

FULL ISSUE (PDF)

Solid Oxide Fuel Cells (Fall 2009)

To cite this article: 2009 Electrochem. Soc. Interface 18 1

View the article online for updates and enhancements.

You may also like

- Classified
- Exhibition guide CMMP'94
- <u>ASE exhibitions: Manufacturers' exhibition</u> Bob Lovett

The Electrochemical Society

Solic

VOL. 18, NO. 3 Fall 2009



IN THIS ISSUE

- 3 Kicking the Fossil Fuel Habit
- 7 Lots of Energy in Vienna
- 13 Vienna, Austria Special Meeting Section
- 36 Tech Highlights
- 38 Solid Oxide Fuel Cell Commercialization, Research, and Challenges
- 45 The Role of Solid Oxide Fuel Cells in Advanced Hybrid Power Systems of the Future

49 Toward the Miniaturization of Solid Oxide Fuel Cells

53 From Laboratory Breaktbrough to Technological Realization: The Development Path for Solid Acid Fuel Cells

Dxide

2

217th ECS Meeting VOID OF THE STATES Home of the 2010 Olympic Winter Games April 25-30-2010

General Topics

- > Batteries, Fuel Cells, and Energy Conversion
- Biomedical Applications and Organic Electrochemistry
- Corrosion, Passivation, and Anodic Films
- Dielectric and Semiconductor Materials, Devices, and Processing

Deadlines

Registration

Deadline for advance meeting registration is March 26, 2010.

Hotels

Reservations deadlines are variable by hotel. Please see the ECS website.

Short Courses

A number ECS Short Courses will be held at the Vancouver meeting; to date, the course list includes Basic Impedance Spectroscopy and Basics of Cleaning Processing for Integrated Circuit Manufacturing.

- > Electrochemical / Chemical Deposition and Etching
- > Electrochemical Synthesis and Engineering
- > Fullerenes, Nanotubes, and Carbon Nanostructures
- > Physical and Analytical Electrochemistry
- > Sensors and Displays: Principles, Materials, and Processing

ECS Transactions

Full papers presented at ECS meetings will be published in *ECS Transactions* (ECST). Visit the ECS website for more details.

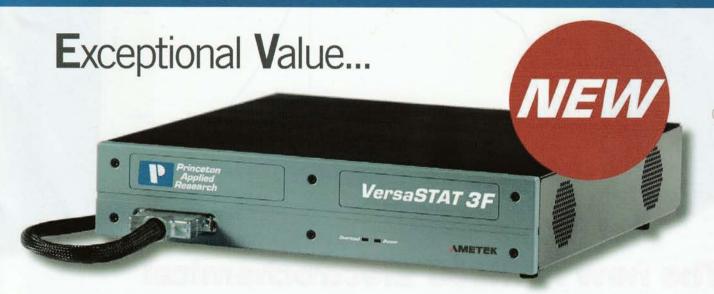
Travel Grants

Travel grants are available for student attendees and for young faculty and early career attendees.

www.electrochem.org

Visit the ECS website for meeting details:

Value \val-(,)yu\ n 1: to achieve performance and quality for a savings in monetary exchange.



The Latest member in our VersaSTAT® Family

- Capable of "floating" for operation with grounded cells and electrodes
- Specialized filters for float mode operation for enhanced signal/noise ratio
- ±650mA / ±10V polarization range as standard
 - ideal for many electrochemical applications including corrosion, sensors, and biomedical
- An internal frequency response analyzer option that provides impedance analysis over the frequency range 10µHz to 1MHz
- Additional bandwidth filtering options for greater stability on capacitive cells
- Easy-to-use VersaStudio software included

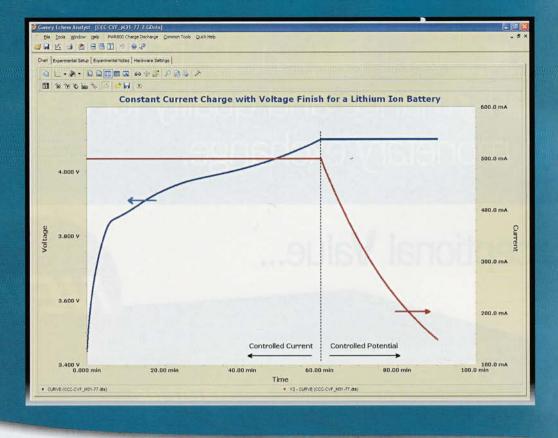
Applied



Princeton 801 South Illinois Avenue, Oak Ridge, TN 37831-0895 USA Tel: (865) 425-1289 or (865) 482-4411. Fax: (865) 481-2410

www.princetonappliedresearch.com pari.info@ametek.com





The new PWR800" Electrochemical Energy Software...

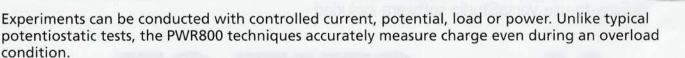
... Designed to test energy conversion devices

The PWR800[™] Electrochemical Energy Software combined with the Reference 3000 Potentiostat is the only electrochemical research system with the flexibility and accuracy you need for batteries, fuel cells, supercapacitors, and dye-sensitized solar cells. The PWR800 can be used to test half-cells, single cells, and cell stacks.

The PWR800 includes the following electrochemical techniques:

- Cyclic Charge-Discharge (CCD)
- Discharge Curves
- Cyclic Voltammetry
- Potentiostatic

- Charge Curves
- CCD Curves with EIS
- Polarization Curves
- Galvanostatic



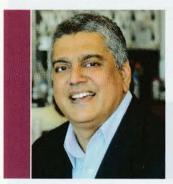
The PWR800 combined with the Gamry Sequence Wizard allows the creation of powerful, complex test scenarios. Flexible stop tests allow complete control over cycle design.

For additional information on the PWR800, call Gamry or your local Distributor or visit www.gamry.com.





FROM THE EDITOR



Kicking the Fossil Fuel Habit

"If future generations are to thrive, we who have consumed Earth's legacy of cheap oil must now provide for a world without it." — David Goodstein, Out of Gas

he title of this column is also borrowed from Goodstein's delightful little book. Energy and health care continue to hog the national headlines but in terms of the technical interests of the Society, energy issues are perhaps more germane. On June 26, the U.S. House of Representatives "passed the most important environmental and energy legislation in our nation's history," in the words of Fred Krupp, President of the Environmental Defense Fund. He was talking about HR 2454, the American Clean Energy and Security Act, sponsored by Reps. Henry Waxman (D-CA) and Edward Markey (D-MA). This bill would implement a cap and trade system limiting the amount of CO₂ or other greenhouse gas that factories, refineries, and power plants emit, with an overall cap on the emissions. This system thus distributes pollution allowances to be bought or sold, depending on whether a given facility exceeds the cap or makes greater pollution cuts than are mandated. Over the years, the cap will be lowered to cut emissions 17% (of 2005 levels) by 2020 and eventually to 83% by 2050. Allowances get scarcer and the price of emitting goes up. The concern with companies moving offshore to countries without emission constraints was addressed by providing 15% free allowances to some 40 basic industry sectors that make and sell products to global markets. Nonetheless, opponents of this energy bill are many; for some examples, see the Web links at the bottom of the page.

While passage of the bill in the House is but a first step (it still faces a difficult slog, fraught with compromises, in the Senate before becoming law), many view this legislation nonetheless as a signal that the U.S. is serious about joining other nations in putting a price on carbon emissions. In particular, passage of the bill will truly help negotiations for the forthcoming treaty talks this December, which should hopefully put in place a global solution to the climate crisis. It is worth noting that a cap and trade program already exists in the U.S. for SO_x, the pollutant linked to acid rain. The European Union also boasts the largest functioning cap and trade system for greenhouse gases in the world. In fact, this system was modeled after the highly successful U.S. acid rain counterpart. The European market sets carbon emissions limits for 11,000 facilities and already it has drawn billions of Euros into innovative. low-emitting energy technologies. One of the concerns, from a global perspective, is that without a comparable U.S. market to spur private investment in low-carbon fuels, this country will wind up having to import new green technologies just as we are spending precious dollars to import (and defend) foreign oil. Again on a global scale, one must not lose sight of the fact that for countries like India and China, coal will continue to be a dominant energy option in the shorter term. Unfortunately, there is little indication that emerging economies like these will accept the higher cost required to accommodate emission constraints because of the urgency associated with their infrastructure needs—a topic I peripherally addressed in my column in the last issue of this magazine.

Clean energy also happens to be the theme of this particular issue of *Interface*. ECS does another "first" in holding its fall meeting in Europe outside of the confines of its previous Paris venue and the eleventh symposium in the highly successful series on solid oxide fuel cells (SOFC-XI) simultaneously makes its appearance in Vienna, Austria. In celebration of this event, Eric Wachsman, Enrico Traversa, and Subhash Singhal have organized a series of three feature articles on SOFCs in the pages that follow. Included as a bonus feature, is another article by Sossina Haile and co-workers, on what they describe as a sixth type of fuel cell: the superprotonic solid acid fuel cell or SAFC. Finally, I would like to thank Nate Lewis and Sossina Haile (both of CalTech) for feedback on a draft of this editorial. Stay tuned.

aj K. Krishnan Rajeshwar Editor

'R'R'R'

Published by:



The Electrochemical Society (ECS) 65 South Main Street Pennington, NJ 08534-2839, USA www.electrochem.org

Editor: Krishnan Rajeshwar, rajeshwar@uta.edu

Guest Editors: Eric Wachsman and Subhash Singhal

Contributing Editors: Donald Pile, donald.pile@ gmail.com; Zoltan Nagy, nagyz@email.unc.edu

Managing Editor: Mary E. Yess, mary.yess@ electrochem.org

Production & Advertising Manager: Dinia Agrawala, interface@electrochem.org

Advisory Board: Nancy Dudney (Battery),

Barbara Shaw (Corrosion), Durga Misra (Dielectric Science and Technology), Lili Deligianni-(Electrodeposition), George K. Celler (Electronics and Photonics), S. R. Narayan (Energy Technology), Prashant V. Kamat (Fullerenes, Nanotubes, and Carbon Nanostructures), Jeff Fergus (High Temperature Materials), Venkat Srinivasan (Industrial Electrochemistry and Electrochemical Engineering), Cornelis R. Ronda (Luminescence and Display Materials), Isao Taniguchi (Organic and Biological Electrochemistry), Wesley Henderson (Physical and Analytical Electrochemistry), Peter Hesketh (Sensor)

Publication Committee Chair: Subhash Singhal

Society Officers: Paul Natishan, President; William D. Brown, Vice-President; Esther Takeuchi, Vice-President; Fernando Garzon, Vice-President; Johna Leddy, Secretary; John R. Susko, Treasurer; Roque J. Calvo, Executive Director

Statements and opinions given in The Electrochemical Society *Interface* are those of the contributors, and ECS assumes no responsibility for them.

Authorization to photocopy any article for internal or personal use beyond the fair use provisions of the Copyright Act of 1976 is granted by The Electrochemical Society to libraries and other users registered with the Copyright Clearance Center (CCC). Copying for other than internal or personal use without express permission of ECS is prohibited. The CCC Code for The Electrochemical Society *Interface* is 1064-8208/92.

Canada Post:

Publications Mail Agreement #40612608 Canada Returns to be sent to: Bleuchip 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 as part of membership service; subscription to nommembers is available; see the ECS website. Single copies \$7.00 to members; \$15.00 to nommembers. © Copyright 2009 by The Electrochemical Society. 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, N108534-2839

Society, 65 South Main Street, Pennington, NJ 08534-2839. The Electrochemical Society is an educational, nonprofit 501(c)(3) organization with more than 8000 scientists and engineers in over 70 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.



The Reference 3000... ...fast, quiet, compact and three amps!

The new Gamry Reference 3000 Potentiostat/Galvanostat/ZRA brings Gamry value and performance to a high-current instrument. With a unique set of capabilities, the Reference 3000 is a powerful tool for battery, fuel cell, corrosion, and physical electrochemistry laboratories.

- Three Amps Maximum Current
- 32 V Maximum Compliance
- 11 Current Ranges from 3 A to 300 pA
- Optional 8-Channel Auxiliary Electrometer
- Special Modes to Control/Measure Battery Stacks up to ±32 V
- 1 MHz EIS with < 2% Error
- Dimensions: 19W x 23H x 28D cm. Weight: 7 kg.



For additional information on the Reference 3000, call Gamry or your local distributor or visit www.gamry.com/reference3000.



+ 1.215.682.9330 • Fax: + 1.215.682.9331 • www.gamry.com • info@gamry.com

The Electrochemical Society

<u>INTERFACE</u>

Vol. 18, No. 3 Fall 2009



Solid Oxide Fuel Cell Commercialization, Research, and Challenges

E. D. Wachsman and S. C. Singhal



The Role of Solid Oxide Fuel Cells in Advanced Hybrid Power Systems of the Future

D. Tucker, M. Shelton, and A. Manivannan



Toward the Miniaturization of Solid Oxide Fuel Cells

E. Traversa



From Laboratory Breakthrough to Technological Realization: The Development Path for Solid Acid Fuel Cells

C. R. I. Chisholm, D. A. Boysen, A. B. Papandrew, S. Zecevic, S.-Y. Cha, K. A. Sasaki, Á. Varga, K. P. Giapis, and S. M. Haile



- From the Editor: Kicking the Fossil Fuel Habit
- 7 Pennington Corner Lots of Energy in Vienna
- Society News
- 18 Vienna, Austria Special Section
- **34** People News
- H Tech Highlights
- **37** Introduction to the Featured Articles
- **Section News**
- Awards
- 55 New Members
- 🔠 Student News

On the cover...

FIB/SEM 3D reconstruction of a Siemens SOFC cathode. Image courtesy of Danijel Gostovic and Eric Wachsman.

Cover design by Dinia Agrawala.

One system, many solutions.

Autolab Potentiostat/Galvanostat electrochemistry systems offer high-resolution solutions with a wide range of techniques for energy storage, biosensors, plating, material research, coatings, corrosion and more.

- Impedance Spectroscopy 10 µHz to 1 MHz
- Modular options: Bipotentiostat, Low Currents, Analog and High-speed Scanning
- Advanced programming for analysis control, data handling, evaluation and transfer

For more information visit: www.metrohmusa.com

U.S.A. 800-727-6768 Canada 866-260-6069 www.metrohmusa.com Email: info@metrohmusa.com

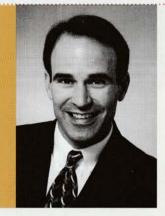
0720.A1.1000-INT © 2009 Metrohm USA, Inc. © and design are registered trademarks of Metrohm AG

OI AUTOLAB

1133333311150



PENNINGTON CORNER



Lots of Energy in Vienna

A n ECS meeting in Europe is always an energetic event because we produce extraordinary technical

programs and attract many of the best scientists in our discipline to one of the world's greatest destinations. The 216th ECS Meeting, which will be held in Vienna, Austria during the first week of October, has certainly created a lot of energy and excitement; and the importance of electrochemistry in solving the world's energy and environmental problems has increased the energy quotient for the meeting... both literally and figuratively.

One of our strategic meeting objectives is to rotate the biannual meetings into major cities in selected regions around the world. Figuratively, this creates a lot of energy around the meetings because it enables ECS to connect with our globally-expanding community. We are committed to holding one of our biannual meetings in a major European city about every four years, and Vienna represents our third major meeting in Europe. The first two European meetings were both held at the Palais des Congrès in Paris, France. We initiated this strategy in the 1980s, when ECS started rotating meetings in Honolulu. Hawaii to generate energy in the Pacific Rim. Since then we have held five joint meetings* in Honolulu with The Electrochemical Society of Japan (ECSJ) and several other partners from the Pacific Rim, and more recently we have ventured into Latin America and China. The formula has been very successful and we have seen an increased interest in ECS in these regions and a lot of good science and energy at our technical meetings.

