by the pharmaceutical industry. Climate change, one of the greatest challenges facing this planet, is real and not a conspiracy by left-wing anarchists to take our freedoms away.

Therefore, in this new "normal," I believe we need a Call to Action to not only *Free the Science* but advocate for it. Describe the wonders of science to your children; explain its positive impacts to your friends and neighbors; and also engage in policy-setting discussions. We are not policymakers, but we should make every effort to ensure that policymakers base their decisions utilizing the best available science.

Moreover, while ECS is not a political organization and will not take a political stance, it should, as part of its vision and in service to its membership, advocate for the use of the best available scientific knowledge in the development of government and industry policy, and funding of electrochemical science. As the President of ECS, I take that as my personal Call to Action and hope you join me in this endeavor.

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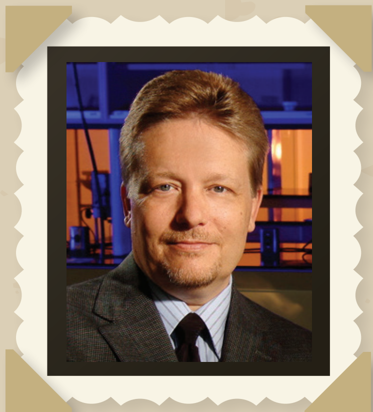
Meet the New 2021 Society Officers

On June 11, the newly elected officers of The Electrochemical Society assumed their posts. We are pleased to welcome Eric D. Wachsman as President and Colm O'Dwyer as 3rd Vice President, joining Executive Committee members Turgut Gür, Senior Vice President; Gerardine Botte, 2nd Vice President; Marca Doeff, Secretary; and Gessie Brisard, Treasurer.

2021-2022



Eric D. Wachsman, ECS President

Eric D. Wachsman

Eric D. Wachsman received his PhD in Materials Science from Stanford University in 1990, and MS and BS degrees in Chemical Engineering from Stanford and the University of California at Berkeley, respectively. Currently, he is Director of the Maryland Energy Innovation Institute and Crentz Centennial Chair in Energy Research with appointments in both the Materials Science and Chemical Engineering Departments at the University of Maryland. He contributed to the next generation of electrochemists by graduating 34 PhD and 30 MS students, supervising 38 postdocs and research scientists, and mentoring several junior faculty, three of whom went on to receive ECS awards. His research focuses on solid ion-conducting materials and electrocatalysts, including the development of solid state batteries, solid oxide fuel cells, and electrolysis cells, ion-transport membranes, and solid state gas sensors, with over 270 publications and 35 patents/patent applications. To date, three companies have been founded based on these technologies.

Eric joined ECS as a graduate student in 1989 to present a paper in the first International Symposia on Solid Oxide Fuel Cells (SOFC-I). He became active quickly in ECS, organizing 16 symposia (he is currently lead organizer for SOFC-XVII, July 2021), and serving on numerous ECS committees. Eric served on the ECS Board of Directors in 2006-2007, then continuously from 2013 through today. A Fellow of The Electrochemical Society (2008), he received the ECS High-Temperature Energy, Materials, & Processes Division Outstanding Achievement Award (2012) and Carl Wagner Memorial Award (2017).

When not engaged in his myriad professional and academic pursuits, you can find Eric doing what he loves and does best: spending time with his wife Nelpe, children David and Natalie, and friends whenever and wherever he can, whether it's right in the neighborhood or anywhere around the world!

As President, Eric will work to not only advance the science and technologies to which he has devoted his professional life, but also to expand the Society's participation in addressing major societal issues. As he mentioned in his candidate's statement, "We need to not only *Free the Science*, but partner with our sister societies to *Stand Up for Science*. We are not policymakers, but we should make every effort to ensure that policymakers base their decisions utilizing the best available science." With his experience and passion, Eric will no doubt make contributions to ECS and its community that have positive impact far beyond his term as President!

Eric and Natalie at the neighborhood Easter Egg Roll, hosted at the White House by the Obamas.
Photo: Eric D. Wachsman

Natalie and David Wachsman during a family tour of Venice.
Photo: Eric D. Wachsman

Time for friends and family during PRiME 2016.
Photo: Eric D. Wachsman

Colm O'Dwyer,
3rd Vice President

Colm O'Dwyer

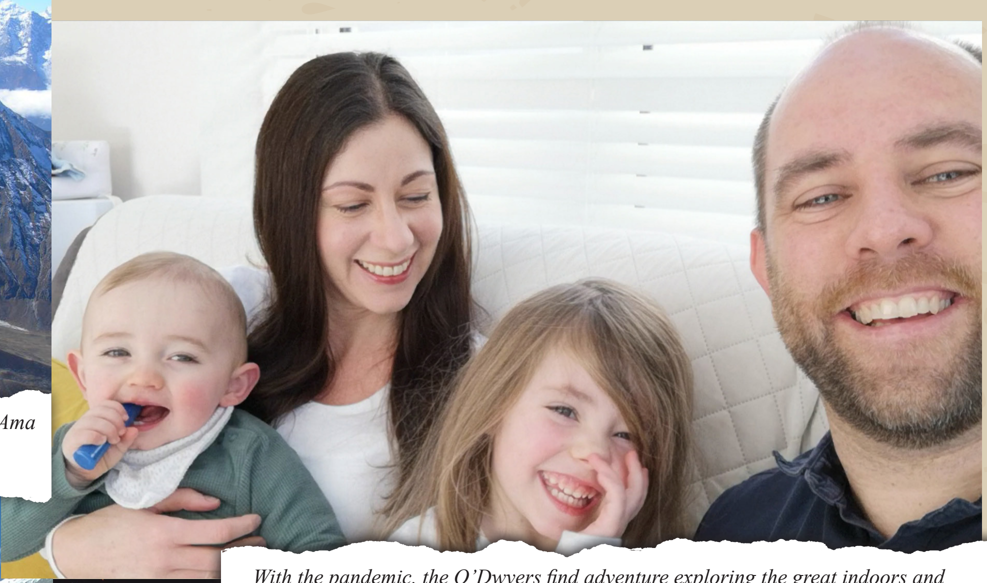
Colm O'Dwyer is Professor of Chemical Energy in the School of Chemistry at University College Cork (UCC), Ireland, and Principal Investigator at Tyndall National Institute, the Environmental Research Institute, and Advanced Materials and BioEngineering Research Centre. He received his PhD with Prof. D. Noel Buckley in 2003 on semiconductor electrochemistry and physics. His postdoctoral research was conducted on ultra-cold atom cooling and surface science in Toulouse, France. Colm has been a Science Foundation Ireland Stokes Lecturer on Nanomaterials since 2008. His multidisciplinary research group, founded at UCC in 2012, develops 3D printed batteries, energy storage materials, optoelectronic materials and processes, and photonic structures.

Over the years, with talented students, postdocs, and collaborators, Colm has coauthored over 230 peer-reviewed articles (27 in JES and JSS), numerous book chapters, and 60 *ECS Transactions* articles, covering most of the Society's technical interest areas.

An active ECS member since 2001, Colm has served ECS continuously in many roles. He organized or co-organized over 35 ECS symposia on electrochemical and solid state topics since 2007, and through the Interdisciplinary Science and Technology Subcommittee, helped deliver new mega symposia across several ECS divisions. An Executive Committee Member of the Electronics and Photonics Division for over 12 years, he was recently named 1st Vice Chair and then Division Chair. He served on several key ECS committees and as a member of the Board of Directors. An award-winning advocate of open access publication, he guest edited four special Focus Issues for JES and JSS on semiconductor electrochemistry, thermoelectrics, and 2D materials and devices.

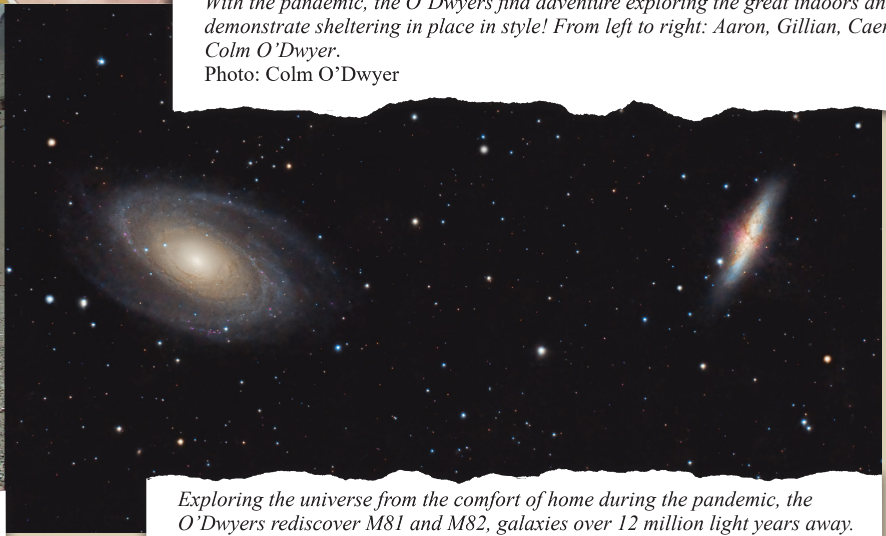
In his personal life, Colm is an avid climber and outdoorsman who can be found trekking the globe in search of adventure and the chance to, as he puts it, "pare things down to bare essentials for several weeks in amazing parts of the world."

The view from Colm's high camp, Ama Dablam, Nepal.
Photo: Colm O'Dwyer



With the pandemic, the O'Dwyers find adventure exploring the great indoors and demonstrate sheltering in place in style! From left to right: Aaron, Gillian, Caera, and Colm O'Dwyer.
Photo: Colm O'Dwyer

Colm hiking in the Vacas Valley, Aconcagua, Argentina.
Photo: Colm O'Dwyer



Exploring the universe from the comfort of home during the pandemic, the O'Dwyers rediscover M81 and M82, galaxies over 12 million light years away.
Photo: Colm O'Dwyer

NAKAMURA, CRAFORD, AND DUPUIS ON THE 2021 QEPRIZE FOR ENGINEERING

by Frances Chaves

**All photos used with permission of the Queen Elizabeth Prize.*

The Queen Elizabeth Prize for Engineering trophy was created by HANNAH GOLDSMITH.

ISAMU AKASAKI, SHUJI NAKAMURA, NICK HOLONYAK, JR., M. GEORGE CRAFORD, and **RUSSELL DUPUIS** received the 2021 Queen Elizabeth Prize for Engineering (QEPrize) "for the creation and development of LED lighting, which forms the basis of all solid state lighting technology… They are recognized not only for the global impact of LED and solid state lighting but also for the tremendous contribution the technology has made, and will continue to make, to reducing energy consumption and addressing climate change." [2]

The prize recipients interacted with ECS throughout their careers, publishing much of their critical research in Society journals. In February, ECS was privileged to interview Dr. Dupuis, Dr. Craford, and Dr. Nakamura, shortly after the announcement that they had won the Queen Elizabeth Prize with Dr. Nick Holonyak, Jr., and Dr. Isamu Akasaki.

QEPRIZE BOOSTS ENGINEERING

Dr. Craford: Receiving the prize is a great honor. It's important that it's given for engineering which tends to be somewhat neglected. Fewer people are going into engineering in the U.S. because it's difficult. You have to enjoy science and math and be willing to take a lot of courses in the engineering field. They're tough, so people seem to be deflecting to other fields. The number of engineers is smaller than everyone connected with the field would like. The hope is that an award like this helps attract engineers to the field, because we certainly need them.

Dr. Dupuis: I hope that more young people see this prize and think about what lighting has done for them and their future, and say they want to be involved in something like this for society. We all believe that engineering is the key to making our lives better and saving our planet, whether you're talking about energy conservation or medicine. The medicines that have come out of the COVID-19 pandemic are possible because of engineering tools that have been developed. With all due respect to chemists and their beakers, this stuff isn't made by chemists and beakers. It's made by engineers and distributed by airplanes with jet engines and soon, autonomous trucks. While fundamental physics, chemistry, and science are the underpinning, getting it done, and getting it to a hundred billion people is an engineering challenge. And those problems need more trained engineers of all kinds. Because we are not the only beneficiaries. If we can improve our energy efficiency, all the animals that are in the sea or on earth, that need trees to live in and vegetation to eat, benefit also. It's not just people; it's the whole earth ecosphere.

Dr. Nakamura: This is engineering's most prestigious award. This year it's a group prize. Drs. Akasaki, Holonyak, Jr., Craford, and Dupuis are my colleagues; they are like friends. It is very enjoyable to share the prize with my friends.

MORE FUNDING, PLEASE

Dr. Nakamura: Funding is critical in this field. We want to do many kinds of research but we can't due to limited funding. We can't hire more students. So we focus on one big project. We collaborate with industry, which asks us to tackle a critical problem. But without enough students, we can't deliver. We need to all address the fundraising problem, which is hard in our field.

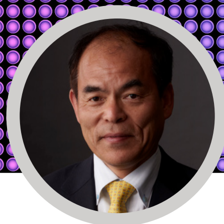
Dr. Dupuis: And the equipment is expensive! We have new ideas, but implementing them, from the point of view of human resources, students, and facilities and equipment, is a challenge. Having consistent funding at a necessary level is critical. This is such an important field for the future; more investment should be made. However, resources in the U.S. get stretched across many different platforms. I hope that we can maintain this area because there are other players and countries in this space. If we're not careful, products and jobs are going to be somewhere else.

Dr. Craford: I've been in industry, which has its own funding. We have to stay within the R&D budget while trying to make a profit. If profits are good, it's easier to get your budget increased or to keep it the same. If they go down, it's not. I was only pressured once to try and get government funding. It was a challenge that we negotiated successfully, but not something I really cared for. However, we sometimes chose to take a government contract if we thought our technology would help the government meet its goals and help us develop better products. We could work with other labs or universities, each bringing a different set of skills to the project. The government is a networking mechanism, which is helpful. Some large government contracts still seem to be offered. However, there is a lot of competition.

QUEEN ELIZABETH PRIZE FOR ENGINEERING

The Queen Elizabeth Prize for Engineering (QEPrize) recognizes groundbreaking innovation in engineering that has benefitted humanity. Since first awarded in 2013, the prize has been bestowed biannually. Recipients receive a total £1 million prize and a trophy, designed by Hannah Goldsmith, a British 20-year-old design student who won the 2021 Create the Trophy competition. Nominations for the prize are sought from the public; self-nominations and posthumous nominations are not accepted. The Queen Elizabeth Prize for Engineering Foundation administers the prize. An international judging panel of distinguished leaders in a range of engineering disciplines is chosen by the foundation trustees to select the prize recipient(s). The foundation receives funding from BAE Systems, BP, GlaxoSmithKline, Hitachi, Jaguar Land Rover, National Grid, Nissan Motor Corporation, Shell UK Ltd, Siemens UK, Sony, Tata Steel Europe, Tata Consultancy Services, and Toshiba. The foundation also runs the QEPrize Ambassador Network, which "brings together the best and brightest early career engineers from all fields around the world, who work to inspire the next generation to follow in their footsteps."[1]

Dr. Isamu Akasaki*



Dr. Shuji Nakamura*

Dr. Nick Holonyak, Jr.*

Dr. M. George Craford*

Dr. Russell Dupuis*

MENTORS (LIKE NICK) MAKE THE DIFFERENCE

Dr. Craford: Getting Nick [Nick Halonyak, Jr., co-QEPrize recipient] as a mentor was clearly one of the, if not *the,* life-changing event for me. I was trained as a physicist and have a physics degree, but I was working on a thesis in low-temperature physics. Nick gave a lecture shortly after arriving in Illinois. Nick had a nitrogen dewar. He took this little red thing, a speck of light that you could only see if you were in the front three rows, and stuck it in the dewar. The whole dewar lit up and glowed. It really worked! Nick's work was revolutionary. I decided immediately that's what I want to do if I can have him as an advisor. I managed to transition away from low-temperature physics. I've been working on LEDs and LED materials for over 50 years now. Nick is very dynamic and approachable. He's very good in the lab and works all the time with students. He was also great at selecting thesis topics that were important, interesting, and challenging, but not directly head-to-head with Bell Labs, etc. Somehow Nick stayed ahead. We worked on the cutting edge, interesting stuff. I don't remember anyone having a problem publishing. He's really good.

Dr. Dupuis: I was in chemical engineering, but hadn't chosen a field. When I got into Nick's undergraduate class that was the most interesting thing I had seen. So I took a second class and it kept getting more interesting. Nick was in the lab every day; he ate his lunch there; he made samples; he etched crystals. He was always involved in the ideas, helping students get over problems or get through difficulties. At some point, the students started training each other. Nick worked as a team. We had a rookie system; the older students trained the younger ones. It was good training for industry or lab work because you already knew how teams worked.

Dr. Craford: I appreciated how Nick mentored. He told me I was ready and had enough data to write a thesis. I asked, "When do you want me to start?" He said, "Now." "When should I get you something to review?" He answered, "Tonight or tomorrow would be good." When you turned a paper or anything in to Nick, usually a few pages at a time, it came back the next day, marked up and read. He had the science; he had the punctuation; he had everything. You knew that he was involved. He was really supportive. You got feedback, you got it fast, and it was good feedback.

Dr. Dupuis: It would be read and red. He "marked" it quickly. Nick was involved in the research and being in the lab. In the lab, we did a lot as a team—changing gas cylinders and bubblers, fixing heaters, replacing pumps. Students appreciated it.

Dr. Nakamura: Mentors are very important. All kinds of students come to me. I have about 20 working for me now. Some are great; others aren't. It's human nature that all kinds of students exist, and that's okay. The ones who don't work hard get bad grades. However, I work to graduate them all because we don't know which students will do great work in the future. As mentors, we work hard and watch over the high and low achievers through the difficult five to six years it takes to graduate. Say out of 10 students there are only one or two who are bad. I talk with those students, identifying and sharing with them the problems in their work. We provide incentives to help them overcome those problems. Graduating is a big incentive!

2021 QEPRIZE RECIPIENTS AND ECS

2014 Nobel Prize in Physics Laureate **Isamu Akasaki** was an ECS member from 1985 until his death in April 2021. He received the Society's 1999 Gordon E. Moore Medal for Outstanding Achievement in Solid State Science and Technology and was awarded Life Membership in the Society in 2013. Akasaki published multiple papers in the Society's journals.

Fellow 2014 Nobel Prize in Physics Laureate **Shuji Nakamura** is CREE Distinguished Professor, Materials, at the University of California, Santa Barbara. At the 218th ECS Meeting, he delivered the ECS Plenary Lecture reviewing the status of III-nitride based light emitting diodes (LEDs) and laser diodes. Nakamura is a great fan of, and frequent participant at the PRiME meetings in Hawaii.

Nick Holonyak, Jr. is the John Bardeen Endowed Chair Emeritus in Electrical and Computer Engineering and Physics, The Grainger College of Engineering, University of Illinois. He received the 1983 Gordon E. Moore Medal for Outstanding Achievement in Solid State Science and Technology and was awarded Emeritus Membership in the Society in 1998.

M. George Craford is Chief Technology Officer at Philips Lumileds Lighting. He received the ECS Electronics and Photonics Division Award in 1976 and published a paper in the *Journal of The Electrochemical Society* in 1971.

Russell Dupuis is Director of the Center for Compound Semiconductors and Steve W. Chaddick Endowed Chair in Electro-Optics at the Georgia Institute of Technology. A former member of ECS, the ECS Georgia Section, and the ECS Electronics & Photonics Division, Dupuis published five papers in ECST and one in *ECS Electrochemical and Solid-State Letters*. He participated in the 220th ECS Meeting in Boston and 224th ECS Meeting in San Francisco.

GAMBLING, FAILING, TRYING AGAIN

Dr. Nakamura: Young scientists at the university must study to get fundamental knowledge through academics and research. As they become confident, they can work for industry or something. But at a certain point, after getting all the scientific knowledge, they have to gamble because research is a gamble. When I started to do research, maybe 99 percent of scientists selected zinc selenide-based material to develop rarities. But only a few scientists chose gallium nitride-based material to develop rarities. Many said about my research, "You are crazy because gallium nitride crystal quality is terrible, with lots of crystal defects. Zinc selenide is almost a perfect crystal with no crystal defects." But I stuck with gallium nitride. I wanted to publish papers and there were only about three gallium nitride papers a year at that time; there were a thousand papers a year on zinc selenide! So, I gambled. Back then, nobody expected gallium nitride could be used the way it is now. Sometimes you have to go in a different direction. Gambling is a very important starting point.

(continued on page 96)

Journal Patent Citations – A New Paradigm for Journal Quality?

by Daniel L. Parr IV, Christopher J. Jannuzzi, E. Jennings Taylor, and Johna Leddy

In a previous article in *Interface*, various measures of "journal prestige" were discussed.[1] Present metrics of journal impact are based largely on researchers citing the peer-reviewed articles of other researchers that lead to an interwoven network of "forward" and "backward" citations.

Backward citations are the references cited in the original publication and forward citations are articles published subsequently that cite the original publication. Forward citations increase with time as new articles cite a publication while backward citations are set at the time of publication. This network of citations is an evolving framework of assumptions, methods, and approaches that serves as a rubric for a research community to approach and solve problems within a scientific field. The framework both advances and hinders scientific progress.

In his seminal work, *The Structure of Scientific Revolutions*,[2] science philosopher and historian Thomas Kuhn discusses scientific progress and introduces the concept of "paradigms." Paradigms are the scientific perspective held by the majority of researchers in a field. Kuhn argues that established paradigms guide research but also resist the changes in perspective that are the paradigm shifts that catalyze scientific revolutions. The successful application of a paradigm to solve emerging scientific and engineering problems reinforces the paradigm within the research community. This increases the number of researchers advocating the paradigm, which adds to the network of citations. However, with staunch adherence to the established paradigm, the research community may inadvertently tend to discount ideas, publications, and data that do not conform to the paradigm. Consequently, articles that do not conform often remain unpublished or, if published, are often relegated to obscure journals and not cited. Kuhn defined progress made by adherence to paradigms as normal science and noted the unintended consequences of normal science.[3]

> *Normal science does not aim at novelties of fact or theory and when successful, finds none.*

Curiously, this evolving network of citations advances scientific progress by strengthening paradigms while simultaneously inhibiting scientific progress through exclusion of novel ideas. Eventually, the novel ideas cannot be ignored, the paradigm shifts, and a "scientific revolution" occurs. Perhaps a less paradigm-adherent metric of journal quality is found in the patent literature.

Patents and patent applications create their own network of forward and backward citations.[4] During the examination of patent applications, the United States Patent & Trademark Office (USPTO) determines if the subject invention meets the standards for patentability: novelty and non-obviousness.[5,6] Printed documents, such as journal publications, represent an important source of prior art used by the USPTO examiner to access both novelty and non-obviousness.[7] The patent examination process identifies citations that originate from the inventors and citations that originate from the USPTO examiner. This augments the network of forward and backward citations that are documented in issued patents.

The inventors are under the obligation of the "Duty of Candor" to disclose to the USPTO all prior art that is materially relevant to the subject invention and, at the same time, warned not to "bury" the examiner with irrelevant prior art citations.[8] The examiner searches for additional prior art relevant to the patent application in terms of the novelty and non-obviousness of the invention. The examiner does not consider the reputation of the authors of the prior art, the reputation of the journals where the prior art is published, or the reputations of the institutions where the invention originated. The examiner does consider established scientific principles such as thermodynamics, but the examiner does not consider conformity of the prior art to the prevailing paradigms. The network of citations generated by the inventors and examiners during the examination of patent applications offers an unbiased metric to assess the journal impact.

We mined USPTO data to measure how often *J. Electrochem. Soc.* (JES) is cited in patents and patent applications relative to other journals in our technical field.[9] The outcomes are startling. Using patent citation information available from the USPTO,[10] we compared how often each of the 7,279 science and engineering journals codified by the University of British Columbia's Woodward Library[11] was cited in a 9.12-year period. Of the 7,279 journals queried in the USPTO

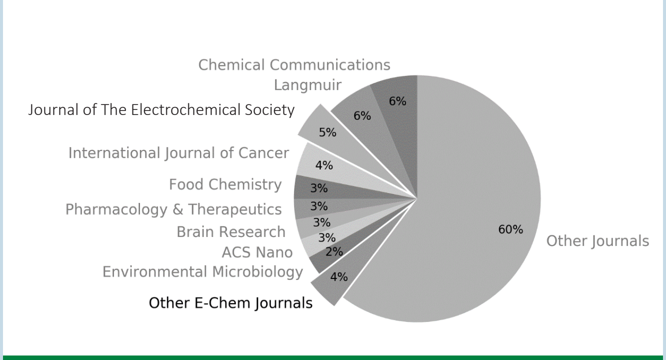


Fig. 1. *Across **all** content domains in the USPTO data, JES received five percent of the citations for the 7,279 journals evaluated. Within the Materials Science and Electrochemistry categories, JES was cited more than all the other electrochemistry journals combined (four percent).*

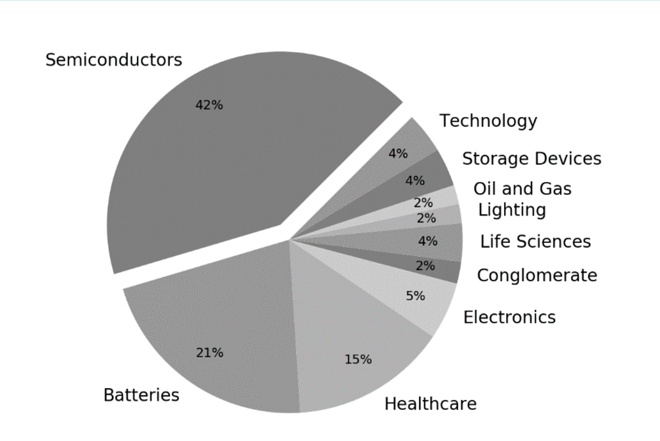


Fig. 2. *The 5,029 citations to JES over 9.12 years, broken down by industry sector.*

database for *all* content domains, five percent of the citations are to *J. Electrochem. Soc.*; see Fig. 1. Furthermore, *J. Electrochem. Soc.* is cited more than all the other journals in the Materials Science and Electrochemistry categories combined. *J. Electrochem. Soc.* is by far the most-cited journal in materials science and electrochemistry in the patent literature. Only *ChemComm* and *Langmuir* were cited more often than *J. Electrochem. Soc.* across all fields.

The frequency with which research published in *J. Electrochem. Soc.* is cited in patent literature, coupled with its long-cited half-life metric, supports the assertion that the Journal's content has both a high degree of utility and a longer period of relevance than similar titles.

Another analysis breaks down the total citations to JES by industry sector. Fig. 2 illustrates the proportion of each industry sector in the total citations. For comparison, USPTO lists 6,587 battery (class 136) patents published during the nine years, of which *J. Electrochem. Soc.* was cited in 1,056 U.S. patents and applications.

Citations of articles published in *J. Electrochem. Soc.* in the patent literature are a measure of journal impact and quality. While there are limitations within the peer review process set by prevailing scientific paradigms, ECS and its publications herald novelty and innovation as evidenced by the preponderance of *J. Electrochem. Soc.* articles found in the network of patent literature citations. Beyond the current factors and half-life metrics that assess the impact of ECS journals, patent citations offer a valuable metric to assess journal impact and quality.

 DOI: 10.1149.2/2.F02212IF.

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9. Period from 01/01/2010 to 02/14/2019.
10. USPTO Patent Full-Text and Image Database,https://patft.uspto.gov/netahtml/PTO/search-adv.htm.
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The 239th ECS Meeting with the 18th International Meeting on Chemical Sensors (IMCS)

From May 30-June 3, 2021, 3,574* people from around the world participated in the online 239th ECS Meeting with the 18th International Meeting on Chemical Sensors (IMCS). This included 2,053 digital participants and 1,521 digital presenters—with 620 of the presenters being students. Participants selected from among 2,497 presentation files, composed of 92 posters, 1,076 slides, and 1,329 videos, covering 1,556 individual presentations. In addition, 49 symposia convened 153 two hour-long live sessions for presenters and participants to engage and exchange ideas.

**as of press time*

ECS Opening Ceremony

ECS Opening Ceremony.

The ECS opening ceremony kicked off the 239th ECS and IMCS 18 digital meetings with a live broadcast streamed around the world. Introductory remarks were given by **Christopher J. Jannuzzi**, ECS CEO and Executive Director, who welcomed event participants and provided an overview of the week ahead. Jannuzzi also thanked ECS Meeting Platinum level sponsors **Gamry Instruments** and **Scribner**, as well as IMCS Platinum level sponsors **National Science Foundation (NSF)** and the **ECS Sensor Division**.

Jannuzzi then welcomed ECS President **Stefan De Gendt**, who gave his opening remarks and reflected on the lead up and planning for this meeting. De Gendt invited IMCS Co-Chair **Peter Hesketh** to give remarks on the IMCS program and partnership with ECS. Other speakers included **Paul Gannon**, the Chair of the High-Temperature Energy, Materials, & Processes (H-TEMP), who looked back on the rich history of the division as they celebrate their centennial in 2021, and ECS President-elect **Eric D. Wachsman**, who looked forward to the future of the society in the coming years.

ECS Plenary Lecture

Jannuzzi introduced **Hiroshi Imahori**, the moderator for the 239th ECS Meeting Plenary Lecture, a highlight of all ECS meetings. Imahori provided a brief biography of the event speaker, **Rodney S. Ruoff**.

Rodney S. Ruoff, Distinguished Professor in the Departments of Chemistry and Materials Science, and the School of Energy Science and Chemical Engineering at the Ulsan National Institute of Science and Technology (UNIST), delivered the 239th ECS Meeting Lecture. In "Nanocarbons, Metal Foils, and...," Ruoff discussed the Center for Multidimensional Carbon Materials' efforts showcasing the range and utility of electrochemistry for basic science: (i) Electrochemical functionalization of single crystal graphene on single crystal Cu(111) foil, and the exquisite control that electrochemistry offers in 'controlling' chemical reactions at the graphene surface; (ii) Formation of what appear to be new forms of carbon in molten salts through electrochemical synthesis; (iii) "Scaled" electrochemical synthesis of a highly branched "polyhydrocarbon" that can be converted to diamond under moderate conditions, and (iv) Electrochemical synthesis of new types of graphite intercalation compounds.

Last, Jannuzzi thanked meeting sponsors and ECS's institutional members for their continued support and commitment.

ECS International Benchmarking of Scientific Status: A DOE BESAC Study

The livestream event showcased preliminary findings of a U.S. Department of Energy's Basic Energy Science Advisory Committee (BESAC) subcommittee conducting an international benchmark study to identify key areas of its mission-relevant research and facility capabilities where U.S. leadership is most challenged.

Committee results included new ways to leverage limited resources and identify incentives to attract and retain scientific talent.

The session included a moderated panel discussion and Q&A with the goal of promoting and facilitating community input for subcommittee representatives' review.

ECS Annual Society Business Meeting and Awards Ceremony

During the Annual Society Business Meeting & Recognition Ceremony, ECS leadership reported on the past year with a focus on the Society's future. Although 2020 was a year filled with challenges, The Electrochemical Society managed to not just survive but also thrive.

The event closed with a celebration of ECS award winners' achievements and recognition of service. Learn more about the award winners in the fall 2021 issue of *Interface*.

ECS Awards and Recognition Highlights

Two Society awards were given during the digital meeting.

The **ECS Allen J. Bard Award in Electrochemical Science** was presented to **Marc Koper**, Leiden University. The award was established in 2013 to recognize distinguished contributions to electrochemical science. Koper's award address, "Electrochemistry of Platinum: New Views on an Old Problem," focused on platinum, the most used electrocatalyst in electrochemical energy conversion devices such as fuel cells and electrolysers. He described his group's recent work on understanding the surface chemistry of platinum in an aqueous electrolyte by combining single-crystal electrochemistry, density functional theory calculations, ultra-high-vacuum modeling, in situ spectroscopy, and in situ electrochemical scanning tunneling microscopy. Koper challenged some existing explanations and interpretations of platinum electrochemistry, and showed the sometimes surprising surface disordering of platinum that happens at both positive (anodic) and negative (cathodic) potentials.

The **ECS Gordon E. Moore Medal for Outstanding Achievement in Solid State Science & Technology** was presented to **Hiroshi Iwai**, National Yang Ming Chiao Tung University and the Tokyo Institute of Technology. The award was established in 1971 as the Solid State Science and Technology Award for distinguished contributions to the field of solid state science and technology. It was renamed in Moore's honor in 2005.

Iwai's award address, "Impact of Micro-/Nano-Electronics, Miniaturization Limit, and Technology Development for the Next 10 Years and After," highlighted the history and development of micro-/nano-electronics which allowed today's smart society to access the internet, artificial intelligence, and more—which would not exist without the invention of micro-/nano-electronics. Iwai considers this to be one of the biggest technological revolutions since that of electronics.

Six division awards were presented through the course of the meeting:

- The Energy Technology Division Research Award was presented to **Bryan Pivovar**, *National Renewable Energy Laboratory* (NREL).
- The Energy Technology Division Supramaniam Srinivasan Young Investigator Award was presented to **Iryna Zenyuk**, *University of California, Irvine*.
- The Energy Technology Division Graduate Student Award sponsored by Bio-Logic was presented to **Charles Wan**, *Massachusetts Institute of Technology*.
- The Industrial Electrochemistry and Electrochemical Engineering Division H. H. Dow Memorial Student Achievement Award was presented to **Akshay Subramaniam**, *University of Washington*.
- The Industrial Electrochemistry and Electrochemical Engineering Division Student Achievement Award was presented to **Eric McShane**, *University of California, Berkeley*.
- The Physical and Analytical Electrochemistry Division David C. Grahame Award was presented to **Bruce Parkinson**, *University of Wyoming*.

Three service recognition awards were presented to past chairs:

- **Marca Doeff**, *ECS Battery Division*
- **Masa Itagaki**, *ECS Corrosion Division*
- **Ajit Khosla**, *ECS Sensor Division*

ECS General Student Poster Session

The General Student Poster Session included 41 posters. The session's award winners are:

1st Place: $1,500 cash award – Joshua Coduto, *University of Iowa*
"An Algorithm for Fitting Tafel Data and Determining Kinetic Parameter"

2nd Place: $1,000 cash award – Claudia Patricia Granja, *Universidad Santiago de Cali*
"Synthesis and Comparative Electrochemical Study of Mixed Metal Oxides Derived from Hydrotalcites Modified with Copper (II) and Nickel (II)"

3rd Place: $500 cash award – Christian D. Haas, *University of Iowa*
"Designing and Implementing a Tailored Alternative Data Analysis Algorithm (TADAA) to Evaluate Quasireversible Heterogeneous Electron Transfer Measurements By Square Wave Voltammetry"

ECS thanks the following individuals who served as judges for the 239th ECS Meeting Z01 General Student Poster Session.

- **Alice Suroviec**, *Berry College*
- **John Flake**, *Louisiana State University*
- **Petr Vanysek**, *Northern Illinois University*
- **Jeffrey Halpern**, *University of New Hampshire*
- **Joshua Gallaway**, *Northeastern University*

IMCS Opening Ceremony

IMCS kicked off their first-ever digital meeting, and event participants were welcomed and provided an overview of the week ahead.

Participants heard from meeting co-chairs about the week's special events and live sessions, and tips on how to take full advantage of the online program.

IMCS Opening Ceremony.

IMCS Plenary Talks

Four of the world's foremost researchers in chemical sensor technology delivered the IMCS plenary talks.

Jong-Heun Lee, Department of Materials Science and Engineering Professor at Korea University, presented "Rational Design of Oxide Chemiresistors for Next-Generation Gas Sensors and Artificial Olfaction." The presentation highlighted how oxide semiconductor chemiresistors have been widely used to detect harmful gases because of their advantages such as high sensitivity, facile integration, and cost effectiveness. However, despite the growth of market demand and technology, Lee says there's still much to improve. To date, various nanostructures with high surface area to volume ratio have been explored to enhance the gas response, and sensing materials have been loaded with noble metal or oxide catalysts for tailoring gas selectivity. Nevertheless, many issues remain unsolved for demand-based design of high performance gas sensors and artificial olfaction, including the detection of ultralow concentrations of analyte gas, highly selective detection of a specific gas, moisture-independent gas sensing, and the establishment of distinctive gas sensing library toward numerous analyte gases as well as complex odors. Lee reviewed suggested new, promising, and general strategies to design sensitive, selective, and reliable chemiresistors for next-generation gas sensors and artificial olfaction.

Lisa Hall, Professor of Analytical Biotechnology and Head of Department in the Department of Chemical Engineering and Biotechnology, University of Cambridge, presented "From Gene to

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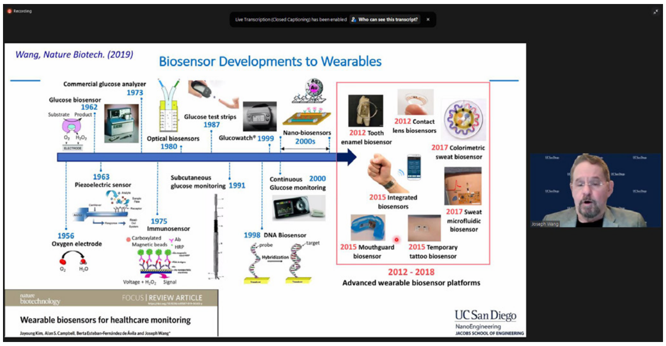
Device: The Route to Diagnostics in Low Resource Countries." Hall discussed how infectious diseases are difficult to diagnose in low-income countries without laboratory testing. As a result, instead of having accurate diagnoses, patient management is more often based on probability and clinical judgment. This means antibiotics are often administered as generic treatment, unfortunately resulting in antibiotic resistance so serious that in some regions half the patients with pneumonia do not respond to first-line antibiotics. Hall and her team have taken the first steps toward providing low-cost diagnostics in resource-poor areas, which could deliver a sustained improvement in healthcare while also developing local economies.

Joseph Wang, SAIC Endowed Chair and Distinguished Professor in the Department of Nanoengineering at the University of California, San Diego, presented "Wearable Sensors for Monitoring Chemical Markers: Beyond Steps and Vitals." He reviewed recent developments in the field of wearable electrochemical sensors for various non-invasive biomedical monitoring applications integrated directly on the epidermis or in the mouth. In particular, Wang highlighted non-invasive monitoring of metabolites and electrolytes using flexible amperometric and potentiometric sensors respectively. Other forms of sensors were also discussed, as well as their current status and future prospects and challenges.



IMCS Plenary Talk by Joseph Wang.

Mark E. Meyerhoff, Philip J. Elving Professor of Chemistry in the Department of Chemistry at the University of Michigan, presented "Electrochemical/Optical Sensors in Medicine: Meeting Needs for the 21st Century." Meyerhoff began with an overview of existing electrochemical/optical sensor technologies that have already made a great impact in medicine. Nevertheless, a number of unmet needs remain in medicine where electrochemical/optical chemical sensing devices could still play important analytical roles. Reviewing the latest research projects occurring at the University of Michigan, he stated, "These gas phase NO generators can potentially replace the use of very high-cost compressed gas cylinders containing NO to provide controlled levels of NO gas on demand for inhalation therapy of patients with pulmonary hypertension (including infants), and for use in the sweep gas of oxygenators to prevent clotting and systemic inflammatory response syndrome (SIRS) in patients undergoing open heart surgery."

IMCS Sponsors and Funders Forum

The IMCS Sponsors and Funders Forum hosted presenters from funding organizations and government agencies. They shared their perspectives on current programs and strategies for securing funding and sustaining research activities on chemical and biosensors at universities and other institutions.

Guest speakers included **Robert Déziel**, Deputy Director for the Natural Sciences and Engineering Research Council of Canada (NSERC); **Christopher M. Hartshorn**, Program Director at the National Cancer Institute (NCI) of the National Institutes of Health (NIH); and **Shekhar Bhansali**, Program Director at the National Science Foundation (NSF).

IMCS Industry Round Table

A range of sensor companies participated in a round table discussion on key steps and barriers to commercializing chemical and biosensors as the field is dynamic, constantly evolving, and one of the easiest to translate into real-world applications, with many commercialization and entrepreneurship opportunities.

IMCS Networking for Young Professionals

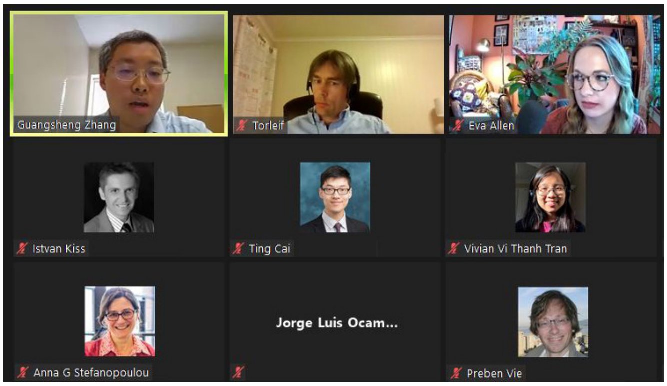
Early career professionals met session chairs, conference organizers, invited speakers, and industry leaders in an informal setting to build networks, establish collaborations, brainstorm new ideas, and find mentors.

IMCS Closing Ceremony

IMCS closed the week by celebrating student presentation award winners, revisiting meeting highlights, and looking ahead to future breakthroughs in chemical sensor technology.

ECS and IMCS Live Topical Sessions

ECS and IMCS hosted a remarkable 153 live topical sessions, which transplanted on-site session rooms into an online environment. Sessions occurred twice daily throughout the meeting, featuring live presentations, question and answer opportunities, topical discussions, and more.



Attendees of ECS's Live Topical Session on "Cell Diagnosis and Failure Detection" gathered digitally to share presentations on the topic followed by two-minute Q&A sessions for each.

Sponsors and Exhibitors

ECS and IMCS applaud the meeting sponsors and exhibitors whose support and participation contributed directly to the meeting's success.

Thank you for developing the tools and equipment driving scientific advancement, sharing your innovations with the electrochemical and solid state communities, and providing generous support for the 239th ECS Meeting with IMCS 18.

239th ECS Meeting – General Meeting Sponsors

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Thank you to our exhibitors and sponsors!

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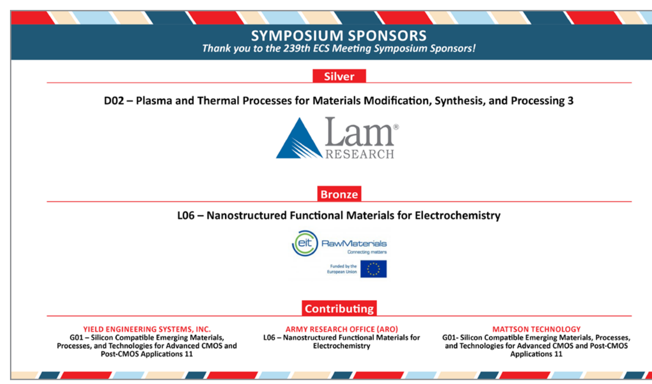
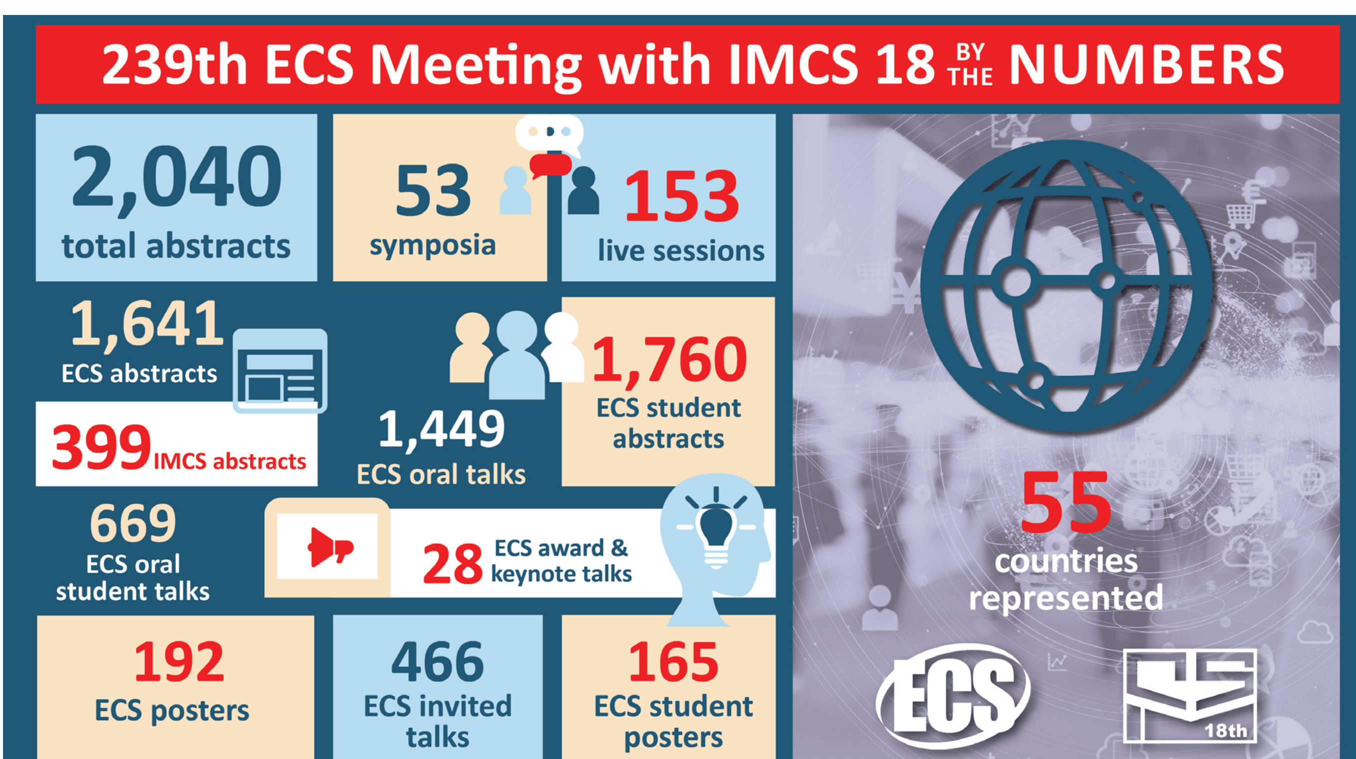
Waterloo Institute for Nanotechnology, University of Waterloo





Publications Update

New Director of Publications

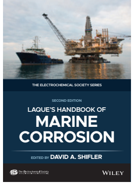
There's big news in the ECS Publications Department. On March 22, **Adrian Plummer** joined the ECS team as our new Director of Publications!