While, figuratively speaking, we have experienced the energy created by the distinguished contributions of both students and research scientists (and the charisma and charm of the extraordinary international destinations), this October, at the Austria Center in Vienna, ECS will literally be concerned with energy like never before. The meeting program will include a broad range of topics in solid-state and electrochemical science and technology that includes a total of 3,196 papers in 44 different symposia with a projected attendance of about 3,400. What distinguishes the Vienna meeting is that we have developed the largest program on energy storage and conversion ever organized at an ECS meeting. The meeting begins on Sunday with our "XYZ... for the Rest of Us" series, where Professor David Shoesmith from the University of Western Ontario (London, Ontario, Canada) will present the XYZs of how electrochemistry is used in solving problems with nuclear waste. From Monday through to Friday, the technical program is loaded with energy-related symposia. Here's just a very small sampling:

- Intercalalation Compounds for Lithium Batteries (M. Wittingham, P. Bruce, C. Julien, M. Palacin, J. Prakash, and M. Thackeray), 115 papers
- Rechargeable Lithium Ion Batteries (M. Winter, K. Abraham, D. Doughty, Z. Ogumi, and K. Zaghib), 218 papers
- Photovoltaics for the 21st Century 5 (M. Toa, J. Brownson, P. Chang, C. Claeys, K. Kakimoto, K. Rajeshwar, M. Sunkara, and D. Yang), 61 papers
- Proton Exchange Membrane Fuel Cells 9 (T. Fuller, P. Bele, S Cleghorn, H. Gasteiger, C. Hartnig, T. Jarvi, D. Jones, C. Lamy, V. Ramani, P. Shrivanian, P. Strasser, H. Uchida, T. Zawodzinski, and P. Zelenay), 370 papers

In addition, we will be hosting a satellite conference in Vienna, namely the Eleventh International Symposium on Solid Oxide Fuel Cells (SOFC XI) organized by S. Singhal and H. Yokokawa. There is a special registration package for the SOFC XI conference attendees but the technical presentations (375 papers) are open to all the meeting attendees in Vienna. Finally, on Friday there is a satellite meeting on "In Situ Diagnosis of Low Temperature Fuel Cells," which is sponsored by the German Federal Ministry of Education and Research and organized by P. Krueger and C. Hartnig.

There will be lots of great science presented and discussed in Vienna this October, and for more information about the program go to www.electrochem.org. The Vienna program reflects the significance of our energy challenges and the role that electrochemistry will have in finding solutions. Lots of energy at ECS meetings generates the critical thinking needed for the future of our planet.

1 June J. Colus

Roque J. Calvo ECS Executive Director

* The joint meetings in Hawaii were re-branded in 2008, to reflect the contributions of the Pacific Rim participants and is now titled the Pacific Rim Meeting on Electrochemistry and Solid-State Science, or PRIME. PRIME 2008 was the fifth joint meeting between ECS and ECSJ, and it also included the co-sponsorship of the Royal Australian Chemical Institute, the Korean Electrochemical Society, the Chinese Society of Electrochemistry, and the Japan Society of Applied Physics. PRIME 2008 had 3,237 attendees, which made it the largest meeting on electrochemistry ever held.

7

Accurate Reliable Trusted Scribner Associates Inc.

850e Fuel Cell Test System



Automated Humidifier By-Pass for Wet/Dry Operation

Equipment setup in 2 to 4 hours

Easy PC connectivity with USB interface

Integrated FRA for EIS and HFR measurements

More Options: Back Pressure, Auto Water Fill, Liquid Reactant Pump, Reformate Simulation, High Temperature, H₂ Alarm and others

850e + High Temperature Includes High Temperature BP unit

Designed for Your High Temperature, High Dew Point Testing Needs

All the features and performance of the 850e +

Stable and Accurate Dew Point control up to 120 °C!

Fan Cooled Radiators and Large SS Water Traps



High Temperature Back Pressure Unit

ribnerAssociates

"I strongly recommend Scribner Associates for fuel cell testing equipment needs. The equipment reliably provides accurate and precise measurements for our research." Prof. James M. Fenton, Director Florida Solar Energy Center University of Central Florida

"While outfitting my lab I chose to go with Scribner's fully integrated, turn-key 850 test systems and have been very satisfied with the reliability and performance of the instruments." Asst. Prof. Vijay K. Ramani, Ph.D. Illinois Institute of Technology

Software tools for Electrochemistry

- FuelCell[®] the most powerful and versatile fuel cell R&D application software in the industry
- MultiStat[®], ZPlot[®] and CorrWare[®] Electrochemical Measurement Software Package

Contact us for your PEM, DMFC and other fuel cell testing needs!

- We have short turn-around times Just 3 to 4 weeks ARO
- Our experienced engineers and researchers are available to support your Fuel Cell testing

910-695-8884 Fax: 910-695-8886 info@scribner.com www.scribner.com



SOCIETY NEWS

Division News

Division Officer Slates Announced

New officers for the 2009-2011 term have been nominated for the following Divisions. All election results will be reported in the winter 2009 issue of *Interface*.

Electrodeposition Division

Chair

Christian Bonhôte, Hitachi Global Storage Technologies Japan, Ltd.

Vice-Chair Hariklia (Lili) Deligianni, IBM

Secretary

Giovanni Zangari, University of Virginia Treasurer (one to be elected)

Lisa Podlaha-Murphy, Northeastern University Stanko Brankovic, University of Houston

Junior Member-at-Large (one to be elected) Natasa Vasiljevic, University of Bristol Philippe M. Vereecken, IMEC

Energy Technology Division

The Energy Technology Division held elections for the offices of Chair, Vice-Chair, and Secretary prior to the ECS spring meeting in San Francisco (see the summer 2009 issue of *Interface* for the results). The election for the office of Treasurer will be held, by online ballot, prior to the ECS fall meeting in Vienna. An e-mail will be sent to all members of the Energy Technology Division to enable them to vote.

Treasurer (one to be elected)

Scott Calabrese Barton, Michigan State University Walter van Schalkwijk, EnergyPlex Corp. Adam Z. Weber, Lawrence Berkeley National Laboratory Jim Zheng, Florida State University

High Temperature Materials Division

Chair

Enrico Traversa, Universita di Roma, "Tor Vergata" Senior Vice-Chair

Jeff Fergus, Auburn University Junior Vice-Chair

Timothy Armstrong, Carpenter Technology Secretary/Treasurer

To be announced

Luminescence and Display Materials Division

Chair Kailash Mishra, Osram Sylvania Vice-Chair John Collins, Wheaton College Secretary/Treasurer

Holly Comanzo, GE Global Research Center

Corporate Member News Spotlight on Faraday Technology Inc.



FARADAY TECHNOLOGY INC. (www.FaradayTechnology. com) was founded in 1991 to develop and commercialize novel electrochemical technologies based on pulse/pulse reverse electrolytic processes. Electrochemical technology areas of interest include: (1.) electrodeposition of copper, trivalent chromium, and tin; (2.) electropolishing of stainless steel semiconductor valves, nickel-titanium stents, and niobium materials; (3.) through-mask etching for internal cooling channels, and microfluidic devices; (4.) electrophoretic deposition of thermal barrier coatings, varactor materials for RF filters; (5.) corrosion services; and (6.) customized electrochemical cells and apparatus.

Faraday embraces the concept of open innovation and plays an important role in the innovation ecosystem as a bridge between the fundamental electrochemical knowledge generated from universities and Federal laboratories and large companies with market channels and technology needs. Faraday works with its strategic partners to move technology from proof of concept/ laboratory feasibility conducted in Faraday's laboratory facilities through α -scale prototype demonstration of manufacturing and engineering readiness in Faraday prototype facilities to β-scale validation at Faraday's strategic partners' facilities. The resulting intellectual property is transferred to the strategic partner via exclusive or non-exclusive license or patent acquisition. Faraday has approximately 22 issued U.S. patents, four foreign patents, and additional patents pending. Faraday was recently acquired and is a subsidiary of Physical Sciences Inc. of Andover, MA and collectively employs 180 staff, of whom about 95 hold PhDs.



- The issue will feature work being done by members of the LUMINESCENCE AND DISPLAY MATERIALS DIVISION.
- There will be coverage of the **216^{rn} ECS MEETING IN VIENNA, AUSTRIA**, (October 4-9), including highlights from The ECS Lecture, given by Martin Stratmann; the "XYZ" Lecture by David Shoesmith; the Olin Palladium Award Lecture by Dieter Kolb; the Carl Wagner Award Address by Henry White; and from the SOFC XI and the EUROCVD 17 symposia.
- A new symposium, **Electrochemistry in Medicine and Biomedical Applications**, scheduled for the 217th ECS Meeting in Vancouver, Canada (April 25-30, 2010) will be showcased.

SOCIETY NEWS

ECS Welcomes New Staff



KARLA T. STEIN joined ECS in March as the new Director of Membership and Development, bringing a wealth of development experience from her 12 years in leadership roles in nonprofit healthcare. She has served as an Executive Director with the American Cancer Society, a Senior Vice-President of Major Gifts with The American Heart Association, and most recently as a Vice-President with the Robert Wood Johnson

Hamilton Hospital Foundation. In these various capacities she has been responsible for establishing major gift and planned giving programs that included the development of Gift Advisory Councils, prospect research and identification, solicitation, establishing cultivation and stewardship activities, grant writing, volunteer development including a Young Professionals Group, board governance, donor relations, event planning, public relations, and brand awareness. Prior to entering the non-profit field, Karla was an International Sales Director for Lenox China & Crystal, Inc. for over a decade where she did market research and established the Lenox brand in Japan, Europe, Bermuda, and the Caribbean. She has had experience in registering the Lenox trademark internationally and most recently the Grounds for Healing® certificate of registration for the hospital foundation.

In her new role at ECS, Karla will be focusing on elevating the global membership and establishing a major gift and planned giving program. Student relations will also be a priority and Karla will be working to augment student membership; increase funding that will support the expansion of the Student Chapters and student awards; increase the amount and number of the travel grants, summer fellowships, and internships; as well as provide a more enriching student program at the ECS meetings. In addition, she will be working collaboratively with the Divisions and Sections to champion their efforts to elevate their membership and symposium fundraising initiatives.

Karla is a native of Indianapolis, Indiana and a business graduate from the University of Evansville. She resides in Lawrenceville, New Jersey and has two sons that live in Richmond, Virginia.



LAUREN GERMANO joined ECS in August 2008 as the Administrative Assistant to the Membership & Development Department. In addition to supporting the Director and Assistant Director of Membership & Development, her responsibilities include maintenance of member, nonmember, student, and donor profiles, processing of dues renewal invoices and new membership applications, as well as enthusiastically

responding to the needs of our ECS callers and visitors. A native of Pennsylvania, Lauren currently resides in Pennington, New Jersey.



websites of note

by Zoltan Nagy

Electrochemical Technology in Microelectronics

The applications of electrochemical technology to microelectronics are expanding rapidly. As the dimensions of the features of microelectronic components have decreased, associated materials effects, interfacial effects, and molecular-scale interactions have become increasingly important for electrochemical metal deposition and removal. Several papers in this site focus on those aspects.

- IBM J. Res. & Dev., Vol. 49, No. 1, January 2005
- http://www.research.ibm.com/journal/rd49-1.html

Electrochemistry of the Nerve Impulse

All you ever wanted to know about electrochemical mechanism of the nervous system. You can learn about "axons," which are responsible for the transmission of information between different points of the nervous system—their function is analogous to the wires that connect different points in an electric circuit. Membrane potentials, action potentials, ionic pathways, ion channels, reversal potentials, voltage clamps, and capacitive currents are all explained in detail.

- F. Bezanilla, University of Chicago
- http://nerve.bsd.uchicago.edu/med98a.htm

Famous Electrochemists

A large collection of short biographies, illustrated with many pictures, of electrochemists and scientists in related fields. The collection starts in the 1500s and extends to this time. Over one hundred are listed, and unfortunately details are not available for all. Numerous further links are provided in every case, making this site a very extensive historical collection.

- Evgeny Katz, Clarkson University
- http://people.clarkson.edu/~ekatz/scientists/electrochemists.htm

About the Author

ZOLTAN NAGY is a semi-retired electrochemist. After 15 years in a variety of electrochemical industrial research, he spent 30 years at Argonne National Laboratory carrying out research on electrode kinetics and surface electrochemistry. Presently he is at the Chemistry Department of the University of North Carolina at Chapel Hill. He welcomes suggestions for entries; send them to nagyz@email.unc.edu.

Innovation in Materials Science



The new SurPASS – unsurpassably versatile

- SurPASS: the Surface Potential Analyzer for Solid Samples
- Works with streaming potential and streaming current measuring principle
- Various measuring cells provided
- Includes titration unit



Anton Paar® USA

800-722-7556 info.us@anton-paar.com www.anton-paar.com

SOCIETY NEWS

Highlights from IC4N-2009, Rhodes, Greece



CONSTANTIN POLITIS (IC4N co-Chair), MICHAEL GRAETZEL (Plenary Speaker), KRISHNAN RAJESHWAR (Plenary Session Chair), RON ELSENBAUMER (UTA VP Research), and STATHIS MELETIS (IC4N Chair)

The second international conference, "From Nanoparticle & Nanomaterials to Nanodevices & Nanosystems" (IC4N) was held June 28-29 on the Island of Rhodes (the Island of Knights) in Greece. The Aegean Nanoscience and Nanotechnology Workshop, sponsored by the National Science Foundation, was also held at the same venue on July 2 and 3.

The IC4N was co-sponsored by ECS and the conference had many member attendees and symposia organizers including Krishnan Rajeshwar (Editor of *Interface*), Claude Levy-Clement, Joachim Lewerenz, Trung Van Nguyen, and others. Professor Michael Grätzel of Ecole Polytechnique Fédérale de Lausanne (EPFL) kicked off the conference with a plenary talk entitled, "Mesoscopic Systems for Solar Energy Conversion and Storage." Professor Stathis Meletis (Chair of the Materials Science & Engineering Department of the University of Texas at Arlington) organized this conference (as well as its predecessor in Halkidiki last year) and more than 70 experts from around the world delivered keynote and invited talks. The conference topics (covered in ten symposia) included: Fundamentals of Nanoscale Materials (Theory/Simulation/Experiments); Functional Nanomaterials; Nanoclusters; Nanoparticles; Self-Assembly at the Nanoscale; Nanofabrication and Implications (Bio/Energy/Environment/Human Health/ Cultural); Nano-electronics and Nanophotonics; and Nanoscale Sensors and Devices.

The Workshop that followed the conference on Thursday and Friday engendered vigorous discussions on the above topics and effectively addressed nano-themes of interest. These discussions followed invited speakers setting up the stage with reviews of the state-of-the-art and outstanding issues in each field. The winners of the Best Poster Awards were Mee-Na Park (Myongji University, Korea), for "Improvement of Height Uniformity of ZnO Nanowire Arrays by Using Electropolishing Method;" and Spiridon Pappas (University of Patras, Greece), for "Photoluminescence Performance of SiO₂ Thin Films Produced by Reactive RF Sputtering." Each of these winners received \$1,000.

The ECS Student Poster Award winner was Mohamed Gharbi (University of Houston), for "The Origins of Electromechanical Indentation Size Effect in Ferroelectrics." This winner received one year of ECS student membership; registration waiver to the 217th ECS Meeting in Vancouver, Canada on April 25-30, 2010; and a \$1,000 travel grant to attend this meeting.

All in all, both the 2nd IC4N and the workshop were a resounding success and all indications are that this meeting series will continue to be held every summer in the Greek isles.

ECS Cosponsored Conferences for 2009

In addition to the regular ECS biannual meetings, ECS, its Divisions, and Sections cosponsor meetings and symposia of interest to the technical audience ECS serves. The following is a list of the cosponsored meetings for 2009. Please visit the ECS website for a list of all co-sponsored meetings.

- Microelectronic Technology and Devices (SB Micro 2009), August 31-September 3, 2009, Natal, Brazil, www.lasic.ufrn.br/chiponthedunes2009/
- BATTERIES 2009 The International Power Supply Conference and Exhibition, September 30-October 2, 2009, Cannes-Mandelieu, France, www.batteriesevent.info
- 6th International Conference on Electromagnetic Processing of Materials (EPM 2009), October 19-23, 2009, Dresden, Germany, www.epm2009.de
- 2009 Fuel Cell Seminar & Exposition, November 16-20, 2009, Palm Springs, CA, USA, www.fuelcellseminar.com

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

216th ECS Meeting

with EuroCVD 17 and SOFC XI - 11th International Symposium on Solid Oxide Fuel Cells

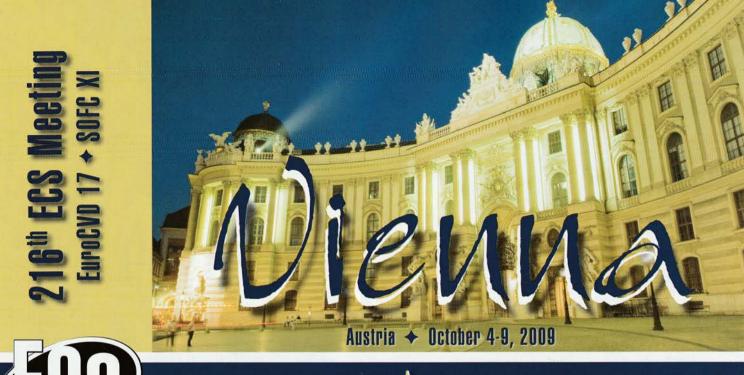
Vienna, Austria + October 4-9, 2009

Special Meeting Section





SOFC XI

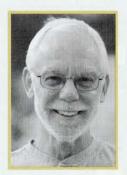


welcome

Provide State State And State And State And State And State And State And State And State And State And State And State And State And State And State And State And State And State And State And State And State And State And State And State And State And State And State And State A

Featured Speakers

SUNDAY, OCTOBER 4



For the Rest of Us... 1830h, Hall H, Level U2-Blue

Electrochemistry and the Performance Assessment of Nuclear Waste under Permanent Disposal Conditions

by David Shoesmith

All national programs for the permanent disposal of high level nuclear waste involve its containment

within a deep geological repository. These repository concepts are based on multiple barriers to radionuclide release with no common mode of failure. Within this sequence, the waste form itself (most commonly the spent fuel discharged from a reactor) and the metallic container within which it is sealed are the key engineered (as opposed to natural geologic) barriers. The key geological property controlling container corrosion, and waste form corrosion inside a failed container, will be the groundwater redox condition that will evolve with time as environmental oxidants in the groundwater are consumed and the radiation fields that produce radiolytic oxidants (via the decomposition of water primarily within a failed container) decay. Models must be capable of assessing with reasonable certainty the evolution of repository behavior from the initial excavated damaged state to the original undisturbed state. Given the long time frames involved (103 to 106 years) this is a unique challenge for engineered structures.

Electrochemical approaches, coupled to a wide range of supplementary analytical and spectroscopic methods, have been applied to this task. This presentation will illustrate how electrochemical methods have been used to: (1.) develop the mechanistic understanding of materials corrosion processes; (2.) generate the databases essential for model development; (3.) provide the framework for the computational models capable of predicting the evolution of corrosion damage with time and estimate the lifetimes of waste containers and the release rates of radionuclides; and (4.) provide the essential feedback required for the engineering design of optimized barriers able to provide adequate performance at reasonable cost.

DAVID SHOESMITH is a professor in the Department of Chemistry at the University of Western Ontario (London, ON, Canada) and specializes in research on the electrochemistry, surface analysis, and corrosion of materials. He has held this appointment since June 1, 1998, and is the Canadian Natural Sciences and Engineering Research Council and Nuclear Waste Management Organization (NSERC/NWMO) Industrial Research Chair holder in Nuclear Fuel Disposal Chemistry (since November 2000). Initially a five-year appointment, this chair was renewed for a further five years in November 2005. Previously, he worked for Atomic Energy of Canada Ltd. for 25 years, achieving the rank of principal scientist. Since 1980 he has been an active researcher in the Canadian Nuclear Waste Disposal Program, and is a recognized international expert on waste form and waste container issues. He is an elected fellow of the National Association of Corrosion Engineers (1996) and the Canadian Society for Chemistry (1985). He has won awards from ECS (Lash Miller), the Canadian Society for Chemistry, the Canadian Institute of Mining and Metallurgy (Cohen Award), Atomic Energy of Canada (Discovery Award), and a University of Western Ontario Distinguished Professorship. He is currently funded by waste management organizations in Canada, Sweden, and Switzerland. He has served on program review boards in Switzerland, USA, and France, and as a consultant on corrosion issues for many nuclear and non-nuclear companies. He has written over 350 publications, 210 of which are in refereed journals and conference proceedings.

MONDAY, OCTOBER 5



Plenary Session 0730h, Hall D, Level U2-Blue

The ECS Lecture

Electrochemical Design of Novel Zinc Alloys for the Corrosion Protection of Steel

by Martin Stratmann

Novel zinc alloy coatings containing Mg and other additives are the subject

of current cutting edge research in corrosion science as they seem to possess significantly improved corrosion properties. In this presentation, not only the latest results on zinc and its alloys are shown, but a vision of systematic coating development will be given.

MARTIN STRATMANN studied chemistry at the Ruhr Universität Bochum and received his diploma in 1980. In 1982, at the Max-Planck-Institut für Eisenforschung in Düsseldorf (H. J. Engell, Director), he finished his PhD on electrochemical studies of phase transformations in rust layers; and he spent his postdoctoral studies with Ernest Yeager at Case Western Reserve University. The habilitation in Physical Chemistry followed in 1992 at the University of Düsseldorf with electrochemical studies on metal surfaces covered with ultrathin electrolyte layers. 1994 he took over the Chair in corrosion science and surface engineering at the University of Erlangen, and since 2000 he has been a scientific member of the Max Planck Society and Director of the Max-Planck-Institut für Eisenforschung in Düsseldorf, leading a department of interface chemistry and surface engineering. He is also a faculty member of the Materials Science Department and of the Chemistry Department at the Ruhr-Universität Bochum.

Prof. Stratmann's research interests lie in the area of corrosion-related electrochemistry with an emphasis on microscopic aspects and in situ spectroscopy, electrochemistry at buried metal/polymer interfaces (an area where he pioneered novel electrochemical techniques), atmospheric corrosion, adhesion, and surface chemistry of reactive metal substrates. He has received a number of awards, among others the Otto-Hahn medal of the Max Planck Society, the T. P. Hoar Award (twice), the Masing Award of the German Society of Materials Science, the DECHEMA Award of the Max Buchner Forschungsstiftung, the U. R. Evans Award of the Institute of Corrosion, and the W. R. Whitney Award of the International Association of Corrosion Engineers. In 2008, he received the H. H. Uhlig Award of the ECS Corrosion Division. Prof Stratmann is an ECS Fellow and a member of the North Rhine-Westphalia Academy of Science and of the Austrian Academy of Science.

In 2008, on Prof. Stratmann's initiative, the International Centre for Advanced Materials Science (ICAMS) was founded in Bochum. He served as chair of the Chemistry, Physics, and Technology Section of the Max Planck Society from 2006 to 2008. In 2008 he was elected Vice-President of the Max Planck Society; with this position he also became an executive of the Minerva Foundation. He has published about 170 papers, various monographs, and together with Allen Bard he edited the *Encyclopedia of Electrochemistry* in ten volumes.



ECS Carl Wagner Award Lecture 1350h, Hall N, Level 01-Green

Electrochemistry in Synthetic and Biological Nanopores

by Henry White

Prof. White's talk will describe recent investigations of molecular and particle transport in synthetic nanopores and protein ion channels. The work of his research group

has focused on the use of nanopores for single molecule detection, particle analysis, and sequencing of biopolymers (*e.g.*, DNA) using glass and quartz nanopore membranes.

HENRY S. WHITE received a BS in chemistry from the University of North Carolina (1978) and a PhD in chemistry from the University of Texas (1983). Following a postdoctoral appointment at the Massachusetts Institute of Technology, he joined the faculty of the Department of Chemical Engineering and Materials Science at the University of Minnesota. During a nine-year period at Minnesota, he was a McKnight and a Shell Professor of Chemical Engineering. In 1993, he moved to the University of Utah, where he is currently is Distinguished Professor and Chair of the Department of Chemistry.

Prof. White and his students have made contributions in several areas of electrochemistry including pioneering research on electrochemistry using nanoscale electrodes, and the development of a theory describing voltammetry of surface-confined redox and acid-based molecules and molecular transport within electrical double layers. White and coworkers developed scanning electrochemical microscopy to visualize and identify transport pathways through human skin and contributed to materials synthesis in microfluidic channels, demonstrating the application of laminar flow streamlines to control the growth of polymer fibers. His group recently developed an ion channel recording platform based on nanometer-scale orifices in glass membranes that is being applied for DNA sequencing and stochastic sensors.

being applied for DNA sequencing and stochastic sensors. Prof. White is a past Vice-Chair and Chair of the ECS Twin Cities Section, and has organized a number of ECS symposia over the past 25 years. He is currently an Associate Editor of the Journal of the American Chemical Society. Prof. White has been recognized for educational contributions at the University of Utah, including the W. W. Epstein Outstanding Educator Award and the Associated Students of the University of Utah Teaching Award. He is actively involved in undergraduate research, having supervised ~50 undergraduates and high school students over a 25-year period. He is the recipient of the D. C. Grahame Award of the ECS Physical Electrochemistry Division, the C. N. Reilley Award of the Society of Electroanalytical Chemistry, the Faraday Medal of the Royal Society of Chemistry (Electrochemistry Group), and the ACS Analytical Division Award in Electrochemistry.

TUESDAY, OCTOBER 6

Olin Palladium Award Lecture 1700h, Hall F1, Level OE-Yellow

The Metal-Solution Interface: What We Know and What Needs to Be Done

by Dieter M. Kolb

The electrode–electrolyte interface constitutes the heart of electrochemistry; it is the place where electrochemical reactions take place

via an electron or ion transfer. Although for many cases the

simple model of a plate condensor appears to be sufficient, a more detailed understanding of the double layer structure seems desirable. Starting from the Helmholtz model, questions about the exact potential distribution across the double layer, particularly in the case of specific adsorption, are addressed. It is demonstrated how the electrochemical shift in X-ray photoelectron spectroscopy or surface state spectroscopy can help to gain new information. Impedance spectroscopy has been successfully employed to elucidate the doublelayer behavior of reactive metals like Pt, Rh, or Ir in aqueous solutions. Although water undoubtedly constitutes the most important solvent, little is known about the physical properties of the interfacial water and dependence on the electrode potential. Finally, a first glimpse on double-layer capacities for metals in contact with ionic liquids is offered.

DIETER M. KOLB studied physics at the Technical University of Munich, where he did his thesis work under the supervision of the late Prof. Heinz Gerischer on ESR of electrochemically generated radical anions. After receiving his doctorate in 1969 he spent two years at Bell Laboratories in Murray Hill, NJ, studying the optical properties of electrode surfaces by in situ reflectance spectroscopy in the UV-Vis range. In 1971 he again joined Heinz Gerischer, then at the Fritz-Haber-Institut der Max-Planck-Gesellschaft in Berlin, where he took a position as a group leader to perform research in electrochemical surface science, using a wide variety of structure-sensitive techniques to study the metalelectrolyte interface at an atomic level. At the same time, Dr. Kolb conducted research on matrix-isolated metal atoms and clusters, including synchrotron radiation studies, at BESSY. In 1990 he left the Fritz-Haber-Institut and accepted the offer of a full professorship at the University of Ulm, where he is now Director of the Institute of Electrochemistry.

Professor Kolb's research activities are directed toward a molecular understanding of electrochemical processes at metal electrodes, including surface reconstruction, structural transitions in adlayers, metal deposition and dissolution, structure-reactivity relations in electrocatalysis, and nanostructuring. He is the author of over 300 technical papers in refereed journals and books. Dr. Kolb has been honored in the past by being named recipient of the 1980 Haber prize of the Deutsche Bunsengesellschaft, the 1990 Pergamon Gold Medal of the International Society of Electrochemistry, the 1997 D. C. Grahame award of the ECS Physical and Analytical Electrochemistry Division, the 2000 Luigi Galvani medal of the Italian Chemical Society, the Walther-Nernst-Denkmünze of the Deutsche Bunsengesellschaft, the 2002 ECS Electrodeposition Division Award, and the 2003 Faraday Medal of the Royal Society of Chemistry. He was president of the International Society of Electrochemistry (2003-2004) and head of the evaluation committee for chemistry of the Deutsche Forschungsgemeinschaft (2000-2004). He is a Fellow of ECS and the International Society of Electrochemistry, and a Corresponding Member of the National Academy of Sciences, Argentina.

2009 Olin Palladium Award Reception—All meeting attendees are invited to attend the award reception honoring Dieter M. Kolb, recipient of the 2009 Olin Palladium Award, on Tuesday, October 6, 1800-1845h, in Rondo, Level OE-Yellow (no ticket required).

Short Courses & Workshops

Seven Short Courses will be offered in conjunction with the 216th ECS Meeting. These courses will be held on Sunday, October 4, 2009, from 0900h to 1630h. The registration fee is \$510 (\$425 + \$85 VAT) for ECS Members, and \$624 (\$520 + \$104 VAT) for Nonmembers. **Students are offered a 50% discount; the registration fees are as follows. For ECS Student Members: \$255 (\$212.50 + 42.50 VAT), and for Nonmember Students: \$312 (\$260 + 52 VAT).**

The registration fee for the course covers the course, text materials, continental breakfast, luncheon, and refreshment breaks; it does not cover the meeting registration, and it is not applicable to any other activities of the meeting. **The deadline for registration for a course is August 28, 2009.** Interested parties may register using the Advance Registration Form on the ECS website. Written requests for refunds will be honored only if received at ECS headquarters before September 4, 2009. **Pre-registration is required. All courses are subject to cancellation pending an appropriate number of advance registrants. Before making any flight or hotel reservations, please check to make sure the course is running!**

Visit the ECS website for full course descriptions and instructor biographies.

Short Course #1

Basic Impedance Spectroscopy M. Orazem, Instructor

This course is intended for chemists, physicists, materials scientists, and engineers with an interest in applying electrochemical impedance techniques to study a broad variety of electrochemical processes. The attendee will develop a basic understanding of the technique, the sources of errors in impedance measurements, the manner in which experiments can be optimized to reduce these errors, and the use of regression to interpret measurements in terms of meaningful physical properties.

Short Course #2 PEM Fuel Cells

H. Gasteiger and T. J. Schmidt, Instructors

This course develops the fundamental thermodynamics and electrocatalytic processes critical to polymer electrolyte membrane fuel cells (PEMFC). Topics will include relevant half-cell reactions, their thermodynamic driving forces, and their mathematical foundations in electrocatalysis theory. This theoretical framework will be applied to catalyst characterization and the evaluation of kinetic parameters. Also covered will be the different functional requirements of actual PEMFC components and basic in situ diagnostics. This will be used to develop an in-depth understanding of the various voltage loss terms that constitute a polarization curve. Also described will be the principles of fuel cell catalyst activity measurements, the impact of uncontrolled-operation events, and the various effects of long-term materials degradation.