Adrian comes to us from the IEEE where, for the past 5+ years, she has been the Operations Manager for the Engineering in Medicine & Biology Society (EMBS). "Coming from a Society similar in size and scope to ECS, Adrian brings a wealth of technical society leadership experience, a deep understanding of how societies like ours operate, and a steadfast commitment to ECS's vision and mission of leveraging science and technology for the betterment of all," said ECS Executive Director Christopher J. Jannuzzi.

Prior to joining IEEE, Adrian was the Finance & Operations Manager for the New Jersey Coalition for Battered Women (NJCBW), where she worked to promote and support the organizational mission and execution of the strategic plan, appearing before members of the United States Congress and New Jersey State Legislature as a social justice advocate. In addition to her professional experience, Adrian holds an MA in Public Administration & Non-Profit Management from Kean University, a BA in Political Science from Rutgers University – New Brunswick, and a BS in Business Administration & Management from Thomas Edison State College. With such a background, it is easy to see why I am so eager for Adrian to join our team!

Beyond her professional life, Adrian and her husband, Daryn, are the co-founders of the Warrior For Life Scholarship Foundation, an organization dedicated to supporting life-changing scholarships, critically-important community and student programs, and philanthropic community causes for the town of Franklin, NJ, where they live with their children, Lena and Jaxin.

Latest Edition from Wiley



In other publications news, we are excited to announce the upcoming release of *La Que's Handbook on Marine Corrosion, 2nd Edition*, edited by David A. Shifler. Completely rewritten for the 21st century, this new edition reflects current environmental regulations, best practices, materials, and processes, with special emphasis placed on the engineering, behavior, and practical applications of materials.

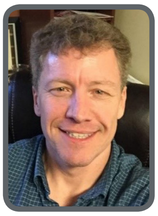
Interface Online

INTERFACE

Finally, to close this hefty publications update, we are pleased to announce that the project to digitize back copies of *Interface* continues apace. Since January of this year, we have launched the editions from 2000-2009 live on the ECS Digital Library on IOP Science. Look for more back issues of *Interface* to be posted live in the coming months!

Editorial Board Appointments for ECS Journals

JSS Associate Editor-at-Large



Paul A. Maggard has received a two-year reappointment as Associate Editor-at-Large for the *Journal of Solid State Science and Technology*. Maggard handles manuscripts related to the molecular area. He is an associate professor in the Department of Chemistry, North Carolina State University. Maggard's research focuses on solid state synthesis using flux and hydrothermal methods, characterization of their crystalline structures and chemical compositions, and measurements of their catalytic and photoelectrochemical properties for solar energy conversion. His research team currently focus on the discovery and design of novel mixed-metal semiconductors with ordered or disordered crystalline structures as well as new carbon nitride phases and aerogel-type materials. His term will end on February 29, 2023.

JES Associate Editor

John Staser has received a three-year reappointment as Associate Editor for the *Journal of The Electrochemical Society*. Staser handles manuscripts related to electrochemical engineering. He is an associate professor in Chemical and Biomolecular Engineering, Russ College of Engineering and Technology, Ohio University. His research interests include electrochemical engineering, materials for energy conversion and storage, electrochemical biosensors, and electrochemical conversion of biomass. His term will end on February 19, 2024.

JES Associate Editor

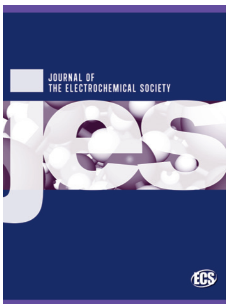
Photo: Texas A&M University

Perla Balbuena has received a two-year reappointment as Associate Editor for the *Journal of The Electrochemical Society*. Balbuena handles manuscripts related to battery and energy storage. She is a professor in the Artie McFerrin Department of Chemical Engineering, Texas A&M University. Her research interests include catalysis on metal nanoparticles for fuel cell electrocatalysts; catalyzed growth of single-walled carbon nanotubes; gas separation and storage in metal organic frameworks; solid-electrolyte interphase layer nucleation and growth in Si and carbon anodes of Li-ion batteries; materials for photocatalysis: oxygen evolution in doped oxides; materials for solar cells and hydrogen production: hydrogen evolution on coated semiconductors covered by co-catalysts; and shale gas thermodynamics: phase behavior of hydrocarbon + water mixtures in confined media. Her term will end on April 1, 2023.

ECS Journals

Current and Upcoming Focus Issues

Journal of The Electrochemical Society (JES)



READ ONLINE

International Meeting on Chemical Sensors (IMCS) 2020 – Volume One
Technical Editor: Ajit Khosla
Guest Editors: Peter Hesketh, Steve Semancik, Udo Weimar, Yasuhiro Shimizu, Joseph Stetter, Gary Hunter, Joseph Wang, Xiangqun Zeng, Sheikh Akbar, Muthukumaran Packirisamy, Rudra Pratap

Selected Papers of Invited Speakers to IMLB 2020
Technical Editor: Doron Aurbach
Associate Editors: Thierry Brousse, Scott Donne, Brett Lucht, Venkat Srinivasan, Nae-Lih (Nick) Wu

Proton Exchange Membrane Fuel Cell & Proton Exchange Membrane Water Electrolyzer Durability
Technical Editor: Xiao-Dong Zhou
Guest Editors: Jean St-Pierre, Deborah Myers, Rodney Borup, Katherine Ayers

Characterization of Corrosion Processes in Honor of Philippe Marcus
Technical Editor: Gerald S. Frankel
Guest Editors: Dev Chidambaram, Koji Fushimi, Vincent Maurice, Vincent Vivier

UPCOMING

Energy Storage Research in China
Technical Editor: Doron Aurbach
Guest Editors: Hong Li, Yi-chun Lu, Kai Jiang, Haijun Yu, Kothandaraman Ramanujam, Chunmei Ban, Venkataraman Thangadurai
Submissions Open: July 22, 2021
Deadline: October 20, 2021

Women in Electrochemistry
Technical Editor: Ajit Khosla
Submissions Open: August 5, 2021
Deadline: November 3, 2021

Advanced Electrolysis for Renewable Energy Storage
Technical Editor: Xiao-Dong Zhou
Guest Editors: Hui Xu, Bryan Pivovar, Grigorii Soloveichik
Submissions Open: September 10, 2021
Deadline: January 9, 2022

Biosensors and Nanoscale Measurements: In Honor of Nongjian Tao and Stuart Lindsay
Technical Editor: Ajit Khosla
Guest Editors: Larry Nagahara, Erica Forzani, Huixin He, Jin He, Tianwei Jing, Jessica Koehne, Chenzhong Li, Patrick Oden, Shaopeng Wang, Nick Wu, Bingqian Xu, Peiming Zhang
Submissions Open: October 7, 2021
Deadline: January 5, 2022

NOW IN PRODUCTION

Molten Salts and Ionic Liquids II
Technical Editor: David Cliffel
Guest Editors: David P. Durkin, Paul C. Trulove, Robert A. Mantz

Recent Advances in Chemical and Biological Sensors & Micro-Nanofabricated Sensors and Systems
Technical Editor: Ajit Khosla
Guest Editors: Michael Adachi, Netz Arroyo, Thomas Thundat

Future of Intercalation Chemistry for Energy Storage and Conversion in Honor of M. Stanley Whittingham
Technical Editor: Doron Aurbach
Guest Editors: Brett Lucht, Louis Piper, Shirley Meng

ACCEPTING SUBMISSIONS

Solid Oxide Fuel Cells (SOFCs) and Electrolysis Cells (SOECs)
Technical Editor: Xiao-Dong Zhou
Guest Editors: Eric D. Wachsman, Subash Singhal
Deadline: August 8, 2021

18th International Meeting on Chemical Sensors (IMCS) – Volume Two
Technical Editor: Ajit Khosla
Guest Editors: Peter Hesketh, Steve Semancik, Udo Weimar, Yasuhiro Shimizu, Joseph Stetter, Gary Hunter, Joseph Wang, Xiangqun Zeng, Sheikh Akbar, Muthukumaran Packirisamy, Rudra Pratap
Deadline: August 4, 2021

Modern Electroanalytical Research in the Society for Electroanalytical Chemistry (SEAC)
Technical Editor: David Cliffel
Guest Editors: Lane Baker, Lanqun Mao, Frank Zamborini, Bo Zhang
Deadline: September 1, 2021

ECS Journals

Current and Upcoming Focus Issues

ECS Journal of Solid State Science and Technology (JSS)

READ ONLINE

Photovoltaics for the 21st Century
Technical Editor: Fan Ren
Associate Editor: Meng Tao
Guest Editors: Hiroki Hamada, Thad Druffel, Jae-Joon Lee

Solid State Reviews
Technical Editors: Ajit Khosla
Contributing Technical Editors: Jennifer Bardwell, Francis D'Souza, Peter Mascher, Kailash C. Mishra, Fan Ren
Associate Editors: Michael Adachi, Netz Arroyo, Thomas Thundat, Meng Tao
Guest Editors: Sheng-Joue Young, Zhenhuan Zhao, Sandeep Arya, Sajjad Husain Mir, Kumkum Ahmed, MD Nahin Islam Shiblee

NOW IN PRODUCTION

4D Materials and Systems + Soft Robotics
Technical Editor: Ajit Khosla
Associate Editors: Michael Adachi, Netz Arroyo, Thomas Thundat
Guest Editors: Hidetmisu Furukawa, Koh Hosoda, Sheng-Joue Young, Zhenhuan Zhao, Tsukasa Yoshida, Yoon Hwa, Sathish K. Sukumaran, Masahiro Shimizu, Jessica E. Koehne

Photovoltaics for the 21st Century II
Technical Editor: Fan Ren
Associate Editor: Meng Tao
Guest Editors: Jae-Joon Lee, Doo-Hyun Ko, Yoonmook Kang, Hyeok Kim

Semiconductor Wafer Bonding: Science, Technology, and Applications
Technical Editor: Jennifer Bardwell
Guest Editors: Roy Knechtel, Chuan Seng Tan, Tadatomo Suga, Helmut Baumgart, Frank Fournel, Mark Goorsky, Karl D. Hobart

Solid State Electronic Devices and Materials
Technical Editor: Fan Ren
Guest Editors: Chao-Sung Lai, Chia-Ming Yang, Yu-Lin Wang

Selected Papers from the International Conference on Nanoscience and Nanotechnology 2021 (ICONN-2021)
Technical Editor: Francis D'Souza
Guest Editors: Senthil Kumar Eswaran, S. Yuvaraj, M. S. Ramachandra Rao, Masaru Shimomura

Molecular Electronics
Technical Editor: Krishnan Rajeshwar
Guest Editor: Jean Christophe Lacroix

ACCEPTING SUBMISSIONS

Dedicated to the Memory of George Blasse: Recent Developments in Theory, Materials, and Applications of Luminescence
Technical Editor: Kailash Mishra
Guest Editors: John Collins, Jakoah Brgoch, Ron-Jun Xie, Eugeniusz Zych, Tetsuhiko Isobe, Ramchandra Pode, Andries Meijerink
Deadline: July 28, 2021

UPCOMING

Selected Papers from the International Electron Devices & Materials Symposium 2021 (IEDMS 2021)
Technical Editor: Fan Ren
Guest Editors: Wei-Chou Hsu, Yon-Hua Tzeng, Shoou-Jinn Chang, Meng-Hsueh Chiang, Sheng-Po Chang
Submissions Open: January 20, 2022
Deadline: April 20, 2022

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ECS Celebrates the International Day of Women and Girls in Science

The Electrochemical Society fosters full and equal access to, and participation in, science for women and girls. To mark February 11, 2021—designated the International Day of Women and Girls in Science by the United Nations—the Society saluted women's critical role in advancing electrochemistry and solid state science and related technologies—and the Society. ECS has supported and celebrated women at the forefront of science for over half a century.

Jan Talbot

ECS presidents exemplify organizational and scientific leadership. "Since the beginning of my career, I realized the responsibility of being one of a few women to follow this career path," said **Jan Talbot**, chemical engineer and former ECS Board Vice President, President (2001-2002), and *Interface* Editor. As one of the few women in her field, Talbot achieved many firsts throughout her trailblazing career including being the first woman hired in her department at the University of California San Diego. She contributed countless research papers to the ECS Digital Library and contributed her body of work to the Society's open access initiative, *Free the Science*.

Talbot followed in the footsteps of the Society's first female president, **Joan Berkowitz**, who served in that role from 1979-1980. The fortieth anniversary of her presidency was celebrated with "40 Years After: Diversity for All," a symposium at the 236th ECS Meeting. The symposium applauded past successes and looked toward the future, encouraging conversations and examining options to promote the continued support of not only women in the sciences, but diversity and inclusiveness overall.

Joan Berkowitz

Berkowitz designed experiments in metals melting and eutectic solidification in space for the lunar space program. Kathryn Bullock, president from 1995-1996, is known for her work in developing valve-regulated lead-acid batteries. Robin Susko, president from 2004-2005, has more than 25 U.S. and foreign patents for polymeric formulations, plasma processing, and semiconductor packaging design and reliability performance. Esther Takeuchi, president from 2011-2012, was credited by President Obama for "saving millions of lives" for contributing to the development of the battery system used to power cardiac defibrillators. Johna Leddy served first as ECS Secretary from 2008-2012, then as President from 2017-2018. Her research group's incorporation of magnetic microparticles into ion exchange polymers such as Nafion® and other viscous matrices led to improved polymer electrolyte membrane (PEM) fuel cells and higher capacity, rechargeable alkaline batteries. Christina Bock, ECS President from 2019-2020, developed several novel approaches for the characterization and determination of relevant performance properties of electrocatalysts.

Gerardine Botte

Gessie Brisard

Women in ECS Board leadership roles today are **Gerardine Botte** as Second Vice President; **Marca Doeff**, Secretary; and **Gessie Brisard**, Treasurer. Shelley Minteer chairs the Honors & Awards Committee. ECS topic interest area divisions elected women to lead the ECS Battery Division (Shirley Meng); Sensor Division (Jessica Koehne); and Electronics and Photonics Division (Jennifer Hite).

To attract and retain talented women in the sciences, women must be included, recognized, and heard. Early on, ECS awards and fellowships provided acknowledgement and encouragement. In the 1960s, summer fellowships supported women researchers including Kathleen Lehman (1966) and Kathryn Bullock. In the 1970s, they were awarded to Roberta G. Reed (1970), W. Jean Horkins (1970 and 1971), Beverly Alexander (1973), and Mary Suchanski (1975). Jeanne Burbank shared the 1966 Battery Division Research Award. Early career women scientist received ECS Young Author Awards for the best papers published by young authors in ECS journals. Honorees included Jean Horkans (1978), Hannah Reller (1981), Jocelyn Richer (1987), and Jennifer Bardwell (1989). Suzanne Mohney received the 1999 High-Temp J. B. Wagner Division Award, which was awarded to Sossina Haile in 2000.

Marca Doeff

The Fellow of The Electrochemical Society recognizes advanced individual technological contributions in the field of electrochemical and solid state science and technology, and active membership and involvement in the Society. ECS Fellows include, among others, Geraldine C. Schwartz (1990), Stella Pang (1997), Kathryn Bullock (1999), Cammy Abernathy (2000), Robin Susko (2003), Jan Talbot (2004), Esther Takeuchi (2012), Elizabeth Opila (2013), Shelley Minteer (2013), Johna Leddy (2013), Nancy Dudney (2013), Geraldine G. Botte (2014), Ellen Ivers-Tiffee (2015), Deborah Jones (2015), Clare Grey (2017), Marca Doess (2017), Christina Bock (2017), Y. Shirley Meng (2018), Alison Davenport (2019), Jie Xiao (2020), Diana Golodnitsky (2020), and Katherine Ayers (2020).

Lisa M. Housel

ECS women leaders actively mentor younger women scientists. **Lisa M. Housel** received the 2020 ECS Energy Technology Division Graduate Student Award sponsored by BioLogic. She is a fifth-year PhD candidate in Chemistry at Stony Brook University, U.S., under the mentorship of Esther S. Takeuchi (ECS President, 2011-2012), Kenneth J. Takeuchi, and Amy C. Marschilok.

Travel Grants—another important form of support ECS provides women students and early career scientists——are more than funding; they are gateways to the future. Madeline Sciullo was a fourth-year student studying electrical and computer engineering at the University of Florida when she received a grant to attend the ECS biannual PRiME meeting in Honolulu, HI. She knew travelling there would be costly, but she felt she had to attend. "These international meetings are so crucial to the development of the field. A lot of the work that I'm doing, nobody in the United States is doing. Collaborating and understanding research from all across the world is really important. I definitely learned a lot (at the meeting), not just about my field, but everything else that could be related with the work that I do." Today, Madeline is a Space and Radiation Effects Engineer at Amazon. We hope the ECS Travel Grant helped her get there.

Female scientists have been the star speakers at ECS biannual meetings for many years. Janet G. Osteryoung, Director of the Division of Chemistry at the National Science Foundation, presented the ECS Lecture in 1995. Carol A. Bessel, Acting Division Director at the National Science Foundation (NSF), was the highlighted speaker at the 235th ECS Meeting annual business meeting. Valerie Browning, Director of the Defense Advances Research Projects Agency (DARPA)'s Defense Sciences Office (DSO), delivered the ECS Lecture at the plenary session of the 236th ECS Meeting.

Today, with opportunities for face-to-face meetings limited by the COVID-19 pandemic, ECS continues highlighting women's contributions in digital biannual meetings. The new ECS Webinar Series spotlights international women scientists including María Escudero-Escribano (University of Copenhagen, Denmark), Anita Ho-Baillie (University of Sydney, Australia), Jie Xiao (Pacific Northwest National Laboratory), Sharon Hammes-Schiffer (Yale

University), and Shelley D. Minteer, (University of Utah). Jenny Pringle (Deakin University, Australia) and Kelsey Bridget Hatzell (Vanderbilt University) also held webinars.

The Society recognizes that gender equality in the sciences is critical to solving pressing problems facing the global community. “There is clearly a change in attitude; women are accepted in the workplace as engineers and scientists. Though there has been a lot of progress getting women in powerful positions and in Science and Technology careers, the numbers are still lower than what we would like to see… For things to change dramatically, we (need) many more women in STEM careers, many more women who climb to the top of the technical careers… So please encourage your daughters, mentees, and friends to pursue STEM careers, and push them to stay with it,” said long-term ECS member Hariklia (Lili) Deligianni (entrepreneur and Adjunct Full Professor Biomedical Engineering, Columbia University; ECS Secretary from 2012-2016). There is still much work to be done. ECS is committed to the cause.

WOMEN IN ELECTROCHEMISTRY

The *Journal of The Electrochemical Society* (JES) announces the 2022 publication of a focus issue on Women in Electrochemistry. To reduce gender inequality and encourage diversity in STEM, the issue celebrates and promotes the outstanding achievements of eminent women researchers around the world investigating electrochemistry. Fifty female scientists will edit the issue and contribute to peer review of all submissions. Ajit Khosla will be the technical editor. Now accepting papers in ECS topical interest areas in the form of: new research result papers and communications; methods papers; reviews of the history and development of specific fields; and perspectives on future research. The primary author or co-author must be a female researcher; male co-authors are accepted.

Submissions Open: August 5, 2021
Deadline: November 3, 2021

Free the Science Week 2021

ECS held its fifth annual *Free the Science* Week from April 5-11.The paywall to the entire ECS Digital Library on IOPscience came down, making over 160,000 journal and magazine articles and meeting abstracts accessible to everyone at no cost. The April 2021 overall downloads for JES, JSS, ECST, ECS Meeting Abstracts, and *Interface* reached 227,489. While this was a 16 percent decrease from 2020, downloads for *Free the Science* Week (April 5-11, 2021) increased by 62 percent. ECS saw a total of 182,085 downloads that week.

The week supports ECS’s long-term *Free the Science* vision to move beyond the old restrictive publishing paradigm of pay to publish, pay to read. Today, ECS authors can choose to publish their work as open access at little or no cost through programs including ECS institutional membership benefits, and affiliation with an ECS Plus member institution. Since the Society began offering open access as a publishing option in 2014, over 35 percent of all ECS journal content has been published as open access—and 47 percent of articles published in 2020 were open access. The Society seeks to advance science through *Free the Science*. The research published in ECS publications directly addresses the sustainability of the planet. Electrochemistry and solid state science continue to hold the keys to innovation in renewable energy, biomedical applications, water and sanitation, communications, transportation, technology, infrastructure, and beyond.

ECS Webinar Series Draws Global Audience

In June 2020, ECS launched the ECS Webinar Series showcasing distinguished speakers and members of the ECS community. Through these webinars, speakers and audiences benefit from sharing and exchanging ideas on a global level with people of similar interests and areas of expertise. They are also a valuable resource for continuing education.

The series is broadcast on PhysicsWorld.com, the official website of the Institute of Physics (ECS's publishing partner). The site hosts webinars from many of the world's leading scientific manufacturing firms and routinely generates more than 800,000 monthly page views.

ECS thanks ACS, Admiral Instruments, Biologic USA, Comsol, Inc., Gamry Instruments, Hiden Analytical, HORIBA Scientific, The Royal Society of Chemistry, Scribner, and Semilab Semiconduct. Their sponsorship makes it possible to offer the webinars at no cost to the ECS community. Interested in sponsoring a webinar? Contact sponsorship@electrochem.org.

The ECS Webinar Series is searching for speakers and new presentation topics. If you are interested in serving as an ECS webinar speaker, complete the Webinar Booking Form and email education@electrochem.org.

PAST ECS WEBINAR SERIES PRESENTATIONS

(Available for viewing at PhysicsWorld.com, or visit electrochem.org/webinars.)

- **Adapting Electrochemical Sensing to Population-Scale Monitoring of SARS-CoV-2 Infection Spread**, **Netzahualcóyotl (Netz) Arroyo Currás**, *Johns Hopkins University School of Medicine*
- **Autonomous Discovery of Battery Electrolytes with Machine Learning and Robotic Experimentation**, **Venkat Viswanathan**, *Carnegie Mellon University*
- **Bioelectrocatalysis for Electrosynthesis**, **Shelley D. Minteer**, *University of Utah*
- **Chemo-mechanics of Preventing Dendrite Penetration in Li Metal Cells**, **Stephen Harris**, *Lawrence Berkeley Lab*
- **The Development of New Ionic Electrolytes for Energy Storage Devices**, **Jenny Pringle**, *Deakin University*
- **Durable Perovskite Solar Cells**, **Anita Ho-Baillie**, *University of Sydney*
- **Dynamic Light Scattering in Electrochemical Energy Conversion Systems**, **Iryna Zenyuk** and **Prantik Saha**, *University of California, Irvine*
- **Electrochemical CO2 Reduction: Path Towards a Carbon Neutral Chemical Industry**, **Paul Kenis**, *University of Illinois at Urbana-Champaign*
- **Electrochemistry in Rechargeable Lithium Metal Batteries**, **Jie Xiao**, *Pacific Northwest National Laboratory*
- **Graphene and Its Supercapacitor Applications**, **Richard B. Kaner**, *University of California, Los Angeles*
- **Intricacies of High-Energy Cathodes for Lithium-Ion Batteries**, **Arumugam Manthiram**, *Texas Materials Institute, University of Texas at Austin*
- **Microbiologically Influenced Corrosion: Tips, Myths, Skills**, **Reza Javaherdashti**, *Eninco Engineering B.V.*
- **New Directions for Energy from Sunlight**, **Harry Atwater**, *California Institute of Technology*
- **Next-generation Batteries for Electric Transportation and Stationary Storage**, **Yan Yao**, *University of Houston*
- **Novel Carbon Electrodes for Neurochemistry**, **Jill Venton**, *University of Virginia*
- **Opportunities and Fundamental Challenges for the Development and Deployment of Anion Exchange Membrane Fuel Cells**, **William (Bill) Mustain**, *University of South Carolina*
- **Oxygen and Carbon Monoxide Electrocatalysis for Renewable Energy Conversion**, **María Escudero-Escribano**, *University of Copenhagen*
- **Physics of Dopant Emission to Harness the Rainbow Emission of Nanocrystals**, **Ranjani Viswanatha**, *Jawaharlal Nehru Centre for Advanced Scientific Research*
- **Proton-Coupled Electron Transfer in Electrochemistry**, **Sharon Hammes-Schiffer**, *Yale University*
- **Removal and Inactivation of Bacterial and Viral Species with an Electrochemical CNT Filter**, **Chad Vecitis**, *CTO & Co-Founder, Nth Cycle*
- **Synchrotron Characterization of Buried Interfaces in Solid State Batteries**, **Kelsey Bridget Hatzell**, *Vanderbilt University*
- **Two-dimensional Materials for Scalable Modular Electronic Pathogen Sensors**, **Christopher Muratore**, *University of Dayton*
- **Without Sound and Fury, Signifying Something: Acoustics and Batteries**, **Daniel Steingart**, *Columbia Electrochemical Energy Center*

2021-2022 ECS Committees

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Christopher J. Jannuzzi .... *Term as Executive Director*

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Gessie Brisard .... *Treasurer*, Spring 2022
Robb Micek .... *Nonprofit Financial Professional*, Spring 2022

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Svitlana Pylypenko .... Spring 2024
Paul Gannon .... Spring 2024
Keryn Lian* .... Spring 2021
David Hall* .... Spring 2021
Vimal Chaitanya .... Spring 2022
Takayuki Homma .... Spring 2022
Walter Van Schalkwijk .... Spring 2023
Tobias Glossman .... Spring 2023
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William Mustain .... *Chair, Individual Membership Committee*, Spring 2023

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E. J. Taylor .... Spring 2023
Bruce Weisman .... Spring 2023
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Robert Micek .... Spring 2022
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Tim Gamberzky .... *Chief Operating Officer, Term as COO*

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Mikhail Brik .... Spring 2024
Diane Smith .... Spring 2024
Viola Birss* .... Spring 2021
Francis D'Souza* .... Spring 2021
Scott Calabrese Barton* .... Spring 2021
Junichi Murota .... Spring 2022
Dev Chidambaram .... Spring 2022
Wei Tong .... Spring 2022
Nianqiang Wu .... Spring 2023
John Flake .... Spring 2023
Fernando Garzon .... Spring 2023
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Individual Membership Committee

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Alice Suroviec .... Spring 2023
Neal Golovin .... Spring 2023
Toshiyuki Nohira* .... Spring 2021
Chi-Chang Hu* .... Spring 2021
James Burgess .... Spring 2022
Luis A. Diaz Aldana .... Spring 2022
Mohammadreza Nazemi .... Spring 2022
Seyyedamirhossein Hosseini* .... Spring 2021
Marion Jones .... *Chair, Institutional Engagement Committee*, Spring 2022
Marca Doeff .... *Secretary*, Spring 2024

Institutional Engagement Committee

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Hemanth Jaganathan .... Spring 2023
Thomas Barrera .... Spring 2023
David Carey .... Spring 2023
Jie Xiao* .... Spring 2021
Christopher Beasley* .... Spring 2021
Florika Macazo* .... Spring 2021
Alex Peroff .... Spring 2022
Alok Srivastava .... Spring 2022
Craig Owen .... Spring 2022
William Mustain .... *Chair, Individual Membership Committee*, Spring 2023
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James Fenton* .... Spring 2021
Graham Cheek* .... Spring 2021
Colm O'Dwyer .... *Third Vice President*, Spring 2022

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Christopher J. Jannuzzi .... *Executive Director, Term as ED*

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Krishnan Rajeshwar .... *JSS Editor*, 12/31/2021
Robert Savinell* .... *JES Editor*, 6/3/2021
Jeffrey Fergus* .... *ECS Transactions Editor*, 12/31/2020
Robert Kelly .... *Interface Editor*, 5/31/2022
Kang Xu .... Spring 2022
Cortney Kreller .... Spring 2022
New Member* .... Spring 2023
New Member* .... Spring 2023

Meetings Subcommittee of the Technical Affairs Committee

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Jennifer Hite .... Spring 2023
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Diane Smith* .... Spring 2021
Jessica Koehne* .... Spring 2021
James Fenton* .... Spring 2021
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Nick Birbilis .... Spring 2022
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Jennifer Hite .... *Chair, Electronics and Photonics Division*, Spring 2023
William Mustain .... *Chair, Energy Technology Division*, Spring 2023
Sadagopan Krishnan .... *Chair, Organic and Biological Electrochemistry Division*, Spring 2023
Andrew Hillier .... *Chair, Physical and Analytical Electrochemistry Division*, Spring 2023
Philippe Vereecken .... *Chair, Electrodeposition Division*, Fall 2021
Paul Gannon .... *Chair, High Temperature Materials Division*, Fall 2021
Jakoah Brgoch .... *Chair, Luminescence and Display Materials Division*, Fall 2021
Peter Mascher .... *Chair, Dielectric Science and Technology Division*, Spring 2022
Hiroshi Imahori .... *Chair, Nanocarbons Division*, Spring 2022
Shrisudersan Jayaraman .... *Chair, Industrial Electrochemistry and Electrochemical Engineering Division*, Spring 2022
E. J. Taylor .... *Chair, Interdisciplinary Science and Technology Subcommittee*, Spring 2022

Other Representatives

Society Historian
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American Association for the Advancement of Science
Christopher J. Jannuzzi .... *Term as Executive Director*
Science History Institute
Yury Gogotski* .... *Heritage Councilor*, Spring 2021
National Inventors Hall of Fame
Shelley Minteer .... *Chair, Honors & Awards Committee*, Spring 2023

* *The results from the ECS Board Meeting were to be announced after* Interface *went to press. The results will be highlighted in the fall issue.*

ECS Division Contacts

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Ajit Khosla, *Journals Editorial Board Representative*

Division News

Battery Division

ECS Battery Division member **Venkataraman Thangadurai** received the 2021 Award for Research Excellence in Materials Chemistry from the Materials Chemistry Division of the Chemical Institute of Canada. The award is presented to a Canadian citizen or landed immigrant who has made an outstanding contribution to materials chemistry while working in Canada. Dr. Thangadurai is a professor of chemistry at the University of Calgary. His research focuses on the development of novel solid state electrolytes and electrodes for advanced all-solid state batteries, solid oxide fuel cells, electrolyzers, and electrochemical gas sensors. Thangadurai pioneered the development of fast Li-ion conducting garnet-type structure oxides, which form a singular class in all-solid state lithium batteries because of their unique functional properties, such as high ionic conductivity, excellent electrochemical stability window, and chemical stability with high voltage Li cathodes and elemental Li anode. An active ECS member, Thangadurai is an ECS Fellow and currently serves as member at large of the ECS Battery Division and ECS Canada Section. He upholds one of the highest academic and professional standards as a Fellow of the Royal Society of Chemistry and is Co-founder and Associate Director of the Calgary Advanced Energy Storage and Conversion Research Technologies (CAESR-Tech.), and Co-founder and Scientific Advisor of Ion Storage Systems.

Dielectric Science and Technology Division & Electronics and Photonics Division

Zia Karim, an ECS Member since 2005, and member at large of the DST and EPD divisions, was recently appointed Chief Technical Officer of Yield Engineering Systems, Inc. (YES), a leading semiconductor equipment company for backend advanced packaging and life sciences equipment. YES is a frequent corporate sponsor of ECS symposia. Dr. Karim received a PhD in Electronic Engineering from Dublin City University, and BSc and MSC degrees in Electrical and Electronic Engineering from the Bangladesh University of Engineering and Technology. He started his career at Sharp Microelectronics in 1994, and has held senior management positions at Applied Materials and Novellus. Karim worked for over 15 years at AIXTRON/Genus before moving to YES, where he was Senior Vice President and Chief Marketing Officer before his recent promotion. Since 2006, Dr. Karim has served as Organizer or Co-Organizer of several ECS symposia. He holds 17 patents and has authored more than 40 published papers in peer-reviewed journals.

Photo: Yield Engineering Systems, Inc.

New Division Officer Slates

New division officers for the fall 2021–fall 2023 term have been nominated for the following divisions. All election results will be reported in the spring 2022 issue of *Interface*.

Electrodeposition

Chair
Nastasa R. Vasiljevic, University of Bristol
Vice-Chair
Luca Magagnin, Politecnico di Milano
Secretary
Andreas Bund, Technische Universität Ilmenau
Treasurer
Rohan Akolkar, Case Western Reserve University
Antoine Allanore, MIT

High Temperature Energy, Materials, & Processes

Chair
Sean R. Bishop, Sandia National Laboratories
Vice-Chair
Cortney R. Kreller, Los Alamos National Laboratory
Jr. Vice-Chair
Xingbo Liu, West Virginia University
Secretary/Treasurer
Teruhisa Horita, National Institute of Advanced Industrial Science & Technology
Kang Taek Lee, Daegu Gyeongbuk Institute of Science and Technology

Luminescence and Display Materials

Chair
Rong-Jun Xie, Xiamen University
Vice-Chair
Eugeniusz Zych, Uniwersytet Wroclawski
Treasurer
Dirk Poelman, Universiteit Ghent

ECS Board of Directors Report

2021 is proving to be a busy year for the ECS Board of Directors. In addition to the Board's critical role in helping the Society navigate the challenges of COVID-19, including handling the cancelation of our third in-person meeting since the pandemic started, the Board has met twice thus far to advance critical new initiatives to help propel the Society forward.

Kicking the year off with a bang, the Board of Directors met in late January to review a number of proposals coming from the Publications Subcommittee. While still too soon to share the details, what we can say now is that the technical scope of two proposed new journals for ECS were approved, and planning is well underway to help bring these new titles to life in the coming year. Stay tuned for more information soon!

The Board of Directors is also pleased to announce the launching of a revised book program with Wiley Publishing. Building on longstanding joint imprint, the Board, working closely with the ECS staff and Publications Subcommittee, is extremely excited about this reinvigorated effort. The first title under the agreement was released earlier this year, *Electrochemical Systems, Fourth Edition*, by John Newman and Nitash P. Balsara.

If you would like to explore the possibility of authoring or editing a book within the ECS-Wiley joint imprint, please reach ECS Executive Director Christopher J. Jannuzzi at chris.jannuzzi@electrochem.org for more information.

Results of the 2021 Election of Officers & Slate of Officers for 2022

Eric D. Wachsman
President

Colm O'Dwyer
3rd Vice President

The Electrochemical Society has announced the results of the 2021 Society election with the following persons elected: President–Eric D. Wachsman, University of Maryland; 3rd Vice President–Colm O'Dwyer, University College Cork. The terms of Marca Doeff (Secretary) and Gessie Brisard (Treasurer) were unaffected by this election.

At the Board of Directors meeting held on June 10, 2021, members voted to approve the slate of candidates recommended by the ECS Nominating Committee. The slate of candidates for the next election of ECS Officers, to be held from January to March 2022: President–Turgut Gür, Stanford University; 3rd Vice President–James Fenton, University of Central Florida, and Doron Aurbach, Bar-Ilan University; Treasurer–Nianqiang (Nick) Wu, University of Massachusetts Amherst, and Elizabeth Podlaha-Murphy, Clarkson University. Full biographies and candidate statements will appear in the winter 2021 issue of *Interface.*

Staff News

30 Years with ECS

On July 15, 2021, ECS Editorial Manager **Paul Cooper** will celebrate his 30th Anniversary with The Electrochemical Society.

Hired in 1991 as a Publications Assistant, Paul began his career with the Society copyediting papers accepted for publication in the *Journal of The Electrochemical Society* and overseeing the production of the *Proceedings* series. He helped launch *Interface* in 1992 as its first Production Coordinator and advertising salesperson, then moved on to become the Journals Production Manager in 1997, producing the Society's first online journal, *Electrochemical and Solid-State Letters*, in 1998. Paul served as the Publications Department Supervisor and as Assistant Director of Publications before relocating to the Washington, D.C. area in 2004 and focusing on the peer-review process for the ECS journals.

"Thirty years of exceptional work is an amazing accomplishment in and of itself, but what impresses me most about Paul is the continually fresh perspective he brings to the job every day. He is a fount of knowledge and experience. His insight into ECS's past is vital to informing our evolving strategy for the Society's future and we are truly fortunate to have him on the team. Many happy returns Paul. I know all the ECS staff and volunteers join me in wishing you our sincerest thanks and congratulations," said ECS Executive Director Christopher J. Jannuzzi.

When not working, Paul enjoys spending his time cooking, reading, and planning cross-country motorcycle trips.

Meet the New Digital Engagement and Marketing Specialist

Jennifer Ortiz joined ECS in 2018 as Web Content Specialist. Since then, her experience and role has evolved, giving her the opportunity to take on a new and exciting position as Digital Engagement and Marketing Specialist. In this role, she supports the Society with the development and implementation of digital marketing and communication efforts.

"ECS has a lot to offer its community, from biannual meetings, ECS journals, calls for papers, networking events, fellowships and awards; the list goes on! I'm thrilled to have the task of sharing that information with the public so that established and up-and-coming scientists and engineers continue to have a platform to take their work to new heights," said Jennifer.

Shannon Reed, Director of Community Engagement, is excited for Jennifer in her new role. "ECS continues to evolve, especially engaging the global community. Jen is eager to excel and support the organization's growth," he said.

Jennifer holds a BA in Journalism and Media Studies from Rutgers University. She is boy mama to a one-year-old son with a second little one due in August. She is a beach fanatic, enjoys eating out, and is currently learning to garden.

2021 Colin Garfield Fink Fellowship Recipient

Ali Othman will pursue research over the summer on wearable biosensors by introducing stimuli responsive (smart/intelligent) functional nanomaterials with exploring the use of artificial enzymes. Othman completed his PhD in Chemistry at Clarkson University in May 2019 with Silvana Andreescu as his advisor. Since February 2021, he has worked as a Research Associate in Clarkson's Department of Chemical & Biomolecular Science. Before that, he performed research in the Laboratory of Bioelectronics & Bionanotechnology at Clarkson with advisors Evgeny Katz and Artem Melman. Othman received the Shipley Graduate Fellowship at Clarkson (2019); American Chemical Society Division of Environmental Chemistry Graduate Student Award (2018); and ECS Travel Grant (2017). The Clarkson Department of Chemistry and Biomolecular Science awarded Othman a Research and Teaching Assistant Scholarship (2018) and Outstanding Teaching Assistant Award (2017). He was Team Leader of the second place-winning project of the 2017 New York State Pollution Prevention Institute R&D Student Competition; and won first place of the top four finalist projects in the Global Impact Challenge Singularity University's Global Solution Program. Othman served as Guest Editor for a special 2021 issue of *Chemosensors*. His h-index is 12. He has published 19 articles and two book chapters, and holds three patents.

ECS 2021 Summer Fellowships

2021 Edward G. Weston Fellowship Recipient

Krishnakanth Sada's summer fellowship project is "Structural Diversity of AxMn3O7 (A=Li, Na K and Zn) Class of Layered Oxide Insertion Materials: Versatile Battery Cathodes." He works at the Faraday Materials Laboratory (FaMaL) and explores the synthesis-structure-electrochemistry of economic battery cathodes. The "A2M3O7 Class of Oxide Materials as Versatile Battery Cathodes" project has led to the development of suites of novel cathode materials based on AxM3O7 (A= Li/Na/K/Zn/Mg/Ca/Al; M= Mn/V) chemistry. The structural flexibility of layered A2M3O7 class of materials have paved a new approach for the rational designing of robust nonaqueous battery electrode materials. Sada is in the final year of his PhD at the Indian Institute of Science, Bengaluru, with Prabeer Barpanda as PhD advisor. He has an h-index of 7, and has published nine articles and one conference proceeding publication. Sada completed his BS and MS (2014) in Chemistry at Kakatiya University. He was an INSPIRE Scholar through the Department of Science and Technology from 2009-2014 and 2016-2021. With support from the Newton-Bhabha Fund PhD Placement Program, he visited the University of Cambridge from November 2, 2020 – March 31, 2021. In 2019, as Japan Society for the Promotion of Science HOPE Fellow, he attended the 11th HOPE Meeting with the 2019 Nobel Laureates in Okinawa, Japan.

2021 Joseph W. Richards Fellowship Recipient

Derrick Butler will work on "Exploring 2D Materials in Biosensing of Small Molecules and Bacteria" this summer. He is currently pursuing a PhD in Electrical Engineering at Pennsylvania State University (Penn State), under the supervision of Aida Ebrahimi. His focus in the Ebrahimi Bioanalytical and Biosensor Engineering Lab is on the development of electrochemical, electronic, and optical analytical platforms for biomedical and environmental applications, ranging from drug screening to medical diagnostics, and food, soil, and water monitoring. His h-index is 5; he has published seven research articles (three as first or co-first author); is co-first author of one review paper; and authored a chapter on impedimetric detection of bacterial viability for a book that is currently being published. At Penn State, Butler received the Harry G. Miller Fellowship in Engineering Award (2020) and University Graduate Fellowship (2018-2019). Butler was a member of the Sigma Pi Sigma Physics Honor Society at the University of Vermont, where he completed his BS in Physics (2015). He received an MSE in Materials Science and Engineering from the University of Pennsylvania (2017). Butler serves as President of the ECS Pennsylvania State University Student Chapter.

UPCOMING 2021 ECS SPONSORED MEETINGS

In addition to the ECS biannual meetings and ECS satellite conferences, ECS, its divisions, and sections sponsor meetings and symposia of interest to the technical audience ECS serves. The following is a partial list of upcoming sponsored meetings. Please visit the ECS website (**www.electrochem.org/upcoming-meetings**) for a list of all sponsored meetings.

The 17th International Symposium on Solid Oxide Fuel Cells (SOFC-XVII)
July 18-23, 2021, Digital Meeting
www.electrochem.org/sofc-xvii

To learn more about what an ECS sponsorship could do for your meeting, including information on publishing proceeding volumes for sponsored meetings, or to request an ECS sponsorship of your technical event, please contact ***ecs@electrochem.org.***

2021 F. M. Becket Fellowship Recipient

Wesley Chang will pursue "Understanding chemo-mechanical behavior of lithium metal anodes with techniques including operando acoustic transmission" over the summer. He is a PhD student at Princeton University with Daniel Steingart as his advisor. Chang's PhD thesis focuses on interfaces and interphases for anode-free lithium metal cells, developing a new operando ultrasound characterization and imaging technique for batteries, and fast-charging and temperature-driven electrode phase behaviors. As a Princeton Graduate Fellow, Chang participates in the Scholars Institute Fellows Program, advising first-generation low-income graduate students on STEM careers. He received his BS (2014) and MS (2016) at Stanford University, where he received Questbridge Match Scholarships. In 2016-2017, Chang worked on grid-scale storage batteries as a Battery Scientist at Primus Power. Chang has published 10 articles.

2021 H. H. Uhlig Fellowship Recipient

Photo:Robb Cohen Photography

Sathish Rajendran will research "Engineering electrode-electrolyte interfaces of all-solid-state electrochemical cells," this summer. The goal is in situ probing of solid-state battery interfaces to elucidate the electro-chemo-mechanical properties at relevant length scales. Rajendran is currently a fourth-year PhD student in Mechanical Engineering (2018-2022) at Wayne State University. His advisor is Leela Arava. With support from a 2019 ECS High-Temperature Energy, Materials, and Processes Division Travel Grant, Sathish attended the 236th ECS Meeting. He received the Thomas C. Rumble Graduate Fellowship for the years 2018-2019 and 2019-2020. Through a 2016 Academy of Scientific & Innovative Research (AcSIR) Dr. APJ Abdul Kalam Fellowship, Rajendran participated in the 2016 AcSIR Dr. APJ Abdul Kalam Summer Training Program at the Indian Institute of Chemical Technology. His h-index is 5; he has published 15 articles; and holds two patents.

2021 Summer Fellowship Subcommittee

ECS thanks the 2021 Summer Fellowship Subcommittee for its time and effort in selecting this year's recipients. Committee members are:

Vimal H. Chaitanya, Subcommittee Chair
New Mexico State University, U.S.

Peter Mascher
McMaster University, CAN

David S. Hall
University of Cambridge, UK

Kalpathy B. Sundaram
University of Central Florida, U.S.

Jennifer A. Bardwell
Nuclear Regulatory Commission (retired), Maryland, U.S.

Yaiza Gonzalez-Garcia
Delft University of Technology, Delft, Netherlands

2022 Summer Fellowship Dates

Applications for the Colin Garfield Fink Fellowship and ECS Summer Fellowships open on September 15, 2021. The application deadline is January 15, 2022.

In the Next Issue of INTERFACE

- The Fall 2021 issue of *Interface* will focus on "Recycling." Xiao Su, Zheng Chen, Jean St-Pierre, and Natasa Vasiljevic will be the guest editors for this special issue. The lead editor is Chock Karuppaiah.
- Technical feature topics for Fall 2021 *Interface* include the following.
  1. Electrochemistry for Nuclear Fuel Recycling
  2. Maximizing the Value Recovered from Li-Ion Batteries: Hydrometallurgical and Direct Recycling
  3. Electrodeposition/Molten-Salt Electrochemistry for Materials Recovery
  4. Circular Economy and Energy Materials
- Fall 2021 *Interface* also will include a centennial celebration for an ECS division, *Pennington Corner*, column favorites like *The Chalkboard*, *Free Radicals*, and *Looking at Patent Law*, and the latest news about people, students, and the Society.

Podcasts of Note

Suggested for you by Alice Suroviec.

The Life Scientific

Host: BBC Radio 4
Site: https://www.bbc.co.uk/programmes/b015sqc7

The Life Scientific is a weekly podcast that can accessed through BBC's Sounds. The podcast is hosted by Prof. Jim Al-Khalili. He interviews scientists from a variety of backgrounds about their life and work to see what inspires them. Many of the podcasts focus on their present work and future applications of their research.

Carboline Tech Service Podcast

Host: Carboline
Site: https://carboline-tech-service-podcast.pinecast.co

The ***Carboline Tech Service Podcast*** is hosted by Jack Walker and Paul Atzemis. The Carboline Technical Service Engineers cover testing, case studies, and maintenance. They discuss common industrial coatings and linings products, problems, solutions, and painting and testing techniques. End users can subscribe through iTunes, Google Play, or Spotify.

Science Vs

Host: Gimlet Media
Site:https://gimletmedia.com/shows/science-vs/episodes#show-tab-picker

Hosted by Wendy Zukerman, ***Science Vs*** examines the latest debates, fads, and trends with a scientific viewpoint. Available through Spotify, this weekly podcast handles controversial topics with an eye for humor. The podcast features a variety of scientists speaking on their areas of expertise.

Chemical Engineering Guy(s)

Host: Emmanuel Ortega
Site: https://www.chemicalengineeringguy.com/podcast

Chemical Engineering Guy(s) is a weekly podcast available on most streaming podcast apps. Podcast hosts interview chemical engineers from all around the globe. These podcasts have a variety of topics, including academics, searching for jobs, and climbing the corporate ladder.

 DOI: 10.1149.2/2.F03212IF.

Alice Suroviec is a professor of bioanalytical chemistry and dean of the College of Mathematical and Natural Sciences at Berry College. She earned a BS in chemistry from Allegheny College in 2000. She received her PhD from Virginia Tech in 2005 under the direction of Dr. Mark R. Anderson. Her research focuses on enzymatically modified electrodes for use as biosensors. She is currently associate editor of the PAE Technical Division for the *Journal of The Electrochemical Society*.
https://orcid.org/0000-0002-9252-2468

17th International Symposium on Solid Oxide Fuel Cells (SOFC-XVII)

The **ECS High-Temperature Energy, Materials, & Processes Division** and the **SOFC Society of Japan** are honored to present the 17th International Symposium on Solid Oxide Fuel Cells (SOFC-XVII)!

This international forum gathers exclusively online for the presentation and discussion of the latest research and developments on solid oxide fuel cells (SOFCs), solid oxide electrolysis cells (SOECs), and related topics. Join us for this meeting and participate from the comfort of your own workspace.

- View digital presentation files (video, and/or slide deck or poster) for the majority of the 300 meeting abstracts.
- Engage with presenters via a question and answer/comment field for every presentation.
- Communicate with other attendees and all meeting authors via a built in peer-to-peer messaging tool.

Participants can also join live daily plenary talks and topical Q&A sessions covering the various areas of SOFC and SOEC technology.

Speakers from the National Energy Technology Laboratory/NETL (U.S.), Office of Energy Efficiency and Renewable Energy/EERE (U.S.), Advanced Research Projects Agency – Energy/ARPA-E (U.S.), New Energy and Industrial Technology Development Organization/NEDO (Japan), and Fuel Cells and Hydrogen Joint Undertaking Program/FCH JU (EU) speak about the progress of their respective programs and future challenges that they are tackling.

The daily question and answer sessions allow for participant engagement in the discussions on submitted SOFC-XVII topics and presentations. With 12 topical areas (plus posters) covering 300 presentations, these Q&A sessions are excellent opportunities to connect and share with fellow researchers.

SOFC-XVII also presents the awarding of the inaugural ECS High-Temperature Energy, Materials, & Processes Division Subhash Singhal Award with a featured live address by the recipient.

Plenary Talks

(Please visit the SOFC online program for detailed information.)

Monday, July 19

- *Update on the SOFC Program at the DOE's National Energy Technology Laboratory*
  S. Vora (United States Department of Energy), **M. Williams**, and **G. Jesionowski** (KLS, Inc.)
- *Introduction of National Projects Concerning Fuel Cells in Japan*
  D. Hara (New Energy and Industrial Technology Development Organization)
- *ECS High-Temperature Energy, Materials, & Processes Division Subhash Singhal Award Address*

Tuesday, July 20

- *The Status of SOFC and SOEC R&D in the European Fuel Cell and Hydrogen Joint Undertaking Program*
  M. Atanasiu, **D. Tsimis**, **A. Aguilo-Rullan**, **N. Lymperopoulos**, and **D. Dirmiki** (Fuel Cells and Hydrogen Joint Undertaking)
- *U.S. DOE EERE Activities in High Temperature Electrolysis and Reversible Fuel Cells*
  D. Peterson, **N. Stetson**, **D. Papageorgopoulos**, **W. T. Gibbons**, and **K. Randolph** (Hydrogen and Fuel Cell Technologies Office, U. S. Department of Energy)

Wednesday, July 21

- *Integrate to Extend the Reach of Solid Oxide Fuel Cells*
  D. Tew (Advanced Research Projects Agency – Energy), **R. Cox-Galhotra**, **V. Lecoustre** (Booz Allen Hamilton), **R. Radhakrishnan** (Advanced Research Projects Agency – Energy), and **G. L. Soloveichik** (United States Department of Energy)

Topical Question and Answer Sessions

(Please visit the SOFC online program for detailed information.)

Monday, July 19

- Cells, Stacks, and Systems
- Cells, Stacks, and Systems Modeling

Tuesday, July 20

- Solid Oxide Electrolysis and Reversible Cells and Systems
- Proton Conducting Cells
- Metal Supported Cells

Wednesday, July 21

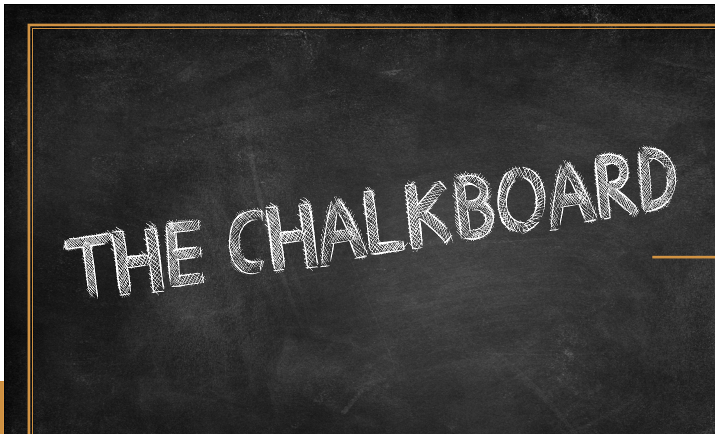
- SOFC Cathodes
- SOFC Anodes
- Durability and Reliability

Thursday, July 22

- Characterization and Testing
- Electrolytes
- Interconnect and Sealing
- SOFC and SOEC Posters

Every student and technical registration fee includes access to meeting abstracts, digital presentation files, and all plenary/Q&A events, as well as an electronic copy of the SOFC-XVII proceedings published in *ECS Transactions*. **Please note that all participants, including authors and invited speakers, are required to pay meeting registration fees.**

For the latest event information, visit
www.electrochem.org/sofc-xvii



A Positive Spin on Corrosion Measurements: The Rotating Ring-Disk Electrode

by Jamie Noël

Introduction

Within the inventory of highly sensitive, selective, and broadly useful electroanalytical techniques available nowadays resides a very clever approach to the measurement of reaction rates, including those of certain non-electrochemical reactions, and the simultaneous quantitative identification of reaction products, including short-lived intermediates. Conceived by Alexander Frumkin in 1958[1] and first built by Lev Nekrasov,[2] the rotating ring-disk electrode (RRDE) was a spin-off of the rotating disk electrode (RDE) for which Benjamin Levich developed the hydrodynamic equations defining the electrochemical response.[3] A fascinating account of the development of the RRDE technique by Soviet, American, and British electrochemists during and despite the Cold War can be found in an earlier issue of *Interface*.[4]

What is an RRDE?

The RRDE consists of a ring-shaped electrode encircling and concentric with a disk electrode that is centered on the longitudinal axis of a rotating shaft, as depicted in Fig. 1. The disk is made of a material of interest, and the ring is a stable, relatively inert conductor, such as Pt or Au. An electrically insulating material (commonly polytetrafluoroethylene, PTFE) surrounds and forms a tight seal with the central disk and both sides of the ring so that the two electrodes are not in electrical contact and only the faces of the ring and disk at the butt end of the rotating shaft (i.e., not the sidewalls) contact the electrolyte solution. The requirements that the ring and disk be concentric, centered on the rotational axis of a straight shaft that rotates smoothly with no wobble, and tightly sealed to the insulating shroud in several places demands careful precision machining of these components. These can be purchased from a commercial supplier or custom-made at a capable machine shop. Electrical contact with the potentiostat is made via brush contacts on the rotating shaft, where a solid connection is not possible. The brush contacts connect with the back of either the ring or the disk underneath the insulating shroud to avoid exposure to the electrolyte solution. Usually, the ring and disk each act as independent working electrodes, which then requires the use of a bipotentiostat for electrochemical control and measurement, although certain applications may require electrochemical connection only to the ring. The RRDE system is completed by a drive mechanism with smooth bearings and speed control to rotate the electrodes, an electrochemical cell in which to do the chemistry, and possibly a seal between shaft and cell that enables maintenance of a controlled atmosphere (e.g., anoxic) inside the cell while permitting unhindered rotation of the electrodes.

How does it work?

Exactly like the RDE,[5] the RRDE rotating in an electrolyte solution causes the solution to be drawn in a laminar flow pattern, first toward the disk surface and then, as it approaches the surface, outward, in a direction parallel to the plane of the disk, at a velocity dependent on the rotation rate, which affords the operator control over the rate of convective mass transport (Fig. 1). Near the disk, the flow rate of the solution toward the end of the rotating shaft is dependent on the square of the distance, z, from the flat surface, with, of course, a flow rate of zero immediately at that surface. This velocity gradient means that the forced convection set up by the rotation brings solution species close to the surface, but a small mass transport gap remains to be bridged by diffusion, with the diffusion layer thickness, δ, being given by $\delta = 1.61\nu^{1/6} D^{1/3} \omega^{-1/2}$, where ν is the, kinematic viscosity of the solution, D the diffusion coefficient of the diffusing species, and ω the angular velocity of rotation in radians/s ($\omega = 2\pi f$, where f is the rotational frequency in Hz). Adjacent to the end of the rotating shaft, a stagnant layer of solution, the Prandtl layer, with thickness $p = 3.6\left(\frac{\nu}{w}\right)^{1/2}$, is dragged by the surface (i.e., the radial solution velocity, v_r, of this layer with respect to the butt of the rotating shaft is zero). Beyond the Prandtl layer, the radial velocity of the solution is given by $v_r = 0.51\,\omega^{3/2}\,\nu^{-1/2}\,rz$, where r is the radial distance from the disk center.[5]

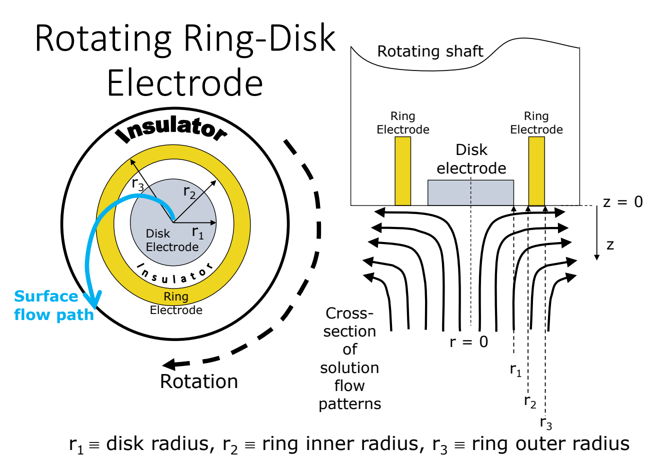


Fig. 1. *End-on and cross-sectional views of a rotating ring-disk electrode showing the locations of the disk, ring, and insulating components on the rotating shaft, the critical dimensions of the RRDE, and the solution flow patterns.*

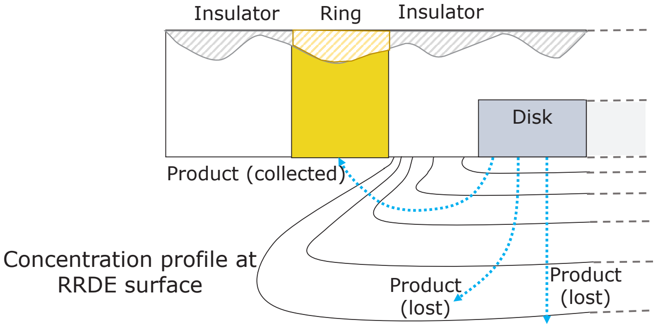


Fig. 2. *Cut-away cross-sectional view of an RRDE operating in collection mode and the near-surface concentration profile of reaction products released from the disk surface, including possible trajectories of individual particles that could lead them to reaction at the ring electrode or out into the bulk solution where they will be lost to the RRDE.*

This arrangement is crucial to the function of the RRDE. It means that chemical species produced at the disk electrode have little chance of diffusing along the Prandtl layer from disk to ring (too narrow a region for diffusion over such a long distance), and there is no chance of species traveling inward (upstream) from the ring to disk. Instead, they will diffuse away from the disk surface, eventually reaching the radially flowing layers of the solution and being swept away from the disk and over the ring, on their way off the butt of the rotating shaft (Fig. 2). As the solution flows past the ring, some of the products from the disk diffuse back through the Prandtl layer to the ring electrode surface, where they are oxidized or reduced, depending on the ring electrode potential and the nature of the chemical species. Thus, the ring could be used as an analytical detector for redox-active species produced at the disk. This mode of RRDE operation is known as "collection mode" (there is also a "shielding mode" in which the disk is set to consume redox-active species from the bulk solution, and the ring detects any residual species that get by the disk in unreacted form, as well as a "reaction mode" in which reactive species produced at the disk and other species of complementary reactivity produced at the ring meet and react together near the inner radius of the ring, such as in "ring-of-fire" electrochemiluminescence).[6,7] The ring, however, only collects a fraction of the species produced at the disk; the rest are lost to the bulk solution. Therefore, for the RRDE technique to be made quantitative, the collection efficiency of the ring, N, must be known. The mathematics required to determine it are rather difficult and eluded Frumkin, Levich, and others until electrochemical math whiz John Albery finally provided a solution for the differential equations involved[8] (not reported here in the interest of conserving space). Fortunately, the collection efficiency depends only on the geometry of the RRDE (radius of the disk and inner and outer radii of the ring) and is therefore constant for each RRDE regardless of other experimental variables. Moreover, the efficiency is easily and accurately measurable experimentally under appropriate conditions, ($N = \frac{i_R}{i_D}$, where i_R is the current measured at the ring and i_D the disk current).

What can it do?

With the ring electrode potential held constant at a value at which it will oxidize or reduce a chemical species of interest generated at the disk electrode at the mass-transport-limited rate, one can accurately quantify the rate of production of such species at the disk by measuring the current at the ring. The disk potential can be scanned or held constant during the measurement, depending on the experiment objectives. This flexibility opens many opportunities for innovative experiments to access data that are difficult to obtain by other means. For example, depending on the size of the gap between disk and ring, the rotation rate, and other factors, the transit time between disk and ring for chemical species may be milliseconds,[9] allowing for the detection of short-lived reaction intermediates. In fact, one of the original and most reported uses of the RRDE is to probe the oxygen reduction reaction (ORR) to determine whether the mechanism proceeds via a direct, 4-electron pathway, or by two 2-electron steps, with hydrogen peroxide as an intermediate.[10-14] This determination is accomplished by setting the ring electrode at a potential at which H_2O_2 will be oxidized back to oxygen and then watching for a ring current indicating H_2O_2 oxidation as dissolved oxygen is reduced at the disk electrode polarized to different potentials under various conditions, as illustrated schematically in Fig. 3.

Use in Corrosion

The RRDE is a valuable tool in corrosion science. In addition to enabling studies of the cathodic half-reactions that comprise half of the overall corrosion process,[14,15] such as the oxygen reduction mentioned above, RRDE techniques can contribute to understanding materials dissolution and corrosion product film formation. Using a disk electrode made of a material of interest, one can employ the ring to detect and quantify the release of soluble species from the disk occurring as a result of its degradation during free corrosion or under electrochemical polarization. This approach may provide key information about the oxidation state of the species dissolving from

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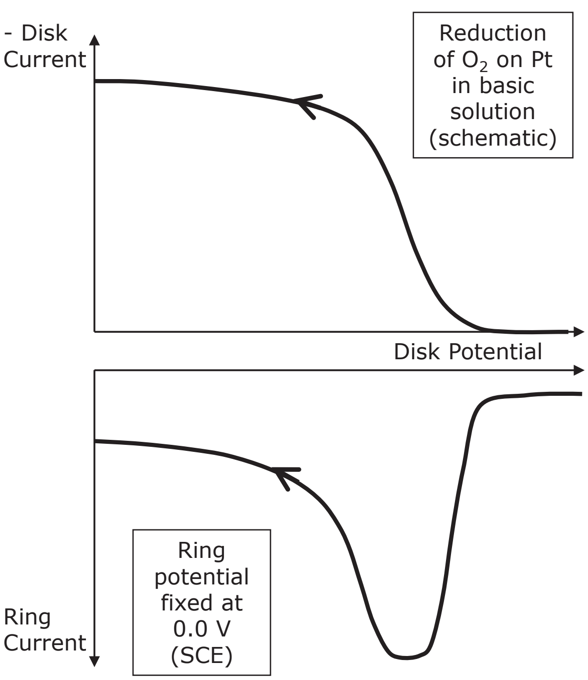

Fig. 3. *Schematic illustration of the current response of the disk (upper panel) and ring (lower panel) currents to a sweep of the disk potential through a range over which the reduction of dissolved oxygen molecules occurs in basic solution. The ring potential is held constant at a value at which H_2O_2, an intermediate species in the oxygen reduction reaction, is oxidized back to oxygen and protons (be careful of the sign conventions in this figure). The ring current has a peak, because even though the production of H_2O_2 at the disk increases as the potential decreases, the rate of H_2O_2 consumption by reduction to water at the disk itself, before it can get to the ring, increases as well.*

the disk surface[16-20] or allow the identification and quantification of individual components dissolving from an alloy,[21-25] oxide,[26,27] or even a polymer.[28] For example, the dissolution of magnetite, Fe_3O_4, an oxide containing both ferrous and ferric ions, was deconvoluted to determine the relative amounts of Fe(II) and Fe(III) released under open-circuit conditions and at different applied potentials to quantify the contributions of congruent dissolution and reductive dissolution mechanisms to the overall process as a function of potential, as can be seen in Fig. 4.[27] Additionally, a comparison of the disk current with that of the ring (with corrections for collection efficiency) can provide information about the fraction of corrosion products dissolving into the solution vs. those being incorporated into a solid deposit on the electrode surface (e.g., oxide film formation), or even probe localized corrosion (e.g., pitting).[29]

In some ways, the RRDE could be considered a low-tech forerunner of the clever AESEC (atomic emission spectroelectrochemistry) technique developed in the laboratory of Kevin Ogle at Chimie ParisTech,[30] in which an inductively-coupled plasma-atomic emission spectrometer (or ICP-mass spectrometer in some adaptations) analyzes the output from an electrochemical flow cell to identify and quantify metal-containing species released from a material undergoing corrosion or degradation under electrochemical polarization. However, rather than being replaced by AESEC, the RRDE is clearly a complement to it because the RRDE has some sensitivity to the chemical state of species emitted by the disk material, whereas the ICP atomizes everything that enters and allows one to determine only the elements present and the total amount of each. Additionally, the ability of the RRDE to probe reactive intermediates is unavailable in AESEC.

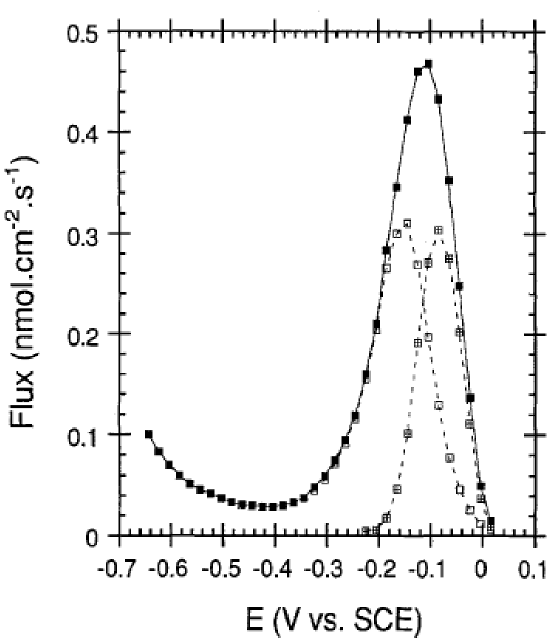

Fig. 4. *Dissolution fluxes of Fe(II) (□) and Fe(III) (⊞) as a function of applied potential on a magnetite disk, converted from measured ring electrode currents acquired on an RRDE consisting of a magnetite disk and Au ring exposed to 0.1 M $KClO_4$ + 1 mm EDTA at pH 3.0, a temperature of 20°C, and a rotation rate of ω = 209 radians/s. The total Fe dissolution flux (■) is also given. Congruent dissolution of magnetite (i.e., without redox conversion of Fe ions in the mixed oxidation state oxide) can be seen to occur at a potential E~ ~−0.09 V/SCE where the number ratio of Fe(II) to Fe(III) ions released is 1:2; this is also (by necessity) the open circuit potential of the magnetite in this solution. However, the solid curve shows that magnetite dissolves fastest in this solution at E~−0.11 V/SCE, where a small amount of reductive dissolution enhances the process.* (*Figure published in reference 27.*)

Variations on the RRDE

Barry Miller[31,32] recognized that the ring electrode could be made into a simultaneous multi-component detector that would be particularly useful for corrosion studies by splitting it into two or more electrically independent arc electrodes, as illustrated, for the simplest case, in Fig. 5. This represented a substantial expansion in the utility of the RRDE. For instance, the magnetite dissolution study discussed above[27] was performed by conducting the same experiment twice—once with the ring set to detect the release of species containing ferrous ions and again with the ring set to reduce any released ferric species to ferrous. The measurements could have been completed in half the time, with greater reliability (no concerns about the reproduction of identical experimental and disk surface conditions), had a split-ring-disk electrode been available. The split-ring-disk electrode depicted in Fig. 5 would require a tripotentiostat to control and measure from its three independent working electrodes, and the capture efficiency of each ring component would decline in proportion to its smaller surface area. Further variations of this sort, such as an RRDE with two concentric split rings[33] (that is oddly reminiscent of a biplane) are possible but would require a multipotentiostat capable of servicing the required number of working electrodes.

Conclusions

Though it is approaching its 65th birthday, the RRDE is not ready to be retired and remains an excellent option in the repertoire of electrochemists and corrosion scientists. The *Journal of The Electrochemical Society* and other publications offer many accounts of innovative applications of the RRDE and its offshoots, which are also excellent fodder for provoking ideas for more novel RRDE

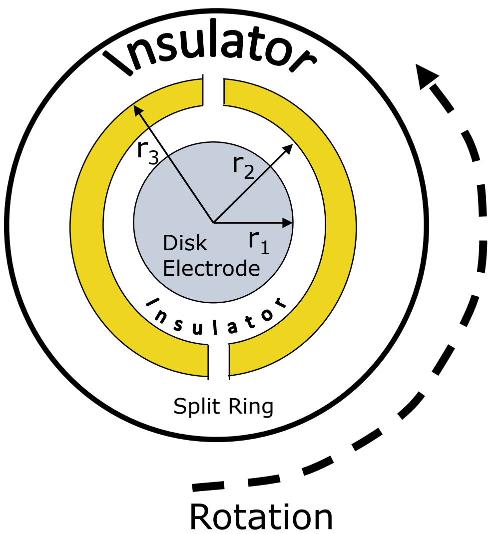

Fig. 5. *Schematic representation of the working end of a split-ring RRDE. The disk and each of the arc electrodes derived by splitting the ring are electrically independent working electrodes. This device, therefore, must be operated using a tripotentiostat.*

approaches. Helpful training on the theory and practice of RRDE electrochemistry and other electrochemical techniques is also available through some of the technical short courses offered by The Electrochemical Society at its biannual meetings.

About the Author

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Education: B.Sc., M.Sc. Guelph; Ph.D. Manitoba

Research Interest: Studies of the degradation of nuclear fuel and container materials for permanent disposal of nuclear fuel waste.

Work with Students: A research group of 25 graduate and undergraduate students, postdoctoral fellows, and research scientists conducting experimental research on corrosion aspects of copper, carbon steel, uranium dioxide, stainless steels, nickel alloys, and other materials.

Research Partners: The Nuclear Waste Management Organization; the Swedish Nuclear Fuel and Waste Management Company; the National Cooperative for the Disposal of Radioactive Waste; the Nuclear Waste Management Organization of Japan; Imperial Oil.

Pubs & Patents: 50 refereed conference proceedings papers, 20 commercial reports, 5 book chapters, coauthored 100+ refereed journal articles. Associate Editor, *CORROSION Journal*.

Awards: ECS R. C. Jacobsen and Lash Miller Awards and the Western University Faculty of Science Distinguished Research Professorship (twice).

Work with ECS: ECS Corrosion Division Chair, ECS Education Committee Chair, Short Course Instructor (Fundamentals of Electrochemistry) at ECS biannual meetings.

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Kelly Receives Whitney Award

Robert G. Kelly

Robert G. Kelly has earned NACE International's Willis Rodney Whitney Award, the highest scientific award from the world's largest corrosion science and engineering society. This award recognizes Kelly's seminal research in localized corrosion and his pioneering efforts to elucidate corrosion processes and prevention in metals, alloys, and nonaqueous and mixed solvents. He delivered the Whitney Award lecture at the CORROSION 2021 Conference & Expo in April.

Kelly is the AT&T Professor and professor of materials science and engineering at the University of Virginia (UVA). He has graduated over 25 PhD students and coauthored 120+ papers. Kelly is an ECS fellow and serves as the editor of *Interface*.

Professorship for Opila

Beth Opila

Beth Opila will be named the Rolls-Royce Commonwealth Professor in Engineering at the University of Virginia (UVA), effective August 25, 2021. This professorship was established to enhance the research and curriculum at UVA in areas of interest to Rolls-Royce and the Commonwealth of Virginia. Beth is an internationally renowned scholar and educator in high-temperature materials with a record of impressive achievements and mentoring of students. In 2010, Opila left NASA-Glenn and established the Advanced High Temperature Materials research group at UVA, which focuses on materials for use in extreme environments. The work can be applied to materials for use in aircraft engines, rocket engines, energy conversion technologies, and thermal protection systems. Opila is a member of the High-Temperature Energy, Materials, & Processes (H-TEMP) Division, and served on its executive committee. She was named as an ECS fellow in 2013.

In Memoriam ...

Isamu Akasaki

1929-2021

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Photo: A. Mahmoud

The Electrochemical Society mourns the passing of Nobel Laureate and long-term member, **Isamu Akasaki**, who died on April 1, 2021. Prof. Akasaki is best known for winning the 2014 Nobel Prize in Physics with Hiroshi Amano and Shuji Nakamura for "the invention of efficient blue light-emitting diodes, which has enabled bright and energy-saving white light sources."

Prof. Akasaki joined ECS in 1985. Throughout his long career, he attended numerous Society meetings and published multiple papers in ECS journals. "The world knew Isamu Akasaki as the pioneering scientist who invented the blue LED. At the Society, we came to know him on a more personal level during his 35-plus years of membership, said Christopher J. Jannuzzi, ECS Executive Director and Chief Executive Officer. "We tracked the extraordinary progress of Professor Akasaki's research at ECS meetings and in ECS journal articles. We also noted his remarkable humility and how he always credited his success to the support of co-researchers, students, and colleagues. Prof. Akasaki was both a leader in the field, and mentor to a generation of scientists following his lead in finding solutions to reducing global dependence on fossil fuels."

Prof. Akasaki was born in Chiran, Japan, in 1929. He graduated from Kyoto University in 1952 with a degree in Electrical Engineering. He worked at Kobe Kogyo Corp. for a period before returning to university to complete his PhD in 1964 at Nagoya University. From 1964-1981, Akasaki worked at the Matsushita Research Institute, Tokyo, growing high-quality crystals of the semiconductor gallium nitride. Prof. Akasaki's research went against prevailing scientific opinion, which considered that gallium nitride could never make light-emitting diodes because of flaws in its crystal structure. He joined the faculty of Nagoya University in 1981, where Hiroshi Amano, co-winner of the 2014 Nobel Prize in Physics, was his graduate student. They continued to work together and in the late 1980s, they generated blue light from their chips. Prof. Akasaki joined the Faculty of Science and Technology at Meijo University in 1992. In 2010, he was named University Professor there, and in 2015, Distinguished Professor.

The importance of Prof. Akasaki's work cannot be overstated. The LED technology that he helped invent is used in televisions, computer screens, smartphones, traffic lights, cars, planes, and more. It produces less carbon and has a longer life than previous lighting sources—contributing enormously to the reduction of global warming.

Prof. Akasaki's research continues there by a consortium investigating gallium nitride. Dr. Amano is part of the group.

Prof. Akasaki's distinguished contributions to the field of solid state science and technology were recognized with many awards. The Society honored him with Life Membership in 2013, and the 1999 ECS Gordon E. Moore Medal for Outstanding Achievement in Solid State Science and Technology. A Focus Issue of the ECS *Journal of Solid State Science and Technology* was devoted to Prof. Akasaki in 2000: "Recent Advances in Wide Bandgap III-Nitride Devices and Solid State Lighting: A Tribute to Isamu Akasaki." His work in semiconductor technology earned him Japan's highest honor, the Kyoto Prize in Advanced Technology, in 2009. IEEE honored Prof. Akasaki with the 2011 Edison Medal. He shared the 2021 Queen Elizabeth Prize for Engineering for the development of LED lighting with Shuji Nakamura; Nick Holonyak, Jr.; M. George Craford; and Russell Dupuis.

In a much-quoted 2017 interview with then ECS Vice President Yue Kuo, Prof. Akasaki described his personal philosophy with a quote from Thomas Edison (ECS member, 1903-1931): "No pain, no gain. As Edison said, 'Genius is one percent inspiration and 99 perspiration.' I say this to younger people: experience is the best teacher. Sometimes there is no royal road to learning."

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SEARCHING FOR PEOPLE NEWS

Interface is searching for People News for upcoming issues. If you have news you would like to share with the Society about a promotion, award, retirement, or other milestone event, please email the content to:

MaryBeth.Schwartz@electrochem.org.

In Memoriam ...
C. (Charles) Austen Angell
1933-2021

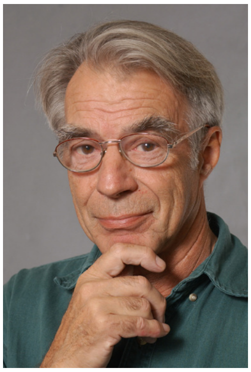


Photo: Arizona State University

C. (Charles) Austen Angell, a world-renowned Regents Professor of Chemistry at Arizona State University, passed away on March 12, 2021, after a long battle with cancer. Angell is best known for his work on supercooled liquids and the glass transition. He was the recipient of the 2010 ECS Physical and Analytical Electrochemistry Division's Max Bredig Award in Molten Salt and Ionic Liquid Chemistry. Prof. Angell was a member of The Electrochemical Society from 2000-2001, and 2014-2015. Over the years, his papers were published in the *Journal of The Electrochemical Society*, *Electro-chemical and Solid-State Letters*, and *ECS Transactions*.

From Dr. Kang Xu, U.S. Army Research Laboratory

"It is with the utmost sadness that we announce to the DOE Battery Research Community that our good friend, dear colleague, and outstanding scientist Prof. Austen Angell passed away. Austen was an intellectual giant and scientific hero to all of us, in addition to being an incredibly warm and wonderful human being. His contribution to the battery materials and chemistries includes the breakthrough concept of "polymer-in-salt" electrolyte, which serves as the ancestor of the modern superconcentrated electrolytes for Li-metal batteries, and the development of advanced electrolytes, such as sulfones and LiBOB. He also educated numerous young scientists who are now major players in various DOE programs. He will be forever missed."

In Memoriam ...
Susan Anne Odom
1980-2021

Photo: University of Kentucky

Susan Anne Odom passed away on April 18, 2021, in Lexington, Kentucky. That day, The Electrochemical Society lost a brilliant scientist, and many of us lost a dear colleague, friend, and mentor. Dr. Odom was born in Paducah, Kentucky, on November 16, 1980. In her short but prolific life, Dr. Odom brought inspiration, laughter, and warmth to everyone around her.

Born into a science family, Dr. Odom found her passion for science at a young age. She was always curious about the world and brimming with new ideas, which she would keenly test out and share with others as she grew into a real scientist and teacher. After receiving a BS in Chemistry from the University of Kentucky (UK) in 2003, Dr. Odom completed a PhD at the Georgia Institute of Technology in 2008. Later, she moved to the University of Illinois at Urbana-Champaign (UIUC) as a postdoctoral fellow, working with Jeffrey S. Moore. Dr. Odom returned to UK as Assistant Professor of Chemistry in 2011, and was promoted to Associate Professor in 2017.

Dr. Odom was a great inspiration to her students, especially young women who she encouraged to pursue their scientific dreams. "In 2018 (Susan) received an SEC travel grant to visit me at Texas A&M University, during which time my sons had the pleasure of knowing her. 'She was awesome,' according to my oldest son," recalled friend and conference roommate Jodie Lutkenhaus, Texas A&M University. "She cared very deeply about her graduate students. Many of our conversations centered around our 'academic children,' and how best to train and mentor them to be successful. In the last few months, Karen Wooley and I were working on a manuscript with Susan on redox active polypeptides for flow batteries. The week before Susan's passing, we Zoomed. I wish that conversation had gone on longer. Susan has left an enormous gap in our lives, in our scientific community, and in our hearts."

Dr. Odom established a legacy of scientific excellence through her creative and well-rounded research in the field of energy storage and conversion materials. Her trailblazing work on the development of highly soluble, highly stable electron donors to serve as the electroactive electrolyte components has generated, and will continue to generate, momentum for true breakthroughs in large-scale energy storage systems.

"Susan was an incredible researcher and a wonderful person," said Dan Steingart, Columbia University. "She added insight, warmth, and grace to everything she touched. Her pioneering research on stability windows for organic redox couples provides a critical foundation for future long-duration storage systems. She had the unique ability to bridge challenges and opportunities in fundamental organic chemistry to the techno-economic needs of a full-scale system. She was a key member of the battery community. Susan was present for us all and made all our interactions and events remarkably brighter and more inviting. She will be deeply missed, but her kindness and spirit will be with us always."

Jeff Dahn from Dalhousie University described one of Dr. Odom's most recent projects. "I first heard of Susan around 2004 when we were working on organic redox shuttle additives for overcharge protection of lithium-ion batteries. She became interested in this area of work, and went on to develop many of her own molecules and establish a strong reputation in the area. Susan was a pleasure to interact with, as she was always upbeat and cheery. She visited us at Dalhousie a few times and her visits were great fun. Just a few weeks ago, Susan sent us a molecule that she believed would be an excellent electrolyte additive for high-voltage lithium-ion cells. We will carry out the testing of this molecule and dedicate the resulting paper(s) to Susan. Her passing is a true tragedy. I will miss her greatly."

Dr. Odom's pride extended beyond her students and research. A true cat lover, she spent several years breeding huge Maine Coon cats, and later rescued strays. "Susan was very welcoming to me when I was in my first year as a new professor. As we both liked cats a lot, we showed each other pictures of our cats on many occasions at conferences. The last time I saw her, we were on an NSF panel together (virtually) and she showed us one of the cats which was on her desk during the review," Joshua Gallaway, Northeastern University, recollected.

"Susan and I had a lot in common—postdocs with Jeff Moore, a strong dislike of the font Calibri, and dedication to well-written manuscripts with perfect, clear figures. We shared many hobbies, like exchanging cool or silly scientific illustrations, an obsession with cats, and gardening endeavors," said close friend, Dr. Lily A. Robertson, Argonne National Laboratory. "What impressed me about Susan was her commitment to research excellence along with strong mentoring and championing her group members' successes. She brought many ideas, valuable insights, and provocative questions to the table. And she wasn't afraid to share…her chemistry if others were excited about studying it, too. Susan was a special human being. Her inquisitive nature and love of science, animals, and helping others made her a remarkable person."

After Susan's passing, Lily created a special painting in her memory. "It captures Susan as a great scientist, and more importantly as a wonderful person who has impacted many of us in the Battery Division of ECS. While we mourn the loss, we also want to keep the fond memories of her, so well displayed in this painting, said Dr. Shirley Meng, Battery Division Chair.

Susan jointed ECS in 2014, and maintained memberships with the Battery Division and the Organic and Biological Electrochemistry Division. Her primary division was the Battery Division. Dr. Odom attended several ECS meetings throughout her membership. She also was a frequent donor to ECS and *Free the Science*.

"I'd worked with Susan since she was a postdoc at the University of Illinois at Urbana-Champaign, where she led the UIUC-Argonne work group as part of a battery Energy Frontier Research Center (EFRC, 2009-2011)," Dr. Jack Vaughey from Argonne National Laboratory warmly remembers. "I always enjoyed interacting with her over the years and throughout her career. She always sought to work with others. A leader in a growing field, she was a strong advocate for her people, and brought people together."

Dr. Lily A. Robertson describes her painting[1] *of Dr. Odom: Professor Susan Odom holding her energy-storing MEEPT catholyte molecule with her favorite cat, Mr. Big. The abstract green crystals in the background are her MEEPT molecule in a charged salt form.*

"While I am not an outgoing guy, I fortunately became one of (Susan's) friends. She was always super kind to everyone and kept a keen curiosity for everything," said Lu Zhang, Argonne National Laboratory. "In 2018, we attended a conference in Dalian. That was her first time visiting China. We went to the city to explore the street food. She was so excited about everything she saw, and eager to try everything. She even bought more to take home! Susan had a strong passion for chemistry. I was constantly impressed by her creativity, persistence, and productivity. Her work on phenothiazines and many other molecules has led to numerous important publications and shown promising applications in lithium-ion batteries and redox flow batteries. Her work also resulted in many collaborative efforts and became a major topic of the redoxmer thrust in the Joint Center for Energy Storage Research. It is heartbreaking to lose a friend, a colleague, and a talented scientist at such a young age. I am sure there will be many redoxmer studies following her path, in memory of her name."

The same qualities that marked Dr. Odom's time as a professor, researcher, and proud cat owner, extended to her love and support of The Electrochemical Society and other collaborative efforts she joined. She recently became a member at large of the ECS Battery Division. "Susan was always one of the first to volunteer for division duties," said Dr. Marca Doeff from Lawrence Berkeley National Laboratory. "Over time, I got to know her not only as a colleague, but also as a friend, who regaled me with funny stories about her adored cats and shared pictures of flowers in her beautiful garden. It is so sad to lose someone so young and promising—not only a brilliant scientist, but also a warm-hearted and kind person."

One can only imagine the greater insights and strength that Dr. Odom would have brought to ECS and the larger scientific community. She lived her life seeking to support others. Thank you, Susan. You have been, and will always be, our inspiration and joy.

This notice was contributed by authors Vivian Wen and Shirley Meng. For more notes from people who loved Susan, visit https://www.carecremationservice.com/obituaries/Susan-Anne-Odom?obId=20843630#/celebrationWall.

1. Lily A. Robertson, *Susan and Her Molecules*, 18" x 24", acrylic.

In Memoriam ...
Waldfried Plieth
1937-2021

Photo: Adriana Ispas

When we met him for the last time, Waldfried Plieth said, "there is a time for everything in life: a time to laugh, a time to cry, a time to struggle, a time of achievements. There is also a time when you travel, and a time when you just lean back in the circle of your beloved ones and enjoy small happiness that life still has in store for you. Now it is time to write an obituary about our mentor, teacher, and friend, Prof. Waldfried Plieth. He passed away on February 6, 2021, in Dresden, Germany, after a short and severe illness.

Waldfried Plieth was born on November 7, 1937, in Cottbus near Berlin (Germany). He studied chemistry at Free University Berlin between 1956-1960, post-graduated at Fritz-Haber Institute of the Max Planck-Gesellschaft from 1960-1963, made his PhD at Fritz-Haber Institute/Free University Berlin in 1963, and habilitated at Free University Berlin in 1970, where he soon was appointed full professor in 1971. His doctoral thesis was on passivity and transpassive dissolution of chromium under the supervision of Klaus-Jürgen Vetter, a key founder of rigorous electrochemical kinetics. With Prof. Vetter, he also did his habilitation on the adsorption of redox components and charge transfer. In 1981, he spent a sabbatical at the Lawrence Berkeley Laboratory of the University of California. From this stay emerged one of his most cited papers on the electrochemical properties of metal clusters and their role in surface enhanced Raman scattering [*J. Phys. Chem*, **1982**, *86*, 3166–3170]. In 1992, he moved to Technische Universitaet Dresden where he acted as director of the famous Institute of Physical Chemistry and Electrochemistry. In 2004, he retired from his official duties but he was still very active in science.

He published a series of well-received textbooks on electrochemistry for materials science, metal deposition, and structure formation, as well as about 290 peer-reviewed papers. Furthermore, he was co-author of 25 patents, supervised more than 90 PhD students, and approximately the same number of diploma students.

His research interests were fundamental and applied electrochemistry with a special focus on spectroelectrochemistry and electrochemical phase formation. Our good friend Benedetto Bozzini was inspired so much by a talk of Prof. Plieth on surface enhanced Raman spectroscopy that he also entered this research field. Regarding the mechanism of electrochemical phase formation, Waldfried Plieth developed an atomic-scale theory, which is based on the residence times of the particles at the surface of a growing metal film. This is a very powerful approach that can be applied for tailoring the composition of alloys. He investigated a very broad range of electrochemical systems such as metals, alloys, oxides, composites, and conducting polymers for applications as functional materials, sensors, corrosion protection, and energy harvesting. He always aimed at a good balance between fundamental research, like the atomistic aspects of electrochemical phase formation, and applied topics, like improving the throwing power of a bright nickel-plating bath.

In 2009, he received the Jacobi medal of the German Electroplaters Association (Deutsche Gesellschaft für Oberflächentechnik, DGO) for his pioneering work on the fundamentals of electroplating processes and for the development of innovative processes.

Waldfried Plieth was member of The Electrochemical Society. Since 1987, he was a member of the Electrodeposition Division and Europe Section. Since 2019, Prof. Plieth was an ECS Emeritus Member. Over the years, he had several functions in the International Society of Electrochemistry (ISE) and International Union of Pure and Applied Chemistry (IUPAC). On a national level, he was board member of various science and technology associations.

There was always a great atmosphere in his group with a good balance of experienced researchers, young scientists, and students from all over the world. We have always been intrigued by his broad knowledge of physical chemistry and electrochemistry. Discussing with him has always been a very stimulating experience for us and we invariably left his office with many fresh ideas and full of enthusiasm. His group always benefitted from his excellent international networks and contacts to industry. At every conference, he introduced us to people whose names we so far just knew as the main authors of seminal papers.

He will remain in the memory of the people who knew him personally and through his papers, as one of the electrochemists in Germany writing deep scientific work, being able also to teach electrochemistry with a smile. Here are some quotes that reached us after the sad news of his passing.

From Benedetto Bozzini, Politecnico Milano, Italy
"He had a lovely personality and transferred the impression that the best science can be performed and lived with a gratuitous, benevolent, and smiling attitude."

From Liana Anicai, Polytechnical University Bucharest, Romania
"He was kind and supporting and his attitude induced more confidence in yourself."

From Petr Krtil, J. Heyrovsky Institute of Physical Chemistry, Czech Academy of Sciences
"Waldfried was one of kindest and most generous persons I have encountered in my professional career. I cannot see me being where I am without his continuous support."

From Tetsuya Osaka, ECS President 2013-2014, Prof. Emeritus, Waseda University, Japan
"We enjoyed his warm friendship. Of course, he gave me nice scientific inspiration, but gave us more valuable inspiration how humans should be."

From Mikito Ueda, Professor, Hokkaido University, Sapporo, Japan
"There were a lot of ideas and fun in the research discussions with Prof. Plieth. I will never forget the many precious memories."

Often, he invited the whole group for a barbecue party at his home. And we all remember the delicious dishes that his wife Hildburg prepared. Waldfried Plieth had a passion for good wines, high interest in foreign cultures and countries, and passion for sailing the seas. His visits in Japan stimulated his interest in the fascinating Japanese language that he has been studying over his last years. He was a deeply inspiring person for many generations and an excellent mentor. One could learn a lot from him, in science and for real life. We will miss him greatly.