Short Course #3 Operation and Applications of Electrochemical Capacitors J. Miller, Instructor

Electrochemical capacitors, sometimes called supercapacitors or ultracapacitors, offer extraordinarily high power density compared with batteries, as well as high cycle-life and maintenance-free operation. Capacitor technology is being used to increase the energy efficiency of industrial equipment like fork lifts, earth-moving vehicles, and overhead cranes by capturing energy that is normally wasted. Systems developed specifically for power quality applications are appearing. The fundamentals part of the lecture covers the nature and significance of electrical double layer and pseudocapacitance charge storage and compares and contrasts these charge storage mechanisms with traditional capacitor and battery technologies. Basic design rules for electrochemical capacitor components are covered.

0 3 5 5 TIN uu S _ 4 G 0 3 Vienna +

Short Course #4 Lithium Ion Battery Materials *Y. Shirley Meng, Instructor*

Designing better materials for rechargeable lithium batteries requires understanding of the many physical processes that determine their performance. The aim of this course is to provide a foundation for understanding key materials science and engineering issues underpinning the behavior of electrode and electrolyte materials for rechargeable lithium batteries. With the relevant examples, the course will further illustrate how the direct integration of first principles computation with experimental research can accelerate the pace and efficiency of discovering new higher energy/power density materials for electrochemical energy storage.

Short Course #5

Atomic Layer Deposition A. Londergan, Instructor

Recent advancements in nanotechnology have created a need for precise, conformal atomic level deposition of thin film materials. Atomic Layer Deposition (ALD) can enable the precise deposition of ultra-thin, highly conformal coatings over complex 3D topography, with controlled composition and properties. Consequently, ALD has become a technology of choice for a large variety of applications for and beyond the semiconductor industry, as proven from the countless applications emerging.

Short Course #6

Basics of Cleaning Processing for IC Manufacturing K. Reinhardt and R. Small, Instructors; T. Bearda and P. Mertens, Special Contributors

The course is intended to provide an overview of current challenges and the technical advances associated with wet cleaning, plasma stripping, and other surface conditioning technologies used in the manufacture of integrated circuits. The following topics will be covered: advances in high-k/ metal gate cleaning, in single wafer cleaning, in wet chemical residue removal, in high aspect feature cleaning and drying, and in high dose implant stripping; overviews of Cu/low-k post-etch and post-CMP cleaning and pore sealing, of advances in critical cleaning, of passivated surfaces; and coverage of damage-free particle removal and photovoltaic processing.

Short Course #7

Electrodeposition Principles and Practice S. Roy and G. Zangari, Instructors; W. Hansal, Guest Lecturer

Electrodeposition is a simple but powerful film deposition technique that is increasingly being used in the fabrication of materials systems and devices, and in many instances, by those who have limited formal preparation in the subject. This course will offer the opportunity to students and researchers alike to either be introduced to or to refresh the fundamentals of the subject. The approach will be rigorous but geared toward applications. Attendees will have the opportunity to learn practical aspects of this technology; in particular, lectures on the electrodeposition of noble and transition metals, nanomaterials, and pulse plating are included.

Professional Development Workshops,

John R. Susko, Instructor

ECS will sponsor the following three professional development workshops at no extra cost to meeting registrants. All workshops will be held in Room B552, Level 02-Red. **Writing an Effective Cover Letter and Resume**—The need for a cover letter, how to write it, the many "do's" and "don'ts" in preparing such a letter, and tips for drafting an effective resume. Sunday, 1500-1545h and Monday, 1200-1245h

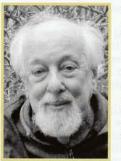
Job Interviewing Tips—How to improve your chances of impressing the interviewer; key questions to ask; and other important pointers for the interviewing process. Sunday, 1600-1645h and Monday, 1300-1345h

Resume Round Table—Designed to provide feedback on resumes by publicly critiquing participants' resumes and offering suggestions on ways to make them more effective. To take full advantage of the workshop, please bring a copy of your current professional resume. Monday, 1400-1700h

Award Winners

NOTE: For complete biographies of the award recipients, and the schedule of their presentations, please see the General Meeting Program on the ECS website: www.electrochem.org/meetings/ biannual/216/216.htm.

2009 Class of ECS Fellows



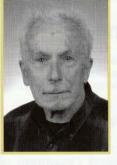
VLADIMIR BAGOTSKY graduated in 1944 from the Chemistry Department of Moscow State University. In 1947 he received his PhD in electrochemistry (under Prof. A. N. Frumkin). As a postdoc he took a substantial part in writing (together with Profs. Frumkin, lofa, and Kabanov) the monograph *Kinetics of Electrode Processes* (1952) that became the first book on electrochemical kinetics in the world. After being fired in 1952 from the University (during the notorious

campaign against cosmopolitans in the Soviet Science), he was forced to switch to applied electrochemistry. At the industrial Quant Power Sources Institute in Moscow, Dr. Bagotsky began the development of new types of batteries. Industrial production of these batteries was organized under his direction in 1954. In 1955 Dr. Bagotsky was given the responsibility for developing batteries for ICBMs and some types of satellites. The first Russian satellite known as Sputnik-1 contained a battery developed by him and assembled under his personal supervision. In 1956 he took part in the preparation of the mission of the first Kosmonaut Yuriy Gagarin, being responsible for the battery part of this mission. For these activities Dr. Bagotsky was awarded in 1959 the degree of Doctor of Sciences without thesis (analogous to a Dr. h.c.).

In 1960, Dr. Bagotsky resumed his research in the field of electrochemical kinetics. At the Institute of Electrochemistry of the Academy of Sciences of the USSR (now A. N. Frumkin Institute of Physical Chemistry and Electrochemistry of the Russian Academy of Sciences), Dr. Bagotsky's group (Dr. Yurij B. Vassiliev, *et al.*) performed investigations in the field of electrocatalytical oxidation of methanol and other simple organic compounds on platinum electrodes. It was shown that these reactions proceed via a first dehydrogenation step with a subsequent interaction of the chemisorbed organic residue with oxygen-containing adsorbed species. These views and the role of Dr. Bagotsky in their development are now generally recognized.

Another direction of Dr. Bagotsky's group was connected with research in the field of porous electrodes. In this group (Dr. Yurij M. Volfkovich, *et al.*), the method of standard contact porosimetry was developed, which played an important role for optimizing fuel cells and other electrochemical devices. From 1962 to 1976 Dr. Bagotsky was a deputy to Prof. A. N. Frumkin as head of the Scientific Council on Fuel Cells of the USSR Academy of Sciences. In this capacity he organized three national Meetings on Fuel Cells.

For political and security reasons ("bearer of classified information") he was for a long time barred from visiting foreign countries and participating in international scientific meetings. After moving for health reasons to California he wrote a new revised and enlarged second edition of his monograph, *Fundamentals of Electrochemistry*, which was published in 2005. In 2009 his new book *Fuel Cells: Problems and Solutions* was published. Both books became a part of The Electrochemical Society Monograph Series, sponsored by ECS and published by John A. Wiley & Sons.



UGO BERTOCCI began his career as an assistant professor at the Institute of Electrochemistry of Milan Polytechnic in 1950. He was involved in the improvement of measurement methods related to electrochemical kinetics, a topic of considerable interest at the time. The Institute was among the first in the world to initiate the study of the electrochemical behavior of metal single crystals and the structural sensitivity of reactions thereof.

In 1961 Dr. Bertocci joined the Solid State Division at Oak Ridge National Laboratory, working on the influence of surface and defect structure on the electrochemical behavior of Cu single crystals, nucleation processes in electrocrystallization, and computer simulations of certain aspects of crystal growth.

In 1971 he joined the Corrosion Group at the National Bureau of Standards (now NIST). There he worked in various projects concerning new electrochemical methods for the study of corrosion processes. Activities ranged from the measurement and interpretation of photopotentials on copper oxides, to the effect of alternating voltages on corrosion rates, an area of practical interest for underground corrosion. He also investigated the breakdown of passive films and stress corrosion cracking. During this time he was also involved in the measurement and interpretation of impedance spectroscopy and in the application of random fluctuation analysis to corrosion studies.

Dr. Bertocci retired from NIST in 1992 but he continued working, first, as a consultant at the Federal Highway Administration (FHA) and subsequently, as an invited scientist at Laboratory "Physique des Liquides et Électrochimie" of the French CNRS in Paris. At FHA the effectiveness of corrosion inhibitors added to commercial highway deicing salts was evaluated using electrochemical impedance spectroscopy and electrochemical noise analysis. In cooperation with Dr. F. Huet of the French CNRS, a model for the interpretation of some aspects of random noise in corroding systems was developed. This work continued at CNRS where, from a combination of experimental and theoretical work on electrochemical noise (EN), they developed the concept of noise resistance, a quantity derived from the analysis of the random fluctuations of current and potential in corroding systems. This work has shown the close connection between EN and electrochemical impedance spectroscopy, putting EN on a firm theoretical ground, and contributing to its establishment as a practical experimental method with commercial applications for corrosion monitoring in the laboratory and in the field.

Since 1996, Dr. Bertocci has been a consultant to the Thin Film and Nanostructure Processing Group at NIST, working on a variety of topics dealing with the composition and properties of oxide films on Cu, thin film stress, nanogravimetric measurements of underpotential and overpotential deposition of heavy metals and most recently, the deposition of electrocatalytic Pt alloys. In January 2009, Dr. Bertocci was elected a Fellow of the AAAS.



MANFRED ENGELHARDT received a PhD in Solid State Physics from the University of Regensburg, Germany, in 1984. He then joined Siemens (Munich), where he was in charge of the development of plasma etch processes for advanced memory and logic products. He pioneered deep single crystal silicon etching for DRAM storage capacitors and significantly contributed to the elucidation of the reaction mechanisms. In the joint Siemens-Fraunhofer 3D-project he

was responsible for unit process development and developed the plasma etch processes for through-silicon-vias. He then was in charge of plasma patterning of new materials for FeRAM and MRAMs and for the company's copper Damascene metallization. He also pioneered techniques to assess plasma damage.

With the founding of Infineon Technologies in 1999 he was with Corporate Research, where his responsibilities included managing the nano interconnect project team, investigating conventional and disruptive interconnect scenarios with down to end-of-roadmap feature sizes. The investigation and electrical characterization of nano interconnects utilizing both Damascene and RIE approaches has substantially contributed to the understanding of size effects in metallic conductors (Al, Cu, W, Ag). The work on copper interconnects insulated by air gaps showed for a first time the importance of barrier films for the mechanical stability, integrity, and reliability of sub-50 nm scaled metallization systems. His group published the first paper indicating a cross-over of the resistivities of copper and aluminum due to size effects.

In 2005 Dr. Engelhardt joined the Development Center of Qimonda in Dresden where he was responsible for Development and Strategy in Plasma Etching.

Since 1986 Dr. Engelhardt has been an active member of ECS and has served on various ECS committees. He has served in organizing ECS symposia and is co-editor of the corresponding proceedings volumes. In 2001 he served as conference chair of the Plasma- and Process-Induced Damage Symposium and is one of the founders of the International Symposium on Integrated Circuit Design and Technology (ICICDT), whose mission is to bridge the gap between design and technology. Dr. Engelhardt has delivered more than 100 presentations at international conferences. He has authored more than 150 reviewed papers and holds 44 patents. During 25 years in the semiconductor industry he has been the supervisor of numerous diploma and PhD students who did both the experimental and the theoretical parts of their theses under his guidance.



TOM FULLER is a professor in the School Chemical & Biomolecular Engineering at the Georgia Institute of Technology. He also holds a joint appointment as a Principal Engineer at Georgia Tech Research Institute (GTRI) where he directs the GT Center for Innovative Fuel Cell and Battery Technologies.

Dr. Fuller received a bachelor of science degree from the University of Utah in chemical engineering in 1982. After completing his undergraduate studies, Dr. Fuller served for five years in the U.S. Navy in the submarine

force working as a nuclear engineer. He continued to serve in the Naval Reserve and retired at the rank of Commander in 2001. In 1992 he obtained a PhD from the University of California, Berkeley, also in chemical engineering. Subsequently, Dr. Fuller developed advanced lithium batteries when working as a postdoctoral fellow at Lawrence Berkeley National Laboratory. He then moved to United Technologies Corporation in 1993. As a senior engineer he was Principal

in 1977, where he has recently been nominated Chair of the Chemical Engineering Department. Professor Landau's research includes the study of deposit distribution and patterning on the macro and micro scales; electrosynthesis of novel compounds, alloys, and semiconductors; evolution of deposit morphology including the effects of plating additives, electrodeposition on nonconductors, electrochemistry of diamond, and the modeling of corrosion processes. Professor Landau has also performed research on various battery and fuel-cells systems. Professor Landau's modeling of current and potential fields has led to the development of the first electrochemical CAD system that is currently being used world-wide for the design of electrochemical systems. His earlier work on roughness evolution in plating introduced the concept of morphological stability to electrodeposition.

Recently, Professor Landau has been involved in research on copper metallization of interconnects on semiconductor wafers, where he has introduced with his student (R. Akolkar) a transient transport model coupled to a multi-additive competitive adsorption mechanism to provide a comprehensive, quantitative model for bottomup fill of interconnects. This model was verified by additive injection studies, a technique which is now being widely adapted for characterizing multi-additives systems. Prof. Landau has also introduced the low-acidity electrolyte for copper electrodeposition of semiconductor interconnects, a formulation that has become the industry standard for this application.

developing electroplating processes for the electronics

industry. Dr. Landau joined Case Western Reserve University

Professor Landau is a member of ECS and the American Electroplaters Society. Dr. Landau was the 2008 recipient of the Ernest B. Yeager Award of the ECS Cleveland Section for his contributions to the advancement of electrochemistry in the U.S. Midwest and Great Lakes region.

DOLF LANDHEER received his BSc in chemistry and physics at the University of Waterloo and his MSc and PhD degrees at the University of Toronto (1976), working in the area of molecular and solid state physics and laser spectroscopy. After a Fellowship at Imperial College (U. of London, UK), he worked on electrographic printing with micro-plasmas at Xerox Research Centre of Canada and nearby Delphax Printing Systems. In 1983 he pursued his interest in plasma

processing and the effect of plasmas on materials by moving to the Institute for Microstructural Sciences at the National Research Council of Canada, in Ottawa, where he is now a Principal Research Officer. He established the first plasma processing facilities at the Institute for early work on the fabrication of solid state waveguide lasers and detectors based on III-V (GaAs, InP, etc.) and Si-Ge multilayers. He has contributed to understanding plasma processing damage on III-V laser facets and the interfaces of Si, GaAs and InP with silicon nitride and silicon dioxide. Later he studied high-k dielectric layers produced by chemical vapor deposition (CVD) using electron-cyclotron plasma sources, pulsed metalorganic CVD, and atomic layer deposition (Hf and Gd oxide and silicate). Recently he has been working on the fabrication, analysis, and modeling of bio-affinity sensor micro-arrays based on floating-gate field-effect transistors fabricated using CMOS.

Dr. Landheer has published 190 articles in refereed journals and conference proceedings and received seven patents. He was co-chair of the Canadian Semiconductor Conference (2003 and 2005) and has been on organizing committees for symposia for the MRS (2004), the International Workshop on Device Technology (2001), and the Passivity of Metals Conference (2006). His contributions to ECS include the co-

Investigator for DARPA and DOE programs in direct methanol fuel cells. In subsequent assignments Dr. Fuller was manager and then director of engineering. He was responsible for technology development, design, assembly, and test of cell stacks for UTC Fuel Cells.

His research group at Georgia Tech is focused on durability challenges for electrochemical systems such as fuel cells and batteries. Fundamental understanding of the physical phenomena serves as a guide to the development of new materials and systems solutions to mitigate degradation in batteries and fuel cells. This research is a blend of experiments and mathematical modeling. In addition to his research, Dr. Fuller is the faculty advisor for GT EcoCAR team, a student led competition to developed advanced hybrid technologies.

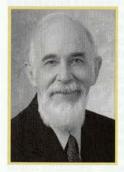
Dr. Fuller is active in ECS, he is a past Chair of the Energy Technology Division, and for a number of years chaired the Fuel Cell Coordinating Group. Fuller has also served on the Honors and Awards Committee, the Nominating Committee, and the New Technology Subcommittee. In 2008 he received the Research Award from the Energy Technology Division. In July 2009, Dr. Fuller began serving as an Associate Editor for the *Journal of The Electrochemical Society*.



PETER HESKETH graduated with a BSc in electrical and electronic engineering from the University of Leeds, in 1979. He worked at the BBC. Engineering Research Department in Kingswood, Surrey, developing novel electronic circuits for broadcast applications. He was a Thouron Fellow at the University of Pennsylvania, obtaining an MS (1983) and PhD (1987) in electrical engineering. He worked in the Microsensor Group at the Physical Electronics Laboratory of Stanford

Research Institute and then Teknekron Sensor Development Corporation before joining the faculty at the University of Illinois in 1990 in the Department of Electrical Engineering and Computer Science. He was Co-Director of the Microfabrication Applications Laboratory from 1995-1998 and Director of the Microfluidics Center 1996-1998.

Prof. Hesketh is currently a professor of mechanical engineering at the Georgia Institute of Technology and Director of the MEMS Group in the School of Mechanical Engineering. He is a past Chair of the ECS Sensor Division and a Fellow of the American Association for the Advancement of Science. His research interests include microfabrication of chemical and biosensors, microvalves, miniature gas chromatography systems, and the use of stereolithography for microsystem packaging. He currently has active research programs on microcantilever sensors, in collaboration with Sandia National Laboratories (Livermore), and NSF-sponsored projects on nanopore biosensors and curriculum development in nanotechnology. He has published over 60 journal papers and edited 15 books on microsystems. He is a member of the AAAS, ASME, ASEE, AVS, ECS, and IEEE.



UZIEL LANDAU is a professor of chemical engineering at Case Western Reserve University, Cleveland, Ohio. Professor Landau's research centers on electrochemical engineering with primary focus on modeling of electrochemical systems and on electrodeposition of advanced materials and structures. Professor Landau is a native of Israel, where he received his BSc (1964) and MSc (1968) degrees from the Technion, the Israel Institute of Technology. He earned his

PhD (1975) from the University of California, Berkeley, with Prof. Charles Tobias as a research advisor. After graduating, Dr. Landau joined AT&T Bell Laboratories at Murray-Hill, NJ, organization of symposia on SiN/SiO₂ thin insulating films (2001, 2003, 2005), High-k Dielectrics (2005-2009), Dielectrics and Engineered Interfaces in Biological and Biomedical Applications (2009), and was lead-organizer for Biosensors, Bioelectronics, and Biomedical Engineering (2005-2006). He is presently Treasurer for the ECS Dielectric Science and Technology Division and an Associate Editor of the *Journal of The Electrochemical Society*.



5

5

2

-

(1)

ш

0

3

Vienna +

THOMAS P. MOFFAT is a member of the Thin Film and Nanostructure Processing Group in the Metallurgy Division at the National Institute of Standards and Technology (NIST). He began his research career as an undergraduate student working part time in the laboratory of Barry D. Lichter and William F. Flanagan at Vanderbilt University. He completed his BE and MSc degrees in materials science and engineering in 1982 and 1984, respectively. He then joined

Ron Latanision's group in the H. H. Uhlig Laboratory at the Massachusetts Institute of Technology. In 1989 he received a ScD degree for his work exploring the chemical passivity of chromium-based metallic glasses. This was followed by a two year stint as a postdoctoral associate in A. J. Bard's chemistry laboratory at the University of Texas, Austin, studying the corrosion and passivity of metals using scanning tunneling microscopy.

Since joining NIST in 1991 Dr. Moffat's efforts have focused on using electrochemical methods to understand the deposition and performance of thin films. His activities have ranged from the synthesis of strained-layer metallic superlattices to explorations of the coupling between underpotential deposition and 3D alloy formation. His most recent efforts have focused on studying the role of surfactants in morphological evolution during thin film growth with particular attention given to systems that exhibit void-free "superfilling" of recessed surface features. In 2001 he received the Gold Medal of the U.S. Department of Commerce for his work on the mechanism of superconformal copper electrodeposition.

Dr. Moffat was the recipient of the 2006 Research Award of the ECS Electrodeposition Division. To date, he has authored or coauthored more than 125 technical papers. Dr. Moffat has been a member of ECS since 1982. He is active in organizing symposia and has served as an Associate Editor of the *Journal* of *The Electrochemical Society* as well as *Electrochemical and Solid-State Letters*. He is also involved with the Electrochemical Materials Science Division of the International Society of Electrochemistry, the Materials Research Society, and the American Association for the Advancement of Science. In 2008 he chaired the Gordon Research Conference on Electrodeposition.



IKUZO NISHIGUCHI received his BA in 1966, MA in 1968, and PhD in 1971 from Kyoto University. After two years of postdoctoral study at the University of Florida and the Ohio State University, he worked at Prof. T. Shono's group as an assistant professor. He moved to Osaka Municipal Technical Research Institute in 1978. He was invited to Nagaoka University of Technology (NUT) as a full professor in the Chemistry Department in 1966, where he is currently an Executive

Director and Vice-President of NUT. During 2003-2006, he was one of the leaders of the two 21st century COE (Center of Excellent) programs of his university.

Dr. Nishiguchi has made numerous contributions to the area of synthetic and industrial organic electrochemistry

over 35+ years. He has developed a number of methods for efficient and facile electrochemical single and double Cacylation of activated olefins and carbonyl compounds, highly regio- and stereo-selective C-C bond formation between a carbonyl group, and an isolated C-C double bond thorough electrochemical and Mg (or Zn)-promoted electron-transfer methods. This body of work has received much attention from not only organic electrochemists but also those in organic synthetic chemistry. He has also made tremendous contributions toward the establishment of some industrial electro-organic processes.

Dr. Nishiguchi has been involved in a variety of activities such as administrating scientific societies, editing scientific journals, and organizing international and domestic meetings relating to electro-organic chemistry, such as serving as an executive director during 2003-2005 and as a vice-president of the Society of Synthetic Organic Chemistry (Japan) during 2006-2007. He has also organized two international symposia (ISOETC-2005 and ISOR/Kobe-2006). He has been a committee member of the ECS Organic and Biological Electrochemistry Division. He served as the chair of the Organic Electrochemical Division of The Electrochemical Society of Japan during 2002-2004.

Dr. Nishiguchi has been the recipient of many important awards in synthetic and electro-organic chemistry fields, for example the Manuel M. Baizer Award of the ECS Organic and Biological Division in 2006, the Synthetic Organic Chemistry Award of the Society of Synthetic Organic Chemistry (Japan) in 2008, the 1986 Chemical Technology Award of the Kinki Chemical Society, the Niigata Nippou Culture Award (Academic Section) in 2006, and the 1983 Incentive Award in Synthetic Organic Chemistry (Japan).



KOHEI UOSAKI is a professor of chemistry in the Graduate School of Science, Hokkaido University. He received his B Eng and M Eng degrees in applied chemistry from Osaka University. He worked at Mitsubishi Petrochemical Co. Ltd. between 1971 and 1978, during that period he studied in the Flinders University of South Australia on "Photoelectrochemical Production of Hydrogen" for his PhD under the supervision of Prof. J. O'M. Bockris for 2.5 years.

After postdoctoral work on "Electrochemistry of Metalloproteins" at the Inorganic Chemistry Laboratory, Oxford University, with Prof. H. A. O. Hill, he joined the Chemistry Department of Hokkaido University in 1980 as an assistant professor, was promoted to an associate professor in 1981, and to full professor in 1990. He served as Director of Catalysis Research Center of Hokkaido University between 2000 and 2002. He has been a principal investigator at the International Center for Materials Nanoarchitectonics (MANA) of the National Institute for Materials Science (NIMS) since 2008.

Prof. Uosaki has contributed to a wide variety of fundamental aspects of electrochemistry including photoelectrochemistry of semiconductor electrodes, electrochemical epitaxial growth of metal on well-defined electrode surfaces, and the formation, structure, and functions of self-assembled monolayers. He has been utilizing single crystalline electrodes and novel *in situ* techniques such as STM, AFM, SHG, SFG, electro- and photo-luminescence, SXS, and XAFS. He was a project leader of a Priority Area Research on "Electrochemistry of Ordered Interfaces" (1997-2000), supported by Ministry of Education, Culture, Sports, Science, and Technology, Japan, to which about 100 Japanese electrochemists contributed. In relation to this project, he organized several international meetings on "Electrochemistry of Ordered Interfaces," including one at the 196th ECS Meeting.

Prof. Uosaki has published more than 300 scientific papers, 50 review articles, and 40 books and book chapters, filed

20 patents, and presented more than 100 invited lectures at international meetings. He has been a member of ECS for more than 25 years, co-organized several symposia and regularly presented papers at ECS meetings, and published many papers in the Journal of The Electrochemical Society and in the ECS proceeding volumes. He has served as an editor and on the editorial boards of several physical chemistry and electrochemistry journals.

Battery Division Technology Award



EIII ENDOH received BE, ME, and PhD degrees in chemical engineering from Tohoku University. Since 1974, he has worked in the Research Center of Asahi Glass Co., Ltd., where he is currently the team leader of the High Temperature MEA team in the PEMFC project at the Research Center of Asahi Glass Co., Ltd. From 2001 to 2002, he was a visiting professor at Tohoku University; and from 1984 to 1985, he was a visiting scientist at the University of Texas at Austin.

Prof. Endoh invented

an exceptionally durable PFSA based composite membrane for PEMFC under high temperature and low humidity operations. The membrane can operate for more than 6,000 hours at 120°C and 50% relative humidity. This achievement has opened up a new era of operating PEM Fuel Cells in the temperature range of near freezing to120°C for an extended period of time.

During the period 1976-1984, he invented highly durable activated cathodes for the chlor-alkali ion-exchange membrane process. The activated cathodes produce 5 million metric tons of NaOH/year and reduce electricity consumption by one billion kWh/year, which is equivalent of eliminating 740,000 tons of CO₂ emissions. During the 1974-1975 year, he researched a wide range of ion-exchange polymers, including perfluorinated ion exchange membranes for PEM Fuel Cells as well as for the chlor-alkali electrolysis process.

Dr. Endoh's professional awards include the Tanahashi Technology Award of The Electrochemical Society of Japan (2008) for developing the highly durable membrane for PEMFCs. In the area of the development of highly durable activated cathodes, Prof. Endoh received a number of awards, including Japan's State Minister of the Environment Award (2006), the New Electrochemical Technology (NET) Award of the ECS Industrial Electrochemistry and Electrochemical Engineering Division (1999), and the Tanahashi Technology Award of The Electrochemical Society of Japan (1991).

Battery Division Research Award



LINDA NAZAR obtained her BSc (hons) from the University of British Columbia, achieving top standing in her graduating class, and conducting her BSc thesis in the area of inorganic chemistry. She moved on to the University of Toronto to carry out her PhD studies with Prof. Geoffrey Ozin, an internationally recognized pioneer of zeolite materials chemistry. After declining an offer of an NSERC postdoctoral fellowship and work in Prof. Green's lab at Oxford, she accepted one of ten Postdoctoral

Fellowships at the Exxon Corporate Research Labs in Annandale, NJ. There, she worked in the Inorganic Materials Division under the stewardship of the group head, Dr. Allan Jacobson (now Robert A. Welch Professor of Solid State Chemistry at the University of Houston).

Dr. Nazar was appointed an assistant professor at Waterloo in 1987, and obtained tenure and was promotion to Associate Professor in 1992. After a sabbatical leave in the Department of Materials Science at UCLA in 1995, she became full professor in 1998. She was awarded a Senior Canada Research Chair in Solid State Materials in 2004. She has spent sabbaticals at UCLA Department of Materials Science: the Institute for Materials in Nantes, France; and at the CNRS Laboratoire de Chemie de Solide in Grenoble, France as a CNRS fellow. She will be carrying out a sabbatical at CalTech as a Moore Distinguished Scholar in 2009-10.

Professor Nazar has served the academic community internally at UW in numerous ways, among these by developing the inorganic solid state chemistry program and nanotech program; and sits on the advisory board of the Waterloo Institute for Nanotechnology, and the Waterloo Institute for Sustainable Energy. In external service, she has served as member and Chair of the NSERC Strategic Grants Committee (1997-2000); as organizer of the Materials Research Society Symposium, "Advanced Materials for Batteries and Fuel Cells"; on the NSERC Discovery Grants Committee (2006-2009); as member, representative of Canada and Chair of the NATO (Brussels) Science for Peace Funding Committee (2006-2009); on the board of the International Meeting for Lithium Batteries (2005-present); as co-organizer of IMLB-15 in 2010; and as recent member of a DOE (USA) panel to chart new directions for Electrochemical Energy Storage.

Professor Linda Nazar is at the helm of a multidisciplinary, internationally-recognized group studying the solid state electrochemistry of inorganic materials, with a specific focus on structural, inorganic-synthetic and physical property studies of new materials for energy storage and conversion. Devices include lithium-ion batteries, supercapacitors, and fuel cells. She is the author of well over 100 chapters and patents and publications. Nearly all her publications are complex combinations of new materials synthesis and detailed electrochemical studies, combined with thorough physical studies using multidisciplinary techniques such as X-ray and neutron diffraction/scattering, solid state NMR, and X-ray absorption spectroscopy. Her research has been continuously supported by Canadian and international grants along with international industrial contracts since 1987.

Corrosion Division H. H. Uhlig Award



JOHN R. SCULLY is the Charles Henderson Chaired Professor of Materials Science and Engineering and the Co-Director of the Center for Electrochemical Science and Engineering (CESE) in the School of Engineering and Applied Science at the University of Virginia, USA. He has been active in the corrosion field for 30 years and joined the faculty of the University of Virginia in 1990. Previous to this, Dr. Scully was a senior technical staff member in the

Metallurgy Department at Sandia National Laboratories and a materials engineer at the Naval Ship Research and Development Center. Professor Scully received a PhD in materials science and engineering from The Johns Hopkins University studying the topics of hydrogen production, adsorption, absorption, and transport in high performance alloys. He subsequently was a visiting scientist at AT&T Bell Laboratories.

Professor Scully has long been devoted to research, engineering, and education in corrosion. In particular, he and his students have focused on the influence of material structure, composition, physical geometry, and environment on aqueous and atmospheric corrosion phenomena including hydrogen embrittlement, stress corrosion cracking, localized corrosion, passivity, and corrosion under coatings. His interests span various materials and coating systems including high performance alloys, bulk metallic glasses, glass "composite" alloys, and intermetallic compounds. His research efforts in CESE have supported education and training of over 28 MS and 25 PhD degree holders, which include underrepresented groups, as well as 10 post-doctoral researchers. His work reflects fundamental advances in corrosion as found in his archival publications, book chapters, and a co-authored book. Given that corrosion is an applied science, several innovations, practical applications, experimental methods as well as important contributions to national and international failure analyses teams, and industry standards have resulted from his work. He is a Fellow of NACE and ASM. He received the A. B. Campbell and H. H. Uhlig Awards from NACE, the T. P. Hoar Award from the Institute of Corrosion, and the Francis LaQue Award from ASTM.