This notice was contributed by Prof. Plieth's former students Adriana Ispas and Andreas Bund.

In Memoriam ...
Morton Schwartz
1919-2020

Morton Schwartz passed away in February of 2020, at the age of 100. He was born in the Bronx, New York, in 1919, but his family moved to Brooklyn shortly afterwards. His lifelong interest in chemistry began when he was a child. For instance, when he was in school, he appropriated some of his mother's kitchen implements to produce rayon. He attended Indiana University in Bloomington, where he received a BS in 1940, and an MS in 1942. His college career was interrupted by the United States entering into World War II. He was recruited to work on the war effort at Curtiss-Wright in St. Louis.

After the war, Schwartz continued to work in the electroplating industry, and moved from the Midwest to California, where he spent the rest of his life. He worked at various companies. After retiring from private industry, Mort decided to train next-generation electroplaters by serving as a visiting scholar and then a visiting research engineer at the UCLA Electrochemical Laboratory to supervise the research of graduate and postdoctoral students, and visiting professors from other institutions and universities. During this time, he published about 50 peer-reviewed journals and proceeding papers with his students, many published in the *Journal of The Electrochemical Society*. When he was 100, he was still working on a paper and researching articles about electrochemistry.

His professional activities included various positions of the Los Angeles Branch of The American Electroplaters and Surface Finishers Society (AESF), member of the Advisory Committee, and past chairman of the Southern California-Nevada Section of The Electrochemical Society. Schwartz joined ECS in 1943, and was a longtime member of the Electrodeposition Division. He was named ECS Emeritus Member in 2008.

Schwartz had been an instructor/lecturer for numerous short courses on deposition technology, electroplating, and metal finishing for UCLA extension, AESF, and the Continuing Education Institute-USA/Europe. He received the Millhorn Award of the LA Branch, AESF (1973), Metal Finishers Association of Southern California "Man-of-the-Year Award" (1975), and AESF's Leadership (Proctor) and Past Presidents (1993) awards. He was an honorary member of AESF, and emeritus member of the American Society for Metals.

His industrial experience included the preparation of copper-nickel-chromium composite (plated) coatings for ASTM Committee B8's environmental evaluation program (1946-47). He developed commercial processes for: a) the electrodeposition of ferrous metal-tungsten alloys and cobalt-iron-tungsten ternary alloys; b) electrodeposition of coatings containing dispersed (occluded) material such as carbides, graphite, alumina, referred to this process as dispersion/inclusion plating; c) the first low (room) temperature electroless nickel-phosphorus alloy process; d) co-developed (with V. Zentner) an electrodeposited nickel-phosphorus alloy process; e) process and design of an automatic preparation and industrial (hard) chromium plating line of aluminum cylinders for internal combustion engines; and f) investigated and developed cobalt-phosphorus alloys containing iron and/or nickel, zinc for hard magnetic (high coercivity) thin films on aluminum disks for computer memory storage. He also developed marketed products and processes for low-temperature iron and zinc phosphate coatings, descaling of oxides from high-temperature alloys, and various cleaning and etching compositions for metals.

His connection with Los Angeles began when his family moved to California during the Great Depression. It was in Los Angeles that he met the love of his life, Annette. They were married for 69 years until she passed away in 2010. He had an extensive personal library and enjoyed reading both general literature and non-fiction works about science and scientists. His main hobby around the house was woodworking, and he built a number of cabinets and bookcases using his large Shopsmith. He also enjoyed traveling and camping with his family. He and his wife Annette often combined professional conferences with an extensive trip. They once followed a conference in Hawaii with a trip to New Zealand and Australia. Morton Schwartz is survived by his two children, Lennie and Janet.

This notice was contributed by Prof. Nosang V. Myung.

From Dr. Wendy Li

"Mort was a distinguished scholar in the field of electroplating and electrodeposition. His love and passion for science and teaching were contiguous to those around him. He was always very patient with any questions we had and offered help whenever he could. I was fortunate to have Mort Schwartz provide guidance and support during my graduate work at UCLA."

From Dr. David Grimmett

"Mort's in-depth, practical knowledge of electroplating and his positive, encouraging attitude helped all of us in our research. Mort made a difference in many lives and he will be missed."

From Prof. Nosang V. Myung

"Mort is my role model as a researcher and teacher. His true dedication, passion, and hard work towards electrodeposition helped to modernize electroplating. I cannot say how joyful it was when my son and I visited him and discussed electroplating and coordination chemistry. I will truly miss him."

In Memoriam ...

George Edward Thompson

1946-2020

It is with deep sadness that we share the news that our dear friend and colleague, Prof. George Edward Thompson, OBE, DSc, FREng, who passed away after a long illness on December 9, 2020. George was a towering presence in the light metal corrosion and protection field over his long career almost entirely based at UMIST and then at the University of Manchester. His exceptional talents were widely recognized throughout the worldwide corrosion community. His tireless commitment over more than 40 years was key to the success of the UMIST Corrosion and Protection Centre, and underpinned its reputation for excellence, both in the UK and internationally. The major financial support he gained from the UK research councils, the European Union, and industry was critical to its longevity. Of all his achievements, perhaps his greatest, was the opportunity he gave to the many MSc and PhD students and postdoctoral workers, to study with him at the Centre, and afterwards to establish themselves in careers in academia, industry, and elsewhere. He was generous with his time and support. There are many cherished memories that will remain forever in the hearts of everyone he worked with, and these are reflected in the many deeply moving messages of condolence received by his family.

George was born on the March 7, 1946, in Old Swan neighbourhood of Liverpool. He graduated with a first-class honours degree in metallurgy in 1967 at the University of Nottingham. He decided to continue studying under the supervision of Brian Noble, who was just beginning to establish a research group into precipitation in aluminium alloys. A significant part of George's thesis was into alloys containing lithium. This topic would dominate aluminium aerospace alloy research for 20 years thereafter. From the thesis presented in 1970, George and Brian were able to publish six high-quality papers in leading journals. After completing his thesis, George stayed in the department to work on the effects of heat and mass transfer on the corrosion behaviour of selected metals under the supervision of Peter Boden. Throughout his career, George made frequent contact with Brian and Peter, and they made many visits to UMIST to act as examiners of George's PhD students. In 1973, he joined Howson Algraphy, (now Agfa), to do fundamental R&D work and was seconded to the Corrosion and Protection Centre at UMIST. In 1978, he joined the academic staff at the Corrosion and Protection Centre. In 1990, he became Professor of Corrosion Science and Engineering. He served as both Head of the Corrosion and Protection Centre and as Deputy Head of the School of Materials at the University of Manchester.

George wasn't what you'd call self-effacing, but he had every reason not to be as for several decades he was considered by many to be the "go-to" in international academic circles for all things related to aluminium oxidation and corrosion control, particularly for the fundamentals of aluminium oxide growth mechanisms and the use of advanced characterization techniques. By combining tracer and marker techniques with high-resolution transmission electron microscopy, quantitative ion beam analysis, and the use of model alloys, new insights were obtained into ionic transport processes in amorphous and crystalline anodic films; the migration of alloying element species; the enrichment of alloying elements in the substrate that accompanies film growth, and the mechanism of pore formation in porous anodic oxides. Such information provided a sound basis for understanding the effects of alloying elements on anodizing of compositionally complex commercial alloys, in which second phases often have detrimental influences, for instance degrading corrosion protection. He was a world-leading authority in his area, as reflected in his international collaborations across the world and the demand for him as an invited speaker over several decades.

His expertise was not only demonstrated by his academic collaborations, but also in his significant industrial collaborations across the aluminium industry sectors, including aerospace, automotive, and lithography. Notably, indispensable to these achievements was the longstanding collaboration between George and Professors Ken Shimizu and Hiroki Habazaki, at Keio and Hokkaido Universities, which also led to the extension of the approaches used so successfully with aluminium to the study of anodic oxide growth on other metals, such as hafnium, niobium, tantalum, titanium, tungsten, and zirconium.

In addition to his scientific leadership in the aluminium sector, George was also a leading innovator in introducing and developing novel instrumental approaches to material characterization. Equally, beyond the sphere of academic fundamentals, George's role impinged successfully on many industrial collaborations outside of what might be considered his base knowledge; one example being his 3D characterization of semiconductor materials employed in industrial cabling.

George was fully focused on his aluminium studies—his scientific life revolved around Atomic Number 13 (aluminium) practically to the exclusion of all else except, possibly, for magnesium and titanium. That said, George was an amiable companion over many lunches, occasionally drifting off science to discuss the success or otherwise of the Liverpool F.C. More occasionally, he would discuss his latest car purchase—usually a new top-of-the-range BMW—however, his car was rarely seen, because George took the tram to work at the Mill most days. One of the most enduring images that many will have of George is turning up his university office every day with his newspaper sticking out of his jacket pocket. Such seemingly minor images are part of his enduring character.

George's research interests were largely focused on the corrosion and protection of light alloys with applications in the architectural, automotive, aerospace, lithographic, and packaging sectors. He collaborated with many industrial companies, including Alcan, Airbus, Akzo Nobel, Avic, BAE Systems, BIAM, Constellium, CSIRO, Elval, Magnesium Elektron, Novelis, Poeton, Rolls-Royce, and Sapa. He collaborated extensively with scientists in the UK, China, Europe, Japan, and the United States. He made extensive use of electrochemical, electron-optical, surface analytical techniques to develop a deep understanding of the influence of microstructure and composition on corrosion and its control. This successful research was recognized by his appointment as an OBE for research services to the Defence Industries and by election as Fellow of the Royal Academy of Engineering and many other prestigious awards. He received the TP Hoar Award from the Institute of Corrosion and the Kape Memorial Medal (on three occasions) from the Institute of Metal Finishing, both for best papers in journals. He also was awarded the Beilby, European Corrosion, IOM3 Platinum, Sainte-Claire Deville, and Cavallaro medals, and the UR Evans Award, from top International Learned Societies. He was the first UK scientist named Fellow of The Electrochemical Society (1998), and in 2009, received the Distinguished Achievement Medal from the University of Manchester as Researcher of the Year.

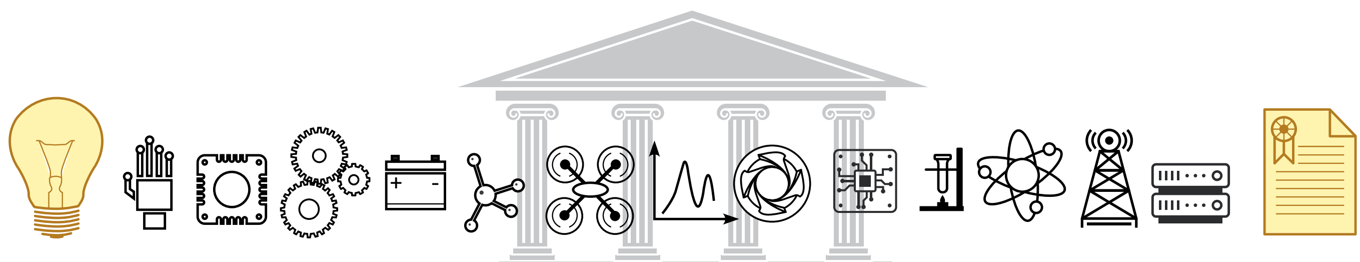
In his final years, George suffered increasingly from the cruel effects of dementia. Despite the toll it took on his mental and physical abilities, he endeavoured to come to the university as often as possible and reminisce about earlier days. The Corrosion and Protection Centre meant so much to his life he could not leave it easily.

George will be sadly missed by his friends, colleagues, and collaborators around the world. Our sincerest condolences go to his wife Marilyn, son James, and daughter Sarah.

This notice was contributed by ©Geoff Scamans, Peter Skeldon, and Xiaorong Zhou. Licensed under CC-BY-NC. The authors thank Prof. Thompson's family, many friends, and colleagues who shared memories of George and his life.

Looking at Patent Law:
Patenting an Electrochemical Nondestructive Corrosion Evaluation System for Ships, Buildings, and Bridges – A Case Study

by E. Jennings Taylor and Maria Inman



In this installment of the "Looking at Patent Law" articles, we present a case study of a system for nondestructive evaluation (NDE) of corrosion on ships, buildings, and bridges. We have chosen this invention to align with the focus of this issue of *Interface* on the ECS Corrosion Division.

Recall from our previous article, the prosecution history (examination record) of a patent application is publicly available in the file wrapper at the U.S. Patent & Trademark Office (USPTO) Patent Application Information Retrieval (PAIR) system. With the USPTO PAIR system as the primary source of information for this case study, we illustrate the prosecution "events" encountered during the examination of U.S. Patent No. 9,835,586; "Portable Electrochemical Cell with Temperature Control and Surface Morphology Independence." The '586 patent issued on December 5, 2017, with co-inventors Ryan C. Dunn, Guy D. Davis, Robert A. Ross, and Paul A. Bell. The patent is assigned to ElectraWatch, Inc. of Charlottesville, VA.

ElectraWatch, Inc. is described as a technology leader in developing and deploying portable NDE probe devices that measure the degree of sensitization (DoS) of aluminum surfaces. Simply stated, DoS is a measure of the extent of precipitation of phases within, and subsequent corrosion of, grain boundaries. While there are a number of techniques for measuring DoS, ElectroWatch uses an electrochemical approach. The portable DoS probe is fast, accurate, and designed for onsite or field measurements. The DoS probe is a NAVSEA05-approved, quantitative NDE alternative to ASTM G67 destructive testing procedure for 5XXX aluminum alloys. The company supports maintenance activities across a broad range of U.S. Navy ships. On May 1, 2018, ElectraWatch, Inc. was purchased by Austal USA as a wholly owned subsidiary. Austal is an advanced ship manufacturer, servicer, and sustainment provider.

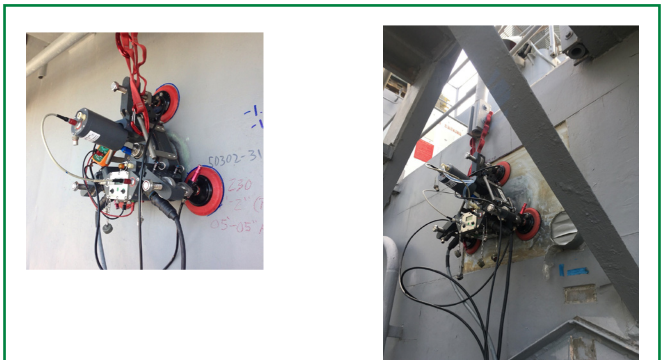


Fig 1. *ElectroWatch DoS probe.*

The DoS probe is pictured in Fig. 1. The '586 patent abstract generally describes the invention as follows.

"The invention comprises portable, rugged, and relatively compact electrochemical cells. Each may be removably and nondestructively secured to one surface of a substrate of indefinite size. In-situ electrochemical measurements may be made on portions of existing structures such as ships, bridges, or buildings. An electrochemical cell is disclosed, which comprises an analytical chamber, which can be utilized with either onboard or external potentiostats. The electrochemical cell has a mounting means, which permits the cell to be secured to substrates with irregular surface morphology and to horizontal, vertical, or intermediately oriented surfaces. The electrochemical cell provides a means to control the temperature of the electrolyte and the substrate area of interest to permit more accuracy and consistent electrochemical measurements. Said probe is capable of performing electrochemical measurements, such as a monitoring corrosion, effectiveness, or integrity of conductive and nonconductive coatings on bare and coated metallic or conductive substrates."

Patent Applications

The patent applications associated with the subject invention are presented in Table I. U.S. provisional Patent Application No. 61/297,947 was filed on January 25, 2010. Subsequently, U.S. utility Patent Application No. 13/522,524 was filed on January 24, 2011.

(continued on next page)

The U.S. utility filing was within one year of the filing date of the provisional patent filing date and thereby maintained the priority date (January 25, 2010) of the provisional patent application. A provisional patent acts as a filing date "placeholder" for the subsequently filed utility patent application and is not examined and does not issue as a patent. The '586 patent is a continuation-in-part (CIP) of U.S. Patent Application No. 13/522,524, now patent number 9,599,588. The '588 patent is more generally directed towards "Portable Electrochemical Cells," issued on March 21, 2017, with the same co-inventors and also assigned to ElectraWatch, Inc. A CIP patent application must be filed during the pendency of an earlier patent application. The CIP repeats a substantial portion of the earlier patent application and adds new content not disclosed in the earlier patent application. The factors leading to the additional patent and application will become evident as we review the prosecution events herein.

Fig. 2 reproduces a figure from the '586 patent that illustrates the electrochemical cell **108** of the subject invention. The figure clearly and distinctly illustrates the elements of the invention. Cell **108** comprises a cylinder **110** that is open at the top end and has sealing means **112** attached to the bottom end. This sealing means may take the form of an O-ring, gasket, or any other suitable sealing means. Ports **114** and **116** are provided for the insertion of a reference electrode and a counter electrode (not shown). These ports are designed such that the port with an electrode inserted therein would be liquid-tight. This sealing means could be accomplished, for example, by the use of a plug that held the electrode therein. The plug could be secured and sealed within port **114** and/or **116** using an O-ring, gasket, screw threads, or any other suitable means.

At least one mounting means **118** is provided to removably and nondestructively secure cell **108** to a surface of substrate **102**. In Fig. 2, a mounting means **118**, and an identical mounting means **118′** are shown. Mounting means **118**, **118′** provide for adjustment of the cell **108** towards and away from substrate **102**. This mounting means allows for the bottom end of cylinder **110** to be electrochemically biased relative to substrate **102** and permits sealing means **112** to seal cell **108** against substrate **102**. Mounting means **118**, **118′** have a generally horizontal attachment arm **120**,**120′** that secures the mounting means to cylinder **110**. In addition, mounting means **118**, **118′** have a generally vertical leg **122**, **122′** to hold securing means **124**,**124′**. As shown, leg **122**,**122′** can move vertically on arm **120**,**120′**. Securing means **124**,**124′** may comprise a suction cup, a magnet, releasable adhesive means, or any other device capable of releasably and nondestructively securing cell **108** to one surface of substrate **102**. Certain applications may be such that only one mounting means **118** is necessary, however, two mounting means **118** will be necessary in many applications, and three mounting means **118** is considered the optimal number for general usage, although more may be provided, as the situation requires. Each mounting means is independently adjustable in the vertical direction. This permits cell **108** to be used on non-planar surfaces.

Fig. 3 reproduces another figure from the '586 patent illustrating a side view of an embodiment of the electrochemical cell **700** of the subject invention. Electrochemical cell **700** is adapted to make electrochemical measurements on horizontal surfaces, sloped surfaces, vertical surfaces, and even on surfaces that are slightly beyond vertical. Cell **700** comprises a base **726**, which has a shape of an irregular hexagon. Obviously, other shapes could be used. Base cover **732** is mounted to the upper portion of base **726**. Also mounted to base **726** are leg base mounts **712**, **712′**, and **712″**. These leg base mounts provide the mounting means for the suction cup assemblies **701**, **701′**, and **701″**.

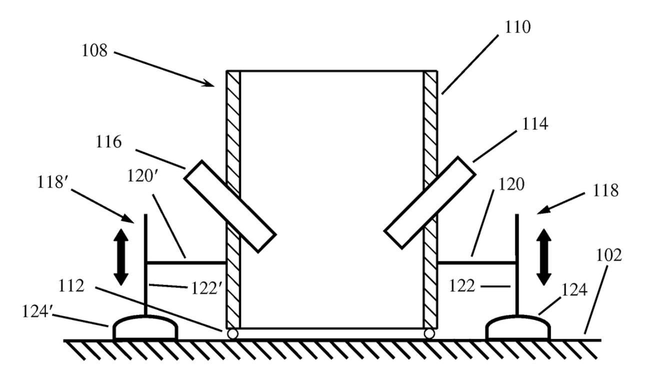


Fig 2. *Figure 4 from '586 patent illustrating the basic electrochemical cell of the subject invention.*

Each suction cup assembly comprises a large bellows-type pneumatic suction cup **703**, **703′**, and **703″** with a coaxial venture **702**, **702′**, and **702″** mounted to the upper portion thereof. Venturi mount assemblies **708**, **708′**, and **708″** attach coaxial venturis **702**, **702′**, and **702″** to adjustment screws **704**, **704′**, and **704″**. Adjustment screws **704**, **704′**, and **704″** are carried in adjustment screw mounts **710**, **710′**, and **710″**. Adjustment nuts **706**, **706′**, and **706″** permit fine height adjustment of adjustment screws **704**, **704′**, and **704″** with respect to the adjustment screw mounts **710**, **710′**, and **710″**.

Adjustment screw mounts **710**, **710′**, and **710″** are attached to base **726** by leg base mounts **712**, **712′**, and **712″**. The means attaching the adjustment screw mounts to the leg base mounts permits a coarse height adjustment of adjustment screw mounts **710**, **710′**, and **710″** with respect to the leg base mounts **712**, **712′**, and **712″** as will be further described below.

An electronics component (not shown in this figure) is attached to base **726** between suction cup assemblies **701** and **701″**. This electronics component comprises a miniature potentiostat and a digital display **736**. The electronics component may also comprise temperature control circuitry, whose function will be further discussed below. In addition, electronics control may interact with one or more electromechanical interlock switches as described below.

Electrolyte tank **716** is mounted to cell **700** at a slight angle to the vertical to avoid problems with air bubbles in the electrolyte solution in the electrochemical analytical chamber **724**, which will be further described below. The particular angle is 10° from the vertical, although other angles obviously may be suitable. Electrolyte tank **716** is connected to base cap **732** by quick-disconnect fittings **718** and **720** and positioned on base cap **732** by means of fluid tank base **714**, **714′**. Fluid tank base **714**, **714′** is mounted on base cap **732** and comprises a curved wing on each side, which receives the outer portion of fluid tank **716**. Reference electrode **729** is mounted on one side of base **726** and slightly angled downwards from the horizontal. This angle is present to avoid problems with air bubbles in the electrochemical analytical chamber **724**.

Table I. Patent Applications and Patents Associated with the Portable Electrochemical Cell with Temperature Control and Surface Morphology Independence Invention.

APPL. TYPE	APPL. No.	PAT. No.	TITLE	FILING DATE	ISSUE DATE
U.S. Provisional	61/297,947	N/A	Portable Electrochemical Cells	Jan. 25, 2010 (Priority Date)	N/A
U.S. Utility	13/522,524	9,599,588	Portable Electrochemical Cells	Jan. 24, 2011	March 21, 2017
U.S. Utility (CIP)	13/561,032	9,835,586	Portable Electrochemical Cells with Temperature Control and Surface Morphology Independence	July 28, 2012	Dec. 5, 2017

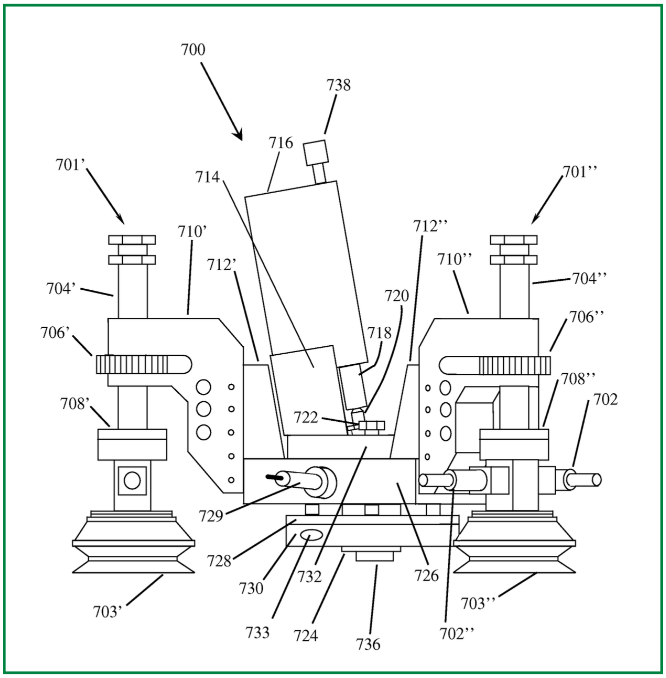


FIG 3. *Figure 23 from the '586 patent illustrating a pulse reverse waveform.*

In order to **establish** a filing date, a utility patent application must include the following.

1. Specification

"…a written description of the invention, and the manner and process for making it…to enable any person skilled in the art…to make and use* [the invention]*…"

2. Minimum of one claim

"…particularly pointing out…the subject matter… as the invention…"

3. Drawings

"…where necessary for understanding the subject matter…to be patented…"

In order to **maintain** the filing date, the following additional criteria are required.

1. Filing fee in accordance with the current USPTO fee schedule.
2. Inventor oath or declaration asserting
   a. The patent application was authorized by the inventor(s),
   b. The inventor(s) believe he/she is the original inventor or they are the original joint inventors.

The '032 patent application was filed on July 28, 2012. The patent application included a specification, claims, drawings, and the required filing fee. Consequently, the '032 patent application met the requirements to **establish** a filing date.

The specification included a description of the prior art, problems within the prior art, a summary of the invention describing various embodiments of the invention addressing the prior art problems, and a detailed description of the invention regarding the compact and portable electrochemical cell. The '032 patent application also included drawings highlighting the elements of "prior art" devices. We have found these prior art drawings are very helpful in educating ourselves as well as the United States Patent & Trademark Office (USPTO) examiner on the novel aspects of the subject invention. The utility patent application contained claims directed towards one statutory patent class: an *apparatus*.

On August 9, 2012, the USPTO notified the applicants that the inventor oath/declaration had not been filed and that failure to do so would result in abandonment of the patent application. The applicants were given two months to respond. On October 9, 2012, the applicants submitted the declaration. The declaration included an assertion by the inventors stating,

"We believe that we are the original and first inventors of the subject matter which is claimed and for which a patent is sought."

The declaration also acknowledged that the inventors were aware of the penalties for a false statement,

"All statements made herein of my/our own knowledge are true, all statements made herein on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like are punishable by fine or imprisonment, or both, under 18 U.S. C. 1001, and may jeopardize the validity of the application or any patent issuing thereon."

Please note that the **"named inventors"** must be correctly represented on a U.S. patent application. Specifically, the *inclusion* of a colleague as a co-inventor who did not participate in the conception of the invention is known as a *misjoinder* and invalidates an otherwise valid patent. Similarly, *exclusion* of a co-inventor who participated in the conception is known as a *nonjoinder* and invalidates an otherwise valid patent. If an inventor is erroneously omitted or erroneously included as an inventor, the *misjoinder/nonjoinder* may be corrected, and the patent remains valid.

With the submission of the inventor oath along with the filing fee provided in the original patent application, the requirements to **maintain** a filing date were fulfilled. On April 16, 2013, the USPTO issued a filing receipt, and the utility patent application was assigned patent application number 13/561,032 with a filing date of July 28, 2012.

Inventor Assignment, Power of Attorney

The assignment of the inventor's rights to ElectraWatch, Inc. was recorded at the USPTO on August 3, 2017. One of the co-inventors, Paul A. Bell, is a registered patent agent (Reg. No. 67,413). The inventors appointed co-inventor Bell as power of attorney

"…to prosecute the application identified above and to transact all business in the United States Patent and Trademark office connected therewith…"

Information Disclosure Statement

Rather than submit a separate "Information Disclosure Statement" (IDS), the applicants included a list of prior art patents within the patent application specification. The applicants stated within the specification that

"These patents involve a variety of different means to detect corrosion or the corrosivity of the environment, including fiber optic measurements, strain gauges, electrical resistance, electrochemical noise, current between two electrodes, and degradation of witness material. Some are valid only for metal surfaces; others only for painted surfaces. None include a self-contained electrochemical cell that directly measures electrochemical properties of the structure of interest, stores the results, and transfers them to a portable computer or similar device."

(continued on next page)

The submission within the specification is unconventional but presumably meets the requirements for an IDS, specifically the submission of background or relevant art or information to the USPTO by the applicants. The "Duty of Candor" requires that the inventor submit an IDS within a reasonable time of submission of the patent application disclosing

"…to the Office* [USPTO] *all information known to that individual to be material to patentability…"

The "Duty of Candor" is specific to any existing claim and requires that the IDS be continually updated while the claim is pending. The "Duty of Candor" ceases only when the claim is allowed and the patent issue fee is paid.

The "Duty of Candor" extends to any individual *associated* with the filing of the patent application including:

1. inventor(s),
2. patent counsel, or
3. persons who are substantially involved in the preparation or prosecution of the patent application.

Substantial involvement in the preparation of the patent application could include technical assistants, collaborators, or colleagues. Substantial involvement would generally not extend to clerical workers. Furthermore, the inclusion of a reference in an IDS

"…is not taken as an admission that the reference is prior art against the claims."

If a finding of a violation of the "Duty of Candor" resulting in "inequitable conduct" regarding any claim in a patent is determined, then all the claims of the subject patent are rendered invalid. Finally, in spite of the requirement of the "Duty of Candor," the applicant is cautioned not to "bury" the examiner with a long list of non-material references in hopes that the examiner will not notice the relevant material references. The specific guidance from the USPTO is to

"…avoid the submission of long lists of documents if it can be avoided…If a long list is submitted, highlight those documents which have been specifically brought to the applicant's attention and/or are known to be of most significance."

Notice of Publication

The USPTO informed the applicants that the '032 patent application would be published on July 25, 2013. U.S. utility patent applications are published 18 months after their priority. The '032 patent application was a continuation-in-part of a foreign patent application filed on January 24, 2011. In addition to the publication of the patent application, the prosecution file became available to the public through the USPTO PAIR system.

Office Actions

In the description of the patent drawings, as well as throughout the specification, abstract, and claims of the '586 patent, the applicants use the term "means" to describe a function of a particular element of the invention. For example,

"…permits sealing means 112 to seal cell 108 against substrate 102."

This "means plus function" language is often used in patent applications. At first glance, means plus function language appears to be a way to obtain a breadth of coverage for the function desired, in this case, "sealing." This assumption is not the case. In a non-final office action dated September 11, 2014, the USPTO examiner cautioned the applicants that

"…Use of the word "means" (or "step for") in a claim with functional language creates a rebuttable presumption that the claim element is to be treated in accordance with 35 U.S.C. 112(f)…"

35 U.S.C §112(f) states

"…An element in a claim for a combination may be expressed as a means or step for performing a specified function without the recital of structure, material, or acts in support thereof, and such claim shall be construed to cover the corresponding structure, material, or acts described in the specification…"

Consequently, when "means plus function" language is used, the "means" is specifically interpreted and limited to the description of the "means" in the specification. The examiner then stated that sealing means, based on the specification, corresponds to

"…O-rings, gaskets…"

The non-final office action also noted that all of the claims were rejected based on obviousness in view of the prior art. The office action stipulated that the period to respond was three months with the possibility of extension for an additional three months.

Abandonment of Patent Application

On March 18, 2015, the USPTO mailed a Notice of Abandonment of the patent application for failure to respond within the six-month period set forth in the non-final office action dated September 11, 2014.

Applicant Response

On December 11, 2015, the applicants responded to the non-final office action dated September 11, 2014. The response included a "Petition for Revival of an Application for Patent Abandoned Unintentionally." Per procedure, the petition included:

1. Petition fee,
2. Reply to the Non-Final Office Action, and
3. Statement that the entire delay was unintentional.

The petition was automatically allowed based on the above.

After several USPTO office actions and applicants' responses, the main independent claim was issued and is reproduced herein.

Claim 1. A compact and portable electrochemical cell for making electrochemical measurements on the surface of a substrate of indefinite size comprising:

A. an analytical chamber with a top and a bottom end;
B. sealing means associated with the bottom end of said chamber to seal said bottom end to one surface of a substrate of indefinite size;
C. means to mount a counter electrode in said analytical chamber;
D. means to mount a reference electrode in said analytical chamber;
E. securing means to removably and nondestructively secure said bottom end of said analytical chamber against one surface of a substrate of indefinite size, said securing means further comprising adjustment means to adjust the distance between said analytical chamber toward the surface of a substrate of indefinite size; and,

wherein said adjustment means further comprises:

a. at least two attachment arms mounted generally perpendicular to the analytical chamber outer surface on opposing sides thereof;

b. a leg mounted generally perpendicular to each said attachment arm, with said leg comprising first and second segments;
c. means permitting the first segment of each said leg to be moved in a first direction perpendicular to said attachment arm;
d. said means also permitting said first segment to be moved in a second direction perpendicular to said attachment arm and in opposition to said first direction; and
e. joining means joining said first and second leg segments, said means comprising a locking universal joint to permit the angle between said first and second leg segments to be widely varied and to lock said segments in position when said angle has been set.

In order to overcome the prior art used in the "obviousness" rejections, the applicants amended the main independent claim by adding limitations (elements) from dependent claims 2 through 8. The deleted content is indicated in **red strikethrough**, and the added content is in **green**.

Claim 1. **(Amended)**

1. A compact and portable electrochemical cell for making electrochemical measurements on the surface of a substrate of indefinite size comprising:
   ~~a~~A. an analytical chamber with a top and a bottom end;
   ~~b~~B. sealing means associated with the bottom end of said chamber to seal said bottom end to one surface of a substrate of indefinite size;
   ~~c~~C. means to mount a counter electrode in said analytical chamber;
   ~~d~~D. means to mount a reference electrode in said analytical chamber;
   ~~e~~E. securing means to removably and nondestructively secure said bottom end of said analytical chamber against one surface of a substrate of indefinite size, said securing means further comprising adjustment means to adjust the distance between said analytical chamber ~~and one surface of a substrate of indefinite size in order to bias said analytical chamber towards the surface of a substrate of indefinite size.~~
~~2. The compact and portable electrochemical cell of claim~~ 1 toward the surface of a substrate of indefinite size; and, wherein said ~~securing~~ adjustment means further comprises ~~one or more suction cups.~~
~~3. The compact and portable electrochemical cell of claim 1 further comprising a first plate closing said bottom end of said analytical chamber, said first plate having an opening therein and with said sealing means surrounding said opening to seal said:~~
   a. at least two attachment arms mounted generally perpendicular to the analytical chamber ~~to one~~outer surface o~~f a substrate of indefinite size~~.
~~4. The compact and portable electrochemical cell of claim 3 wherein said first plate is integral with said bottom end of said analytical chamber.~~
~~5. The compact and portable electrochemical cell of claim 3 further comprising a second plate closing said top end of said analytical chamber.~~
~~6. The compact and portable electrochemical cell of claim 5 further comprising: a. a filling means attached to said analytical chamber; b. a venting means attached to said analytical chamber; c. said filling means permitting introduction of an electrolyte to the interior of said analytical chamber~~n opposing sides thereof;
   b. a leg mounted generally perpendicular to each said attachment arm, with said leg comprising first and second segments;
   c. means permitting the first segment of each said leg to be moved in a first direction perpendicular to said attachment arm;
   d. said ~~venting~~ means also permitting ~~the venting of gases contained in said analytical chamber when an electrolyte is introduced therein; and, e. wherein said second plate is integral with said top end of said analytical chamber.~~
~~7. The compact and portable electrochemical cell of claim 6 wherein: a. said filling means comprises a valve penetrating said second plate; and b. said venting means comprises an air-liquid separator.~~
~~8.~~ said first segment to be moved in a second direction perpendicular to said attachment arm and in opposition to said first direction; and
   e. joining means joining said first and second leg segments, said means comprising a locking universal joint to permit the angle between said first and second leg segments to be widely varied, and to lock said segments in position when said angle has been set.

Allowance of Patent Application

Based on the claim amendments, the USPTO issued a notice of allowance on November 16, 2016. After payment of the issue fee on February 2, 2017, the 13/561,032 patent application issued as U.S. Patent No. 9,835,586 on December 5, 2017.

Continuation in Part

As noted earlier and presented in Table I, the '586 patent is a continuation-in-part (CIP) of the foreign counterpart of U.S. Patent No. 9,599,588 issued on March 21, 2017, to the same inventors and assigned to ElectraWatch, Inc. The CIP 9,835,586 patent repeated a substantial portion of the earlier 9,599,588 patent and added new content not disclosed in the earlier patent application. The new content in the '586 CIP was directed towards the ability to mount the DoS device onto uneven surfaces. The new content in the main independent claim is reproduced here.

Claim 1. A compact and portable electrochemical cell…wherein said adjustment means further comprises:

a. at least two attachment arms mounted generally perpendicular to the analytical chamber outer surface on opposing sides thereof;
b. a leg mounted generally perpendicular to each said attachment arm, with said leg comprising first and second segments;
c. means permitting the first segment of each said leg to be moved in a first direction perpendicular to said attachment arm;
d. said means also permitting said first segment to be moved in a second direction perpendicular to said attachment arm and in opposition to said first direction; and
e. joining means joining said first and second leg segments, said means comprising a locking universal joint to permit the angle between said first and second leg segments to be widely varied, and to lock said segments in position when said angle has been set.

Summary

In this installment of our "Looking at Patent Law" series, we present a case study of the prosecution of U.S. Patent No. 9,835,586; "Portable Electrochemical Cell with Temperature Control and Surface Morphology Independence." We have chosen this invention to align with the focus of this issue of *Interface* on the ECS Corrosion Division. The '586 patent issued on December 5, 2017, with co-inventors Ryan C. Dunn, Guy D. Davis, Robert A. Ross, and Paul A. Bell. The patent is assigned to ElectraWatch, Inc. of Charlottesville,

(continued on next page)

VA. The case study begins with a brief synopsis of the background of the invention followed by 1) a discussion of the patent applications associated with the invention, 2) inventor assignment and power of attorney designations, 3) submission of an information disclosure statement and duty of candor, 4) summary of office actions, 5) abandonment and revival of the patent application, and 6) allowance of the patent application. The applicants made substantial use of "means plus function" language in the abstract, specification, and claims. As noted above, when "means plus function" language is used, the "means" is specifically interpreted and limited to the description of the "means" in the specification. The '586 patent is a continuation-in-part (CIP) of U.S. Patent No. 9,599,588 also assigned to ElectraWatch, Inc. with the same inventors. A CIP '588 patent added additional content or new matter to the earlier '588 patent. With this case study, we hope to demystify the patent prosecution process and better prepare electrochemical and solid state scientists, engineers, and technologists to interact with their patent counsel regarding their inventions.

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Work with ECS: Member for 25 years. Serves ECS as a member of many committees.
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23. 35 U.S.C. §103(a) Conditions for Patentability; non-Obvious Subject Matter.
24. 37 CFR § 1.136(a) Extensions of Time.
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Theoretically Quantifying the Effect of Pre-Lithiation on Energy Densityof Li-Ion Batteries

Pre-lithiation method has been widely accepted in practical lithium-ion batteries (LIBs) as an effective means of compensating initial Li loss during the first charging process and improving Coulombic efficiencies (CEs). The current studies in pre-lithiation area mainly focus on pre-lithiation methods or new electrode materials development. In this work, Jin *et al.* present a mathematical model to quantify the impact of pre-lithiation on the effective specific density of LIBs, and developed a practical guideline for designing high-energy LIBs with imperfect CEs. The model has a few assumptions, including two components of electrode capacity (reversible and irreversible capacities) and irreversible reactions happening only on the anode. Three types of effective specific capacities considering the extra Li source were discussed in the model: effective specific capacities based on the electrode weight, cell weight, and cell volume. These effective specific capacity parameters provide quantitative insight into the effect of pre-lithiation or extra Li source, porosity, and mass density by evaluating an NMC/Si-C LIB system. This work also defined a reduction factor to demonstrate how the effective specific capability of an extra Li source strongly impacted the specific capacity/energy density away from its maximum value.

From: L. Jin, J. Zheng, and J. P. Zheng,
J. Electrochem. Soc.*, **168**, 010532 (2021).*

Corrosion Behavior of High Nickel Alloys in Molten Nitrate Solar Salt

Renewable energy sources, such as wind and solar, often require additional backup energy sources (e.g., fossil fuels) for the intermittent times throughout the day that those sources of energy are unavailable. Concentrated solar power (CSP) is the reflection and concentration of sunlight onto a central point or receiver that contains a heat transfer fluid (HTF) for direct generation of power or storage in a thermal energy storage (TES) medium. CSP with TES alleviates the need for backup energy sources and is a promising form of sustainable energy. Molten salts are being considered for use as both the TES medium and the HTF. However, a critical research need is an understanding of the corrosion behavior of container materials, such as high nickel alloys in these molten salt environments. Recent accelerated electrochemical testing by researchers at the University of Nevada and VDM Metals has demonstrated promising results for a range of high nickel alloys with corrosion current densities on the order of 10^{-4} A cm^{-2} in a solar salt blend. Material characterization of the samples indicated the formation of nickel-chromium-iron oxides, and future work will characterize the potential passivation behavior of these alloys.

From: K. O'Neill, Z. Karmiol, J. Groth, et al.,
J. Electrochem. Soc.*, **168**, 021502 (2021).*

Effects of Cuprous Ion on Electrodeposition of Aluminum from $AlCl_3$-BMIC Ionic Liquid

Aluminum scrap recycling could be made more cost-effective by using electrorefining in chloroaluminate ionic liquids. A team led by Kunming University has reported on the beneficial effect of small amounts of Cu(I) on Al electrodeposition. The amount of Cu(I) was under 1 mm, and the beneficial effect was due to Cu co-electrodeposition. The researchers synthesized $AlCl_3$-BMIC (1-butyl-3-methylimidazolium chloride) and dosed the electrolyte with controlled levels of Cu(I) by anodic oxidation of Cu metal. From this, they demonstrated via cyclic voltammetry that Cu(I) decreased the nucleation overpotential and served as a promoter for Al electrodeposition. Both with and without Cu(I), the electrodeposition of Al followed an instantaneous nucleation mode, but with Cu(I) present, the rate of nucleation of Al greatly increased due to the preferential formation of Cu nuclei upon which Al^{3+} then reduced. This effect also altered the crystallographic orientation of the deposited metal layer and resulted in a more compact deposit with smaller grain size. While Cu impurity was introduced into the Al, the deposits under investigation all remained pure industrial aluminum (>99%). An improved process along these lines could increase the ease of Al scrap recycling.

From: S. Wang, Q. Pei, C. Xu, et al.,
J. Electrochem. Soc.*, **168**, 012502 (2021).*

Demonstration of Electrochemically-Driven CO_2 Separation Using Hydroxide Exchange Membranes

Fuel cells have a critical role to play in decarbonization and Hydroxide Exchange Membrane Fuel Cells (HEMFCs). With good electrochemical kinetics and use of non-noble metal catalysts, they can enable mass-market commercialization. A key challenge with HEMFCs is their sensitivity to ambient CO_2 leading to reduced performance. A team at the University of Delaware led by Prof. Yushan Yan has demonstrated an innovative concept to remove the CO_2 in the air stream. Their approach involves using a stack configuration similar to HEMFCs and running the stack under a very low current. The paper summarizes their work on creating a 1D model, validating this model with experimental results, and then demonstrating the cell performance for 100 hours. Experimental studies included studying the effect of catalyst layer thickness, residence time, pressure drop driven by the flow field design, and the use of a buffer layer between the cathode and the membrane. The researchers found out that the higher residence time and increased volume of hydroxide ionomer in the reaction layers helped improve the CO_2 separation. Based on the insights gleaned, they demonstrated a cell that removed 98% of incoming CO_2.

From: S. Matz, B. P. Setzler, C. M. Weiss, et al.,
J. Electrochem. Soc.*, **168**, 014501 (2021).*

Photocatalytic Application of TiO_2-Loaded Viscose-Based Activated Carbon Fibers Composite Catalyst: Degradation of Low Concentration Formaldehyde and Simultaneous Anti-Microbe

Volatile organic compounds (VOCs) and microbial contamination are two of the main factors affecting indoor air quality. VOCs are emitted as gases, e.g., formaldehyde, from many common products, including paints, cosmetics, and cleaning products. Microbial contamination includes the presence of microbes such as mold, yeast, and other bacteria. Concentrations of VOCs and microbes can be significantly higher indoors, and prolonged exposure may lead to short- and long-term adverse health effects. Innovative solutions are required to tackle these challenges to improve air quality. To that end, the ability of TiO_2-loaded, viscose-based activated carbon fibers (VACFs) to simultaneously degrade low concentration formaldehyde and act as an antimicrobe has been investigated. TiO_2@VACF composites were prepared by facile spray coating of an aqueous solution of anatase TiO_2 onto the surface of VACFs. The formaldehyde conversion rate for VACFs was ~80% under visible light conditions, and the bacteriostasis rate reached ~97%. The VACFs presented in this work have demonstrated promising results for the degradation of formaldehyde. They may also be applied for the degradation of other low-concentration VOCs, such as cyclohexane and nitric oxide.

From: S. Yan, J. Yu, B. Zhu, et al.,
J. Solid State Sci. Technol.*, **10**, 011002 (2021).*

Tech Highlights was prepared by Joshua Gallaway of Northeastern University, Mara Schindelholz of Sandia National Laboratories, David McNulty of Paul Scherrer Institute, Chao (Gilbert) Liu of Shell, Chock Karuppaiah of Vetri Labs, and Donald Pile of EnPower, Inc. Each article highlighted here is available free online. Go to the online version of Tech Highlights in each issue of Interface*, and click on the article summary to take you to the full-text version of the article.*

High-Temperature Corrosion in Advanced Energy Systems

by Dev Chidambaram

Our energy demands will be increasing for the near future due to factors such as population growth, improved standards of living, increased automation, and increased mobility. New power generation systems are being designed to meet this growing demand efficiently. These designs are also being influenced by our desire to meet more of our energy needs using sustainable sources. One of the primary goals of these advanced designs is to improve operational efficiency, which is low at ~35% for thermal power plants. A straightforward method to improve efficiency is by operating the thermal power cycles at higher temperatures of up to 1000°C. Higher temperature operations, in turn, require newer heat transfer fluids such as molten salts, molten metals, or gases. The design criteria for these newer power systems are often limited by the choice of materials that can operate under these harsh environments. All of these demands mean that corrosion scientists need to study, understand, and develop strategies to control corrosion in these newer and harsher environments. This issue of *Interface* aims to provide an overview of some of these corrosion issues, identify promising materials, and highlight the research needs.