Electrodeposition Division Research Award



ECTIOI

~

-

(25)

0

5

Jienna +

JOHN STICKNEY received his BS in chemistry from Humboldt State University, 1981, and a PhD from UC Santa Barbara, 1984. His dissertation, "Metal Deposition on Well-Defined Platinum Electrodes," was under Prof. Arthur Hubbard, and involved the first studies of the surface structures formed by underpotential deposition (UPD). He joined the University of Georgia (UGA) in 1985 as an assistant professor.

At UGA, his first studies were of Cu single crystal surfaces in aqueous electrolytes. The intention was to study electrodeposition on Cu surfaces, of significant importance industrially. At that time, he learned of atomic layer epitaxy (ALE) from Prof. Mike Norton, and was encouraged to see if UPD could be applied. The result was a patent in 1994 for electrochemical ALE (EC-ALE). ALE is a subset of atomic layer deposition (ALD), and the development of electrochemical ALD has been the focus of his research since.

ALD is the use of surface limited reactions to form deposits an atomic layer at a time. Surface chemistry is critical to ALD. Initial studies concerned compounds relevant to photovoltaics, such as CdTe, and more recently CulnGaSe₂ or CIGS. In addition, with the development of surface limited galvanic displacement by Adzic, Brankovic, *et al.*, it has been possible to form metal nanofilms, greatly expanding the applicability of electrochemical ALD.

Professor Stickney has started a small company (Electrochemical ALD L.C.) to produce ALD equipment and is exploring the range of materials that can be formed. His work focuses on chemistry at the interfaces of electrodeposited metals, semiconductors, etc.

High Temperature Materials Division J. B. Wagner Award



JUAN CLAUDIO NINO is an Associate Professor in the Materials Science and Engineering Department at the University of Florida (UF) in Gainesville, FL. He obtained his bachelor's degree in Mechanical Engineering in 1997 at Los Andes University (Bogotá, Colombia). He was a Lecturer at the Colombian Engineering School before joining The Pennsylvania State University in 1998, where he completed his doctoral degree in materials science and engineering in 2002.

After a postdoctoral appointment focusing on ferroelectric thin films at the Materials Research Institute (State College, PA),

he joined UF in the fall of 2003 as an assistant professor. Since then, he has established the Nino Research Group (NRG) with a main focus of the investigation of fundamental relationships governing energy-related materials towards enhancing their efficiency, performance, and sustainability. NRG's research investigates ceramics, polymers, bio-inspired materials, and their composites. Current research concentrates on five main areas: (1.) enhancement of electrolytes for intermediate temperature solid oxide fuel cells (SOFCs); (2.) rational design of high temperature proton conducting membranes for hydrogen fuel cells; (3.) determination of structure-property relationships in dielectric ceramics for capacitive (energy storage) applications; (4.) optimization of inert matrix nuclear fuel systems for reducing nuclear waste; and (5.) development of semiconducting ceramics for radiation detection devices.

Dr. Nino has over 50 scientific publications and has given over 50 technical presentations and is Coordinating Editor of the *Journal of Electroceramics* and Associate Editor of the *Journal of the American Ceramic Society*. He is a recipient of the CAREER award by the U.S. National Science Foundation.

Organic and Biological Electrochemistry Division Manuel M. Baizer Award



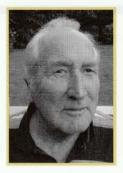
Toshio Fuchigami received a BE degree from Gunma University in 1969, and ME (1971) and PhD degrees (1974) from Tokyo Institute of Technology. He was an assistant professor at Tokyo Institute of Technology from 1974 to 1986 and was promoted to associate professor in 1986 and then to full professor in 1998. He is currently as a senator of Tokyo Institute of Technology.

Dr. Fuchigami has made outstanding and remarkable contributions to the field of synthetic organic

electrochemistry over the past 30 years. By using fluorine as a key element and employing mediators, he developed new organic electrosynthesis methods for hetero-atom compounds containing sulfur, nitrogen, iodine, and silicon atoms, based on their characteristics. His main work, "Selective Electrochemical Fluorination of Organic Compounds," is widely and internationally recognized. Furthermore, he developed methods for volatile organic compound (VOC) free organic electrosynthesis in ionic liquids. Thus, he has developed the new hybrids fields, "Organofluorine Electrochemistry" and "New Electrolytic Systems toward Green Sustainable Chemistry."

Dr. Fuchigami has published over 270 technical papers, 47 review articles, and 35 book chapters. He has organized numerous symposia at ECS meetings and other international meetings, and he currently serves as an officer of the ECS Organic & Biological Electrochemistry Division and as a chair of the ECS Japan Section. He is also a Chair of the Organic Electrochemistry Division of The Electrochemical Society of Japan. He has served as Editor-in-Chief of *Electrochemistry* (Japan) and as an Associate Editor of the *Bulletin of the Chemical Society of Japan*. He also has served on the editorial boards of the Journal of Synthetic Organic Chemistry of Japan and the Journal of Oleo Science (Japan). He is a recipient of the Takeda Award for International Achievement (2006), the Excellent Papers Award of The Electrochemical Society of Japan (2007), and The Electrochemical Society of Japan Award (2008).

Gerischer Award of the European Section



RUDIGER MEMMING, formerly Professor of Physics at the University of Oldenburg and the University of Hamburg, as well as Executive Director of the Institute for Solar Energy Research in Hannover, Germany, will receive the 2009 Gerischer Award of the ECS European Section. Previous awardees have included Akira Fujishima (Japan), Michael Grätzel (Switzerland), and Allen J. Bard (USA), all of them renowned for their accomplishments in the field of semiconductor

electrochemistry and photoelectrochemistry.

Professor Memming has made outstanding contributions in many areas of solar energy research and electrochemistry of semiconductor materials, particularly in the fields of photoelectrochemistry, material science, spectroscopy, dye-sensitization, and charge transfer at semiconductor interfaces. He was among the first to study semiconductors sensitized with dyes, and his pioneering work utilizing ruthenium complexes as sensitizers has had an impact on the development of dye-sensitized solar cells. His research interests included both fundamental understanding of the materials and device physics of these cells, and their possible technology development. His studies concerned surface states, etching, impedance spectroscopy of semiconductor electrodes, as well as kinetics of electron transfer. He also contributed to the early design of systems for water splitting and hydrogen evolution. Professor Memming is recognized worldwide as a leading expert in many scientific disciplines but his most significant achievements are in the field of photoelectrochemistry.



General Topics

Please Note the Earlier Abstract Deadline: November 16, 2009

- Batteries, Fuel Cells, and Energy Conversion
 Biomedical Applications and Organic
- Electrochemistry > Corrosion, Passivation, and Anodic Films
- Dielectric and Semiconductor Materials, Devices, and Processing
- Electrochemical / Chemical Deposition and Etching
- > Electrochemical Synthesis and Engineering
- Fullerenes, Nanotubes, and Carbon Nanostructures
- Physical and Analytical Electrochemistry
- Sensors and Displays: Principles, Materials, and Processing

25) 3 251 ~ LUI _ 25 0 3 + Vienna



PLATINUM Bio**Logic**

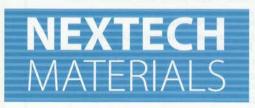
www.bio-logic.info

Science Instruments

CambridgeNanoTech Simply ALD



ADVANCED VAPORIZERS



fuelcellmaterials.com

PLANSEE



MERCK

The SOFC Society of Japan



Technical Exhibit

The Technical Session coffee break is scheduled for 0930h on Level OE-Yellow on Tuesday and Wednesday to allow meeting attendees additional time to browse through the exhibits. The exhibit will feature instruments, materials, systems, publications, and software of interest to attendees.

Exhibit Hours

Monday, May 7 1800-2000h includes the Monday Evening Poster Session

Wednesday, May 9 0900-1400h

Exhibitors as of Press-Time

ECS

Booth 13 ecs@electrochem.org www.electrochem.org

Agilent Technologies

Booth 37 joan_horwitz@agilent.com www.agilent.com/find/afm

AJA International

Booth 4 topgun@ajaint.com www.ajaint.com

ALD Technologies LTD

Booth 7 james.odowd@tyndall.ie www.tyndall.ie/research/ams-group/index.html

ANNEALSYS

Booths 33 & 35 info@annealsys.com www.annealsys.com

Arbin Instruments

Booth 31 Antony.p@arbin.com www.arbin.com

Bio-Logic SAS

Booths 38 & 40 www.bio-logic.info/e-form.php www.bio-logic.info

Brennstoffzellen Initiative Sachsen e.V.

Booths 27 & 29 info@bz-sachsen.de www.bz-sachsen.de

Cambridge NanoTech

Booth 24 klos@cambridgenanotech.com www.cambridgenanotech.com

cyberTECHNOLOGIES GmbH

Booth 36 info@cybertechnologies.com www.cybertechnologies.com

EBZ GmbH Fuel Cells & Process Technology

Booths 27 & 29 eva.spickenheuer@ebz-dresden.de www.ebz-dresden.de

EKTechnologies GmbH

Booths 14 & 15 info@ektechnologies.de www.ektechnologies.de

ESL Elektronik GmbH

Booths 33 & 35 info@esl-elektronik.de www.esl-elektronik.de

Forschungszentrum Julich GmbH

Booths 22 & 23 m.wilms@fz-juelich.de www.fz-juelich.de

Fraunhofer IKTS

Booth 8 Mihails.kusnezoff@ikts.fraunhofer.de www.ikts.fraunhofer.de

Gamry

Booth 39 ppeterson@gamry.com www.gamry.com

Gelest Inc.

Literature Display jzazyczny@gelest.com www.gelest.com

HEKA Elektronik Dr. Schulze GmbH

Booth 11 sales@heka.com www.heka.com

IJ Cambria Scientific Ltd.

Literature Display info@ijcambria.com www.ijcambria.com

IMLB 2010

Booth 30 Raymond.nathalie@hydro.qc.ca www.imlb.org

Ingenieurburo Peter Schrems (IPS)

Booth 1 ibschrems@ips-jaissle.de www.ips-jaissle.de/

International Society of Electrochemistry (ISE)

Booth 20 info@ise-online.org www.ise-online.org

Ivium Technologies

Booths 14 & 15 info@ivium.nl www.ivium.com

KEMSTREAM

Booths 33 & 35 info@kemstream.com www.kemstream.com

KERAFOL

Booth 21 info@kerafol.com www.kerafol.com

Maccor

Booths 5 & 6 m.hulse@maccor.com www.maccor.com

MALT Group

Booth 32 malt@kagaku.com www.kagaku.com/malt

MaTeck GmbH

Booth 3 info@mateck.de www.mateck.de

Materials Mates Italia

Booth 12 lupotto@mmates.it www.mmates.com

Merck KGaA

Booth 19 marlies.watermann@merk.de www.ionic-liquids.com

Metrohm Autolab / Inula

Booth 25 iosif@ecochemie.nl www.autolab-instruments.com

NexTech Materials

Booth 2 Sales@nextechmaterials.com www.nextechmaterials.com

Ningbo Institute of Material Technology and Engineering (NIMTE)

Booth 16 wgwang@nimte.ac.cn www.nimte.ac.cn/

PEC

Booth 18 peter.ulrix@peccorp.com www.peccorp.com

The Electrochemical Society Interface • Fall 2009

26

Plansee AG

Booths 9 & 10 info@plansee.com www.plansee.com

Princeton Applied Research / Solartron Analytical

Booths 26 & 28 ari.tampasis@ametek.com www.ametek.com

Scribner Associates

Booth 34 info@scribner.com www.scribner.com

Springer Business+Media

Literature Display Kenneth.howell@springer.com www.springer.com

Staxera GMBH

Booths 27 & 29 jeremy.lawrence@staxera.de www.staxera.de

Webcom Communications

Literature Display jessicat@infowebcom.com www.infowebcom.com

ZAHNER-elecktrik GmbH & Co. KG

Booth 17 ms@zahner.de www.zahner.de



Join now for exceptional discounts on all ECS publications, page charges, meetings, and short courses.

- Journal of The Electrochemical Society
- Electrochemical and Solid-State Letters
- ECS Transactions
- Interface, the ECS Member Magazine

- Discounts on Meetings and Publications
- Professional Development and Education
- Honors and Awards Program
- Career Center
- Member Directory

www.electrochem.org

*

VIENMA

EUROCVD 17

SCHEDULE OF EVENTS EuroCVD registration required, except where noted.

MONDAY, OCTOBER 5

1200h	EuroCVD Luncheon, Lounge 3, Level 01-Green
1540h	EuroCVD Coffee Break, Hall F1, Level OE-Yellow
1800h	EuroCVD Poster Session, Hall F2, Level OE-Yellow (EuroCVD registration not required.)

TUESDAY, OCTOBER 6

1200h	EuroCVD	Luncheon,	Lounge	3, Le	vel 01-0	Green	
1400h	EuroCVD entrance a		Vienna"	Tour,	Meet a	t ACV	main

WEDNESDAY, OCTOBER 7

1200h	EuroCVD Luncheon, Lounge 3, Level 01-Green
1540h	EuroCVD Coffee Break, Hall F1, Level OE-Yellow
1800h	EuroCVD Poster Session, Hall F2, Level OE-Yellow (EuroCVD registration not required.)

THURSDAY. OCTOBER 8

1200h	EuroCVD Luncheon, Lounge 3, Level 01-Green
1540h	EuroCVD Coffee Break, Hall F1, Level OE-Yellow
1800h	EuroCVD Banquet, Lounge 3/4, Level 01-Green

SOFC XI

SCHEDULE OF **E**VENTS

SOFC registration required, except where noted.

MONDAY, OCTOBER 5

0830h	Coffee Break, Foyer B, Level 02-Red
1540h	SOFC Coffee Break, Hall B, Level 02-Red
1800h	SOFC Poster Session, Foyer B/C, Level 02-Red (SOFC XI registration not required.)

TUESDAY. OCTOBER 6

0930h	Coffee Brea	ik, Foyer I	B/C, Level	02-Red
1540h S	SOFC Coffe	ee Break	Hall B. Lev	el 02-Red

1800h......SOFC Poster Session, Fover B/C, Level 02-Red (SOFC XI registration not required.)

WEDNESDAY, OCTOBER 7

0930h	Coffee Break, Foyer B/C, Level 02-Red
1800h	SOFC Banquet, Lounge 3/4, Level 01-Gree

THURSDAY, OCTOBER 8

0930h	.Coffee Break, Foyer B/C, Level 02-Red
1540h	SOFC Coffee Break, Hall B, Level 02-Red
1800h	SOFC Poster Session, Foyer B/C, Level 02-Red (SOFC X registration not required.)

FRIDAY, OCTOBER 9

0930h	Coffee	Break,	Foyer	B/C,	Level	02-Red
1540h	SOFC	Coffee	Break,	Hall	B, Lev	el 02-Red

Luncheons, Business **Meetings & Special Events**

See sidebar (left) for EuroCVD 17 and SOFC XI **Schedule of Events**

All luncheon and special event tickets are nonrefundable and should be purchased in advance. Tickets are priced as follows.

Luncheons: \$36 (\$30 + \$6 VAT) in advance, \$42 (\$35 + \$7 VAT) onsite

Receptions: \$16.80 (\$14 + \$2.80 VAT) in advance, \$19.20 (\$16 + \$3.20 VAT) onsite Other Events: price as noted

SUNDAY, OCTOBER 4

1900h Electronics & Photonics Division Award Reception & General Meeting, Hall O, Level 01-Green (No ticket required.)

MONDAY, OCTOBER 5

1215h Battery	Division	Luncheon	& Business	Meeting,
Lounge	e 4, Level	01-Green		

1215h High Temperature Materials Division Luncheon & Business Meeting, Lounge 1, Level 01-Green

TUESDAY. OCTOBER 6

1215h Corrosion Division Luncheon & B	susiness Meeting,
Lounge 5, Level 01-Green	

- 1215h Sensor Division Luncheon & Business Meeting, Lounge 6, Level 01-Green
- 1800h Corrosion Division Award Reception, Lounge 5, Level 01-Green
- 1800h ECS Olin Palladium Award Reception, Rondo, Level OE-Yellow (No ticket required.)

WEDNESDAY. OCTOBER 7

1215h	Electrodeposition	Division Luncheon	& Business
	Meeting, Lounge	1, Level 01-Green	

- 1215h Luminescence & Display Materials Division Luncheon & Business Meeting, Lounge 5, Level 01-Green
- 1830h European Section Heinz Gerischer Award Reception, Lounge 6, Level 01-Green (No ticket required.)
- 1900h Battery Division Award Reception, Lounge 2, Level 01-Green
- 1800h SOFC Banquet, Lounge 3/4, Level 01-Green

THURSDAY, OCTOBER 8

1800h EuroCVD Banquet, Lounge 3/4, Level 01-Green

Hotel & Travel Information

The 216th ECS Meeting, EuroCVD 17, and SOFC XI will be held at the Austria Center Vienna (ACV), located at IAKW, AG, Bruno-Kreisky-Platz 1, A-1220, Vienna, Austria. Several hotels are located within walking distance or a quick subway ride. Guest room reservations can be made online from the ECS website. The discounted meeting rates, deadlines, and terms vary by hotel and can be accessed from the ECS website.

Ground Transportation—To get from the Vienna Airport at Schwechat, located outside the city limits, to the city center, you can choose from the City Airport Train, an Airport Express bus, the Schnellbahn (City Train), the Vienna Airport Service, or a taxi. See the ECS website for further details.

Companion Registrant Program-Guests of Technical Registrants are invited to register for the 216th ECS Meeting as a "Companion Registrant." The companion registration fee of \$60 in advance (\$50 + \$10 VAT) or \$66 onsite (\$55 + \$11 VAT) includes admission to non-ticketed social events: an exclusive lounge (Lounge 7, Level 01-Green) with beverage service; Monday through Thursday, 0800-1000h; and a special "Welcome to Vienna" orientation presented by the Vienna Convention Bureau on Monday, October 5 at 0900h in the Companion Registrants Lounge. On Thursday, October 8 at 0900h, there will be a group discussion of the book Mozart's Wife by Juliet Waldron-the story of her passion for her husband and her struggle to survive being a married to a musical genius who gave little care to the money required to support a lifestyle of parties, hard drinking, and chasing after women and the fickle patronage of aristocrats, upon whom they depended. The book is available online at Amazon.com.

Technical Program

Technical Session Co-Chair Orientation—We encourage all Symposium Organizers and Technical Session Co-Chairs to attend this important informational session in Hall N, Level 01-Green on Sunday from 1500-1700h. The Co-Chair Orientation will take place during the first 10 minutes of the meeting.

Oral Presentations and Audio-Visual—Oral presentations must be in English. Only LCD projectors will be available for oral presentations. Authors will be required to bring their own laptop computers for presentation. We strongly suggest that presenting authors verify laptop/projector compatibility in the speaker-ready rooms at the meeting. Speakers requiring special equipment must make written request to ECS headquarters (meetings@electrochem.org) no later than three weeks before the meeting, and appropriate arrangements will be made at the expense of the author.

Poster Presentations and Sessions—Poster presentations must be in English, on a board approximately 35" high x 75" wide (90 cm high x 190 cm wide), corresponding to the abstract number and day of presentation in the final program. Please arrive approximately two to four hours before the start of your session to begin setting up your poster displays. Please do not begin setting up your poster until all the poster boards have been numbered. Plan your display to fit on one upright panel approximately 35" high x 75" wide (90 cm high x 190 cm wide). Present displayed information from left to right, starting at the top left of the panel. The paper title,

number, names, and affiliations of all authors MUST be at the top of the display. The recommended print size for the title is approximately 1'' to 2'' (2.5 cm to 5 cm) high. Authors should minimize written text but use it when necessary to emphasize essential data and/or to stimulate discussion. All illustrations, drawings, charts, pictures, graphs, figures, and written text should be large enough to allow easy reading from a distance of 5' (1.5 m). Matted and finished photographs are recommended to enhance visibility. Pushpins and/or thumbtacks will be supplied at the meeting. Commercial advertisements or publicity will NOT be permitted in poster presentations. Authors violating this regulation will be asked to remove their presentations immediately. Authors are responsible for setting up their displays, for being present during the entire scheduled poster session, and for removing their displays at the conclusion of the poster session. No posters will be displayed without author participation. NO EXCEPTIONS WILL BE GRANTED. Authors are responsible for the security of their displays and all items of value. ECS will not assume any responsibility for lost, stolen, or broken articles. Additional information or special requirements should be addressed to the individual symposium organizers prior to the meeting.

The **GENERAL SOCIETY STUDENT POSTER SESSION** will be held as a part of the Monday Evening Mixer and Technical Exhibit, which features instruments, materials, systems, publications, and software of interest to meeting attendees. All meeting registrants are invited to attend. Formal presentations will begin at 1800h. Students may start setting up their presentations on Level 01-Green, at 1400h; judging of the posters will begin at 1700h. Participants are encouraged to attend the Technical Exhibit on Tuesday at 1200h where the winners will be announced and given an award plaque.

Speaker-Ready Room—Two Speaker-Ready Rooms will be available Sunday through Friday, in Rooms U542 & U544, Level OE-Yellow. These rooms are available to allow speakers the opportunity to preview and prepare for their presentations. We highly recommend that speakers verify their laptop's compatibility with the sample LCD projector that will be located in this room, prior to their presentation. Additionally, there will be audiovisual technicians available for your assistance.

Speaker Indemnification—The ideas and opinions expressed in the technical sessions, conferences, and any handout materials provided are those of the presenter. They are not those of ECS, nor can any endorsement be claimed.

(continued on page 31)

SPECIAL SYMPOSIUM: "IN SITU DIAGNOSIS OF LOW TEMPERATURE FUEL CELLS"

Friday, October 9, 0800-1200h, Hall H, Level U2-Blue

An optimized water management is one of the key factors for the performance and durability of low temperature fuel cells. A variety of methods are currently employed to evaluate and optimize materials for a fine-tuned water balance. *In situ* investigations gained an increasing importance within the last years and have led to great improvements of state-of-the-art fuel cell designs.

In this special symposium, recent achievements in the field of *in situ* technologies and results of related studies will be presented. Different diagnostic methods like neutron radiography, locally resolved current density measurements, high resolution synchrotron radiography, and electrochemical impedance spectroscopy (EIS) provide an informative basis and helpful insights in operating fuel cells. The focus of this symposium is a complimentary presentation of transport process in operating fuel cells and their effects on performance, aging, and material degradation. In addition to applied methods, new modeling approaches to describe the structure of porous media will be discussed which serve as basis for fundamental understanding of transport pathways in gas diffusion media. The list of contribution is completed by an insight to recent improvements in reconstruction algorithms as employed for three-dimensional imaging of tomographic applications.

The program is guided by activities of the network RuNPEM, funded by the German Federal Ministry of Education and Research (BMBF); the network unites the competencies of partners from universities and institutes in Germany working on different fields and areas from fundamental up to industrial research projects.

All meeting attendees are invited to participate in this symposium.

Symposium Topics and Organizers

Sessions are marked to indicate if they run on Sunday (S), Monday (M), Tuesday (Tu), Wednesday (W), Thursday (Th) and/or Friday (F).

HC — Hard-cover (HC) editions of ECS Transactions will be available for purchase and pick-up at the meeting.

C — Electronic (PDF) editions of *ECS Transactions* issues will be available ONLY via the ECS Digital Library. Electronic editions of the The 216th ECS Meeting, EuroCVD 17 and SOFC-XI "at" meeting issues will be available for purchase beginning October 3, 2009. Please visit the ECS website for all issue pricing and ordering information for the electronic editions.

A — General Topics

- A1 General Student Poster Session V. Desai, G. Botte, V. R. Subramanian, and K. Sundaram
- A2 Nanotechnology General Session C. Bock, J. Li, Z. F. Liu, and E. Traversa
- A3 Michael Faraday: The First Nanotechnologist? An Invited Symposium R. Tweney, D. Misra, and K. Rajeshwar
- A4 Tutorials in Nanotechnology: Focus on Physical and Analytical Electrochemistry, An Invited Symposium — H. De Long, R. Mantz, S. Minteer, and P. Trulove
- B Batteries, Fuel Cells, and Energy Conversion
- B1 Batteries and Energy Technology Joint General Session Z. Ogumi, A. Manivannan, and S. R. Narayanan
- **B2** Alkaline Electrochemistry in Fuel Cells D. Chu, R. Mantz, and C. Wang
- **B4** Intercalation Compounds for Lithium Batteries *M. Whittingham, P. Bruce, C. M. Julien, M. Palacin, J. Prakash, and M. Thackeray*
- **B5** Rechargeable Lithium Ion Batteries M. Winter, K. M. Abraham, D. Doughty, Z. Ogumi, and K. Zaghib
- B7 Photovoltaics for the 21st Century 5 M. Tao, J. Brownson, P. Chang, C. Claeys, K. Kakimoto, K. Rajeshwar, M. Sunkara, and D. Yang
- B8 PEM Fuel Cells 9 T. F. Fuller, P. Bele, S. Cleghorn, H. A. Gasteiger, C. Hartnig, T. Jarvi, D. J. Jones, C. Lamy, V. Ramani, P. Shirvanian, P. Strasser, H. Uchida, T. A. Zawodzinski, and P. Zelenay
- **B9** Semiconductor Electrolyte Interface and Photoelectrochemistry K. Rajeshwar, M. A. Ryan, and T. A. Zawodzinski
- B10 Solid Oxide Fuel Cells 11 (SOFC XI) S. Singhal and H. Yokokawa 🛛 🗳 🕜

C — Biomedical Applications and Organic Electrochemistry

- C1 Organic and Biological Electrochemistry General Poster Session J. Burgess
- **C2** New Biomimetic Materials for Electrochemical Sensing C. Kranz, M. Bayachou, and H. De Long
- **C3** Synthetic and Mechanistic Organic Electron Transfer Reactions *T. Fuchigami, G. Cheek, D. Evans, and F. Maran*

\mathbf{D} — Corrosion, Passivation, and Anodic Films

- D1 Corrosion General Session D. C. Hansen
- **D2** Coatings for Corrosion Protection G. Frankel, G. Grundmeier, H. N. McMurray, and T. Shinohra
- **D3** Corrosion of Electronic and Magnetic Materials L. Garfias, A. Gebert, and N. Missert
- D4 High Temperature Corrosion and Materials Chemistry 8 E. Wuchina, J. W. Fergus, T. Markus, T. Maruyama, P. J. Masset, E. J. Opila, and D. Shifler
- D5 Surface Treatment for Biomedical Applications 2 S. Djokic, Z. P. Aguilar, D. C. Hansen, and S. Virtanen
- D6 Oxide Films P. Marcus, S. Fujimoto, and H. A. Terryn

— Dielectric and Semiconductor Materials, Devices, and Processing

- E1 Analytical Techniques for Semiconductor Materials and Process Characterization 6 — B. Kolbesen, M. Bersani, C. Claeys, and L. Fabry EC @
- E2 Atomic Layer Deposition Applications 5 S. De Gendt, S. F. Bent, A. Delabie, J. Elam, S. B. Kang, A. Londergan, and O. Van der Straten
 Image: Ima

- E3 Cleaning Technology in Semiconductor Device Manufacturing 11 J. Ruzyllo, P. Besson, T. Hattori, P. Mertens, and R. Novak
- E4 High Dielectric Constant Materials and Gate Stacks 7 S. Kar, M. Houssa, H. Iwai, D. Landheer, D. Misra, and S. Van Elshocht
- E5 Processing, Materials and Integration of Damascene and 3D Interconnects — J. C. Flake, O. Leonte, G. S. Mathad, P. Ramm, H. S. Rathore, and F. Roozeboom
- E6 One-Dimensional Nanoscale Electronic and Photonic Devices 3 L. Chou, G. Duesberg, S. Jin, J. Li, S. Roth, and Z. L. Wang
- E7 Organic Semiconductor Materials, Devices, and Processing 2 M. J. Deen, D. Gundlach, B. Iniguez, H. Klauk, and K. Worhoff
- E8 Semiconductor and Plasmonics: Active Nanostructures for Photonic Devices and Systems — M. Gerhold, S. Chen, D. Rogers, F. Teherani, and J. Xu
- E9 State-of-the-Art Program on Compound Semiconductors 51 (SOTAPOCS 51) — E. Stokes, O. Ambacher, R. Goldhahn, J. Huang, G. Hunter, E. Kohn, C. O'Dwyer and M. E. Overberg
- E10— ULSI Process Integration 6 C. Claeys, S. Deleonibus, H. Iwai, J. Murota, and M. Tao

F — Electrochemical / Chemical Deposition and Etching

F1 — Current Trends in Electrodeposition, An Invited Symposium — W. Schwarzacher

HC O

- F2 Electrodeposition of Nanoengineered Materials and Devices 3 N. V. Myung, S. R. Brankovic, L. Deligianni, J. Mallet, E. J. Podlaha, J. F. Rohan, J. B. Talbot, N. J. Tao, and G. Zangari
- F3 EuroCVD 17 and CVD 17 M. T. Swihart, R. A. Adomaitis, D. Barreca, and K. Worhoff
- F4 Fundamentals of Electrochemical Growth: From UPD to Microstructures, A Symposium in Memory of Prof. Evgeni Budevski — S. R. Brankovic, P. Allongue, M. Innocenti, L. Peter, N. Vasiljevic, and G. Zangari
- F5 Semiconductors, Metal Oxides, and Composites: Metallization and Electrodeposition of Thin Films and Nanostructures — G. Oskam, J. Fransaer, I. Shao, and P. M. Vereecken
- H Fullerenes, Nanotubes, and Carbon Nanostructures
- H1 Carbon Nanotubes and Nanostructures: From Fundamental Properties and Processes to Applications and Devices — R. B. Weisman, S. De Gendt, M. Kappes, M. Meyyappan, and M. Prato
- H2 Nanostructure and Function of Fullerenes N. Martin, D. Guldi, A. Hirsch, and J. F. Nierengarten

— Physical and Analytical Electrochemistry

- 11 Physical, Electroanalytical, and Bioanalytical Electrochemistry P. J. Kulesza, M. Fojta, A. Kuhn, S. Minteer, and Z. J. Stojek
- 12 Electrochemistry: Symposium on Interfacial Electrochemistry in Honor of Brian E. Conway — B. MacDougall, C. Bock, E. Gileadi, S. Gottesfeld, D. Harrington, J. Leddy, W. Lorenz, S. Morin, B. Scrosati, and S. Trasatti
- 13 Physical and Analytical Electrochemistry in Ionic Liquids P. Trulove, H. De Long, and R. Mantz
 - Sensors and Displays: Principles, Materials, and Processing
- J1 Sensors, Actuators, and Microsystems General Session R. Mukundan
- J2 Impedance Techniques: Diagnostics and Sensing Applications V. Lvovich, C. C. Hansen, M. E. Orazem, B. Tribollet, and P. Vanysek
- J4 Physics and Chemistry of Luminescence Materials, W. M. Yen Memorial Symposium — U. Happek, J. Collins, D. J. Lockwood, and A. M. Srivastava

(continued from page 29)

No Recording Allowed—Photographing and/or recording of presentations IS NOT PERMITTED unless specifically allowed by the speaker. Anyone making unauthorized photographs or recordings will be asked to leave the session.

Registration & General Meeting Information

Meeting Registration—The meeting registration area will be located on Level OE-Yellow. Registration will open on Sunday and the technical sessions will be conducted Sunday through Friday.