The first article, "Corrosion in Advanced Nuclear Reactors," is written by University of Michigan Professors Gary S. Was and Todd R. Allen. The newer Generation IV nuclear reactors have all been designed to improve operational safety, efficiency, economics, and waste management. They are also designed to operate under higher temperatures than our current fleet of light water reactors. They use coolants such as sodium, lead, molten salt, or helium. Thus, it is crucial for us to understand the corrosion behavior of structural materials in these fluids so that the degradation can be controlled and managed. The authors summarize the corrosion concerns in these Gen IV reactors designs.

The second article, "Corrosion in Molten Salts for Solar Thermal Power," authored by Kodi Summers and myself (University of Nevada, Reno), is on the corrosion of materials in molten-salt based concentrating solar power plants (CSP). This article is a natural extension of a section of the previous article that described corrosion in molten salt nuclear reactors. CSPs are attractive because the molten salt can also act as the thermal energy storage system to provide continuous power even when the sun is not shining. Thus, CSPs eliminate the need for expensive secondary energy storage systems. While common CSPs use nitrate salts, the desire to improve efficiency and increase thermal storage leads to considerations for the use of molten chloride and carbonate salts. Corrosion in these salt systems are discussed, and knowledge gaps have been identified.

The third article, "High-Temperature Compatibility of Structural Alloys with Supercritical and Subcritical CO_2," is by Bruce A. Pint of Oak Ridge National Laboratory. The article highlights the current use of steam in power generation and why other high-temperature fluids are needed. Then, the case is made for use of sCO_2 and the concerns arising with its use regarding corrosion at temperatures up to 800°C. The article describes the behavior of various materials and how Ni-based alloys and advanced austenitic stainless steels show promise.

The last article, "Corrosion by Hot CO_2 Gases," by Professors David J. Young and Jianqiang Zhang, University of New South Wales, is on the corrosion experienced by alloys in environments containing hot CO_2 gases. These alloys not only undergo oxidation but also carburization in hot CO_2 environments. This article describes the carburization process and the underlying mechanism. The strategies that have been developed and demonstrated to control carburization are also discussed.

It should be noted that these four articles only provide a preview of corrosion issues in a small set of advanced energy generation systems. The primary goal here is to highlight the corrosion issues and generate excitement about the vast opportunities that exist for further experimental studies. These articles also highlight the scientific challenges in studying corrosion under these harsh environments that may not be common knowledge to others; for example, there are currently no true reference electrodes that can be used for studies in molten salts. Thus, corrosion studies in these environments often use pseudo-reference electrodes. The design of apparatus for such studies is another challenge that the researchers must overcome, as often there are no commercial setups that are available. This situation also means that variations in the design of experiments can greatly affect the results. In many ways, these studies are just the beginning of a long road for us to comprehend the corrosion behavior under these harsh environments to the same level as our current understanding of corrosion in ambient aqueous systems. These challenges are the reason that drives many of us to study these exciting systems. I hope you enjoy these articles and that many of you join the small family of high-temperature corrosion researchers.

© The Electrochemical Society. DOI: 10.1149.2/2.F06212IF.

About the Author

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Research Interest: Electrochemical engineering, corrosion, and spectroscopy.

Work Experience: Goldhaber Distinguished Fellowship and a staff scientist at Brookhaven National Laboratory. In 2009, joined the University of Nevada, Reno. In 2017, promoted to full professor.

Pubs & Patents: 95+ publications, 120+ presentations, and 5 patents.

Awards: ECS Corrosion Division Morris Cohen Graduate Student Award, Hans-Jürgen Engell Prize (ISE)

Work with ECS: Life Member, Corrosion Division Vice-Chair

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Corrosion in Advanced Nuclear Reactors

by Gary S. Was and Todd R. Allen

Commercial nuclear power plants in the United States are light water reactors (LWRs) that use water as a coolant, with temperatures ranging between 280°C and 320°C. Water purity is tightly controlled; nevertheless, the high temperatures expose components in the water circuit to degradation by corrosion by many different types of environmental attack. Uniform corrosion occurs across the entire surface of a material and is prevalent in engineering systems to some extent. Site-specific corrosion processes, such as crevice corrosion, intergranular attack, or galvanic corrosion, are common in complex engineering systems that consist of multiple materials joined by welds or other solid state joining processes. Even within a single component, if second phase strengthening is used or if surface defects are present, localized corrosion can occur.

The history of corrosion in nuclear power plants evolved from early corrosion problems that stemmed from "epidemics" caused by improper water chemistry control, ingress of chlorides that induced pitting in steam turbine discs and blades and pitting and stress corrosion cracking in stainless steel, poor secondary side pH control that resulted in wastage and crevice corrosion in steam generator tubes, and denting of steam generator tubes due to high corrosion rates of tube support plates. Problems were also caused by poor microstructure or alloy chemistry control, such as high corrosion rates of zirconium fuel cladding and stress corrosion cracking (SCC) of stainless steel BWR piping due to sensitization or weld knife-line attack.[1] More recently, corrosion degradation has emerged in the form of stress corrosion cracking of stainless steel steam lines, nickel-based steam generator tubes and reactor vessel head penetrations, flow-assisted corrosion in low alloy steels, and nodular corrosion, shadow corrosion, crud-induced localized corrosion, and fretting of zirconium alloy fuel cladding.[2] For over 60 years, irradiation has played an increasingly important role in accelerating corrosion and in irradiation-assisted stress corrosion cracking (IASCC).[3-5] As plants age, the most important corrosion issues will center around stress corrosion cracking and the role of irradiation in both IASCC and corrosion.

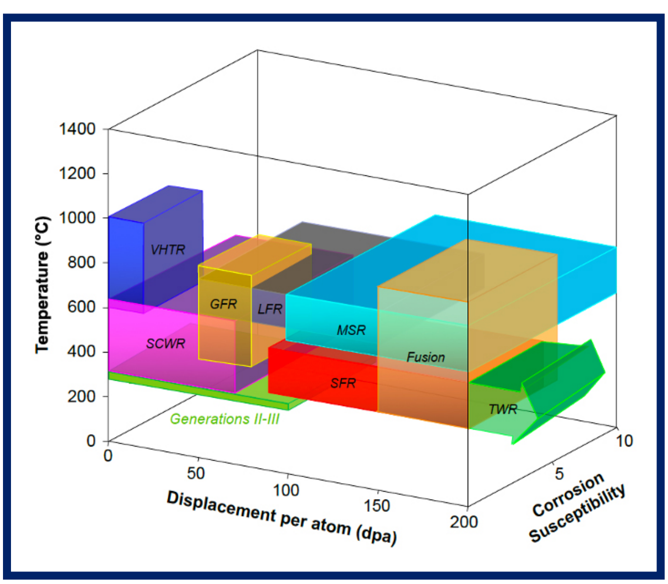

FIG. 1. *Placement of various advanced reactor concepts on scales describing the ranges of values of components of the environment for core materials. VHTR: Very High-Temperature Reactor; SCWR: Supercritical Water Reactor; GFR: Gas Fast Reactor; SFR: Sodium Fast Reactor; LFR: Lead Fast Reactor; MSR: Molten Salt Reactor; TWR: Traveling Wave Reactor; Generations II-III: Current light water reactors.*[7]

The Generation IV program proposed several advanced nuclear reactor designs with the objective of improving the safety, proliferation resistance, economics, and waste management of nuclear systems around the globe.[6] While each concept has perceived advantages, they all operate at higher temperatures and more aggressive radiation environments than current light water reactors. These advanced reactor concepts will use coolants other than water such as helium, sodium, molten salt, or lead, and at much higher temperatures than current generation light water reactors. Since each heat transfer fluid interacts with structural materials, corrosion becomes a major concern for all coolants being considered. The control of corrosion in all of its forms will be critical to the success of these advanced plants. Advanced reactors face even harsher environments, as shown in Fig. 1. The roughly 17,000 reactor years of operating experience with today's light water reactors are completely outside the temperature-damage-environment space of all of the advanced concepts, minimizing the benefit of the many lessons learned. The following summarizes the major corrosion concerns in advanced reactor concepts.

Supercritical Water Reactors (SCWRs)

The design that could benefit most from the knowledge base generated by today's LWRs is the supercritical water reactor that uses water as a coolant at high temperatures and pressures in the supercritical water (SCW) regime, enabling higher efficiency of energy production and a simplified system design. Environmental degradation in supercritical water depends on the formation and long-term stability of protective surface layers on the structural/containment materials. The oxide structure on steels exposed to SCW is similar to what is observed under steam conditions for ferritic and ferritic-martensitic (F-M) steels.[8] The biggest difference with SCW is the higher temperature that creates a higher corrosion rate. Because it is generally accepted that chromia-containing spinels are better permeation barriers to cations (metal) and anions (oxygen, OH, etc.) relative to iron oxides,[9] it is the inner oxide layer that can provide the best corrosion resistance in the SCW environment. This has been observed in recent work on steels under nuclear SCW conditions[10-12] in terms of increasing corrosion resistance with an increasing chromium content of the alloy. Fig. 2 shows that nickel-based alloys have the greatest resistance to oxidation in SCW, followed by austenitic stainless steels and then ferritic-martensitic alloys.

The most daunting challenge for materials in the SCW environment is resistance to SCC and IASCC. The very alloys that are most resistant to corrosion in SCW (nickel-based alloys and austenitic stainless steels) are susceptible to SCC. Fig. 3a shows that SCC severity increases exponentially with temperature in two stainless steels (304L, 316L) and two nickel-based alloys (625, 690).[10] Over this same temperature range, ferritic-martensitic alloys are resistant to SCC.[10,14] Irradiation significantly increases the extent of SCC in stainless steels and nickel-based alloys.[15,16] Fig. 3b shows the effect of irradiation on IG cracking of three stainless steel alloys (D9, 316L, 800H) and Ni-based alloy 690 relative to the unirradiated cases. Over the same irradiation and testing conditions, ferritic-martensitic alloys were found to be resistant to cracking. So austenitic alloys are most resistant to oxidation but susceptible to both SCC and IASCC, and ferritic-martensitic alloys exhibit significantly higher oxidation rates but are resistant to SCC and IASCC in SCW. As such, much development will be required to overcome the SCC susceptibility of austenitic alloys or the high corrosion rates of ferritic-martensitic alloys.

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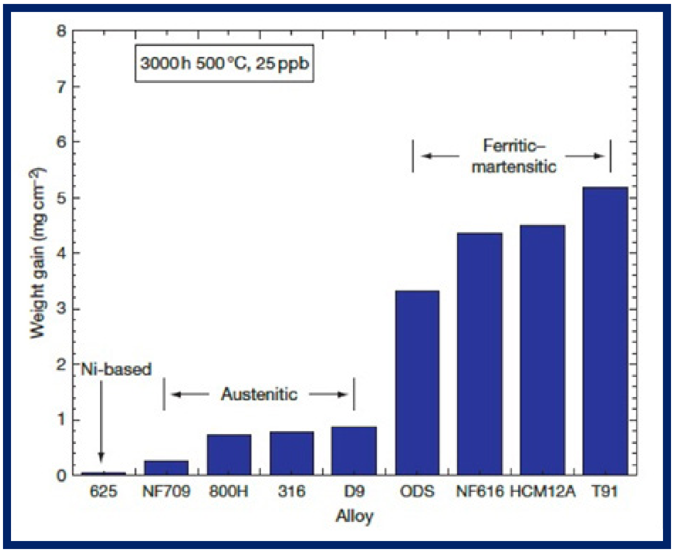

FIG. 2. *Oxide weight gain in nickel-based, iron-based austenitic, and ferritic-martensitic alloys at 500°C.*[13]

Liquid Metal Cooled Reactors (SFRs and LFRs)

Because of their excellent heat transfer ability, liquid metals such as lead alloys and sodium alloys have been proposed as coolants for advanced reactors.[17,18] Sodium alloys were selected in most of the international fast reactor programs, including the U.S. EBR-II reactor, which ran as an experimental facility in Idaho for 30 years and the BN-800 commercial facility currently running in Russia. Sodium was chosen for a combination of its high heat transferability, its ability to support a fast neutron spectrum in a low-pressure system, and its relatively benign corrosion of stainless steel. The use of sodium is challenged by its high reactivity with oxygen, making coolant leaks problematic as seen in the operational challenges and eventual closure of the MONJU reactor in Japan. The use of lead alloys as a reactor coolant, primarily lead and lead-bismuth eutectic alloys, has primarily been developed in Russia (and the former Soviet Union). Lead has the ability to operate at higher temperatures than sodium and does not react with atmospheric oxygen. Compared to sodium, lead is a more corrosive environment for structural steel materials of construction.

Sodium Fast Reactors (SFRs)

In the early days of nuclear reactor development, a significant development effort was conducted on sodium-cooled reactors with a full recycle ability for reactor fuel.[19] The fast spectrum ability of a sodium-cooled system was seen as a necessity in optimizing the use of what was then thought to be a scarce uranium fuel resource. Later the advantages of a fast spectrum towards minimizing waste through transmutation were considered. To date, 10 test fast reactors and six commercial-size prototypes of varying sizes have been constructed and operated.[17]

Sodium is useful as a coolant for many reasons.[20] A large heat capacity and thermal conductivity make it an excellent heat conductor. Its low vapor pressure and high boiling point allow for a non-pressurized system, thus minimizing any consequences to the reactor fuel from a reactor coolant leak. Most reactor structural components in sodium-cooled reactors were constructed from austenitic stainless steel such as alloy 316.

Corrosion occurs in liquid sodium either through the dissolution of alloying element into the sodium or reactions with impurities in the sodium, notably oxygen and carbon.[20-23] Like corrosion in many systems; both general dissolution/oxidation and site-specific attack are possible. In a typical engineering system where the sodium moves through a temperature gradient, material can be transported through hot-leg dissolution and subsequent cold-leg deposition. Finally, where dissimilar metals are used in construction, material transport can occur through the correlated corrosion processes at each of the metals. These materials transport reactions may be missed in simple static corrosion tests so a true understanding of the corrosion response, which then supports acceptable material performance, must be obtained through appropriate test plans.

Cr, Ni, Mn, Mo, and Si are the primary alloying elements from stainless steel that can dissolve into the liquid sodium. Mn, Ni, and Mo are more soluble in sodium than Cr and Fe and will have higher dissolution rates. The loss of Mn and Ni can lead to a transition from the austenitic phase to a ferritic phase near the surface since these two elements stabilize the austenitic phase.[21] The total amount of ferritic phase formed then is determined by the rate at which these austenite stabilizing elements can diffuse to the surface and their local

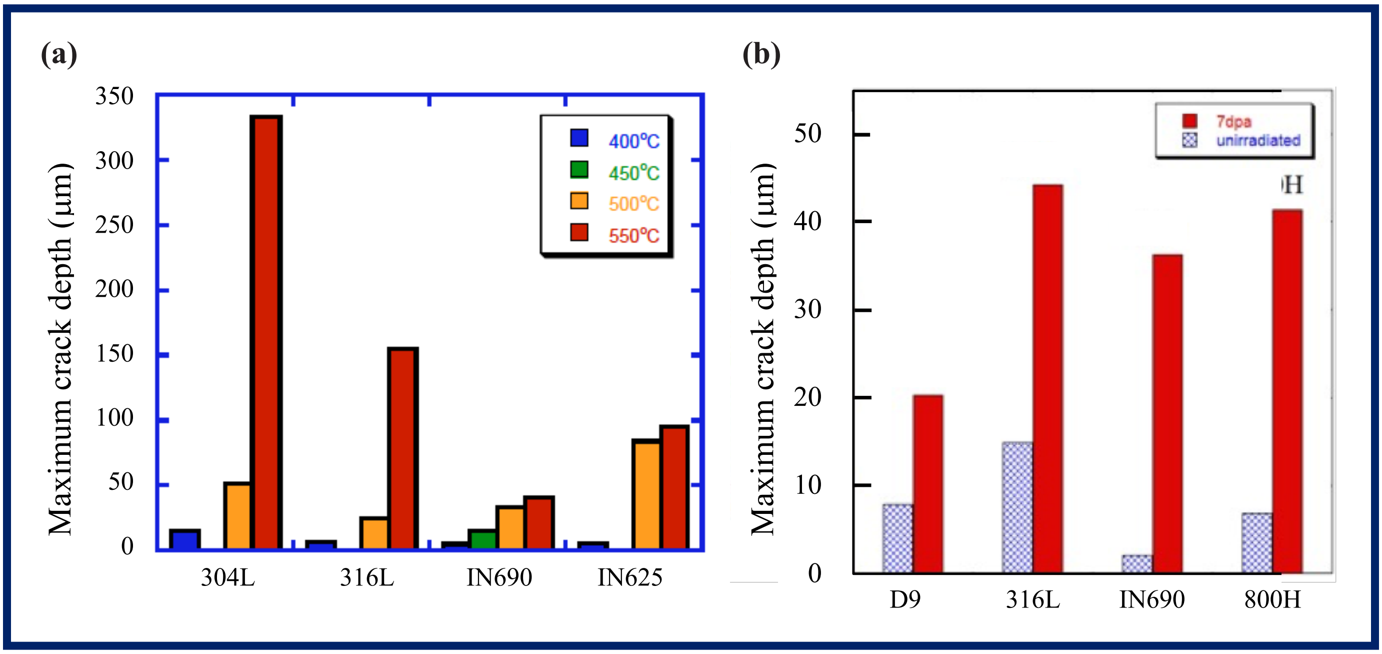

FIG. 3. *a) Temperature dependence of SCC crack depth in two stainless steel and two nickel-based alloys tested in constant extension rate tests, and b) effect of irradiation on crack depth in three stainless steel alloys and one nickel-based alloy.*

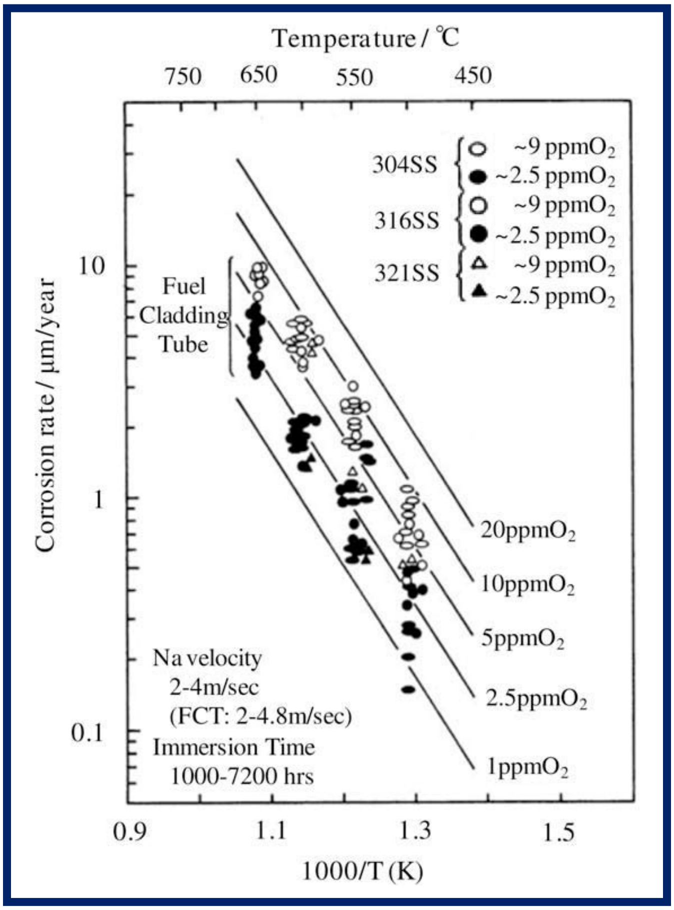

Fig. 4. *Corrosion rate of austenitic steels in sodium*.[24]

concentrations in the sodium-coolant as compared to their solubility in the sodium. The formation of this ferrite layer occurs early in the operation of the system, after which the primary general corrosion response is dominated by interactions between the structural steel and any oxygen in the system.

Fig. 4 demonstrates the importance of oxygen concentration in the sodium and temperature of the sodium on the overall oxidation rates, with similar trends seen for three different austenitic stainless steel. Minimizing the general corrosion during operation depends on an oxygen gettering system to keep the oxygen sodium minimized since stable protective oxides are not formed in a liquid sodium system. While not demonstrated in Fig. 4, flow velocity also affects the overall corrosion rates.

The specific oxides that will form depend on the free energy of the formation of oxides in with sodium, enhanced or mitigated by the local flow conditions. Three specific examples at typical sodium operating temperatures demonstrate the following effects.[20]

- **Retain in the metal**: Molybdenum has limited solubility in sodium and also is not a strong oxide former and tends to stay in the structural steel.
- **Oxide former**: Chromium tends to form a $NaCrO_2$ oxide, which is more likely as the oxygen concentration in the sodium increases.
- **Dissolution**: Nickel oxides are not thermodynamically stable, so any nickel loss from the metal occurs due to dissolution.

One final important aspect of dissolution in a sodium-cooled reactor is material transport through a temperature gradient. Elements of the steel with high solubility can dissolve into the coolant at high-temperature regions of the system and then deposit on metal surfaces in colder parts of the system.[25,26] The elements that can be transported include the primary metallic elements of the steel and also carbon in the steel. This leaching and deposition can possibly change the properties

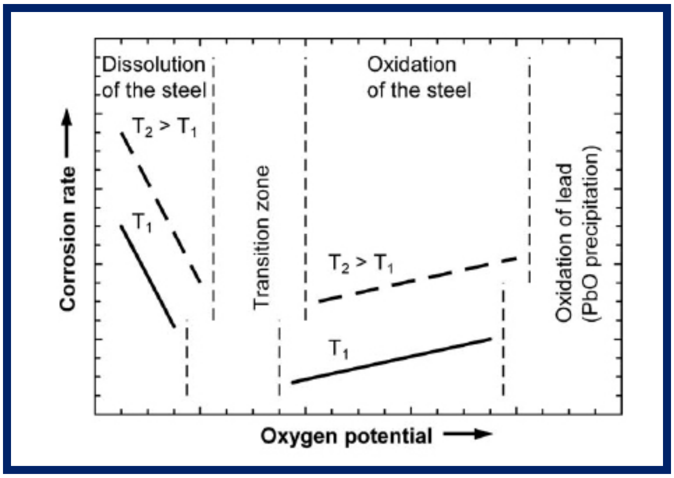

Fig. 5. *Qualitative performance of steels as a function of oxygen potential in liquid lead alloys*.[25]

of the steel if enough material is transported, for instance, thinning the steel and reducing its ability to carry a load or creating new phases (for instance, carbides formed via decarburization in a hotter location and carburization in a cooler region) that change material properties.[17] Other concerns would be the transport of radioactivity or flow blockages if material transported clusters into narrow flow regions.

Lead Fast Reactors (LFRs)

Like sodium-cooled reactors, reactors cooled with either lead or a lead-bismuth eutectic are designed to operate in a fast neutron spectrum. Designers of these systems point to two possible advantages over sodium as a coolant. The lead systems have a much higher boiling point, meaning they potentially can operate at higher temperatures, leading to a more thermodynamically efficient system. Additionally, lead alloys do not react exothermically with oxygen, as does sodium. This should make operating a lead-cooled reactor simpler than operating a sodium system. The negative tradeoffs with lead and lead-alloys as a coolant are more weight from the heavier lead, operational challenges associated with polonium production from bismuth in the lead-bismuth eutectic, and greater corrosivity.

Unlike sodium, stable oxides can be formed in the lead and lead alloy systems. The key then to operating a lead-cooled system is to create stable protective oxides that protect the structural steels by preventing dissolution of metals into the liquid metal. Creating these stable oxides is possible through careful control of the oxygen in the liquid lead system, a task that is more difficult as the temperature of the system increases. A minimum level of oxygen is required to form protective oxides but low enough to prevent the formation of lead oxide in the coolant. As an example, an oxygen concentration of approximately 10^{-6} mass percentage at temperatures near 550°C will establish a protective oxide in the liquid lead. For a lead-bismuth eutectic coolant, a higher oxygen concentration is required.[27] This balance between necessary and excessive amount of oxygen in the coolant can be seen in Fig. 5. At lower temperatures, roughly 300-470°C, protective oxide films can be formed on both austenitic and ferritic-martensitic steels.

At temperatures between 470-550°C, the oxides start to transition from a protective oxide to being unstable. At higher temperature above 550°C, the oxides formed on steels in lead-cooled systems are not as protective, potentially limiting the ability to operate at high temperature. Oxides formed on austenitic stainless steels dissolve into the coolant at these high temperatures. Oxides formed on ferritic-martensitic steels grow very thick and become unstable, exposing the fresh metal to attack. A study by Furukawa identified a magnetite to wustite transition at higher temperatures, with the wustite being less stable.[28] For those temperature ranges where a protective oxide can be formed, mass transport due to temperature differentials is not an issue like seen in sodium-cooled systems.

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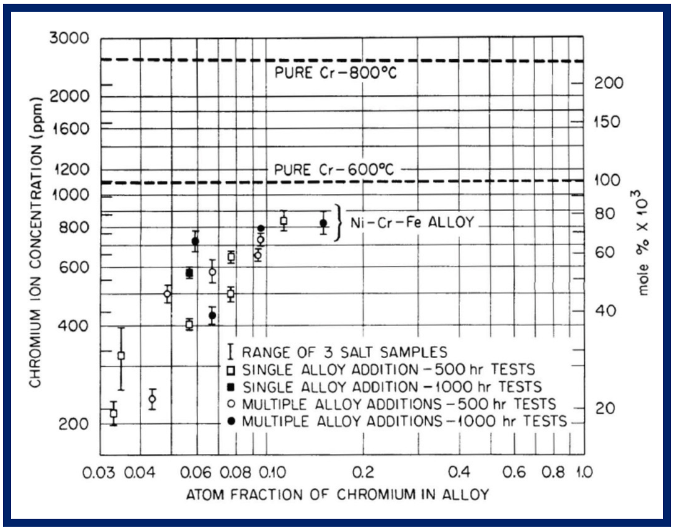

Fig. 6. *Chromium concentration of fluoride salt circulated in thermal-convection loops as a function of chromium content of the loop. Salt Mixture: NaF-LiF-KF-UF_4 (11.2-45.3-41.0-2.5 mole %). Loop temperature: hot leg (815°C), cold leg (650°C).*[30]

Molten Salt Reactors (MSRs)

Reactors that use molten salts come in two varieties. The earliest, and most common concepts, dissolve the fuel into the salt, creating a system where the fuel becomes an integral part of the coolant. There have recently been proposed a few new concepts with more traditional solid fuel pins using the salts as a reactor coolant. Molten salt reactors can operate at atmospheric pressure, simplifying the number of systems by eliminating accidents where the coolant is rapidly lost due to a coolant leak at high pressure. Salts have been considered as both the coolants in the primary system but also as coolants in secondary heat exchangers and recently as thermal storage for providing flexibility in the manner a reactor delivers energy to users. Different applications may choose a different salt, balancing a number of properties, including cost, thermal conductivity, heat capacity, melting point, viscosity, and density.[29]

Corrosion in molten salts differs fundamentally from that in water, or other oxidizing environments in that fluoride salts will dissolve oxides. Thus, corrosion prevention relies on minimizing the dissolution of alloying elements. The dissolution is driven by the free energy of the formation of specific compounds. As shown in Fig. 6, chromium dissolution occurs readily in molten salts, with chromium loss to the fluoride melt increasing as the alloying content of chromium increases. With dissolution being a driver for metal loss, preferential diffusion along microstructural features can be a path for selective dissolution. Fig. 7 provides an example, showing depletion of chromium along grain boundaries where the boundaries are a fast diffusion pathway for the chromium to travel from the bulk to the surface of the metal.

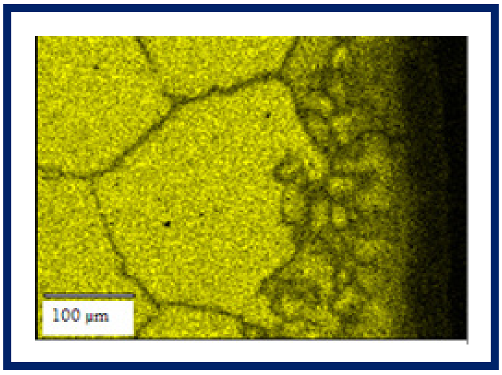

Fig. 7. *EDS map of chromium concentration in a cross section of Alloy 800H exposed to FLiNaK for 500 hours at 850°C. The chromium dissolves from the surface and along connected grain boundary pathways.*[31]

Like in sodium systems, metallic ions can be transported from hot leg to cold leg in a system through selective dissolution with subsequent deposition.[21,32,33] Similarly, a potential corrosion difference between different metals in contact with common salt can also lead to transport. As a simple example, in capsule experiments using a graphite container while exposing metallic samples to high-temperature fluoride salt, chromium has been seen to transport from sample to container walls.[31] Another example of potential issues with material transport is the creation of fission products in the salt which subsequently deposit on the metal surface and potentially form embrittling compounds at grain boundaries.[34] Alloy development and salt composition control have both been proposed as mitigating pathways.

Because metal loss in a salt system is due to dissolution, controlling the metal loss can be performed through redox control.[20] Additions can be made to the salt. For example, adding beryllium to control the fluoride potential in the salt FLiBe,[35] or using the multiple valence states of uranium in a fueled salt. Both techniques have shown the ability to mitigate metal dissolution.

Finally, like in sodium systems, cleanliness is important. Impurities, notably water or oxygen in the salt, have been shown to increase corrosion in fluoride salt systems. Water in the salt can promote the formation of HF, which accelerates further corrosion reactions. Successful operation of a salt-cooled system will require strong systems and protocols to maintain cleanliness.

Very High-Temperature Reactors (VHTRs)

A leading advanced nuclear reactor concept is the Very High-Temperature Reactor (VHTR). High efficiency of electricity production (>50%), high service lifetime (>60 years), combined with a broad range of process heat applications, such as hydrogen production, distinguish it from other "Generation IV" nuclear reactor systems.[36-38] In this concept, helium gas with outlet temperatures in the 850-1000°C range will pass through an intermediate heat exchanger and transfer heat to a secondary coolant. Such temperatures require the use of nickel-based alloys rich in chromium (about 22 wt.%) and strengthened by additions of Mo, Co, and W. For example, Inconel 617 and Haynes 230®.[39]

While He is inert, the coolant of a VHTR inevitably contains parts per million (ppm) level of CO, CO_2, H_2, H_2O, and CH_4 as impurities, which arise mainly from reactions between the hot graphite core and in-leakage of O_2, N_2, and water vapor from seals, welds, and degassing of reactor materials such as fuel, thermal insulation, and in-core structural materials.[40,41] Depending on the impurity concentration, temperature, and alloy composition, the impurities react with the

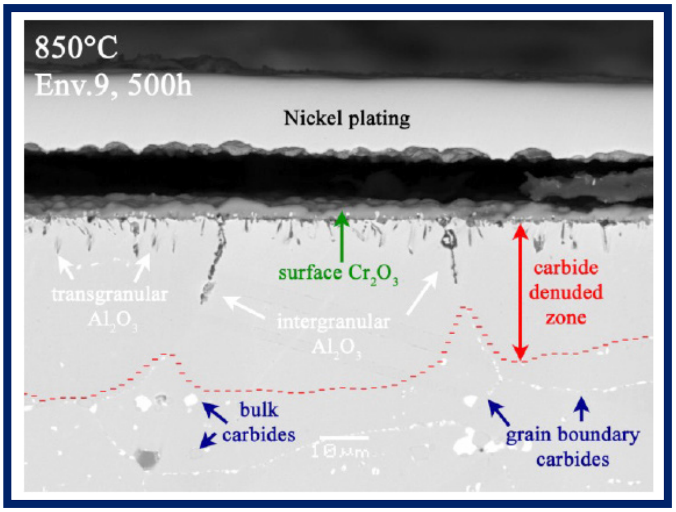

Fig. 8. *Backscattered electron image of the surface microstructure of alloy 617 oxidized at 850°C for 500hr in He containing CO/CO_2 = 9.*[42]

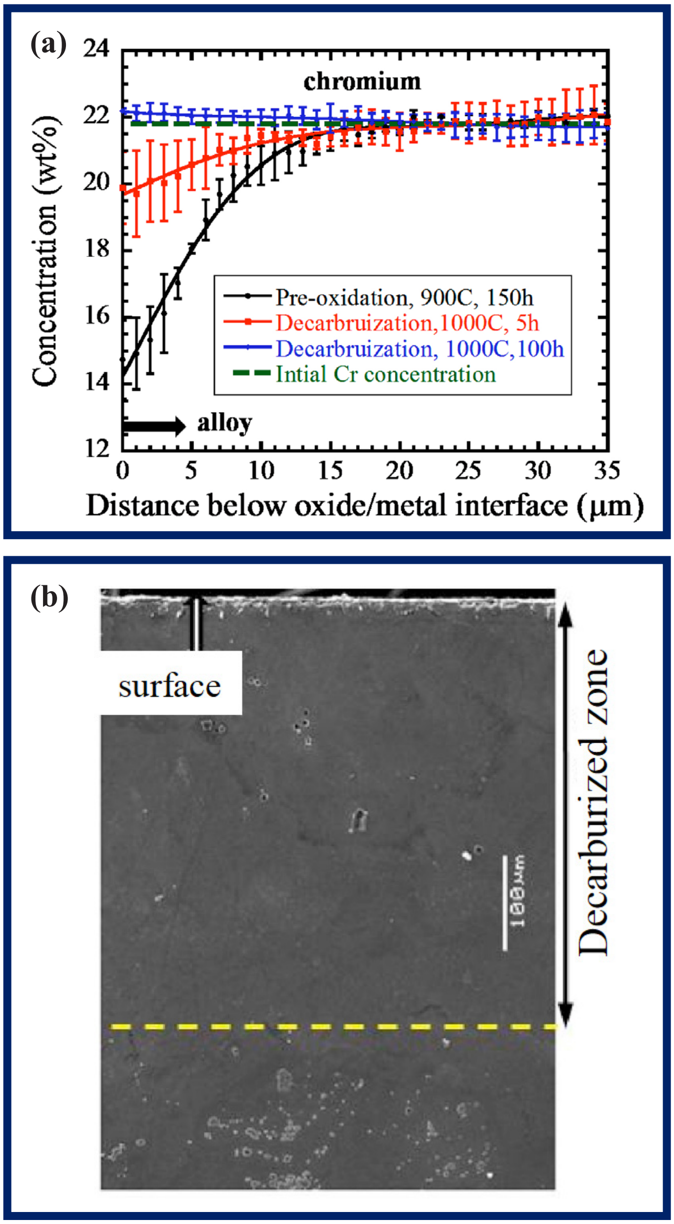

Fig. 9. *a) Concentration profile of Cr near the surface of alloy 617 pre-oxidized at 900°C for 150 h and decarburized for 5 h and 100 h at 1000°C in He containing CO and CO_2 in the ratio CO/CO_2=9; b) carbide structure after exposure for 100 h at 1000°C.*[43]

metallic surfaces of the heat exchanger resulting in oxide formation or reduction and/or carburization or decarburization. Chromium is oxidized at oxygen partial pressures above a critical value and is reduced at partial pressures below this value. Similarly, chromium carbide is stable above a critical carbon activity, and decarburization is expected to occur below the critical value. Oxidation, decarburization, and carburization are processes that can degrade the mechanical properties of the alloy. Oxidation of Ni-Cr alloys in impure helium is governed by the competition between two reactions: Cr with water vapor and Cr with CO_2. Fig. 8 shows a chromium oxide scale on a sample of alloy 617 exposed to He containing CO and CO_2 in the ratio CO/CO_2 = 9 for 500 hr at 1000°C. The rate of growth of the oxide is parabolic in time, most likely indicating solid state diffusion control. The second mode of oxidation is internal oxidation of Al just below the surface at both intra- and intergranular locations. Deeply penetrating "finger-like" internal oxides also occur, and this mode of degradation becomes more significant relative to surface oxidation at temperatures below 850°C. While alumina is a very stable oxide, the Al concentration is below the level that can support a continuous oxide layer.

A coarse and semi-continuous film of carbides forms along the grain boundaries during carburization and may act as a preferential crack initiation and propagation path that could decrease the operating life of the alloy. Exposure to helium with a high CO partial pressure or containing methane produces carburization and prevents an oxide film from forming (or reduces an existing one). If the CO/CO_2 is high enough, surface and bulk carburization of the samples occurs. The surface carbide, Cr_7C_3, is metastable and nucleated due to preferential adsorption of carbon on the chromia surface. The Cr_7C_3 precipitates grow at the gas/scale interface via outward diffusion of Cr cations through the chromia scale until the activity of Cr at the reaction site falls below a critical value. The decrease in the activity of chromium triggers a reaction between chromia and carbide that results in a porous surface scale.

Decarburization of the alloy can occur by a reaction involving chromia and chromium carbides to produce CO, thus decarburizing the alloy. The consumption of Cr by oxidation leads to Cr depletion below the film, resulting in carbide dissolution. Fig. 9 shows the chromium-depleted region below the chromium oxide layer and the resulting decarburization, noted by the disappearance of carbides near the surface. The dissolution of carbides can have a dramatic and deleterious effect on the creep rupture life.[44]

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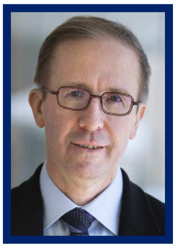

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Corrosion in Molten Salts for Solar Thermal Power

by Kodi Summers and Dev Chidambaram

Global energy needs continue to grow steadily with increasing population and standard of living. While fossil fuels have been a major source of our energy, they are no longer favorable due to their greenhouse gas emissions and atmospheric pollution; the development of carbon-free sources of energy is crucial. Solar energy promises unlimited amounts of emissions-free energy but suffers from intermittency issues that require expensive secondary energy storage systems to act as baseload power. A thermal energy storage (TES) system can store heat and provide a continuous source of power. Concentrated solar power (CSP) is carbon-free and can ideally be combined with a TES system to provide continuous power. These combined systems operate by focusing a large area of sunlight onto a receiver that contains a TES material to convert the sunlight into thermal energy. Thermal energy can be stored as either sensible heat, latent heat, or thermochemical heat. A heat transfer fluid (HTF) is utilized, sometimes in conjunction with a heat exchanger system, to drive a Rankine cycle heat engine (a turbine) to generate electricity, as shown in Fig. 1. In commonly installed configurations, the molten salt acts as the primary TES/HTF and is stored in two separate tanks for the cold leg and the hot leg.

The efficiency of a heat engine is limited by Carnot's theorem:

$$\eta_{max} = 1 - (T_c/T_h)$$

where η_{max} is the maximum theoretical efficiency, and T_c and T_h are absolute temperatures of the cold and hot reservoirs. Thus, increasing the operating temperature (T_h) will improve maximum efficiency and is a major focus of current studies. Additionally, an increased outlet temperature will reduce the amount of HTF required. An ideal HTF would have a very high boiling point, low vapor pressure, high heat capacity, high thermal conductivity, thermochemical stability during repeated temperature cycling, and not be corrosive to the systems carrying the fluid. Various materials can be used as HTF, including water, oil, and molten salts.

Molten salts systems have been considered as HTFs for over 60 years[1] and studied extensively for CSP systems since the 1980s[2] as they inherently meet many of the desirable HTF characteristics mentioned. Due to these properties, molten salts can operate at high temperatures while remaining at or near atmospheric pressure, lowering the cost of pressure vessels and other handling components. Additionally, molten salts also have excellent physical properties for heat transfer, storage, and fluid flow in these environments. While initial studies and most existing power plants use molten nitrate salts, the push to higher operating temperatures has led to consideration of chlorides and carbonates based salts. This article will discuss the general understanding of the corrosion behavior in these media.

Corrosion in Molten Nitrate Salts

In 1982, Sandia National Laboratory (SNL) conducted the Molten Salt Electric Experiment (MSEE) that used molten nitrate salt as TES/HTF to produce electricity. While pure alkali nitrate salts have higher melting points, combining nitrate salts with different alkali cations leads to a reduction in melting point. Because these were initial studies, the focus was more on proof of principle and design, which is easier to accomplish with a low melting salt. Hence, lower temperature salts and low-cost materials were originally preferred. A common molten nitrate salt mixture was a composition of 53% KNO_3, 7% $NaNO_3$, and 40% $NaNO_2$ (by weight), known as HITEC, which has an extremely low melting point of 143°C.[3] However, the cost of producing the HITEC salt was not economical due to the high proportions of $NaNO_2$. Therefore, a composition of 60% $NaNO_3$ and 40% KNO_3 ultimately became the popular choice.[3,4] The elimination of $NaNO_2$ along with the reduction in the proportion of KNO_3 meant significant savings that outweighed the downsides of working with a higher melting HTF.[4]

The MSEE program sought to qualify the 40/60 wt% KNO_3/$NaNO_3$ alkali molten nitrate salt mixture as an HTF and for TES for use in CSP plants. The long-term feasibility of an HTF and, by extension, its use in a TES sytem, is based on its thermochemical stability under operating conditions. Molten nitrate salts may undergo chemical changes due to the cyclic heating nature of an HTF and the composition of the cover gas in the system. The most prevalent reaction that nitrate salts undergo is the decomposition of the nitrate anion into nitrite (NO_2^-) and oxygen, which was determined to be mitigated by a cover gas of air at standard conditions.[4-6] The oxygen partial pressure of the cover gas along with the temperature dependence of the decomposition reaction influenced the rate at which nitrite was formed. As expected, an increase in temperature and/or a decrease in oxygen partial pressure in the cover gas resulted in an increased rate of decomposition.[7] Despite the formation of oxide ions as a result of nitrate decomposition; a study determined that the concentration of dissolved oxide ions was not significant.[7]

Corrosion of structural components in molten nitrate salts is an important aspect to consider when qualifying an HTF-alloy combination for operation. The electrochemical reactions that occur at the interface of the molten nitrate salt HTF and the structural alloy modify the composition and properties of the alloy surface. Because electrochemical reactions are coupled reduction-oxidation reactions, the molten nitrate salt HTF will also undergo a compositional change. However, the volume of the HTF is much larger than the surface area of the structural components, and its influence on the alloy is more significant than the alloy's influence on the molten nitrate salt. Therefore, the selection of the alloy in contact with the molten nitrate salt is important to ensure that a protective, adherent oxide layer is formed that will slow the corrosion rate of the alloy. As if the high-temperature, oxidizing environment was not enough to contend with, the corrosion resistance of alloys is significantly influenced by

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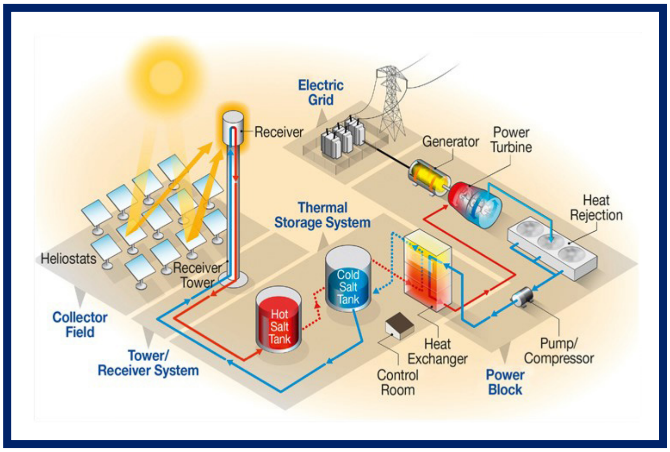

Fig. 1: *Schematic of a solar thermal power system. (Courtesy of the U.S. Department of Energy.)*

the level of impurities in the salt mixture. Due to the hygroscopic nature of molten nitrate salts, the most common impurity is water, and its presence significantly impacts the corrosion performance of most alloys. The oxidation rate of iron immersed in wet $NaNO_3$ and KNO_3 increased by 45% and 11% compared to their dry counterparts, respectively.[8] Similar to aqueous corrosion, the presence of sodium chloride can lead to pitting in mild steels at elevated concentrations.[9]

Various alloys have been subjected to electrochemical studies in molten nitrate salt mixtures to understand the mechanisms of corrosion. The passivation of iron in molten nitrate and nitrite salts has been studied extensively in order to understand the mechanism of iron oxidation. Studies have shown that the formation of oxide ions occurs in the presence of iron, leading to the proposed mechanism shown in Fig. 2.[5,9,10] Electrochemistry has also been used to understand the variable composition of the molten salt due to the thermal decomposition that occurs at high temperatures.[11-14] In addition to electrochemical studies, there have been numerous long-term exposure studies on the corrosion properties of Incoloy 800, SS304, and SS316 in the operating ranges of 300 to 600ºC.[4,15,16] Some key aspects of these long-term exposure studies revealed that some alloys such as Incoloy 800 and aluminized steels saw very little corrosion, while stainless steels corroded at a rate of 6-15 µm/year.[4,17,18] Chemical analysis of molten nitrate salts following long-term exposure studies with alloys containing chromium showed that chromium dissolves significantly in these salts up to the solubility limit.[4] The solubility of Cr corroborates findings that corrosion of Fe-Cr-Ni steel alloys in thermal convection loops exposed to thermal cycling exhibits a three-layer corrosion film consisting of a Cr-depleted outer layer, a Fe and Cr-rich oxide mid-layer, and a Ni-rich in contact with the base metal.[16,18-21] Several studies of the oxide layer formed on Fe-Cr-Ni alloy systems generally show the formation of Fe-Cr spinels in duplex and/or triplex films with the formation of Ni-Fe-Cr oxide phases at the surface.[17-19,22-25] High Ni-content alloys, such as Incoloy 800H, form a thicker Ni-Fe spinel compared to stainless and carbon steels as the Ni in the spinel composition are correlated to the Ni content of the alloy.[19,20]

Corrosion in Molten Chloride Salts

The advantage of molten salts for CSP plants is the ability to increase the Carnot efficiency of power generation. Additionally, integrating a Brayton power cycle that uses supercritical CO_2 will lead to further improvement in efficiencies but will also require an HTF that can operate above 560ºC. Molten nitrate salts are limited to a maximum operating temperature of 565ºC due to the decomposition of the nitrate ions.[6,26] Due to this limitation, the desire to improve efficiency, and store thermal energy for longer periods, the implementation of chloride salts as HTFs has been considered due to their ability to operate at temperatures up to and beyond 800ºC while maintaining thermal stability.[27] Due to attractive thermophysical properties and low cost, $MgCl_2$ and $ZnCl_2$ are also being considered, in addition to LiCl, NaCl, and KCl.[27]

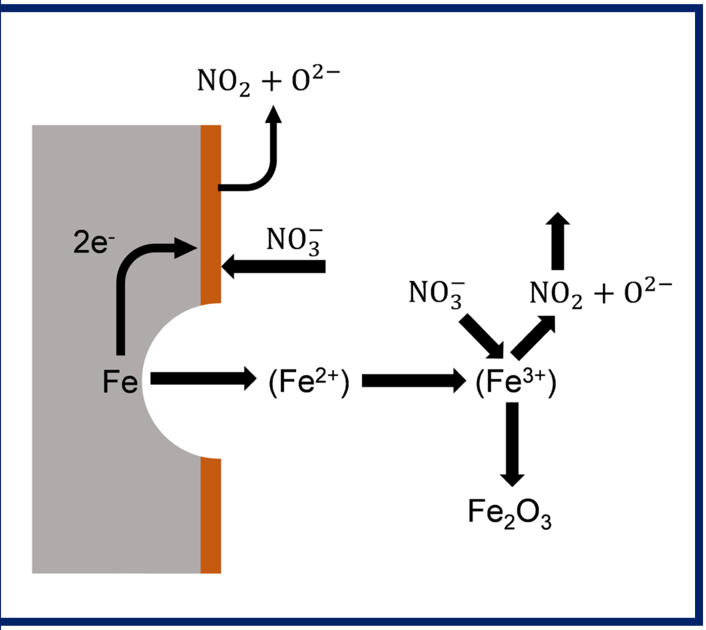

Fig. 2: *Oxidation and pitting mechanism of an iron electrode exposed to molten nitrate salts.*[9]

There are relatively fewer studies on the corrosion resistance of alloys in mixtures of molten chloride salts at various operating temperatures. The results from these studies do not follow a trend, likely due to differences in experimental conditions (such as impurities in salt), and some have shown concerning corrosion rates of ~8000 µm/year.[28-30] For example, SS316 and aluminum exposed to mixtures of $MgCl_2$-KCl-NaCl and $MgCl_2$-KCl-LiCl were found to be severely corroded after just 1 and 3.5 hours at 500°C, respectively.[31] Similarly, high corrosion rates have been seen in other studies for stainless steels,[32] Ni-based alloys,[32,33], and various alumina forming alloys.[33,34] Conditions have been varied as well to study under different cover gases,[35,36] in reducing conditions by adding Li[37] or Mg.[38]

The type and concentration of alloying elements and their effect on corrosion behavior have also been studied.[39,40] In general, chromia forming alloys, as well as Fe/Ni-based alloys, do not perform well in molten chlorides. Cr/Ni/Fe oxides are generally soluble in molten chlorides with oxides of Cr having higher solubility than the oxides of Fe or Ni.[41] Therefore, chromia-forming alloys generally perform poorly. Corrosion is exacerbated by the fact that when chromia dissolves, it liberates oxygen, thus forming a vicious cycle of chromia formation and dissolution. Increasing chromium content in alloys leads to an increase in corrosion.

Similar to molten nitrate salts, impurities in molten chloride salts have a significant influence on the corrosion properties of alloys. Impurity-driven corrosion is a primary mechanism of corrosion in molten salt systems, with water being a major and unavoidable source, even in high-purity salts.[42] SS316L and alloy-N exposed to varying purities of 68KCl:32$MgCl_2$ at 700°C for 100 hours showed increased corrosion for low purity salt compared to moderate and high purity salts.[43] A common impurity in molten chlorides is an oxide of one or more of the constituent salt cations that are the result of hydrolysis of the salt that occurs at high temperatures. For example, hydrated $MgCl_2$ will decompose into MgOHCl at temperatures above 300ºC and MgO above 550ºC.[43] These oxidizing impurities will react with alloying elements and deplete them from alloys by oxidizing the alloying element, followed by dissolution, precipitation, and/or vaporization of the oxidized alloying element. Al, Mn, and Cr are particularly affected and are reflected by the poor performance of stainless steels in various molten chloride mixtures with corrosion rates ranging from 2 to 54,000 µm/year.[42]

Overall, certain conditions have been observed that result in lower corrosion rates: use of high purity salts with low moisture content, use of a reducing agent in the salt, or the presence of Al or other passivating layer forming elements such as Ta in the alloy. Some studies have shown results that are contrary to the generalized behavior characterized above. However, there are relatively fewer studies of corrosion properties in molten chloride systems than nitrate systems, and our understanding of the surface films is less comprehensive.

Corrosion in Molten Carbonate Salts

As mentioned above, higher operating temperatures can lead to higher efficiencies. Carbonates (Li/Na/K ternary carbonate mixture) have been shown to be thermally stable for up to at least 1000ºC under a CO_2 cover gas.[44] These types of ternary carbonate mixtures have a higher specific heat of ~4.9J/g-K in comparison to ~1.54 for binary nitrates. The ~3x higher specific heat leads to a higher heat capacity and the need for smaller storage tanks for similar thermal loads. Hence, carbonates are attracting more attention for use in CSP applications. Most of the molten carbonate knowledge comes from their applications in molten carbonate fuel cells, where they are intentionally set up as an electrochemical cell. However, the conditions are quite different for CSP.[45]

Corrosion in these carbonate systems has been shown to be influenced by the amount and transport of O_2/CO_2 that is dissolved in the melt and the dissolution of oxide scale and its solubility in the melt. The ability to form a protective surface film is primarily determined by O_2 content. For example, exposure temperatures below 580ºC have been shown to lead to the formation of a porous $LiFe_5O_8$ film on SS316L, while higher temperatures led to the formation of a protective $LiFeO_2$ layer.[46] Several Ni-based alloys were studied via long-term exposure in molten eutectic Na/K binary carbonate salt at 900ºC, and corrosion rates of up to several thousand µm/year were observed.[47] Alumina forming alloys were studied in ternary (Li/Na/K) carbonate mixtures at a temperature of 650ºC, and corrosion rates were determined to be as low as 5 µm/year.[48] SS316 and Ni alloys were also studied in this ternary mixture, and corrosion rates were seen to vary with alloy 718 performing the best.[49] SS316, in general, has shown less than desirable performance under these conditions.

Similar to other molten salts, impurities in carbonate salts have been shown to play a significant role in corrosion behavior. Presence of moisture leads to the significant dissolution of Cr, but further studies are needed. The effect of other impurities such as chloride also needs to be evaluated. Further, the protectiveness of chromia is not fully understood as its effectiveness is likely linked to the activity of oxygen. While the formation of alumina has been seen to be protective, the formation of oxides of manganese, zirconium, or titanium is not necessarily equally protective.[45] There are very few studies on the corrosion behavior of alloys in molten carbonates, and our understanding is evolving.

Conclusions

Concentrated solar power is attractive due to the high Carnot efficiencies that can be achieved for power plants taking advantage of the higher operating temperatures allowed by molten salts. The added benefit of using molten salts is their ability to be used as both the heat transfer fluid and the thermal energy storage. While most molten salt-based plants use nitrate-based salts, the ability to achieve even higher efficiencies with molten chlorides and carbonates is appealing. Corrosion mechanisms of alloys in molten nitrate salts have been reasonably well understood, and corrosion rates are generally low. Fewer studies have been conducted in chloride and carbonate molten salts, and the observed corrosion rates were generally high in those studies. However, there are promising materials such as alumina forming alloys and those with a protective film-forming capability that show high corrosion resistance in these salts. Impurity and moisture content in the molten salt has been shown to lead to higher corrosion rates. Further studies under controlled environments are needed to develop a comprehensive understanding of corrosion in chloride and carbonate molten salts.

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High-Temperature Compatibility of Structural Alloys with Supercritical and Subcritical CO_2

by Bruce A. Pint

This article is dedicated to Prof. Hugh Evans.

Abstract

In searching for new working fluids for power generation, supercritical CO_2 (sCO_2) offers some attractive features for efficient cycles. However, compatibility with structural alloys is a concern. NiCr-based alloys have excellent compatibility at 600°-800°C at 20-30 MPa sCO_2. However, conventional steels have restrictions in temperature because of carburization and accelerated oxidation in sCO_2, similar to observations in CO_2. To assess the impact of carburization on steel mechanical properties, small (25mm long) dogbone tensile bars are being exposed and tested after exposure at 450°-650°C. Only highly alloyed advanced austenitic steels are resistant to carburization at 650°-750°C, suggesting that Cr-rich oxide scales are good barriers to C ingress. Above 800°C, it is only possible to conduct subcritical evaluations at this time, but initial results suggest most conventional high-temperature Fe- and Ni-based alloys are more rapidly degraded by CO_2 at higher temperatures. Coatings are a potential solution that require more study.

Background & Introduction: Searching for High-Efficiency Working Fluids

For high-temperature oxidation research, one of the main activities is identifying operating windows for potential new working fluids to replace water/steam, which has been widely used for millennia but has limitations. In an ever-improving world, Rankine cycle steam boiler efficiency has remained stagnant for more than 60 years since the 1960 325 MW Eddystone 1 plant had peak 613°C/34.5 MPa steam conditions (initially designed for 41% higher heating value (HHV) efficiency).[1] Even the "ultra-supercritical" 600 MW John W. Turk plant commissioned in 2013 in Arkansas had only 607°C/25.3 MPa steam and 39.2% HHV efficiency.[2] The Turk plant may be the last coal-fired power plant built in the U.S., and so the development of precipitation strengthened (PS) Ni-based alloys (like 740H and 282) for "advanced ultrasupercritical" steam (760°C/34.5MPa)[3] with ~50% efficiency may have to look for other applications.

So, where do we go beyond steam in the future? Of course, there is the Brayton cycle, which uses air as the working fluid in gas turbines. There also has been research in other gases like helium and ammonia and various liquids, including oils, molten salts, and liquid metals. In the 1960s, Feher proposed a supercritical CO_2 (sCO_2) cycle that takes advantage of its low (31°C/7.4MPa) supercritical point (relative to water at 373°C/22 MPa) and results in higher cycle efficiencies.[4] In 2006, Dostal et al. revived interest in this cycle for nuclear applications,[5] and interest spread to waste heat recovery, concentrating solar and fossil energy. More recently, Allam et al. proposed a revolutionary cycle where fossil fuels could be burned in sCO_2 and thereby save the cost of pressurizing CO_2 for capture.[6] A 50 MWth pilot plant has been built in Texas to demonstrate the technology that could revolutionize clean fossil energy.

Supercritical CO_2 Concerns

So, what is the concern with sCO_2? First, the partial pressure of oxygen (p_{O2}) in sCO_2 is high enough to form all of the typical Fe oxides and NiO and actually has similar values as steam.[7] But after the experience with the CO_2-cooled reactors in the United Kingdom, internal carburization of structural alloys is a major concern.[8-10] In those reactors, the pressure is only 4.2 MPa (subcritical), but the reducing CO_2-1vol.%CO-0.3%CH_4-0.3%H_2O-0.1%H_2 gas mixture to limit oxidation of the graphite reactor components increases the C activity in the gas by more than 10 orders of magnitude compared to pure CO_2. The experience with the early Magnox reactors essentially coined the term "breakaway" oxidation when the mild steel pressure vessels started to experience accelerated attack after many years of service with steady-state parabolic magnetite (Fe_3O_4) growth kinetics.[8,9] Likewise, the next generation (still operating) advanced gas-cooled reactors (AGRs) used Fe-9Cr-1Mo (Grade 9 steel because today's Grade 91 wasn't invented yet) heat exchangers that can become saturated in C and go into breakaway oxidation at 550°-650°C as all the Cr is tied up in the substrate.[10] The early research for CO_2-cooled reactors suggested higher Cr and Ni content alloys were more resistant to internal carburization[11,12] and Nb-stabilized Fe-20Cr-25Ni (similar to current alloys NF709 and Sanicro 25) was selected as the AGR fuel cladding. One of the leaders of the high-temperature oxidation community, Hugh Evans (1940-2019), and his co-workers conducted many fundamental studies defining breakaway oxidation using this material.[13,14]

In recent years, a more concise explanation was developed to explain the thermodynamic driving force for C ingress.[15,16] Fig. 1 shows that as the oxygen activity drops across a thermally grown

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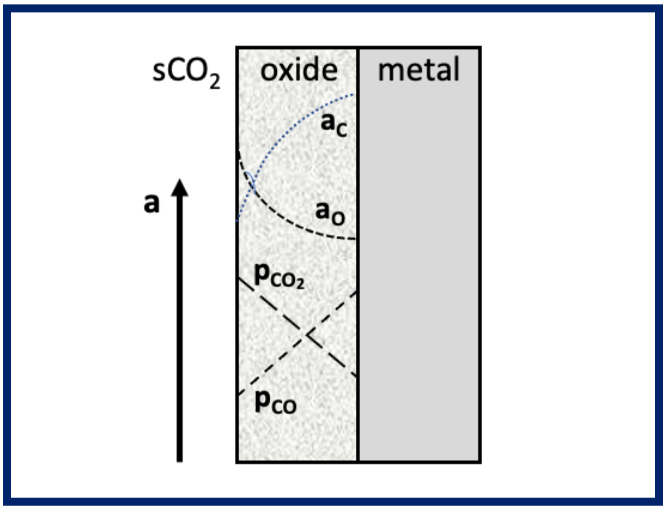

Fig. 1. *Schematic of activity and partial pressure gradients across a thermally grown oxide scale in a CO_2 environment.*[15]

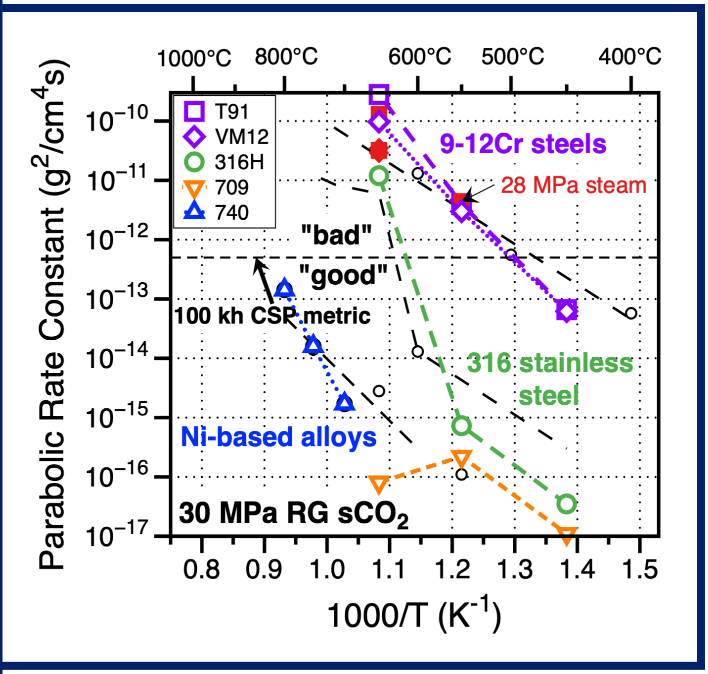

Fig. 2. *Arrhenius plot of literature values and rate constants from 30 MPa RG CO_2 (open symbols) and 27.6 MPa water (closed symbols) with 100 ppb.*[30,31]

oxide or scale (the driving force for transport across this solid state diffusion barrier) from the p_{O2} in the gas to the equilibrium p_{O2} at the metal-scale interface, the CO/CO_2 ratio increases (Eq. 1) and therefore the C activity increases (Eq. 2):

$$CO_2 = CO + \tfrac{1}{2} O_2 \qquad (1)$$
$$2CO = C + CO_2 \qquad (2)$$

Thus, even though the C activity in pure CO_2 is relatively low (10^{-14} at 650°C), a much higher C activity is expected at the metal-scale interface, which drives the internal carburization observed.

When material evaluations began to assess sCO_2 compatibility about 15 years ago, similar observations were made[17,18] with the same major conclusion that Fe-base alloys are limited in temperature because of carburization. The early studies for nuclear energy focused on ferritic-martensitic (FM) 9%Cr or conventional austenitic (types 304, 316, 347, etc.) stainless steels (SS) typically with 8-10%Ni and 16-18%Cr. Sarrade et al. concluded that FM steels were limited to <450°C and SS to <650°C.[19] Especially for FM steels, this is significantly below the 580°-600°C limit for use in steam due to thick Fe-rich oxide exfoliation issues.[20,21]

The next wave of sCO_2 compatibility research in ~2015 was associated with the goal of 50% sCO_2 cycle efficiency at >700°C. Here, the PS Ni-based alloys developed for A-USC applications[3] were attractive, but could they function in sCO_2 at 700°-800°C? For concentrating solar power (CSP) applications, a metric was developed for a 100-kh lifetime goal: a parabolic rate constant of 5 x 10^{-13} g^2cm^4s.[22] Fig. 2 shows a compilation of rate data from the literature[23] and ORNL studies. While >700°C compatibility was relatively unknown in 2015, today it is clear that Ni-based alloys are relatively unaffected by sCO_2,[22-25] with rate constants similar to oxidation in laboratory air.[22] One of the surprising results from this work was that advanced austenitic steels like HR3C (Nb and N modified type 310SS with 25Cr-20Ni) and Sanicro 25 showed no measurable C uptake after 10,000 h at 750°C in 30 MPa research-grade (RG) CO_2.[22] This result suggests that good chromia-forming steels can be compatible with sCO_2. Carbon has been detected on Cr_2O_3 grain boundaries on model Fe-Cr and Ni-Cr alloys,[26,27] but not on commercial alloys.

In contrast to Ni-based alloy performance, Fig. 2 shows that type 316SS (16Cr-10Ni-2Mo) showed low rates at 450°-550°C associated with protective, slow-growing Cr-rich oxide scales. However, at 650°C, Fe-rich oxides were formed with a much faster reaction rate. In fact, the rates were not that different from the FM steels. For both 9% (Grade 91, T91) and 12%Cr (VM12) FM steels, Fe-rich oxides are formed at 450°-650°C. In air, these FM alloys form a thin Cr-rich oxide. Fig. 3b shows the typical thick duplex Fe-rich scale formed on Grade 91 steel after 1,000h at 550°C in 30 MPa RG sCO_2. Fig. 2 and Fig. 3a show that similar scales form in 28 MPa water (<10 ppb O_2) at 550°C[28] at similar rates. This similar behavior also was noted by Rouillard and co-workers.[29] Furthermore, the temperature limits noted by Sarrade et al. (above) are fairly consistent with the CSP metric, although the FM limit would be <500°C in Fig. 2 rather than <450°C from Sarrade et al.[19]

Fig. 2 represents a reasonable compatibility assessment, but there is still concern that mass change and parabolic rate constants are not adequately capturing the possibility of alloy embrittlement by carburization in sCO_2. Therefore, the most recent experiments are repeating the methodology of McCoy[11] and exposing small (SS3 type: 25.4 mm long, 0.76 x 5 mm gage) dogbone tensile specimens to quantify embrittlement and measuring bulk C contents to assess carburization. Fig. 4 captures similar mass change data as in Fig. 2 but plots mass change after 500 and 1000 h against post-exposure ductility.[30,31] For alloy 316H, there is a clear relationship that when the mass change is low and thin Cr-rich oxides form, the ductility remains high. However, when thick Fe-rich oxide formed at 650°C, the room temperature ductility dropped to ≤10% due to carburization. The bulk C content by combustion analysis increased from 0.04 wt.% in the starting material to 0.16% after 1000 h.[31] In contrast, the 20Cr-25Ni alloy 709 showed no change in ductility after any of the 1000 h exposures and no increase in C content, Fig. 4.

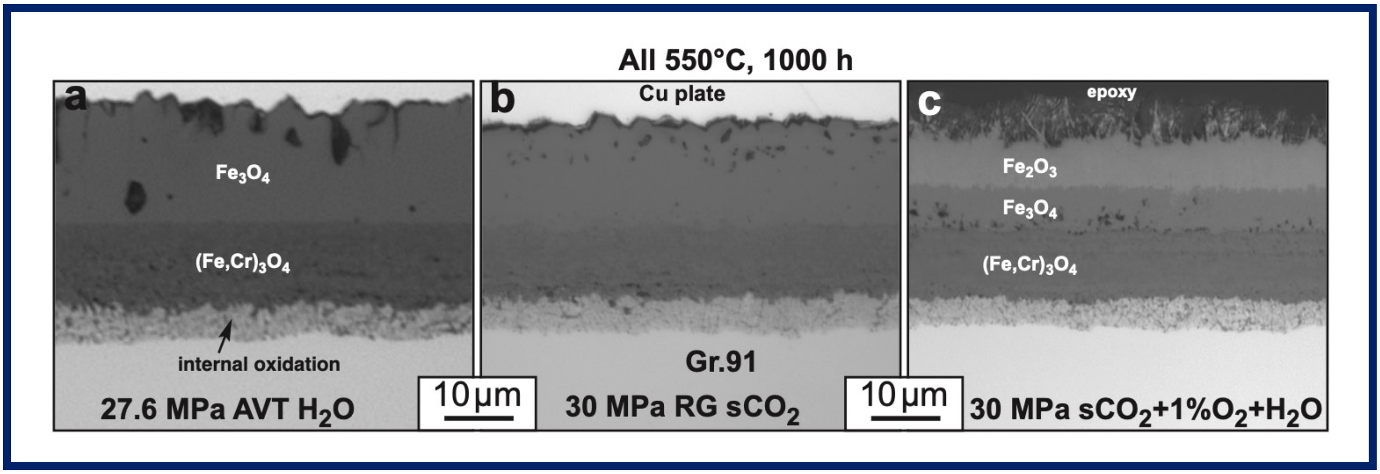

Fig. 3. *Light microscopy of Grade 91 coupons exposed for 500 h at 550°C in (a) 27.6 MPa all volatile treated (AVT) H_2O (<10 ppb O_2), (b) 30 MPa RG sCO_2, and (c) 30 MPa sCO_2 with additions of 1%O_2 and 0.1%H_2O.*

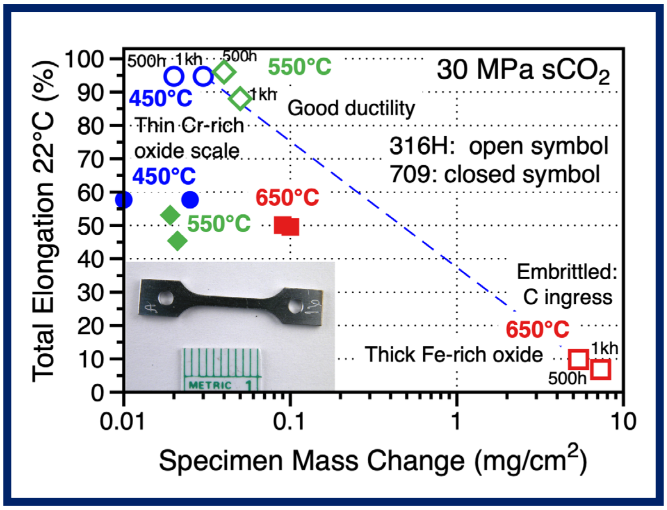

Fig. 4. *Specimen mass change plotted versus the post-exposure room temperature ductility (total elongation in tension with a strain rate of 0.015/min per ASTM E8-13). The open symbols are for 316H stainless steel and the closed symbols for alloy 709 with 20Cr-25Ni.*[30,31]

The last point to make is about impurities in the sCO_2. An extensive comparison was conducted comparing RG (<5 ppm O_2, <5 ppm H_2O) and industrial grade (IG) sCO_2, which contains <50 ppm O_2 and 18±16 ppm H_2O. No statistical difference could be seen between the corrosivity of these two gases at 30 MPa and 750°C after 5,000 h.[32] Furthermore, no significant changes were observed with intentional additions of 50 ppm O_2 and 50 ppm H_2O after 2,500 h at 750°C.[33] However, the open or direct-fired Allam cycle will have significantly higher impurity levels, which some estimate will be several percent O_2 and H_2O.[34] Modest ~2X increases in reaction rates were found for Ni-based alloys with 1%O_2 and 0.25%H_2O at 30 MPa, and 750°C and larger effects were observed for Fe-based alloys where Fe-rich oxides began to form during exposure.[32] These impurity conditions are expected if water can be condensed out after the combustor. At lower temperatures, higher rates were observed for alloys 316H and 709 at 550° and 650°C due to Fe-rich oxide formation after 1,000 h with sCO_2+1%O_2+0.1%H_2O at 30 MPa. The FM steels did not show any increase in reaction rates at 450°-650°C. However, Fig. 3c shows that the 1%O_2 addition did stabilize the formation of Fe_2O_3 at the gas interface, and this may have implications for the exfoliation behavior of these scales.[20,21]

>800°C CO_2 Evaluations

Both the Allam cycle combustion temperature and the search for higher efficiency have posed the question about even higher temperature sCO_2 cycles, perhaps with cermets[35] or other high-temperature materials. However, the Ni-based alloy 282 autoclaves used to generate the data in Fig. 2 are limited to ~800°C to contain supercritical environments. Thus, at higher temperatures, the experiments are limited to 2-4 MPa. Screening tests have been conducted for a range of alloys and SiC at 900°-1200°C. While SiC has performed very well at all temperatures, most of the alloys have performed surprisingly poorly, including the alumina-forming alloys that were thought to form alumina layers that would act as C barriers.[36] Fig. 5 shows Fe-21Cr-5Al-3Mo alloy APMT after only 40 h at 1200°C in 0.1 and 2 MPa of RG CO_2. In 1 atm of CO_2, the alloy experienced an accelerated attack with Fe- and Cr-rich oxides formed within the reaction front and an average scale thickness of 90±30 µm, Fig. 5a. After exposure in 2 MPa CO_2, the scale was more typical of an alumina-forming FeCrAl alloy, Fig. 5b. However, the 20±2 µm thick scale, including some atypical Fe-rich oxide at the gas interface, was thicker than formed on APMT after 1,000 h at 1200°C in laboratory air (14±2 µm). In a subsequent experiment, pre-oxidation did not significantly help APMT performance at 1100°C in similar conditions.

Summary & Outlook

The good news for sCO_2 cycles is that Ni-based alloys and advanced austenitic steels appear to offer some solutions for high-temperature operation at 600°-800°C. A clear challenge is that less expensive steels needed for the majority of the cycle operating at lower (≤600°C) temperatures are carburized in this environment. One of the remaining issues is to model the transition temperature where FM and conventional austenitic steels can be safely used for 25-100 kh structural components, including the impact on mechanical properties, as carburization is known to reduce alloy ductility, Fig. 4. Using the methodology described, a remaining task for a conventional SS like 316H is to assess long-term behavior at 550° and 600°C in sCO_2 and develop a predictive model to give designers confidence in its sCO_2 compatibility. High O_2 and H_2O impurity levels in the sCO_2 Allam cycle also will be a challenge for steels, and more work is needed to quantify the impact of impurities and to explore alternative solutions, such as coatings and surface modifications to inhibit C ingress in this environment. Numerous impurity studies have been conducted in 1 atm CO_2 to support the development of oxy-firing combustion[37] for carbon capture. However, only a limited number of studies have been conducted at supercritical conditions.[30-32,38] The few studies suggest that O_2[38] rather than H_2O may have more of a negative effect for Ni-based alloys, but this needs to be further understood from both a mechanistic and predictive standpoint. Finally, only limited assessments have been conducted above 800°C. This is a challenging environment with accelerated reaction kinetics observed for many conventional high temperature alloys. The initial results e.g., (Fig. 5) need to be further understood.

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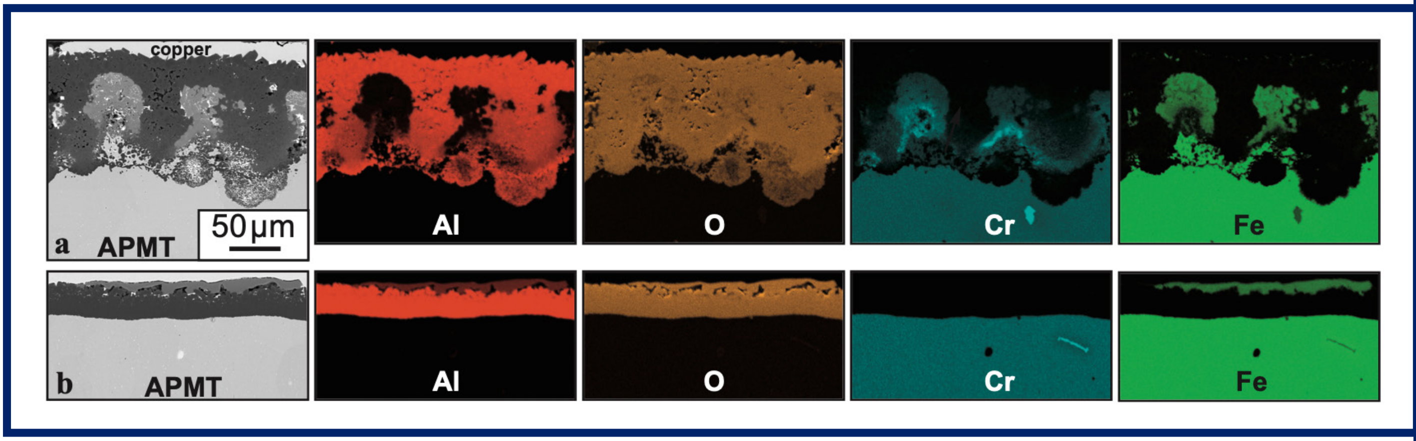

Fig. 5. *SEM images and associated EDX maps for FeCrAlMo alloy APMT after 40 h at 1200°C in (a) 1 bar and (b) 20 bar RG CO_2.*

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Acknowledgements

This contribution is dedicated to the memory of Prof. Hugh Evans from Birmingham University (1940-2019), who was heavily involved in materials issues for CO_2-cooled reactors, made brilliant contributions to the high-temperature oxidation community during his career, and was always a wonderful and engaging friend for discussions on science and everything else. The experimental work was conducted by M. Howell, B. Johnston, T. Lowe, T. Jordan, V. Cox, and T. Geer. R. Pillai and M. Romedenne provided useful comments on the manuscript. This research was funded by the U.S. Department of Energy's Office of Fossil Energy, Crosscutting Research Program, and the Office of Energy Efficiency and Renewable Energy, Solar Energy Technologies Office: SuNLaMP award number DE-EE0001556. The author also is indebted to significant advice from the sCO_2 industry, as well as EPRI and material from alloy producers, including Tenaris, Haynes International, Special Metals, and Sandvik.

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Corrosion by Hot CO_2 Gases

by David J. Young and Jianqiang Zhang

Heat-resisting alloys are designed to survive high-temperature oxidation by forming a slow-growing scale, usually Cr_2O_3, which acts as a barrier between the metal and its environment. However, alloys that succeed in this way when exposed to hot oxygen or air fail to do so in CO_2 gas. Instead, they exhibit rapid "breakaway" corrosion, developing oxides of alloy base metal iron and/or nickel. The growth of these non-protective scales is accompanied by internal carburization of the underlying alloy (Fig. 1). Carbon passes through the oxide, dissolves in the alloy, and precipitates chromium as carbide. Removal of chromium from its matrix makes the alloy incapable of reforming chromia, and recovery from breakaway becomes impossible.

This is a problem with practical implications. It was first studied after breakaway corrosion was seen in CO_2 gas-cooled nuclear reactions.[1-7] Since then, interest has been rekindled by potential greenhouse gas abatement technologies, oxyfuel combustion,[8-10] where the flue gas is largely $CO_2 + H_2O(g)$, concentrated solar power generation and fast nuclear reactors,[11-14] where supercritical CO_2 is used as a heat transfer medium and turbine working fluid.

There have been several difficulties in understanding how a relatively unreactive species like CO_2 can cause such destructive effects. Firstly, how does a gas with low carbon activity (a_C 1.6×10^{-15} in atmospheric pressure CO_2 at 650°C) carburize the alloys? Secondly, how does the carbon transfer through the oxide scale, in which it is thought to be insoluble[15] to the alloy? This occurs not only through iron oxides but also through highly protective chromia scales (Fig. 2)[16]. Thirdly, what are the chemical processes at the scale gas interface (where the equilibrium p_{O_2} value is too low to account for observed iron oxide scaling rates) and at the scale-alloy interface (where carbon is made available and injected into the alloy)? Finally, of course, how can the destructive effects of high-temperature CO_2 corrosion be avoided or at least slowed?

Thermodynamics of Carburization by CO_2

Oxidizing and carburizing potentials are governed by the following gas phase reactions.

$$CO_2 = CO + \tfrac{1}{2}O_2 \qquad (1)$$

$$2CO = CO_2 + C \qquad (2)$$

Equilibrium oxygen potentials due to (1) are relatively high (atmospheric pressure CO_2 yields $p_{O_2} = 1.5\times10^{-8}$ atm at 650°C) and sufficient to oxidize both iron and nickel at relevant temperatures. Breakaway oxidation is therefore always thermodynamically possible.

As seen above, values of a_C resulting from equilibration of the two reactions are insufficient to carburize chromium. However, alloys exposed to CO_2 grow an oxide scale, and the metal is in contact with an oxide, not the gas. The situation is shown schematically in Fig. 3, where p_{O_2} varies between a high value at the scale surface characteristic of the gas and a minimum at the scale-gas interface where it is set by the local equilibrium between the reacting metal, M, and its oxide. Correspondingly, according to (1), the ratio p_{CO}/p_{CO_2} varies between a minimum at the scale surface and a maximum at the scale-alloy interface. In this case, according to the Boudouard equilibrium (2), a_C also varies between a minimum at the scale surface and a maximum at the scale-alloy interface.

Recognizing that CO is produced from CO_2 by oxygen consumption, it is seen that

$$p_{CO} + p_{CO_2} = p_T \qquad (3)$$

where p_T is an unknown constant, which depends on the external CO_2 pressure and scale transport properties. Equations (1) – (3) can be

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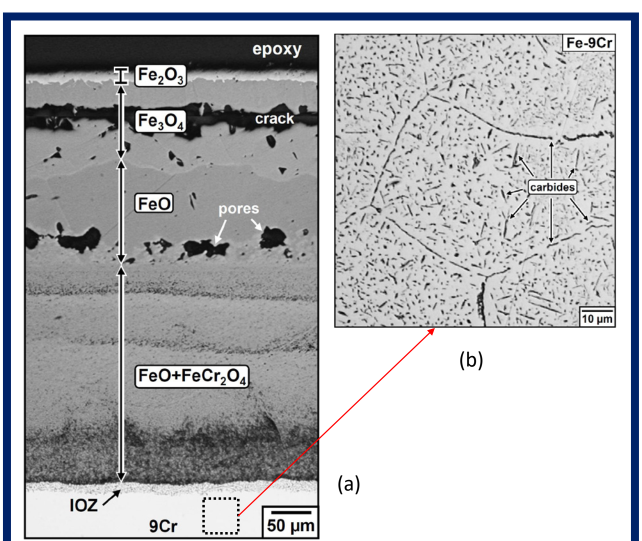

Fig. 1. *Fe-9Cr reacted in Ar-20%CO_2 at 650°C for 1000 h (a) cross-section showing thick oxide scale and (b) dotted lined section in (a) etched by Murakami agent showing carbides in metal matrix.*

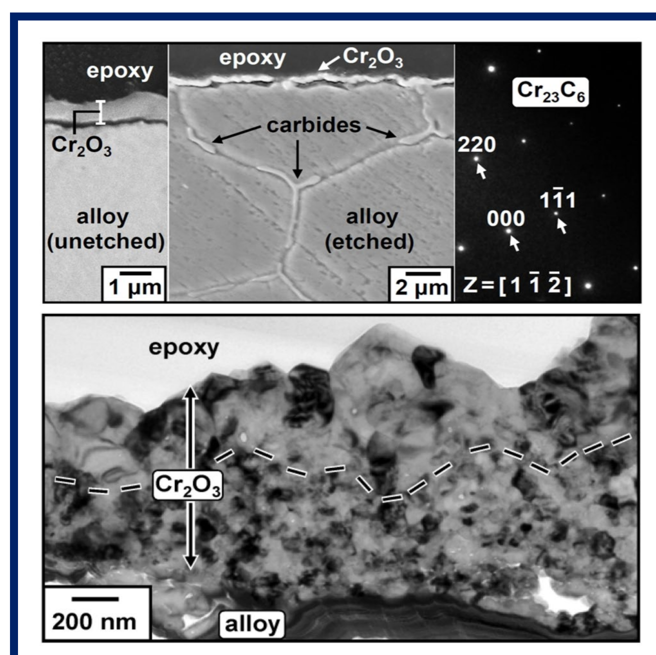

Fig. 2. *Reaction products formed by Fe-20Cr exposed at 650°C to Ar-20O_2 for 24 h, and then to Ar-20CO_2 for 70 h: upper – SEM views with SAD pattern identifying fcc $Cr_{23}C_6$; lower – bright field TEM image showing two-layered chromia scale.*[16]

solved to yield

$$a_C = K_2 \frac{b^2}{1+b} p_T \tag{4}$$

with K_2 the equilibrium constant for (2) and $b = p_{CO}/p_{CO_2}$, a value defined at the scale-alloy interface by the metal/metal oxide equilibrium.

This analysis has been tested[17] for the case of a model Fe-9Cr alloy exposed at 650°C to Ar-20CO_2, forming the scale shown in Fig. 1. The value $a_C = 0.52$ was calculated for the scale-alloy interface from the thermodynamic analysis. The volume fraction of carbide measured in the alloy adjacent to this interface was found from the phase diagram to correspond to $a_C = 0.43$, in good agreement with prediction. As seen below, the rate of alloy carburization is also consistent with the thermodynamically predicted a_C value.

Carbon Transport Mechanisms

Information is available for the penetration of chromia scales by carbon.[18,19] The scale cross-section in Fig. 2 was produced by reacting the model alloy Fe-20Cr at 650°C, first for 24 h in O_2 and then for 70 h in CO_2. The coarser-grained outer layer is characteristic of reaction in O_2, while the finer-grained inner layer is characteristic of reaction in CO_2. Clearly, the second stage reaction in CO_2 involves penetration of the first-formed outer layer by an oxygen species. Carburization of the alloy also took place during the second stage reaction, indicating that both carbon and oxygen penetrated the first-formed Cr_2O_3.

The rate at which the oxide scale thickness, X, increases with time, t, is diffusion controlled, leading to parabolic kinetics[20,21]

$$X^2 = 2k_p t \qquad k_p = \int_{a_O'}^{a_O''} D_i \, d\ln a_O \tag{5}$$

Here k_p is the parabolic rate constant, D_i the diffusion constant for the mobile species, a_O the oxygen activity within the scale, and a_O', a_O'' the boundary values at the metal-scale and scale-gas interfaces (Fig. 3). Because the oxide lattice is so stable, diffusion in chromia scales is confined to grain boundaries and other extended defects.

Approximating the oxide grains in the chromia scale as being square in cross-section, then the fraction of sites within grain boundaries, f, is given by

$$f = 2d/L \tag{6}$$

with d the boundary width and L the grain size. Assuming L is almost constant with time,

$$k_p \propto 1/L \tag{7}$$

comparison of oxide scales grown in O_2 and CO_2[19] at 650°C yields $L^{CO_2}/L^{O_2} = 0.6\pm0.1$ and $k_p^{O_2}/k_p^{CO_2} = 0.8\pm0.2$, confirming that chromia scale growth in CO_2 is supported by grain boundary diffusion.

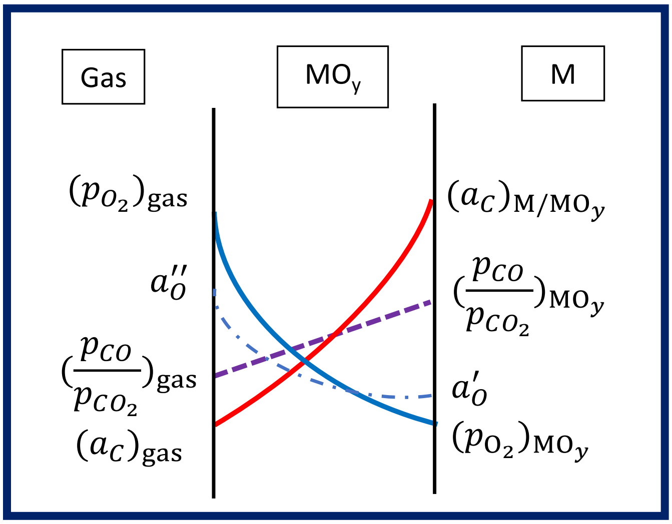

Fig. 3. *Schematic illustration of p_{O2}, a_O, and a_C in growing oxide scale.*

It is reasonable then to expect that carbon also penetrates the scale via its grain boundaries, as was proposed long ago.[22,23] The advent of atom probe tomography has allowed verification of this hypothesis. As seen in Fig. 4, a chromia scale grown in CO_2 has carbon decorating its grain boundaries as well as the scale-metal interface. The chemical state of this grain boundary carbon is unknown. Although elemental carbon is thermodynamically possible, it would presumably contribute negligibly to diffusion. Measurement of surface carbon concentrations yield about 5 atom nm^{-2} on grain boundaries, much less than the 40 atom nm^{-2} in a graphene sheet. Carbon must therefore be present in another form.

Once carbon has entered the alloy, it reacts with solute chromium to precipitate Cr-rich carbides. The rate at which the carburization depth, X_C, increases can be predicted from diffusion theory,[21] using the mass balance between carbon and chromium at the precipitation front

$$X_C^2 = 2k_p^C t \qquad k_p^C = \frac{N_C^{(i)} D_C}{\nu N_{Cr}^{(0)}} \tag{8}$$

Where $k_p^{(i)}$ is the parabolic rate constant for internal carburization, $N_C^{(i)}$ the carbon concentration at the alloy-scale interface, D_C the carbon diffusion coefficient, ν the C/Cr ratio in the carbide, and $N_{Cr}^{(0)}$ the original alloy Cr mol fraction.

If the scale-alloy interface is at equilibrium, then a_C and therefore $N_C^{(i)}$ are fixed, leading to the parabolic carburization kinetics observed commonly at high temperatures. Measurement of k_p^C can, in principle, be used to evaluate $N_C^{(i)}$ and hence a_C, providing an additional check on the thermodynamic analysis. To do this properly requires taking into account the low stability of the carbides, which means some Cr remains in the metal matrix of the carburized region, and of the fact that Fe is dissolved in the carbides to a degree, which varies with a_C. These complexities can be dealt with numerically,[17] based on a description of partial precipitation.[24] For Fe-20Cr exposed to Ar-20CO_2 at 650°C, the carburization kinetics indicated a value $a_C = 0.25$ at the alloy surface beneath Fe-rich oxide scales, still in reasonable agreement with the thermodynamic prediction.

At lower temperatures, the approach to equilibrium is slow[25,26] because the Boudouard reaction is so slow. Carbon drains away into the alloy, slowing the rate at which the carbon concentration at the surface increases (Fig. 5). Examination[27] of a 9Cr-1Mo steel after exposure at 600°C to pressurized (40 atm) CO_2 revealed that a 1mm thick cooling fin took more than 4000 h to reach carbon saturation at its surface. Obviously, the assumption of a fixed boundary condition must be abandoned in order to arrive at realistic lifetime predictions.

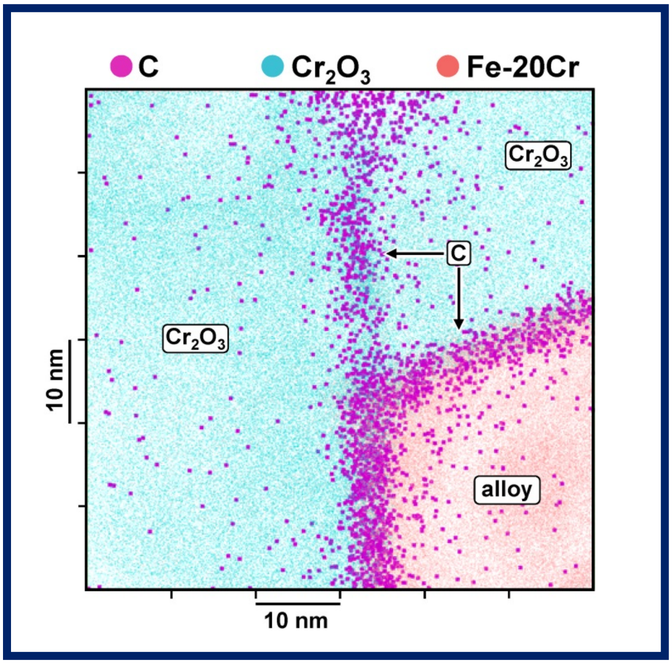

Fig. 4. *Atom probe analysis of the Cr_2O_3 scale of Fe-20Cr reacted at 650°C in Ar-20O_2 for 120 h.*[16]

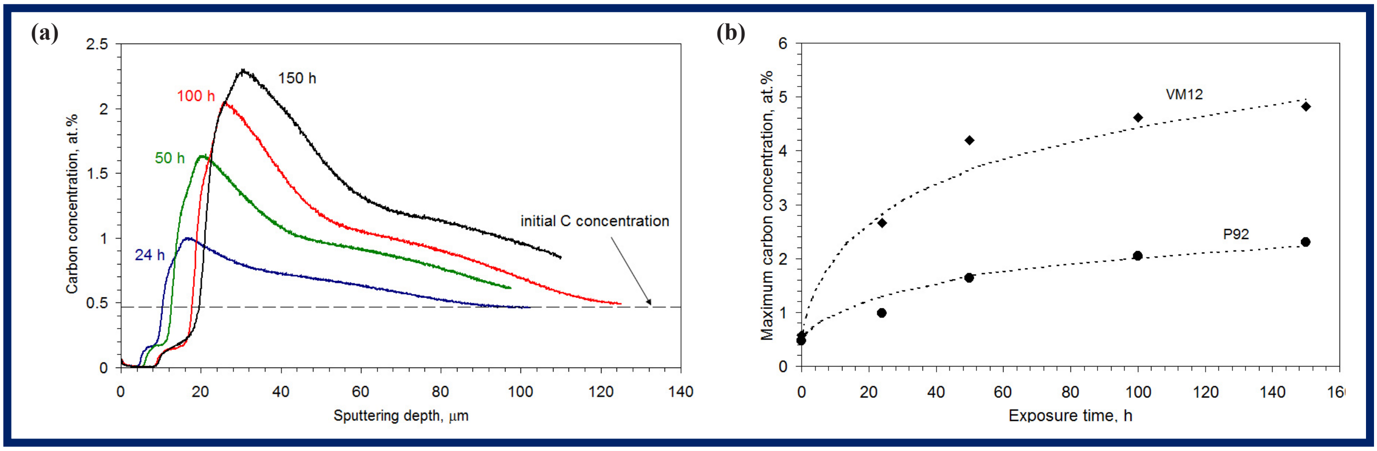

Fig. 5. *(A) carbon concentration profiles (measured by GDOES) in 9% Cr steel P92 after different times of reaction in Ar-50%CO_2 at 550°C. (B) carbon concentration at oxide-alloy interface in P92 and VM12.*[25]

To poceed, it is necessary to develop a kinetic treatment for the processes of carbon formation and injection into the alloy. Recognizing that the Boudouard reaction must be catalyzed to occur at any significant rate, a model can be formulated for the interfacial kinetics.

Scale-Alloy Interface

Much is happening at this boundary: metal is being oxidized; in the case of Fe-rich oxide, the metal is removed and diffuses outward, creating at least momentarily a vacancy. These vacancies can coalesce to form voids, which can then be encapsulated into the inward growing scale, accounting for its observed porosity. Alternatively, they can diffuse into the alloy, accommodating the volume change accompanying carbide precipitation and growth. They can also be filled with new oxide, resulting from a reaction with CO_2. Before they vanish, voids at the scale-alloy interface present bare metal accessible to gas, allowing the catalytic process

$$2CO \rightarrow CO_2 + C \tag{9}$$

to produce dissolved carbon, $\underline{C}$.

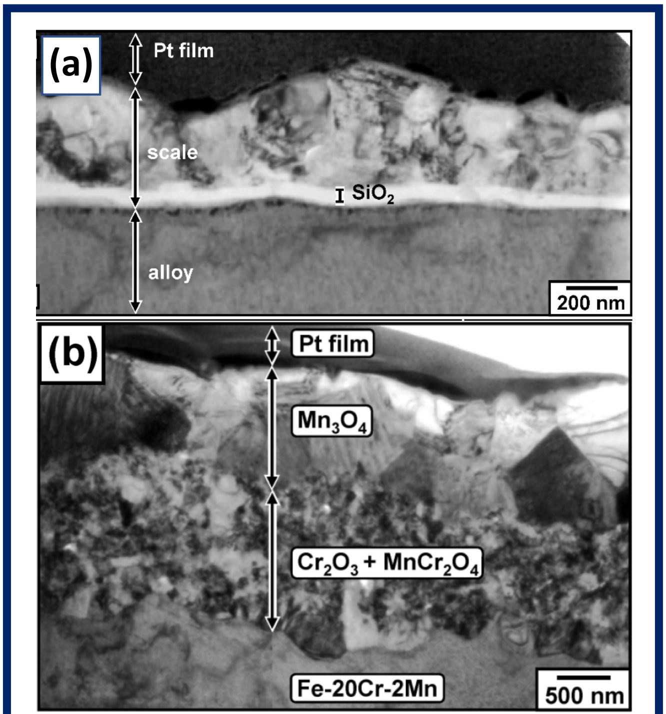

Fig. 6. *BF-TEM images of scales formed in reaction at 818°C with Ar-20CO_2 for 240 h: (a) Fe-9Cr-0.2Si, (b) Fe-20Cr-2Mn.*

The carbon injection process can be modeled on the basis[25,27,28] that the flux of carbon into the alloy, $J_C^{(i)}$, is driven by the difference between the equilibrium carbon activity and its instantaneous value at the interface

$$J_C^{(i)} = A\,\{a_C^{eq} - a_C^{(i)}\} \tag{10}$$

Here the factor A combines the effect of any surface activation barrier with the pre-exponential factor for the Boudouard reaction itself. Eq. (10) then provides a boundary condition for the carbon diffusion equation. The latter is modified to reflect the partitioning of carbon between matrix and precipitates, as determined by the phase diagram for the system.

Numerical solutions, which treat D_C as an adjustable parameter, provide good agreement with the observed time dependence of $N_C^{(i)}$ and X_C, as well as the shape of the N_C vs x profiles in Fig. 5.[25] Under the same reaction conditions, the rate constant A varies with the composition of the alloy, reflecting the catalytic role of the latter.[25]

It is found that D_C increases with depth within the carburized zone, only slightly near the alloy surface but strongly at greater depths.[25,27,28] Precipitate/matrix interfacial diffusion cannot account for this, as the interfacial surface area decreases with increasing depth. It is thought that precipitation-induced strain in the ferrite matrix accounts for the difference: inward vacancy migration from the alloy surface relieves the strain near the surface, but because interstitial carbon diffusion is faster than lattice diffusion, no such relief is available at greater depths.

Controlling Carburization

In high alloy materials, carburization can be prevented by improving scale oxide quality, decreasing alloy carbon permeability, and lowering alloy carbide stability. Chromia scales provide much superior barriers to carbon entry and are obviously preferred. All three pathways are followed by choosing Ni- rather than Fe-base alloys. A relatively high alloy chromium content is required (~25Cr), and the materials choice can be economically unattractive. However, their superior performance in supercritical CO_2 has been established.[29-31]

Austenitic heat-resisting steels such as 310 stainless can perform rather well, but at the modest temperatures expected, ferritic-martensitic steels (9-12Cr) provide good creep life and are economically desirable. As seen above, these intermediate Cr level steels are subject to carburization and relatively rapid scale growth. However, their performance can be improved by minor alloying additions of Si and/or Mn.

Transfer of carbon from a chromia scale into the substrate alloy can be prevented by alloy addition of Si to develop a silica sublayer at the scale-alloy interface. This strategy has been proven to succeed for both ferritic and austenitic alloys in dry CO_2.[32-34] As shown in Fig. 6a, the addition of 0.2% Si in Fe-9Cr alloy leads to the formation of a thin sublayer of silica underneath the chromia layer in CO_2 at 818°C. This

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thin amorphous silica layer serves as an additional diffusion barrier for oxygen and carbon diffusion, and as a result, significantly reduces the scaling rate.[32]

Prevention of carbon entry into chromia scale grain boundaries can also be achieved by alloying with Mn to form an additional, outermost scale layer of Mn-rich oxide. These have been shown to resist carbon entry in both CO_2 and CO_2-H_2O gases[35-37] for Fe-20Cr and Fe-20Ni-20Cr alloys. Fig. 6b shows Fe-20Cr-2Mn alloy in Ar-20CO_2 after 240 h reaction at 818°C, forming outermost Mn_3O_4 and inner Cr_2O_3+$MnCr_2O_4$ scale. However, this beneficial Mn effect does not appear for Fe-9Cr, as a thick oxide scale forms in that case.

In addition to Si and/or Mn alloying, another strategy to reduce carburization is to modify the scale surface/grain boundaries by sulfur uptake. As is well known, sulfur adsorbs strongly on many surfaces. It is expected that sulfur in the gas will be preferentially adsorbed on oxide scale surfaces and grain boundaries, reducing the occupancy by carbon of these sites. As a result, carbon penetration via oxide grain boundary is retarded, as is carburization.[38-40] It was found[40] that adding only 0.1%SO_2 reduced the carburization kinetics of Fe-9Cr-0.5Si alloy significantly (Fig. 7a). Cross-section views in Fig. 7b reveal that addition to the gas of 1% SO_2 prevented breakaway oxidation of Fe-9Cr, achieving largely protective oxidation.

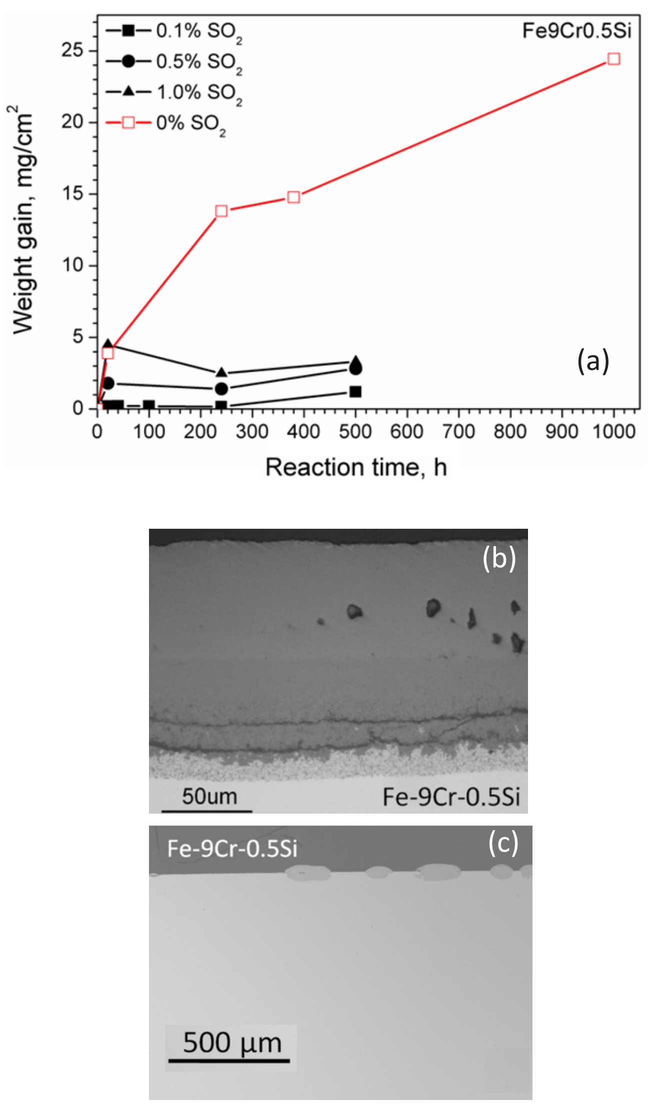

Fig. 7. *(a) Weight gain as a function of reaction time for Fe9Cr-0.5Si in Ar-20CO2-20H2O with and without SO_2, and cross-sections of this alloy in (b) SO_2-free gas for 240 h, and (c) 1.0% SO_2 gas for 240 h.*

Conclusions

CO_2-rich gas produces not only oxidation but also carburization of heat-resisting chromia-forming alloys, accelerating their corrosion. Although carbon activity of the gas is too low for alloy carburization to occur, high carbon activities are produced beneath oxide scales by local equilibrium with the low oxygen activity at the alloy-scale interface. This thermodynamic analysis explains the formation of carbide in low carbon activity CO_2 gas.

Carbon penetration through chromia scales as CO_2 via oxide grain boundaries is confirmed by APT. This suggests possible strategies to resist CO_2 corrosion: alloying with Si and/or Mn to form additional diffusion barriers or modifying grain boundaries by adding sulfur (SO_2) to the gas. The effectiveness of these methods of enhancing corrosion resistance of chromia-forming alloys in CO_2 gases has been demonstrated.

 DOI: 10.1149.2/2.F08212F.

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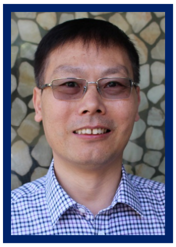

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Perseverance Rover Lands on Mars

by E. Jennings Taylor and Gregory S. Jackson

On February 18, 2021, at 3:55 p.m. EST, NASA's Perseverance rover landed at the Jezero Crater on Mars. Perseverance is NASA's most advanced rover to date and traveled 293 million miles (472 million kilometers) over 203 days; an average speed of over 60,000 miles per hour! After several weeks of testing, Perseverance will begin a two-year exploration of Mars' Jezero Crater.

According to Steve Jurczyk, Acting Administrator of NASA,[1] *"The Mars 2020 Perseverance mission embodies our nation's spirit of persevering even in the most challenging of situations, inspiring, and advancing science and exploration. The mission itself personifies the human ideal of persevering toward the future and will help us prepare for human exploration of the Red Planet."*

The landing and exploration of Mars by the Perseverance rover begins a new era of human space exploration. Important to human space exploration is the development and demonstration of In-Situ Resource Utilization (ISRU) technologies for life support. A key ISRU technology is the production of oxygen from the Martian atmosphere via a process referred to as *MOXIE.*[2] *MOXIE loosely stands* for helping humans explore **M**ars by making **OX**ygen working **I**n situ and is an **E**xperiment. MOXIE is about the size of a car battery. It collects carbon dioxide from the Martian atmosphere and electrochemically forms oxygen in a solid oxide electrolyzer.[3]

In addition to MOXIE, electrochemical and solid state science and engineering will play an important role in numerous aspects of space exploration. At the 235th ECS Meeting (Atlanta, GA) in the fall of 2019, the Interdisciplinary Science and Technology Subcommittee (ISTS) led a symposium on *Electrochemistry in Space* spanning three full days with 46 papers. The symposium included experts from industry, academia, and NASA with sessions including 1) Electrochemistry for Life Support, 2) Power Sources for Space Applications, 3) Batteries for Space Applications, 4) Electrochemical Sensors for Space, 5) Electrochemistry for Space Resource Utilization, and 6) Materials Processing for Space Applications. The symposium was highlighted in the spring 2020 issue of *Interface*.[4] A follow-up symposium, *Electrochemistry in Space 2*, is set for the 240th ECS meeting (Orlando, FL), October 10-14, 2021.[5]

Latest Development

On April 22, 2021, NASA confirmed that MOXIE successfully produced oxygen from the carbon dioxide in the Martian atmosphere. After a two-hour "warm-up" to about 800°C, MOXIE produced 5.4 grams of oxygen. According to Jim Reuter, Associate Administrator, NASA's Space Technology Mission Directorate, "This is a critical first step at converting carbon dioxide to oxygen on Mars. MOXIE has more work to do, but the results from this technology demonstration are full of promise as we move toward our goal of one day seeing humans on Mars."[6]

 DOI: 10.1149.2/2.F11212IF.

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E. Jennings Taylor, Founder of Faraday Technology, Inc.
Research Interest: Faraday Technology, Inc. is a small business focused on developing innovative electrochemical processes and technologies based on pulse and pulse reverse electrolytic principles.
Patent Background: Taylor leads Faraday's patent and commercialization strategy and

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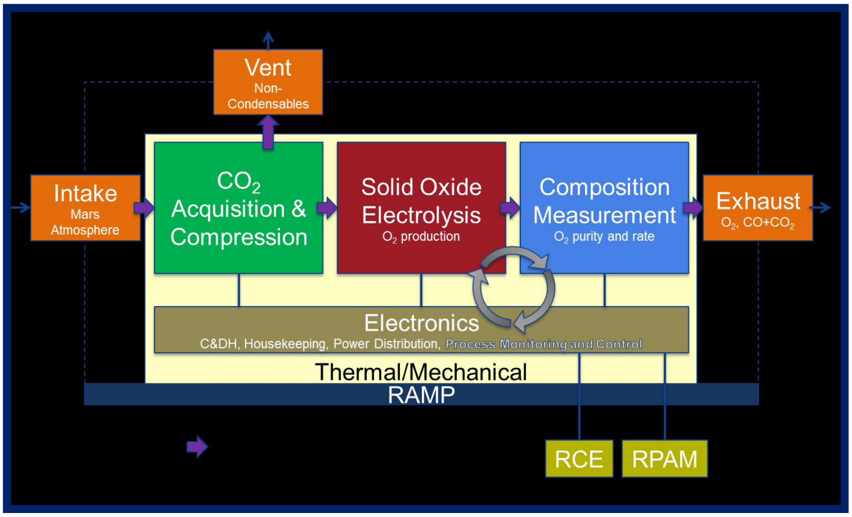
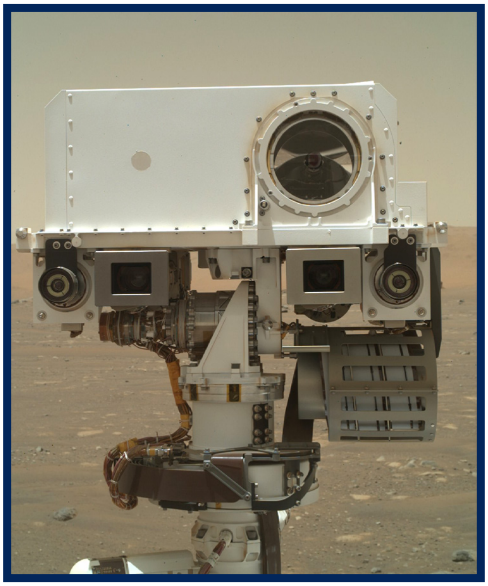


The MOXIE functional block diagram.
Credit: NASA/JPL-Caltech



NASA's Mars Perseverance rover acquired this image using its SHERLOC WATSON camera, located on the turret at the end of the rover's robotic arm. This image was acquired on April 6, 2021, (Sol 45), at the local mean solar time of 11:44:54.
Photo: NASA/JPL-Caltech

[1]https://mars.nasa.gov/news/8865/touchdown-nasas-mars-perseverance-rover-safely-lands-on-red-planet/
[2]https://mars.nasa.gov/mars2020/spacecraft/instruments/moxie/
[3]J. Hartvigsen, S. Elangovan, L. Frost "OxEon Energy Demonstration of Manned-Mission Scale ISRU Process Systems," 49th International Conference on Environmental Systems, July 7-11 Boston, MA (2019).
[4]G. Jackson (guest editor) "Electrochemistry in Space," *Electrochem. Soc. Interface* **29** 47 (2020).
[5]https://issuu.com/ecs1902/docs/2021-orlando-cfp-03?fr=sZjRmODI0OTc1Njk
[6]https://www.cnn.com/2021/04/22/world/mars-rover-oxygen-moxie-scn/index.html

Taylor and Jackson
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has negotiated numerous patents via field of use licenses as well as patent sales. He is admitted to practice before the United States Patent & Trademark Office (USPTO) in patents cases as a patent agent (Registration No. 53,676). Member of the American Intellectual Property Law Association (AIPLA).
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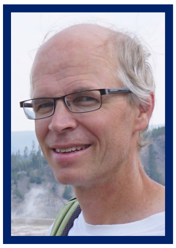

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Technicians in the cleanroom at NASA's Jet Propulsion Laboratory (Pasadena) carefully lower the Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) instrument into the belly of the Perseverance rover. The rover has been inverted so that the interior is more accessible. MOXIE will "breathe in" the CO2-rich atmosphere and "breathe out" a small amount of oxygen, to demonstrate a technology that could be critical for Photo: NASA/JPL-Caltech

Brazil Section

The **ECS Brazil Section** recently received a request from the Brazilian Society of Electrochemistry (SBEE-Sociedade Brasileira de Eletroquimica e Eletroanálise) to promote this year's SBEE symposium. In the past, ECS has supported the SBEE meetings by awarding the two best student presentations with travel grants to attend ECS biannual meetings. The Brazil section's board judges the presentations.

Due to the COVID-19 restrictions, the ECS Brazil Section is starting a series of local web seminars to engage local graduate students. As of now, the following seminars are planned, with dates to be determined: "Self-organization in Electrodeposition Reactions—A Molecular and Kinetic Understanding" by **Raphael Nagao**, University of Campinas; "Recent advances in bioelectrochemistry—Microbial and enzymatic biocells" by **Adalgisa de Andrade**, University of São Paulo-Ribeirão Preto; "Electrochemical Microprobes in Corrosion Studies" by **Luis Dick**, Federal University of Rio Grande do Sul; and "Localized Corrosion of Alloys" by **Gerhard Knörnschild**, Federal University of Rio Grande do Sul.

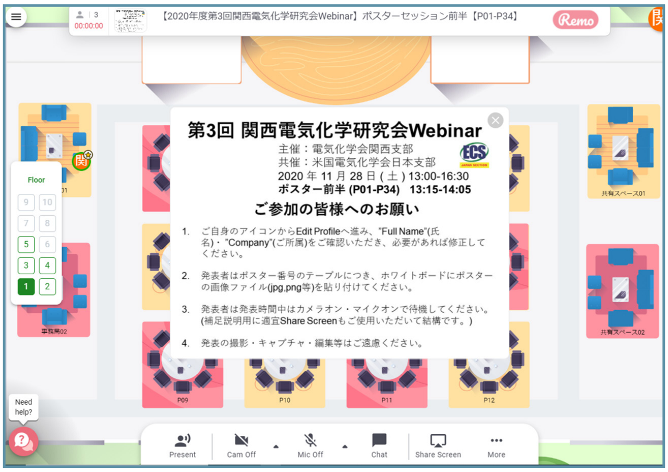
We sadly communicate the loss of three important Brazilian electrochemists during the past few months: **Ernesto Gonzalez**, University of São Paulo; **Carlos D'Alkaine**, Federal University of São Carlos; and **Luis Alberto Avaca**, University of São Paulo. They contributed significantly to the field of electrochemistry in Brazil and will be missed as mentors, as colleagues, and as friends.

Japan Section

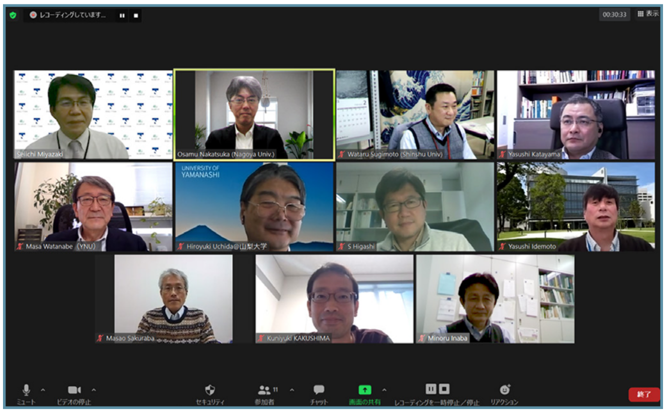
In 2020, while face-to-face events activities were limited under COVID-19, the **ECS Japan Section** cosponsored meetings, activities, and events for young researchers and students in the electrochemical field.

The 3rd Kansai Denki-Kagaku Kenkyukai (Electrochemistry Workshop), held through Zoom webinar on November 28, 2020, drew over 240 participants and one invited lecture. Presentations via Remo were made by 68 student authors below the PhD level. The awards ceremony was also held with 12 authors receiving the Kansai-Denki-Kagaku-Shourei-Shou Award.

The Japan section's 2021-2022 executive committee term launched starting in January. The first committee meeting was held online in March 2021. The newly selected officers are: Section Chair **Seiichi Miyazaki**, Nagoya University; First Vice-Chair **Yasushi Idemoto**, Tokyo University of Science; Second Vice-Chair **Seiichiro Higashi**, Hiroshima University; Section Secretary/Treasurer **Osamu Nakatsuka**, Nagoya University; Members at Large **Takayuki Homma**, Waseda University; **Minoru Inaba**, Doshisha University; **Yasushi Katayama**, Keio University; **Wataru Sugimoto**, Shinshu University; **Hiroyuki Uchida**, University of Yamanashi; **Masao Sakuraba**, Tohoku University; and **Kuniyuki Kakushima**, Tokyo Institute of Technology; and Councilor **Masayoshi Watanabe**, Yokohama National University.



Sixty-eight students at the Japan section's 3rd Kansai Denki-Kagaku Kenkyukai (Electrochemistry Workshop) made presentations via Remo.

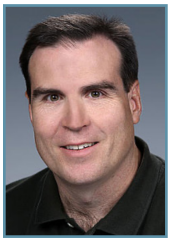


Screenshot of the March 15, 2021, online ECS Japan Section's committee meeting with newly elected officers. Top row, from left to right: Section Chair **Seiichi Miyazaki**, *Section Secretary/Treasurer* **Osamu Nakatsuka**, *Members at Large* **Wataru Sugimoto** *and* **Yasushi Katayama**. *Second row, from left to right: Councilor* **Masayoshi Watanabe**, *Member at Large* **Hiroyuki Uchida**, *Second Vice-Chair* **Seiichiro Higashi**, *First Vice-Chair* **Yasushi Idemoto**. *Third row, from left to right: Members at Large* **Masao Sakuraba**, **Kuniyuki Kakushima**, *and* **Minoru Inaba**.

Pacific Northwest Section

The **ECS Pacific Northwest Section** successfully launched its webinar series in 2021 with quarterly presentations. The recorded presentations are available on the ECS YouTube channel.

Wei Wang



David Reed

On January 28, 2021, **David Reed** and **Wei Wang**, Pacific Northwest National Laboratory (PNNL), presented "R&D Efforts in Energy Storage Technologies for the Grid at the PPNL," highlighting recent PPNL efforts to accelerate the acceptance of energy storage technologies for grid-scale application. They covered the investigation of new and existing systems (i.e., redox flow batteries, Na-ion, and Zn/MnO2) and described the novel digital twin approach to accelerate energy storage discovery and development.

Xiulei (David) Ji

On March 4, 2021, **Xiulei (David) Ji**, Oregon State University, discussed "Aqueous Battery Chemistry: Considerations from a Reaction's Perspective," a conceptual framework for battery design principles. He introduced rocking-chair batteries, dual-ion batteries, and non-metal charge carriers (i.e., proton, ammonium, halides, and superhalides).

Daniel (Dan) Schwartz

Daniel (Dan) Schwartz presented "Clean Energy Institute's Open Access Facilities & Emerging Tools for Battery Science" on April 8, 2021. The webinar shared information on instruments and equipment available for external use such as advance lab-scale X-ray spectroscopies for experiments like XANES and the scale-up facilities for coating, printing, processing, and packaging of thin film devices, and hardware/power hardware-in-the-loop for power electronics and system integration engineering.

The University of Washington and University of Oregon hosted a free "Virtual Industry and Careers Day" for the section on May 14. The goal of this event was to connect undergraduates, graduate students, and postdoctoral researchers with industry and national laboratory representatives that will provide insight into careers in electrochemical fields, valued skills in potential job candidates, and upcoming opportunities in the rapidly expanding electrochemical technology area.

In other news, the section is pleased to announce the new ECS Pacific Northwest Section Electrochemistry Research Award Sponsored by Gamry Instruments. The award recognizes outstanding achievements in electrochemistry and solid state science and technology research by independent scientists or engineers working in Washington State, Oregon, or Idaho. The nomination deadline is July 15, 2021. Learn more about the award, which consists of a framed certificate and $1,000 (USD) prize.

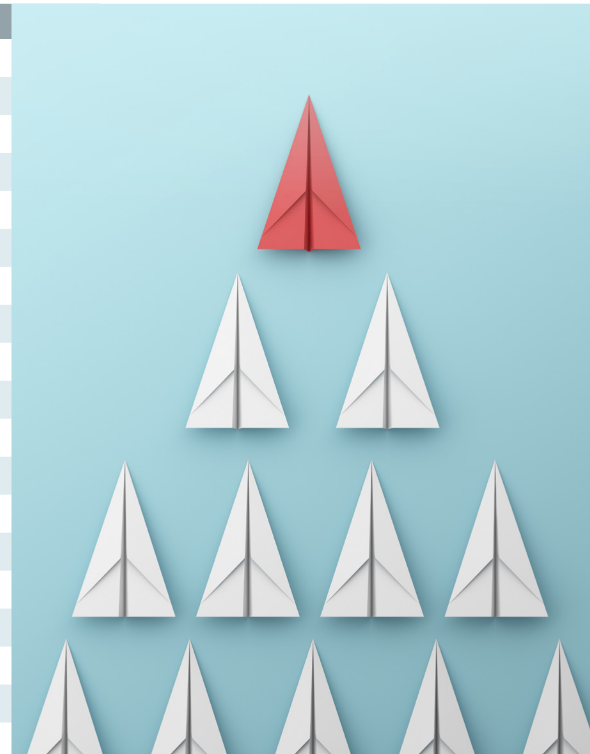
San Francisco Section

The San Francisco area is known for its diverse and vital economy, culture, and innovation. As the carbon neutral economy takes root, electrochemistry-based R&D and manufacturing are booming in the area. The **ECS San Francisco Section** voted in its recent business meeting to establish an Inclusion, Diversity, Equity, and Accountability (IDEA) Committee with the mission of promoting electrochemistry to traditionally disadvantaged individuals, groups, and communities. The IDEA committee will host its first talk with **Marca Doeff** as part of the "ECS San Francisco Section Distinguished Seminar Series." Doeff is Senior Scientist and Division Deputy from Lawrence Berkeley Laboratory, as well as ECS Secretary. She will share the IDEA principles guiding her distinguished research career at the Berkeley Lab, and her outstanding research in sodium-ion and solid state batteries.

Marca Doeff

Section Leadership

Section Name	Section Chair
Arizona Section	Candace Kay Chan
Brazil Section	Luis F. P. Dick
Canada Section	Bradley Easton
Chicago Section	Open
Chile Section	Jose H. Zagal
China Section	Yongyao Xia
Cleveland Section	Heidi B. Martin
Detroit Section	Kris Inman
Europe Section	Philippe Marcus
Georgia Section	Seung Woo Lee
India Section	Sinthai A. Ilangovan
Israel Section	Daniel Mandler
Japan Section	Seiichi Mayazaki
Korea Section	Won-Sub Yoon
Mexico Section	Carlos E. Frontana-Vazquez
National Capital Section	Eric D. Wachsman
New England Section	Sanjeev Mukerjee
Pacific Northwest Section	Jie Xiao
Pittsburgh Section	Open
San Francisco Section	Gao Liu
Singapore Section	Zichuan J. Xu
Taiwan Section	Hsisheng Teng
Texas Section	Jeremy P. Meyers
Twin Cities Section	Vicki Johnston Gelling



To learn more about ECS sections,visit **www.electrochem.org/sections**; or to become involved, contact **customerservice@electrochem.org**.

Awards, Fellowships, Grants

ECS distinguishes outstanding technical achievements in electrochemistry, and solid state science and technology, and recognizes exceptional service to the Society through the **Honors & Awards Program**. Recognition opportunities exist in the following categories: Society Awards, Division Awards, Student Awards, and Section Awards.

ECS recognizes that today's emerging scientists are the next generation of leaders in our field, and offers competitive **Fellowships** and **Grants** to allow students and young professionals to make discoveries and shape our science long into the future.

See highlights below and visit www.electrochem.org/awards for more information.

Society Awards

The **ECS Charles W. Tobias Young Investigator Award** was established in 2003 to recognize outstanding scientific and/or engineering work in fundamental or applied electrochemistry or solid state science and technology by a young scientist or engineer. The award consists of a scroll, a $5,000 prize (USD), Society life membership, complimentary meeting registration, and travel assistance to the designated meeting.

Materials due by October 1, 2021.

The **ECS Edward Goodrich Acheson Award** was established in 1928 for distinguished contributions to the advancement of any of the objects, purposes, or activities of The Electrochemical Society. The award consists of a gold medal and a plaque that contains a bronze replica thereof, a $10,000 prize (USD), Society life membership, and complimentary meeting registration.

Materials due by October 1, 2021.

The **Fellow of The Electrochemical Society** was established in 1989 for advanced individual technological contributions in the field of electrochemical and solid state science and technology, and active membership and involvement in the affairs of The Electrochemical Society. The award consists of a framed certificate and lapel pin.

Materials due by February 1, 2022.

Division Awards

The **ECS Corrosion Division H. H. Uhlig Award** was established in 1972 to recognize excellence in corrosion research and outstanding technical contributions to the field of corrosion science and technology. The award consists of a framed certificate, a $1,500 prize (USD), and possible travel assistance.

Materials due by December 15, 2021.

The **ECS Electrodeposition Division Early Career Investigator Award** was established in 2015 to recognize an outstanding early career researcher in the field of electrochemical deposition science and technology and to enhance their stature and encourage especially promising researchers to remain active in the field. The award consists of a framed certificate, a $1,000 prize (USD), and complimentary meeting registration.

Materials due by April 1, 2022.

The **ECS Electrodeposition Division Research Award** was established in 1979 to recognize outstanding research contributions to the field of electrodeposition and to encourage the publication of high-quality papers in the *Journal of The Electrochemical Society*. The award consists of a framed certificate and a $2,000 prize (USD).

Materials due April 1, 2022.

The **ECS Electronics and Photonics Division Award** was established in 1969 to encourage excellence in electronics research and outstanding technical contribution to the field of electronics science. The award consists of a framed certificate, a $1,500 prize (USD), and the option of up to $1,000 (USD) to facilitate travel to the designated meeting for recognition or ECS life membership.

Materials due by August 1, 2021.

The **ECS Energy Technology Division Research Award** was established in 1992 to encourage excellence in energy-related research. The award consists of framed certificate, a $2,000 prize (USD), and membership in the Energy Technology Division for as long as the recipient is an ECS member.

Materials due by September 1, 2021.

The **ECS Energy Technology Division Supramaniam Srinivasan Young Investigator Award** was established in 2011 to recognize and reward an outstanding young researcher in the energy technology field. The award consists of a framed certificate, a $1,000 prize (USD), and complimentary meeting registration.

Materials due by September 1, 2021.

The **ECS High-Temperature Energy, Materials, & Processes Division Outstanding Achievement Award** was established in 1984 to recognize excellence in research and outstanding technical contributions to the high-temperature energy, materials, and processes field. The award consists of a framed certificate, a $1,000 prize (USD), complimentary registration, and up to $1,000 (USD) in travel expenses.

Materials due by January 1, 2022.

The **ECS Industrial Electrochemistry and Electrochemical Engineering Division New Electrochemical Technology (NET) Award** recognizes significant advances in industrial electrochemistry. The primary motivation in establishing this award is to promote high-quality applied electrochemical research and development.

Materials due by June 15, 2022.

The **ECS Nanocarbons Division Richard E. Smalley Research Award** was established in 2006 to encourage excellence in fullerenes, nanotubes, and carbon nanostructures research. The award is intended to recognize, in a broad sense, those persons who have made outstanding contributions to the understanding and applications of fullerenes. The award consists of a framed certificate, $1,000 prize (USD), and up to $1,500 (USD) in travel assistance.

Materials due by September 1, 2021.

The **ECS Nanocarbons Division SES Research Young Investigator Award** was established in 2007 to recognize and reward one outstanding young researcher in the field of fullerenes, carbon nanotubes, and carbon nanostructures. The award consists of a framed certificate, a $500 prize (USD), and complimentary meeting registration.

Materials due by September 1, 2021.

The **ECS Physical and Analytical Electrochemistry Division David C. Grahame Award** was established in 1981 to encourage excellence in physical electrochemistry research and to stimulate publication of high-quality research papers in the *Journal of The Electrochemical Society*. The award consists of a framed certificate and a $1,500 prize (USD).

Materials due by October 1, 2021.

Section Awards

The **ECS Pacific Northwest Section Electrochemistry Research Award** was established in 2021 to recognize excellence in electrochemistry and solid state science and technology research. The award consists of a framed certificate and a $1,000 prize (USD).

Materials due by July 15, 2021.

Student Awards

The **ECS Canada Section Student Award** was established in 1987 to recognize promising young engineers and scientists in the field of electrochemical power sources and to encourage the recipients to initiate or continue careers in the field. The award consists of a $1,500 (USD) prize.

Materials due by February 28, 2022.

The **ECS Corrosion Division Morris Cohen Graduate Student Award** was established in 1991 to recognize and reward outstanding graduate research in the field of corrosion science and/or engineering and to encourage especially promising researchers to remain active in the field after their graduate research is completed. The award consists of a framed certificate and a $1,000 prize (USD). The recipient may receive up to $1,000 (USD) toward travel expenses to facilitate attendance at a designed Corrosion Division symposium where the recipient will present a lecture on research work.

Materials due by December 15, 2021.

The **ECS Energy Technology Division Graduate Student Award Sponsored by BioLogic** was established in 2012 to recognize and reward promising young engineers and scientists in fields pertaining to this division. The award consists of a framed certificate, a $1,000 prize (USD), complimentary student meeting registration, and complimentary admission to the division business meeting.

Materials due by September 1, 2021.

The **ECS Georgia Section Student Award** was established in 2011 to recognize academic accomplishments in any area of science or engineering in which electrochemical and/or solid state science and technology is the central consideration. The award consists of a $500 (USD) prize.

Materials due by August 15, 2021.

The **ECS India Section S. K. Rangarajan Graduate Student Award** was established in 2017 to assist a deserving student in India to pursue a career in disciplines related to electrochemistry and solid state science and technology. The award consists of a framed certificate, a $500 (USD) prize, and a complimentary one-year ECS membership.

Materials due by September 1, 2021.

The **ECS Industrial Electrochemistry and Electrochemical Engineering Division H. H. Dow Memorial Student Achievement Award** was established in 1990 to recognize promising young engineers and scientists in the field of electrochemical engineering and applied electrochemistry. The award consists of a framed certificate and a $1,000 prize (USD) to be used for expenses associated with the recipient's education or research project: tuition, books, equipment, or supplies.

Materials due by September 1, 2021.

The **ECS Industrial Electrochemistry and Electrochemical Engineering Division Student Achievement Award** was established in 1989 to recognize promising young engineers and scientists in the field of electrochemical engineering. The award consists of a framed certificate and a $1,000 (USD) prize.

Materials due by September 1, 2021.

The **ECS Korea Section Student Award** was established in 2005 to recognize academic accomplishments in any area of science or engineering in which electrochemical and/or solid state science and technology is the central consideration. The award consists of a $500 (USD) prize.

Materials due by December 31, 2021.

NEW MEMBERS

Member Spotlight

Holger Saare

Graduate Teacher and Research Assistant, Department of Chemical and Biomolecular Engineering, North Carolina State University

"I was inspired to join ECS by seeing active members of the Society around me, who have contributed significantly to the field and continue to do so. The most invaluable benefit of being a member is indubitably the connections that it fosters."

Heather Allen

Professor, Chemistry and Biochemistry Department, The Ohio State University

"The biggest benefit right now is the reduced cost for open access publication in the ECS flagship journal, although I anticipate that the student awards will also be utilized/appreciated. I was inspired to join because I felt our work, and our newest research directions, will provide insight to fundamental mechanistic questions in electrochemistry. Our first paper in this new area, "Circuit Analysis of Ionizing Surface Potential Measurements of Electrolyte Solutions," was just published in the Journal of The Electrochemical Society."[1]

ECS is proud to announce the following new members for January, February, and March 2021.

Members

A

Elsa Aguilera, Saltillo, Coahuila de Zaragoza, Mexico
Heather Allen, Columbus, OH, U.S.

B

Aaron Blake, Dayton, OH, U.S.
Anja Boisen, KGS. Lyngby, Hovedstaden, Denmark

C

Isidora Cekic-Laskovic, Münster, Nordrhein-Westfalen, Germany
Jiho Chang, PU.S.n, Gyeongsangnam-do, South Korea
Jang Wook Choi, Seoul, Gyeonggi-do, South Korea
Jorge Colon, San Juan, PR, Puerto Rico
Laurence Croguennec, Talence, Nouvelle-Aquitaine, France
Cecilia de Carvalho Castro Silva, São Paulo, São Paulo, Brazil

F

Mark Flowers, Phoenix, AZ, U.S.

G

Sarah Glanvill, Gloucester, Gloucestershire, UK

H

Nikolaus Herres, Andernach, Rheinland-Pfalz, Germany
Sho Hideshima, Ueda, Nagano, Japan

I

Nick Irish, Keego Harbor, MI, U.S.

K

Hong-Keun Kim, Lemont, IL, U.S.

L

Jinhyuk Lee, Montreal, QC, Canada
Chen Liao, Westmont, IL, U.S.
Jose Louvier-Hernandez, Mexico City, Estado de Mexico, Mexico
Ben Luan, London, ON, Canada
Christopher Lyons, Sunnyvale, CA, U.S.

M

Takashi Matsumae, Tsukuba, Aichi, Japan
Michael Melnyk, Great Mills, MD, U.S.
Mausumi Mukhopadhyay, Surat, GJ, India
Poongs Muthukumaran, Northborough, MA, U.S.

P

Dhiru Patel, City of Industry, CA, U.S.
Louis Piper, Birmingham, NY, U.S.

[1] T. Adel, J. Velez-Alvarez, A. C. Co, and H. C. Allen, *J. Electrochem. Soc.*, **168**, 016507 (2001).

NEW MEMBERS

R

Eric Raub, Carl Junction, MO, U.S.
Marco-Tulio Rodrigues, Naperville, IL, U.S.
Jungki Ryu, Ulsan, Yeongnam, South Korea

S

Yoshiki Seike, Tsukuba-shi, Ibaraki, Japan
Agata Skorupa, Kielce, Świętokrzyskie, Poland
Jeremy Smith, Bloomington, IN, U.S.
Niranjan Sudhakar, Newmarket, ON, Canada
Wei Sun, Münster, Nordrhein-Westfalen, Germany
Shinya Suzuki, Minoh-shi, Osaka, Japan

T

James Thode, Bothell, WA, U.S.

W

Allister Watson, Burgess Hill, West Sussex, UK
Mahlon Wilson, Los Alamos, NM, U.S.

X

Gao Xin, Lexington, KY, U.S.

Y

Hui Ying Yang, Singapore, East Region, Singapore

Z

Wu Zhang, Shenyang, Liaoning, China

Student Members

A

Serife Aksu, Gebze, Kocaeli, Turkey
Taichiro Amino, Sendai, Miyagi-ken, Japan
Kwame Ampofo, Shanghai, Shanghai, China
Harindi Atapattu, Lexington, KY, U.S.
Charles Ault, Bloomington, IN, U.S.

B

Shahid Muhammad Bashir, Vancouver, BC, Canada
Kyle Baustert, Lexington, KY, U.S.
Jenna Berger, Raleigh, NC, U.S.
Ankush Bhatia, Thiais, Île-de-France, France
Buse Bilbey, İstanbul, Marmara, Turkey
Elena Boselli, Chicago, IL, U.S.
Colm Boyle, Dundee, Scotland, UK
Leo Brody, Raleigh, NC, U.S.
Selma Nur Buyukgoz, Gebze, Kocaeli, Turkey

C

Sebastian Calderon Cazorla, West Lafayette, IN, U.S.
Debanjali Chatterjee, West Lafayette, IN, U.S.
Huiyuan Chen, Philadelphia, PA, U.S.
Darren Chow, Deep River, ON, Canada
Cassius Clark, Cambridge, Cambridgeshire, UK
Guillermo Colon, Orocovis, PR, U.S.

D

Somaiyeh Dadashi, Philadelphia, PA, U.S.
Michael Dato, Chicago, IL, U.S.
Jenna DeMartino, Apex, NC, U.S.
J. Dylan Denison, Raleigh, NC, U.S.
Bhavesh Deore, Jamaica, NY, U.S.
Sean Douglas, Dundee, Scotland, UK

E

Aycan Eksioglu, Pendik, Istanbul, Turkey

F

Kehinde Fagbohungbe, Lexington, KY, U.S.
Alexandra Forderhase, Raleigh, NC, U.S.

G

Raghuram Gaddam, Urbana, IL, U.S.
Weiran Gao, Cambridge, MA, U.S.
Rahul Goyal, Tohana, Haryana, India
Claudia Granja, Cali, Valle del Cauca, Colombia
Christiane Groher, Vienna, Oberösterreich, Austria

H

Md Ahsan Habib, Wichita, KS, U.S.
Dong Hou, Blacksburg, VA, U.S.
Anyang Hu, Blacksburg, VA, U.S.
Brittany Huffman, Carrboro, NC, U.S.

I

Nafisa Ibrahim, Urbana, IL, U.S.

J

Meng Jiang, Blacksburg, VA, U.S.
Susan Ju, Los Angeles, CA, U.S.

K

Nishithan Balaji Chidambara Kani, Chicago, IL, U.S.
Bryce Kieffer, Plattsville, ON, Canada
Donghyun Kim, Willimantic, CT, U.S.
Su-Kyung Kim, Seoul, Seoul, South Korea
Sankalp Koduvayur Ganeshan, Hyderabad, TG, India
Adefunke Koyejo, Turku, Turku, Finland
Khagesh Kumar, Chicago, IL, U.S.

L

Egle Latvyte, Coventry, West Midlands, UK
Da-Hoon Lee, Seoul, Jeollabuk-do, South Korea
Tae-Ju Lee, Seongbuk-ku, Seoul, South Korea
Alison Lightfoot, St. Andrews, Fife, UK
Marco Lobato de Faria, Winnipeg, MB, Canada
Luma Lopes, Winnipeg, MB, Canada
Yunkaii Luo, Los Angeles, CA, U.S.

M

Hugh Macrae, Calgary, AB, Canada
Mohamed Mahrous, Cairo, Cairo, Egypt
Andrew Malooley, Westmont, IL, U.S.
Dinorah Martinez, Toa Baja, PR, U.S.
Sahm Matti, Swansea, Wales, UK
Hadley McCormick, Carrboro, NC, U.S.
Ryan McDonnell, Lansdale, PA, U.S.
Tyler McGee, Austin, TX, U.S.
Giovanni Mendoza, Summit Argo, IL, U.S.
Abhiroop Mishra, Urbana, IL, U.S.
Adam Morgan, London, ON, Canada
Michael Mortelliti, Chapel Hill, NC, U.S.

N

Hassina Nadour, Montreal, QC, Canada
Kaustubh Girish Naik, West Lafayette, IN, U.S.
Lukas Neidhart, Vienna, Vienna, Austria
Ky Nguyen, Eastlakes, New South Wales, Australia
Vinh Nguyen, Seattle, WA, U.S.
Saman Nikpour, London, ON, Canada
Masoomeh Nooryani, Calgary, AB, Canada

O

Mariam Odetallah, Winnipeg, MB, Canada
Mohamed Okasha, Waterloo, ON, Canada
Bertan Ozdogru, Stillwater, OK, U.S.

P

Mihui Park, Jung-Gu, Seoul, South Korea
Sheyda Partovi, Bloomington, IN, U.S.
Jacob Pawlik, Burlington, NC, U.S.
Gabriella Pereira Feron, Chapel Hill, NC, U.S.

R

Jay Rawal, Romeoville, IL, U.S.
Milad Rezaei, Calgary, AB, Canada
Kara Rodby, Cambridge, MA, U.S.
Indrani Roy, Chicago, IL, U.S.

S

Holger Saare, Raleigh, NC, U.S.
Tamoghna Saha, Raleigh, NC, U.S.
Laura Sanford, Jackson, WI, U.S.
Merissa Schneider-Coppolino, Vancouver, BC, Canada
Deepak Seth, New Delhi, DL, India
Arqum Shami, Winnipeg, MB, Canada
Sarah Sheffield, University Park, PA, U.S.
Jonathan Simon, Libertyville, IL, U.S.
Deshraj Singh, Moradabad, UP, India
Shaheer Sohail, Lahore, Punjab, Pakistan
Madeline Stark, Carrboro, NC, U.S.
Huabin Sun, Blacksburg, VA, U.S.
Sreeram Sundaresh, Orlando, FL, U.S.
Zia Syed, Stillwater, OK, U.S.

T

Antonio Teixeira, Coimbra, Coimbra, Portugal
Nikita Thomas, Winnipeg, MB, Canada

(continued on next page)

NEW MEMBERS

(continued from previous page)

Jovica Todorov, Raleigh, NC, U.S.
Kalynn Turner, Raleigh, NC, U.S.
Jack Twiddy, Raleigh, NC, U.S.

U

Mustafa Unver, Üsküdar, Istanbul, Turkey

V

Juan Valdez-Moreira, Bloomington, IN, U.S.
Kunal Velinkar, Detroit, MI, U.S.

W

Evelyna Wang, Cambridge, Cambridgeshire, UK
Xiaokang Wang, West Lafayette, IN, U.S.
Zheng Wei, London, ON, Canada
Liam Witteman, Golden, CO, U.S.

Y

Zhijie Yang, Blacksburg, VA, U.S.
Deniz Yildiz, Stockholm, Uplandia, Sweden
Mingyu Yuan, Blacksburg, VA, U.S.

Z

Yuxin Zhang, Blacksburg, VA, U.S.
Xiaoying Zheng, Varennes, QC, Canada
Keren Zhou, State College, PA, U.S.
Yunqian Zou, Philadelphia, PA, U.S.

Member Anniversaries 2021

It is with great pleasure that we recognize the following ECS members who have reached their 30-, 40-, 50-, and 60-year anniversaries with the Society in 2021. ***Congratulations to you all!***

60 Year

Robert F. Amlie
Joan B. Berkowitz
Elton J. Cairns
Theodore H. Dexter
Jerry H. Fishman
Gerald Halpert
Robert P. Hamlen
Hans Erich Hintermann
Zoltan Nagy
Frederick J. Strieter
Barry J. Welch
Fritz G. Will
Richard L. Yeakley

50 Year

Gerard M. Blom
Alan M. Bond
Gerhard L. Holleck
W. Jean Horkans
Gunter H. R. Kegel
Bruce E. Liebert
Anthony F. Sammells
Helmut Tannenberger
Aron Vecht
Shunpei Yamazaki

40 Year

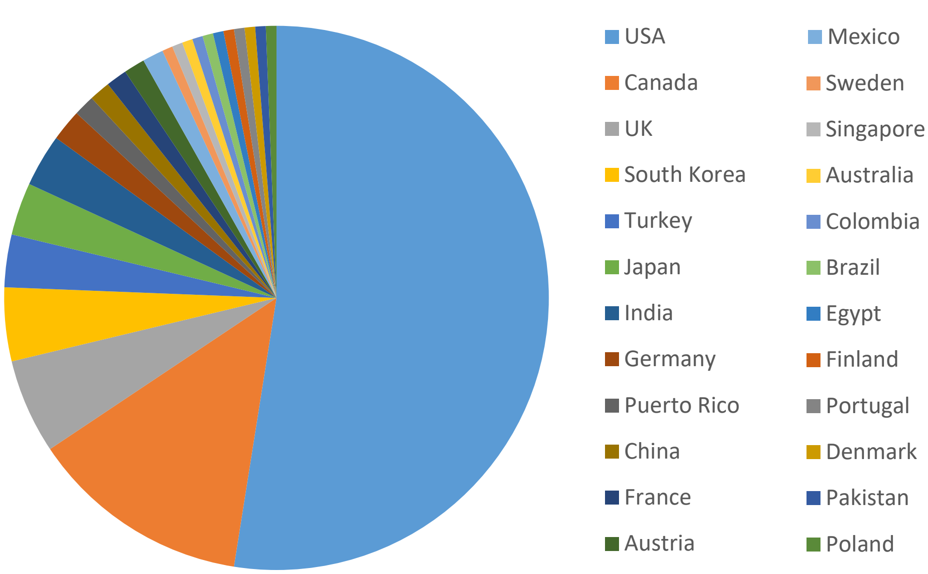
Haruo Akahoshi
George W. Ayrton
Phillip D. Bennett
Sheng-Min Cai
Graham T. Cheek
Sung Nee G. Chu
Bruce Dunn
Juan Genesca
Jens Gobrecht
Enrnesto R. Gonzalez
Douglas P. Hafen
Torben Jacobsen
Emil Kamieniecki
Leslie W. Kennedy
Shahed Khan
Philip Lessner
Christopher H. Leygraf
Tso-Ping Ma
Paul Natishan
Tsutomu Ohzuku
Harald A. Oye
Naum Pinsky
Klaus Ploog
Bruce G. Pound
Krishnan Rajeshear
Rathbun Rhodes
Antonio J. Ricco
Kent Ridgeway
Alan L. Sidman
Tooru Tsuru
Kohei Uosaki
Joseph Wang
Jeremy C. Wright
Glenn D. Zoski

30 Year

Niels J. Bjerrum
V. H. Branneky
Stephen E. Creager
Alvin W. Czanderna
Jeff Dahn
Inam Ul Haque
Hiroyuki Harada
Hans L. Hartnagel
Wilmont F. Howard
Satoshi Kawashima
Sunghyun Kim
Mark E. Law
Shiun Ling
Qingguo Liu
Noboru Matsui
Tatsuo Matsui
Tatsuo Nishina
Roland Oltra
Takahiro Sawaguchi
Greg M. Swain
Junji Tabuchi
Dennis E. Tallman
Reshef Tenne
Josh Thomas
Yoshiharu Uchimoto
Mirna Urquidi-MacDonald
Walter A. van Schalkwijk
Alan C. West
Siyu Ye
Harumi Yokokawa

New Members by Country

Look who joined ECS in the First Quarter of 2021.



USA	84
Canada	21
UK	9
South Korea	7
Turkey	5
Japan	5
India	5
Germany	3
Puerto Rico	2
China	2
France	2
Austria	2
Mexico	2
Sweden	1
Singapore	1
Australia	1
Colombia	1
Brazil	1
Egypt	1
Finland	1
Portugal	1
Denmark	1
Pakistan	1
Poland	1

New ECS Student Chapters

Thanks to students' enthusiasm to join the Society's global community, the ECS Student Chapter program has expanded to 107 chapters in 25 countries. Join us in congratulating the newly chartered student chapters!

ECS Student Chapters Approved by the ECS Board of Directors (Spring 2021)

- Gebze Technical University – Gebze, Turkey
- ECS Manitoba Student Chapter – Manitoba, Canada

ECS Student Chapters Approved by the ECS Board of Directors (Fall 2020)

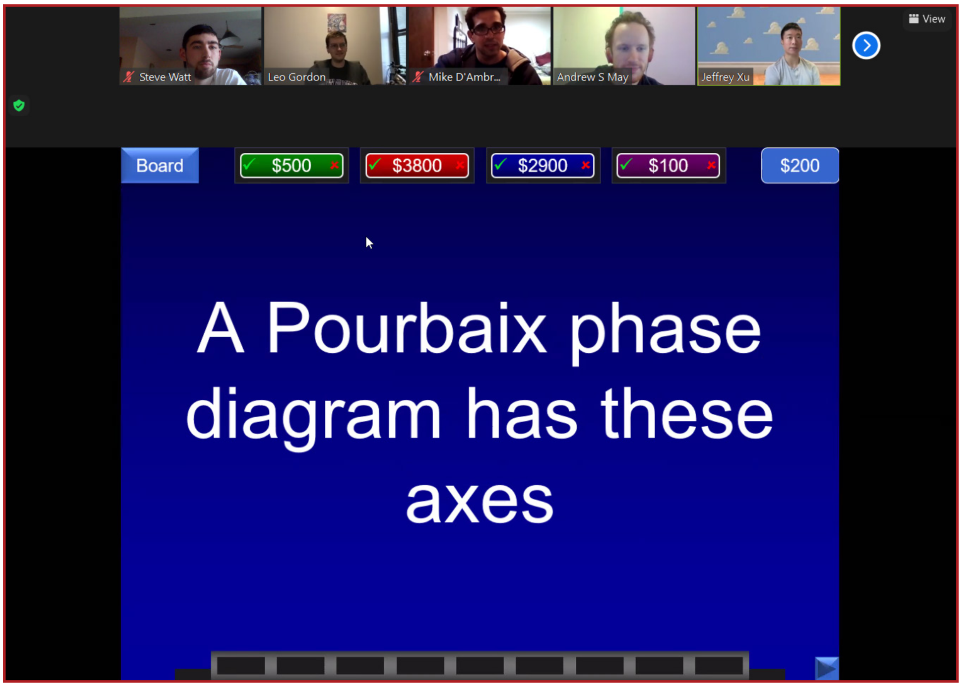
- City College of New York – New York, U.S.
- Pennsylvania State University – Pennsylvania, U.S.
- Swansea University – Swansea, UK
- Texas Technical University – Texas, U.S.
- University of California, Irvine – California, U.S.
- University of Notre Dame – Indiana, U.S.

ECS Student Chapters Approved by the ECS Board of Directors (Spring 2020)

- Ball State University – Indiana, U.S.
- National Tsing Hua University – Hsinchu City, Taiwan
- National Chiao Tung University – Hsinchu City, Taiwan
- Technische Universität Ilmenau – Thuringia, Germany
- University of Cambridge – Cambridge, UK
- University of Münster – Münster, Germany
- University of Nebraska-Lincoln – Nebraska, U.S.
- Wayne State University – Michigan, U.S.

City College of New York Student Chapter

The **ECS City College of New York (CCNY) Student Chapter** hosted a Zoom Jeopardy event on April 9, 2021. The goals were to inform the community about the student chapter and to recruit new members. Including five current chapter members, 11 people were present for the *Jeopardy* event. Many laughs were had, and few questions were left unanswered. The chapter also held a networking event with guest panel speakers. A set of Zoom breakout rooms followed that allowed for networking within the community.



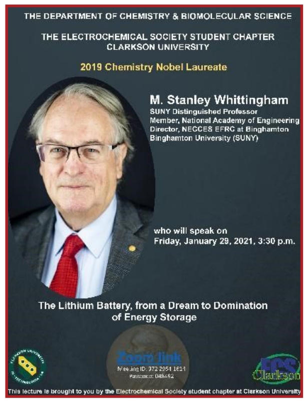
Screenshot from the ECS City College of New York Student Chapter's Zoom Jeopardy Event shows a question on an electrochemistry topic. Participants shown, from left to right: Steve Watt, Leo Gordon, Mike D'Ambrose, Andrew S. May, *and* Jeffrey Xu.
Photo: Steve Watt

Flyer for the ECS City College of New York Student Chapter's April 9 Zoom Jeopardy Event.

Clarkson University Student Chapter

The **ECS Clarkson University (CU) Student Chapter** held its first in-person event since the COVID-19 shutdown. A Halloween dinner on October 23, 2020, brought chapter members together to enjoy fun games and good food, learn more about the chapter, and discuss research updates with professors working in electrochemistry. Social distancing and all safety precautions were practiced. The chapter also held a Trivia Night during the spring term with short quiz session games for all students. Winners received prizes.

The Clarkson student chapter online seminar series presented "Bio-electrochemical Measurements with Nanoscale Pipettes" by Lane Baker, Department of Chemistry, Indiana University, on November 6, 2020. Faculty and students from the Departments of Chemistry, Chemical Engineering, and Environmental Engineering attended the seminar. The 2019 Chemistry Nobel Laureate, M. Stanley Whittingham, presented "The Lithium Battery, from a Dream to Domination of Energy Storage" on January 29, 2021, as part of the seminar series. Faculty members and students from all CU departments participated along with the ECS University of Waterloo Student Chapter and the ECS Montreal Student Chapter.



The ECS Clarkston University Student Chapter virtual webinar series features Nobel Laureate, **M. Stanley Whittingham**.

The Clarkson chapter organized the 25th Shipley Distinguished Lecture on January 22, 2021. The full-day program included short meetings with student chapter officers, the CU provost and president, graduate and undergraduate students, women members of science organizations, and junior and senior faculty members. The ECS University of Waterloo Student Chapter and ECS Montreal Student Chapter were invited along with all CU departments. More than 140 people participated. The lecture was delivered by Zhenan Bao, Stanford University, discussing skin-inspired organic electronics and recent advances in skin-attached electronic devices. He answered questions following the lecture and provided career advice.

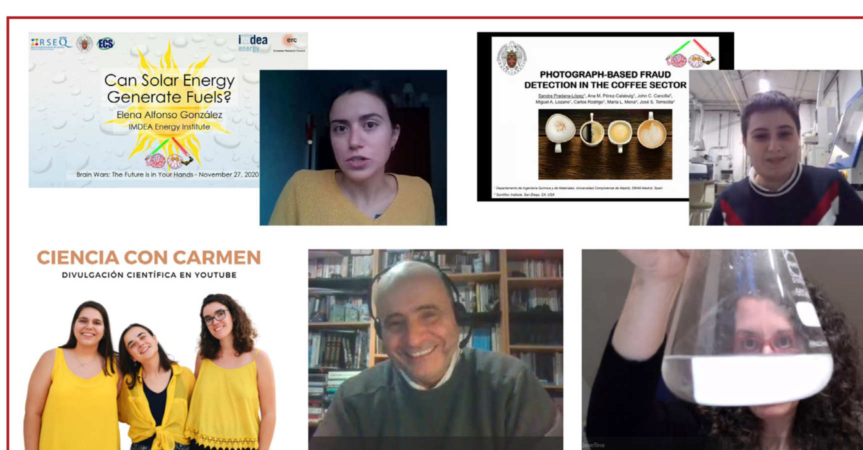
Chapter members engaged in educational outreach programs, presenting at an academic showcase for prospective undergraduate students on November 10, 2020. Chapter officers and two undergraduate student members provided a brief introduction to The Electrochemical Society (ECS) and chapter activities. They described the experience they gained as active members. In January-February 2021, the chapter participated in Project Challenge, a program CU initiated to attract high school students' attention to, and passion and curiosity about, chemistry. Six three-hour lectures about interesting chemistry lab experiments were prepared and demonstrated. Another educational project was the creation, with professors' assistance, of a series of short 10-12 minute publicly accessible lectures/tutorial videos on different electrochemistry topics. The goal was to create high-quality educational videos for students interested in or working in the electrochemistry field. The 1st Annual ECS Student Chapter Joint Symposium took place in collaboration with neighboring ECS student chapters. Research and resources were shared that could help future collaborations with other chapters.

Students attend ECS Clarkston University Student Chapter's first in-person event, a Halloween dinner.

Complutense University of Madrid Student Chapter

The **ECS Complutense University of Madrid Student Chapter** held the third "Brain Wars: The Future Is in Your Hands" contest in November 2020. Due to COVID-19, the contest was reorganized and took place online. The format allowed local and international students to present and assist. It included 19 oral presentations, 10 flash presentations, and six moderators. Elísabet L. Afonso (who received the second oral prize in Brain Wars II) and Gabriel Pinto Cañón, Universidad Politécnica de Madrid, shared their recent research.

The newly elected chapter committee is working on the fourth contest scheduled for November 2021. The main goal of the event is to promote research, debate, critical evaluation, and the dissemination of knowledge by young researchers, and encourage interest in science and technology. The fourth Brain Wars follows the model of the third and replaces the poster category with a 10-minute oral category and three-minute flash category. The two best presentations in each category receive a monetary award and signed



ECS Complutense University of Madrid Student Chapter presented its third Brain Wars contest and a webinar on educating youth about science. Top row left to right: The poster for the Brain Wars contest; **Elena A. González** *received the contest's 1st Oral Prize for "Photograph-based Fraud Detection in the Coffee Sector;"* **Sandra Pradano-López** *was awarded the contest's 1st Flash Prize. Second row from left to right: Participants in the webinar included the YouTube channel Ciencia con Carmen; radio presenter* **Manuel Seara**; *and* **Josefina Perlés** *on teaching crystallography to a young audience.*

certificate. The contest is supported by The Electrochemical Society (ECS) and the Spanish Royal Society of Chemistry Madrid Territorial Section (RSEQ-STM), Solid State Chemistry Section (RSEQ-QES), and Young Chemistry Researchers Section (RSEQ-JIQ).

The chapter organized the webinar, El Mal Del Sabio, in which experienced communicators shared how to promote science through the internet and radio and to young audiences. The chapter is grateful for the participation of the science YouTube channel, *Ciencia Con Carmen*; Josefina Perlés on teaching crystallography to a young audience; and Manuel Seara, former presenter of the radio program, *A Hombros de Gigantes*.

Stay informed about activities planned for the year ahead at www.ecsucm.wordpress.com.

Detroit Student Chapter

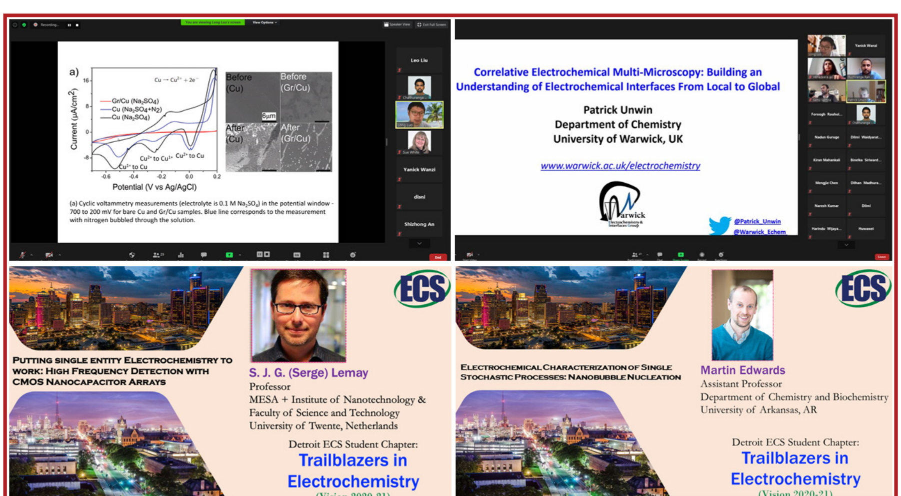
As the first ECS student chapter in Michigan, members wanted to educate the community and bring attention to the **ECS Detroit Student Chapter**. In-person activities could not be organized due to the COVID-19 pandemic, so a series of 90-minute virtual electrochemistry workshops served as the first event. The focus was to refresh participants' fundamental knowledge of electrochemistry, and transition from theoretical understanding to application. Long Luo, Wayne State University, and Tianbiao Liu**,** Utah State University, presented at the workshops. On August 20, "Fundamentals and Techniques in Electrochemistry" attracted 53 participants. "Electrochemistry Applications: Li Batteries, Corrosion" on September 3 had 32 participants. "Applications: Catalysis" on September 10 had 20 participants. Responses to surveys following the workshops were very positive. Many respondents want to join future workshops, indicating the workshops' success. The chapter will continue efforts to strengthen electrochemistry knowledge in interested communities by arranging annual workshops.

The chapter's second event was a seminar series from October 2020 to January 2021 called "Trailblazers in Electrochemistry," with renowned electrochemists from around the world discussing new ideas and long-term visions for the future of electrochemistry research. More than 50 people from around the world—including Denmark, China, India, Sri Lanka, and Canada—participated in each seminar. After the presentations, chapter members interacted and shared their research with the invited speakers.

The first speaker, Patrick Unwin, Department of Chemistry, University of Warwick, UK, discussed efforts to enable a fundamental understanding of electrochemical reactions via building correlations from electrochemical scanning microscopy. In the second seminar, Adam Holewinski, University of Colorado Boulder, spoke on integrating infrared spectroscopy with electrochemical flow cell-based kinetic studies to elucidate reaction mechanisms and the electrooxidation pathways of biomass-derived large molecules to obtain value-added products on single crystal electrodes. Participants included students from Wayne State University, University of Michigan, Purdue University, Michigan State University, Technical University of Denmark, and members of the Michigan Catalysis Society. More than 70 participants in the third seminar heard Shannon Boettcher, University of Oregon (UO), provide novel insights into the development of bipolar membranes for electrochemical systems, which allow the design of electrochemical systems with bifunctional capabilities. Following the webinar, Prof. Boettcher gave encouraging feedback on students' research and invited students to attend UO's new Electrochemical Technology program.

The chapter ushered in 2021 by hosting Serge J. G. Lemay**,** University of Twente, The Netherlands, discussing his group's efforts to study single entity electrochemistry and use these insights toward practical applications. He reviewed the importance of electrochemical measurements at the nanoscale and high frequent electrochemical impedance spectroscopy at a high density of nanoelectrodes. The second 2021 speaker, Martin Edwards, University of Arkansas, described borrowing concepts from mathematics, statistics (stochastic processes), and physical/analytical chemistry to study the electrochemical characterization of nanoscale entities in the form of nanobubbles. The systematic understanding of nanobubbles' nucleation remains crucial to minimizing the loss in efficiency due to their occlusion of electrode surfaces. Song Lin, Cornell University, reviewed efforts to amp up organic synthesis with electrochemistry. As the application of electrocatalysis towards synthetic organic chemistry is underexplored, opportunities remain for inventing new catalytic strategies to improve the scope of synthetic electrochemistry and provide new platforms for reaction discovery and synthetic innovations.

Follow the ECS Detroit Student Chapter on Twitter at @ECS_Detroit.



Screenshots and flyers promoting the ECS Detroit Student Chapter's electrochemical workshop and Trailblazers in Electrochemistry webinar series.
Photo: Ruchiranga Ranaweera

Gebze Technical University Student Chapter

The **ECS Gebze Technical University Student Chapter**, advised by Aligül Büyükaksoy and founded by Materials Science and Engineering Department graduate students, was recently approved by the ECS Board of Directors. The first meeting was held online due to the COVID-19 pandemic. Chapter members were extremely excited and motivated about planning upcoming activities, and look forward to sharing and learning about electrochemistry while expanding the membership.

ECS Gebze Technical University students participate in their first chapter meeting. Left to right, first row: **Aycan Ekşioğlu**, *Secretary*; **Buse Bilbey**, *Chair*; **Emrah Demirkal**, *Vice-Chair*; *second row (from left to right):* **Selma Nur Büyükgöz**, *Treasurer;* **Aligül Büyükaksoy**, *Advisor;* Şerife Aksu, *member; third row:* **Mustafa Ünsal Ünver**, *member*.

Indiana University Student Chapter

The **ECS Indiana University (IU) Student Chapter** attended two digital conferences—the 71st International Society of Electrochemistry Annual Meeting in September 2020, and Pittcon in March 2021. Many chapter members presented oral talks or posters at Pittcon and received positive feedback from the electrochemistry community. The IU Baker Research Group enjoyed watching the Society of Electroanalytical Chemistry (SEAC) Murray and Reilley award symposium and talks over a socially distanced lunch.

Student Chapter President Krista M. Kulesa won the prestigious U.S. Department of Energy Office of Science Graduate Student Research (SCGSR) Award. She will use it to work at the Pacific Northwest National Laboratory (PNNL). Congratulations to Krista—you will be missed! Congratulations to ECS Advisor Lane Baker who received the 2021 Electrochemistry Award of the American Chemical Society Division of Analytical Chemistry.

ECS members contributed fun electrochemical demos to Science Fest, a science outreach day for children of all ages. The chapter enjoys a friendship with the ECS Detroit Chapter and its Wayne State University (WSU) members. The two Midwest chapters hosted a virtual panel of electrochemists in different workforce sectors. Enthusiasm is high for collaborating with the exemplary team at WSU. Overall, this has been a rewarding season for the ECS Indiana University Student Chapter, which looks forward to a more open world and hopes to meet in person at a conference in the near future!

Lewis University Student Chapter

The **ECS Lewis University Student Chapter** invigorated the virtual community outreach world by hosting a COVID-friendly water quality competition. In conjunction with the SMASH (Summer Math and Science Honors) Academy, a virtual water filtration and purification competition was designed for students across the Midwest with sites from Southern Illinois to Chicago, St. Louis, and Detroit.

The competition focused on integrating Lewis chapter students as mentors with high school scholars in order to effectively communicate scientific information and execute teamwork digitally, while successfully purifying and desalinating a sample of contaminated water. Each scholar received a box with the limited supplies allowed for building their purification apparatus. The teams met weekly online with their mentor to build an apparatus that was not only effective but also efficient in the purification process. On competition day, the SMASH scholars effectively communicated to their mentor about building the apparatus and performing the purification of the water sample. After each team ran water through their apparatus, the samples were collected and data analysis was done to compare the efficiency of the purification process. This virtual student-led project empowered the SMASH scholars to address a real-world issue that required complex problem solving and critical thinking, project dissemination, team building/collaboration, and most importantly, built confidence in implementing scientific method.

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El-Cell 19
ECS Transactions 239th ECS Meeting with IMCS 18 56
Gamry 2
Ion Power 24
Pine Research Instrumentation 4
Scribner Associates 1
Wiley 54

Münster Student Chapter

The **ECS Münster Student Chapter** was founded almost a year ago. The COVID-19 pandemic affected all ECS Student Chapters and working groups around the world. But scientific exchange was able to overcome social distancing issues through smart videoconference software, which has found its way into every household. Therefore, the chapter decided to start an online seminar series of electrochemistry talks featuring renowned battery researchers.

More than 90 participants joined the first online seminar on March 1, 2021, with guest speakers Jürgen Janek, Justus Liebig University Giessen, and Andrea Balducci, Friedrich Schiller University Jena. The professors gave interesting presentations on alternative electrolytes, covering both solid state electrolytes and ionic liquids. Chapter Vice President Tjark Ingber moderated an exciting discussion following the presentations. The event was a great start for the series and marked the beginning of a collaboration with the International Graduate School BACCARA (Battery Chemistry, Characterization, Analysis, Recycling, and Application) to organize this and other upcoming events.

On April 16, 2021, Stefano Passerini, Helmholtz-Institute Ulm, and Robert Dominko, National Institute of Chemistry Ljubljana, discussed battery materials beyond lithium such as sodium and divalent metals (Mg, Ca). Chapter President Julia Wellmann, who works in the field of calcium batteries and their application, moderated a lively discussion with professors, postdocs, PhD candidates, and students.

The chapter hosted a joint workshop with the ECS Cambridge University Student Chapter featuring PhD candidates' research. Additional online seminars took place on topics including characterization methods in battery research and novel electrode materials. Alumni working in industry gave talks as well.

The chapter assisted the International Graduate School BACCARA in organizing weekly lectures. More than 70 participants joined the April 12, 2021 lecture by Wolfgang Zeier, University of Münster. The goal of the collaboration with BACCARA is to involve more students and more aspects of electrochemistry.

The ECS Münster Student Chapter is eager to collaborate with other ECS Student Chapters around the world and organize joint online events. Contact the chapter at info.chapter.ecs@uni-muenster.de and follow it on Twitter @ecs_muenster and Instagram at ecs_muenster for coverage of upcoming events and news about prizes and awards.

ECS Münster Student Chapter Vice President **Tjark Ingber** *moderates Alternative Electrolytes, a digital seminar with guest speakers* **Jürgen Janek** *and* **Andrea Balducci**.

Pennsylvania State University Student Chapter

The **ECS Pennsylvania State University Student Chapter** hosted biweekly meetings and activities online this spring due to the ongoing COVID-19 pandemic. The chapter hosted two seminars to promote networking and outreach. The first on March 16, "Scale-Up of Electrochemical Processes for Nuclear Fuel Recycling," by Krista Hawthorne, Argonne National Laboratory, was widely attended by chapter members and the broader university community. Dr. Hawthorne highlighted the research at Argonne to translate electrochemical strategies for uranium fuel recycling from the laboratory scale to the engineering scale and eventually to the production scale. Afterwards, she responded to questions related to her work and the national lab career path and work environment, which was especially helpful for students. The chapter hosted Luis Diaz Aldana, Idaho National Laboratory, on April 27.

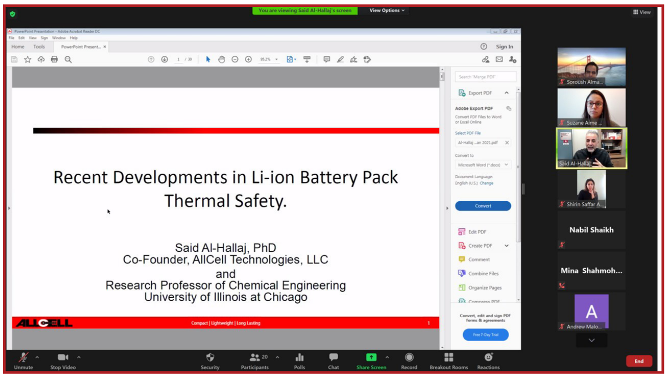
The chapter began an exciting collaboration to help with the battery design for Penn State's Chem-E-Car Competition team car. The competition is organized by the American Institute of Chemical Engineers and features teams from universities throughout the Northeast. Students must design and build a battery-powered car that travels a set distance specified shortly before the start of the competition. Prizes are awarded in November 2021 for top placers, most-creative design, and most-creative drive system. The competition is sure to be fun and challenging!

Members met in April 2021 for a socially distanced hike on a local trail—the first in-person meeting since the chapter was formed last October.

University of Illinois at Chicago Student Chapter

The **ECS University of Illinois at Chicago Student Chapter** hosted a webinar on January 22, 2021. Guest speaker Said Al-Hallaj presented "Recent Developments in Li-Ion Battery Pack Thermal Safety." Dr. Al-Hallaj is Research Professor of Chemical Engineering at the University of Illinois at Chicago (UIC); co-founder of AllCell Technologies LLC, a Li-ion battery manufacturing company; and founder and CEO of NETenergy LLC, a thermal energy storage company. He discussed ongoing AllCEll R&D efforts focused on developing hybrid phase change composite/hydrogel battery packs to improve thermal runaway safety. Twenty undergraduate and graduate students and professors joined the webinar to learn more about electrochemical technologies and applications. Three lucky winners won raffle prizes at the end of the talk. All participants were incentivized to join the chapter and become official student members of ECS.

For more information and/or to join the chapter, contact board members via email at uicecschapter@gmail.com.



Dr. Said Al-Hallaj *gives a Zoom webinar for the student chapter.*

ECS University of Illinois at Chicago Student Chapter webinar attendees.

University of Notre Dame Student Chapter

The **ECS University of Notre Dame Student Chapter** was established at the end of 2020 to bring Notre Dame's leading electrochemical research groups together as one community; enrich collective electrochemical science and engineering knowledge; facilitate collaborations within the University of Notre Dame; and serve as a professional development resource for successful careers in electrochemical science. The chapter's advisors are Paul Bohn, Prashant Kamat, Jennifer Schaefer, Nosang Myung, and Thien-Toan Tran from Notre Dame's Department of Chemistry & Biochemistry and Department of Chemical & Biomolecular Engineering.

"It is commendable to see the enthusiasm of graduate students to start the ECS University of Notre Dame Student Chapter," said Prof. Prashant Kamat, ECS faculty advisor and the Rev. John A. Zahm Professor of Science, Notre Dame. "Given the broad diversity of topics from energy conversion to energy storage, and from diagnostics to sensors, this chapter offers students across the College of Science and College of Engineering a common platform to come together and engage in scientific discussions. I am quite excited to be part of this chapter and participate in the student-led activities."

Screenshot of the March 2021 virtual seminar with **Shirley Meng**.

The chapter kicked off its inaugural event in January 2021 with a virtual seminar by Shelley Minteer, University of Utah, titled "Enzymatic Bioelectrocatalysis for Fuel Cell Applications." She detailed the use of enzyme cascades at bioanodes for improved performance of fuel cells and the important role of metabolons for substrate channeling in multi-enzyme cascades. Shirley Meng, University of California, San Diego, delivered the second virtual seminar in March 2021, "From Atom to System – How to Enable the Tera-scale Energy Transition." New perspectives for energy storage materials were described, including new fast ion conductors, new intercalation compounds and their interfacial engineering, as well as future priority research directions for electrochemical energy storage. Following the seminar, Notre Dame graduate battery researchers engaged with Prof. Meng in a lively small group discussion on their research interests, the future of energy storage systems, and career prospects for battery researchers. Shannon Boettcher, University of Oregon, spoke on "Nanoscale Probes of Carrier-Selective Catalyst/Semiconductor Contacts in Water-Splitting Photoelectrodes."

The virtual events were greatly successful; each was attended by about 50 faculty members, graduate students, and postdoctoral researchers from both Notre Dame departments. "The ECS University of Notre Dame Student Chapter was very fortunate to kick off their activities with such distinguished scientists and speakers," said Prof. Paul Bohn, the chapter's primary faculty advisor, and Arthur J. Schmitt Professor of Chemical and Biomolecular Engineering and Professor of Chemistry and Biochemistry, Notre Dame. "We envision that the chapter will continue to benefit students and young scientists who are at the forefront of cutting-edge electrochemical research here at Notre Dame."

A series of "ECS Notre Dame Student Chapter EChem School" events featured chapter member grad students and postdoc researchers giving practical and informative introductions for beginners/intermediates to various electrochemical techniques and experiments. Due to the pandemic, many chapter events have been virtual. When it is safe, the chapter will move to in-person events and host speakers from industry and student-led discussions on electrochemical research, plan outreach events to promote electrochemical science and engineering to young students, and organize collaborative events with leading Notre Dame institutes, such as ND Energy and the Notre Dame Institute of Precision Health.

"I am excited for our students," said Prof. Jennifer Schaefer, faculty advisor and assistant professor in the Department of Chemical and Biomolecular Engineering, Notre Dame. "Establishment of the ECS Notre Dame Student Chapter has provided a mechanism to bring people together and catalyzed many new professional development opportunities." The chapter hopes to keep the Notre Dame electrochemical research community engaged and informed in of the latest developments in the field.

Follow the chapter on Twitter @ECS_ND for updates on activities.

University of Waterloo Student Chapter

The **ECS University of Waterloo Student Chapter** held several events over the past months, educating and connecting hundreds of students. Virtual events reached countries far beyond the Waterloo chapter. Four companies in the field of electrochemistry participated: Calogy Solutions, focusing on battery thermal management; GBatteries, working on AI for battery charging; Hydrogenics – Cummins, specializing in hydrogen fuel cells; and SUEZ, researching electrochemical water treatment.

The chapter hosted events focused on developing students' research visualization skills. In February, Felice Frankel, Massachusetts Institute of Technology, gave a virtual presentation on how to design scientific figures. Students participated in an interactive session and received direct feedback on how to convey their electrochemical data and figures. In March, Michael Alley, Pennsylvania State University, gave a virtual talk on how to improve and deliver scientific presentations. Students learned how to use an assertion evidence model to more effectively deliver presentations at conferences. The chapter also ran a workshop on electrochemical modeling with COMSOL, Inc.

Western University Student Chapter

During the pandemic, the **ECS Western University Student Chapter** has strived to make the student community more aware of on-campus electrochemical resources. The chapter's virtual workshop series continued with its fourth instalment on April 7. François Lagugné-Labarthet, Scientific Director, Western NanoFabrication (Nanofab) Facility, provided an overview of the state-of-the-art research center focusing on nanoscale fabrication and characterization techniques. He specializes in the study of materials and biomaterials using spectroscopy, microscopy, and nanoscale science. The facility is widely used by industrial clients and various research groups in Western University's Chemistry, Engineering, Physics, and Geology departments. Dr. Lagugné-Labarthet outlined the instruments and research capabilities available and the training process for graduate students to become more comfortable with experimental apparatuses that might be unavailable in their regular lab environment. The virtual workshop attracted more than 25 attendees from faculties across campus.

A screenshot of the virtual workshop with **Dr. François Lagugné-Labarthet**.

In February, three long-serving executive members concluded their graduate studies and departed the chapter's team: Jonathan Adsetts, Lindsay Grandy, and Masoumeh (Masi) Naghizadeh. The chapter thanks them for their efforts in creating and planning many past events, and growing the ECS Western University Student Chapter.

Alongside President Kieran Doyle Davis and Vice President Baian Almusned, three new members joined the executive team: Adam Morgan, Outreach Officer; Elham Salehi Alaei, Treasurer; and Kwang O'Donnell, Secretary. With supervision by James Noël, Elham is completing her PhD research on the influence of copper oxidation on sulfide-induced corrosion and the possible oxide-to-sulfide conversion reaction under different conditions. Morgan, also a Noël student, is completing his MS on the role of hydrogen on the corrosion of titanium using electrochemical and surface analytical techniques. Kwang is completing his MS under Clara Wren's supervision, investigating the non-linear corrosion dynamics of carbon steel in the presence of gamma radiation.

ECS Western University Student Chapter's new executive members are **Adam Morgan**, *Outreach Officer;* **Elham Salehi Alaei**, *Treasurer; and* **Kwang O'Donnell**, *Secretary.*

(continued from page 11)

Dr. Dupuis: A lot of us were gambling on ideas. To do something really new and different takes gambling and focus and failing, then after each failure, continuing, trying to understand the failure, then correcting it, and moving on. Perseverance is important in engineering. You often have failures and don't have a solution, but you have to keep going.

Dr. Craford: If experiments fail or don't come out the way you want, don't consider it a failure. That's Mother Nature screaming at you, "Things aren't the way you thought they were going to be." Think about what you expected or anticipated that didn't happen and see if you can learn something from that. Chances are, there's something to be learned if you look hard enough.

THE NEXT BIG THING

Dr. Craford: I think ultraviolet efficiency improvement is the next big area. COVID-19 reminded us that we live in an environment that can be very dangerous and hazardous. Viruses, while they have no brains, are pretty smart. Staying safe requires a lot of things besides a mask and vaccine. We're able to kill viruses on surfaces that humans come into contact with.

Dr. Nakamura: We are focused on developing high-efficiency far UV-C LEDs because far UV-C LEDs emissions at 222 nanometer frequencies don't cause human health problems as the light does not penetrate the surface of the skin and therefore doesn't destroy DNA. We could install far UV-C LED lighting everywhere around the world and kill all kinds of viruses. Even with new viruses, infections wouldn't develop. With new COVID strains appearing almost daily, pharmaceutical companies constantly have to develop new vaccines. Far UV-C light can solve that problem and relieve fear. This is our obligation as scientists.

THE ROLE OF SCIENTIFIC SOCIETIES

Dr. Dupuis: A major role of ECS and other organizations is organizing conferences which are important for students and exchanging ideas. I missed going to in-person conferences this year and my students missed out on presenting their work and interacting with other students and researchers. Literally, creating a society—social interaction—is important. Journals and online publications are interesting, and now that we've worked out online conferences, they're a substitute, but not a complete substitute. Sponsoring awards, and having industry sponsor awards, is another important society activity.

Dr. Craford: Meetings are a very good place to meet with quite a few people at once and find out what's going on. The breaks are almost more important than the papers that are given!

Dr. Nakamura: Meeting face-to-face is very important. We are humans, not robots. I look forward to meeting in person at a conference, which is critical, even for scientists' mental health. Virtual meetings are not as good; our children's education is suffering; students are frustrated. Mentoring online is frustrating, too.

JOURNALS AND PEER REVIEW

Dr. Nakamura: When I worked in industry, I had to follow the *Journal of The Electrochemical Society*. It became my dream to publish in JES. I wanted to publish the data from my research at the company but they considered it confidential, so I gave up the idea of publishing. When I left and joined a university, I realized my dream and published several papers in ECS journals.

Dr. Craford: It's important to be published in a good high-quality peer-reviewed journal like the ones ECS publishes. I can hardly imagine not publishing in a peer-reviewed journal, because you want to get a strong independent viewpoint of whether your work is good or not. If you publish in a journal that is not peer reviewed, or read something not published in a peer-reviewed journal, you don't really trust it.

Dr. Dupuis: When I was in graduate school, the *Journal of The Electrochemical Society* was important for us to watch carefully. Nick was an ECS member and published a lot of papers there. Peer-reviewed journals have weight with the public view as well. Though I don't expect people who aren't working in technology or physics to read *Applied Physics Letters*, having a publication list that is peer reviewed helps one's career. Having someone with expertise review papers before they appear in print is a valuable contribution to society, and has been since the earliest journals.

Dr. Nakamura: Our students have to publish papers. Peer review is especially good for students because they receive a lot of very strict comments, which improve their research capabilities. It also catches if a professor is lazy and doesn't check the paper's details!

PARTING ADVICE FOR ECS

Dr. Nakamura: ECS PRiME's conference venue in Hawaii is great. Hawaii is a nice place!

Dr. Craford: Maybe you could have a Hawaii meeting one year, and Paris the next year!

 DOI: 10.1149.2/2.F01212IF.

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5. "2021 QEPrize Winners," Queen Elizabeth Prize for Engineering, https://qeprize.org/winners/led-lighting.

ECS Institutional Members

2021 Leadership Circle Awards

Medallion - 65 years

GE Global Research Center

Scribner Associates, Inc.

Gold - 25 years

Technic, Inc.

The Electrosynthesis Company, Inc.

Benefactor

Bio-Logic USA/Bio-Logic SAS (13)*
Duracell (64)
Gamry Instruments (14)
Gelest, Inc. (12)
Hydro-Québec (14)
Pine Research Instrumentation (15)

Patron

Energizer (76)
Faraday Technology, Inc. (15)
GE Global Research Center (69)
Lawrence Berkeley National Laboratory (17)
Scribner Associates, Inc. (25)
Toyota Research Institute of North America (13)

Sponsoring

BASi (6)
Central Electrochemical Research Institute (28)
DLR-Institut für Vernetzte Energiesysteme e.V. (13)
EL-CELL GmbH (7)
Ford Motor Corporation (7)
GS Yuasa International Ltd. (41)
Honda R&D Co., Ltd. (14)
Medtronic Inc. (41)
Nissan Motor Co., Ltd. (14)
Pacific Northwest National Laboratory (PNNL) (2)
Panasonic Corporation (26)
Permascand AB (18)
Teledyne Energy Systems, Inc. (22)
The Electrosynthesis Company, Inc. (25)
Center for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW) (17)

Sustaining

General Motors Holdings LLC (69)
Giner, Inc./GES (35)
Cummins, Inc. (3)
Ion Power Inc. (7)
Kanto Chemical Co., Inc. (9)
Los Alamos National Laboratory (13)
Microsoft Corporation (4)
Occidental Chemical Corporation (79)
Sandia National Laboratories (45)
Western Digital GK (7)
Technic, Inc. (25)
Westlake (26)
Yeager Center for Electrochemical Sciences (23)

*Membership Years

03/21/2021