Key Locations

Meeting Registration	Level OE-Yellow
Information/Message Center	Level OE-Yellow
ECS Headquarters Office	Suite E, Level OE-Yellow
ECS Book Store	Level OE-Yellow
Speaker Ready Rooms	Rooms U542 & U544, Level OE-Yellow
Employment Interview Room	Room U641, Level OE-Yellow

Book Store Hours

Sunday, October 4	0700-1900h
Monday, October 5	
Tuesday, October 6	
Wednesday, October 7	0800-1600h
Thursday, October 8	0800-1600h
Friday, October 9	

Registration Hours

Saturday, October 3	
Sunday, October 4	0700-1900h
Monday, October 5	0700-1900h
Tuesday, October 6	
Wednesday, October 7	0800-1600h
Thursday, October 8	0800-1600h
Friday, October 9	

Registration Fees-ALL PARTICIPANTS AND ARE REQUIRED TO PAY ATTENDEES THE APPROPRIATE REGISTRATION FEE LISTED BELOW. Payment can be made by cash, check or travelers' checks in U.S. funds drawn on a U.S. bank. Visa, MasterCard, American Express, or Discover are also accepted. All prices are in U.S. dollars.

All technical registrations include a copy of the Meeting Abstracts on CD-ROM only. Attendees who wish to have paper copies of abstracts should download and print them in advance of the meeting, from the ECS website, free of charge. Please note that paper copies of meeting abstracts will NOT be available. Additional copies of the Meeting Abstracts on CD-ROM may be purchased by registrants; the cost is \$74 for ECS Members and \$92.50 for Nonmembers.

All students must send verification of student eligibility along with their registration. All technical registrations include a copy of Meeting Abstracts (on CD-ROM only). Attendees who wish to have paper copies of abstracts in advance of the meeting should download copies from the ECS website, free of charge.

Financial Assistance-Financial assistance is limited and generally governed by the symposium organizers. Individuals may inquire directly to the symposium organizers of the symposium in which they are presenting their paper to see if funding is available. Individuals requiring an official letter of invitation should write to the ECS headquarters office; such letters will not imply any financial responsibility of ECS.

Employment Services- Companies desiring to recruit employees may place their announcements on a designated bulletin board in the registration area. Please note that these announcements should be no larger than 8 1/2" by 11". Room U546, Level OE-Yellow will be available as an Employment Interview Room from 0700-1900h Sunday through Friday for representatives from those companies or institutions that would like to interview applicants during the meeting.

ADA Accessibility-Special accommodations for disabled attendees will be handled on an individual basis provided that adequate notice is given to the ECS headquarters office.

		Onsite	
And second at last	Fee	VAT	Total
ECS Member	\$560	\$112	\$672
ECS Student Member	\$290	\$58	\$348
ECS Member: One-Day	\$425	\$85	\$510
Nonmember	\$760	\$152	\$912
Nonmember Student	\$320	\$64	\$384
Nonmember: One-Day	\$505	\$101	\$606
Companion	\$55	\$11	\$66
SOFC Package ¹			
SOFC Technical	\$745	\$149	\$894
SOFC Student	\$455	\$91	\$546
SOFC Banquet Only	\$155	\$31	\$186
EuroCVD Package ²			
EuroCVD Technical	\$1,045	\$209	\$1,254
EuroCVD Student	\$780	\$156	\$936
EuroCVD Tour & Banquet Only	\$200	\$40	\$240

¹Price includes ECS meeting registration, the Meeting Abstracts on CD-ROM, a hard copy (with CD-ROM) of the proceedings published in ECS Transactions, and the Wednesday evening SOFC banquet.
²Price includes ECS meeting registration, the Meeting Abstracts on CD-ROM, a hard copy (with CD-ROM) of the proceedings published in ECS Transactions, "Historical Vienna" tour, lunch Monday through Thursday, and the Thursday evening EuroCVD banquet.
The 20% Austrian VAT is recoverable to some, but not all attendees, via their affiliated institutions. To determine if you qualify, please contact TaxPort: http://www.taxport-usa.com/ecs/



ECS • The Electrochemical Society 65 South Main Street Pennington, NJ 08534-2839, USA Phone: 609.737.1902 Fax: 609.737.2743 E-mail: ecs@electrochem.org Web: www.electrochem.org

ACS TANSACTORS Volume 25-Vienna, Austria

from the ECS Vienna meeting, October 4-October 9, 2009

The following issues of ECS Transactions are from symposia held during the Vienna meeting. All issues are available in electronic (PDF) editions, which may be purchased by visiting http://ecsdl.org/ECST/. Some issues are also available in hard-cover editions. Please visit the ECS website for all issue pricing and ordering information. (All prices are in U.S. dollars; M = ECS member price; NM = nonmember price.)

Available Issues—Hard Cover (HC) & Electronic (PDF)

/ol. 25	Proton Exchange Membrane Fuel Cells 9	Vol.			
No. 1	HCM \$162.00, NM \$201.00	No.			
	PDFM \$142.75, NM \$178.44				
/ol. 25	Solid Oxide Fuel Cells 11 (SOFC-XI)	Vol.			
No. 2	HCM \$167.00, NM \$206.00	No.			
	PDFM \$142.75, NM \$178.44				
/ol. 25	Analytical Techniques for Semiconductor				
Vo. 3	Materials and Process Characterization 6				
	(ALTECH 2009)	Vol.			
	HCM \$94.00, NM \$117.00	No.			

PDF......M \$82.91, NM \$103.64

- Vol. 25 Cleaning and Surface Conditioning No. 5 Technology in Semiconductor Device Manufacturing 11 HC......M \$92.00, NM \$115.00

PDF......M \$83.96, NM \$104.95

- Vol. 25 Physics and Technology of High-k No. 6 Gate Dielectrics 7 HC.......M \$89.00, NM \$111.00 PDF.......M \$82.91, NM \$103.64

PDF......M \$65.46, NM \$81.83

- Available Issues-Electronic (PDF) Only
- Vol. 25 Nanoscale One-Dimensional Electronic No. 10 and Photonic Devices 3 (NODEPD 3)
 - and Photonic Devices 3 (NODEPD 3) No. 11
 PDF......M \$38.78, NM \$48.47
- Vol. 25 First International Symposium on No. 11 Semiconductor and Plasmonics-Active Nanostructures for Photonic Devices and Systems PDF......M \$33.11, NM \$41.39
- Vol. 25 State-of-the-Art Program on Compound No. 12 Semiconductors 51 (SOTAPOCS 51) and Wide-Bandgap Semiconductor Materials and Devices 10
 - PDF......M \$38.78, NM \$48.47

Forthcoming Issues

If you would like to receive information on any of these issues when they become available, please email ecst@electrochem.org. Please include your name, full mailing address, e-mail address, and all issues in which you are interested.

VIE A1	Student Posters (General) - 216th ECS	VIE D1	Corrosion (General) - 216th ECS Meeting	VIE H1	Carbon Nanotubes and Nanostructures:
	Meeting	VIE D2	Coatings for Corrosion Protection		From Fundamental Properties and Processes to Applications and Devices
VIE A2	Nanotechnology (General) - 216th ECS Meeting	VIE D3	Corrosion of Electronic and Magnetic Materials	VIE H2	Nanostructure and Function of Fullerenes
VIE A3	Michael Faraday: The First Nanotechnologist? - An Invited Symposium	VIE D4	High Temperature Corrosion and Materials Chemistry 8	VIE I1	Physical, Electroanalytical and Bioanalytical Electrochemistry
VIE A4	Tutorials in Nanotechnology: Focus on Physical and Analytical Electrochemistry	VIE D5	Surface Treatment for Biomedical Applications 2	VIE I2	Electrochemistry: Symposium on Interfacial Electrochemistry in Honor of Brian E. Conway
	- An Invited Symposium	VIE D6	Oxide Films	VIE 13	Physical and Analytical Electrochemistry in
VIE B1	Battery/Energy Technology Joint (General) VIE E5 Processing, Materials and Integration of	Processing, Materials and Integration of		Ionic Liquids	
	- 216th ECS Meeting		Damascene and 3D Interconnects	VIE J1	Sensors, Actuators, and Microsystems
VIE B2	Alkaline Electrochemical Power Sources	VIE E7	Organic Semiconductor Materials, Devices,		(General) - 216th ECS Meeting
VIE B4	Intercalation Compounds for Lithium Batteries		and Processing 2	VIE J2	Impedance Techniques: Diagnostics and
VIE B5	Rechargeable Lithium and Lithium Ion Batteries	VIE F1	Current Trends in Electrodeposition - An Invited Symposium	Sensing Applications	
VIE B7	Photovoltaics for the 21st Century 5	VIE F2	Electrodeposition of Nanoengineered Materials and Devices 3		
VIE B9	Semiconductor Electrolyte Interface and Photoelectrochemistry	VIE F4	Fundamentals of Electrochemical Growth: From UPD to Microstructures - Symposium		
VIE C1	Organic and Biological Electrochemistry		in Memory of Prof. Evgeni Budevski	Ordering Information	
	Posters (General) - 216th ECS Meeting	VIE F5	Semiconductors, Metal Oxides, and Composites: Metallization and Electrodeposition of Thin Films and		
VIE C2	New Biomimetic Materials for Electrochemical Sensing			To order any of these recently-published titles, please visit the ECS Digital Library, http://ecsdl.org/ECST/	
VIE C3	Synthetic and Mechanistic Organic Electron Transfer Reactions		Nanostructures		

Email:orders@electrochem.org

FREE P R O D U C T I N F O R M A T I O N

	Name:		
Anton Paar	Address:		
🔲 Bio-Logic			
		Apt. No	
🔲 Florida Solar Energy Center	City	State	
Gamry	Zip Code	Country	
Contract Koslow Scientific			
Metrohm USA	Fax #:		
Derinceton Applied Research	E-mail:		
Solartron Analytical			
Scribner	Quick Reader Survey		
	In order to help us serve you better, please take a moment to answer the following questions.		
	 What is your main role in purchasing new equipment/services? Advise/Recommend Grant Purchasing Authority No Role 		
	 2. Are you more or less inclined to consider products you see in <i>Interface</i>? More Inclined Less Inclined No Opinion 		
Check here to receive future mailings about similar products 3. What other products/services would you like to see advertise			

mailings about similar products.

Fa 2009

Place First Class postage here. Post Office will not deliver without proper postage.

INTERFACE

Reader Response Card

THE ELECTROCHEMICAL SOCIETY 65 S MAIN ST STE D1 PENNINGTON NJ 08534-2839

Միսիսիսիսիսիսիսինիսիսիիիսիսիսիսի

CSTIC:中国国际半导体技术大会

The largest annual semiconductor industry technology conference in China

2010 Distinguished Conference Keynote Speakers





tuart S.P. Parkin

Dr. Simon Yang Senior Vice President, Chartered



or, T.P. Ma Director of Yale Center or Microelectronics, ale University



Dr. Zhengrong Shi Chairman and CEO, Suntech

CSTIC (China Semiconductor Technology International Conference) is one of the largest annual semiconductor industry technology conferences in China. CSTIC 2010 will be held on March 18-19, 2010 in Shanghai, China, in conjunction with SEMICON China 2010.

CSTIC aims to provide a platform for executives, managers, engineers and researchers to exchange the latest developments in semiconductor technology and manufacturing. It also offers an opportunity for those who are interested in investing in the semiconductor industry in Asia, particularly in China.

We are soliciting papers from authors around the world on all aspects of semiconductor technology and manufacturing. Prospective authors are requested to submit an abstract of 200-500 words and a 100 word biography by the 30, 2009 on web. More information could be found at http://semiconchina.semi.org/cstic

Topics to be addressed at CSTIC 2010 include, but not limited to the following: Symposium 1: Design and Device Engineering Symposium 1: Metrology Reliability and Testing Symposium 11: Materials and Process Integration for Device and Interconnection Symposium 11: Lithography and Patterning Symposium V: CMP and Post-CMP Cleaning Symposium V: CMP and Post-CMP Cleaning Symposium VI: Thin Film, Etch & Plating Symposium VII: Packaging and Assembly Symposium VIII: Emerging Semiconductor Technologies Symposium IX: Silicon Technology for Electronic and Photovoltaic Applications



March 18-19, 2010 Shanghai, China

Call for Paper Deadline: Oct. 30, 2009

The SEMI ECS Student & Engineer Award (SESEA Award) will be presented during the conference to recognize outstanding work in fundamental or applied semiconductor technology. The nominee must be a graduate student or young scientist or engineer who has contributed outstanding theoretical or experimental work in the semiconductor field. Winners will be awarded a travel grant to attend the next meeting of The Electrochemical Society (ECS).

http://semiconchina.semi.org/csti





Co-organizer:

Co-sponsors:





China's High-Tech Expert Committee (CHTEC)



Contact : **SEMI China** Phone: 86.10.51906086 Fax: 86.10.51906087 E-mail: cstic@semi.org.cn

PEOPLE





Bill Yen 1935-2008

Ed. Note: The following is excerpted from the Preface, written by Uwe Happek, to the ECS Transactions issue from the "Physics and Chemistry of Luminescence Materials, W. M. Yen Memorial Symposium," which will be held at the ECS meeting in Vienna.

This proceedings volume is dedicated to **BILL YEN**, an

eminent scholar in the field of solid state spectroscopy and an ECS Fellow, who passed away on January 17, 2008. We remember Bill as a flamboyant character who enjoyed life, a life in which research was the main part. He always started a lecture with a joke, and everybody who met him will remember his stories (those who regard him as politically incorrect are wrong: Bill was politically unconcerned). Flamboyant is also the proper attribute to Bill's scientific work: always on the lookout for new avenues, novel experimental techniques, and challenging problems.

William M. Yen, was born in Nanjing, China, on April 5, 1935, and grew up in Mexico City where his father was a diplomat with the Chinese government. In 1947 the family moved back to China, only to leave mainland China for Taiwan in 1948. At age 16 Bill moved to Redlands, California where he finished high school.

Bill received his Bachelor of Science degree from the University of Redlands in 1956 and his PhD from Washington University-St. Louis in 1962. He joined Nobel Laureate Arthur Schawlow's group at Stanford University in 1961 for postdoctoral research. In 1965 he took a position on the faculty of the University of Wisconsin-Madison. In 1986 Dr. Yen was hired to fill the first Graham Perdue Chair of Physics position at the University of Georgia.

Bill published 280 research papers and supervised over 31 graduate students and numerous postdoctoral fellows, his awards include a Humboldt Senior Scientist award, a Guggenheim Foundation Fellowship, and Fulbright Senior Scholar award.

The articles in the proceedings volume give an (incomplete) overview of the areas in which Bill left his mark. Often, talks in a memorial session are reminiscent in nature. Here we take a different approach: we celebrate Bill's legacy by presenting the current state of the science, because Bill never looked back.

David Linden 1923-2009

DAVID LINDEN of Little Silver, New Jersey, died September 15, 2009 at age 85 after a long illness. He was a consulting engineer and was associated with battery research, development, and engineering for over 60 years. He joined ECS in 1958. From 1942 to 1978 he was associated with the Power Sources Division,

U.S. Army Electronic R&D Command, Fort Monmouth, NJ, serving as Director of the Division for the last nine of those years. For the next 25 years, he was a consultant with Duracell Inc. During WWII he served in the U.S. Navy.

Mr. Linden served on and chaired many committees and advisory groups responsible for coordinating government-wide battery and fuel cell development and battery performance and safety standards. He received numerous professional awards for his contributions.

Mr. Linden was the editor of two editions of the *Handbook* of *Batteries* published by McGraw-Hill and co-edited the Third Edition (2001) with Thomas B. Reddy. This work is recognized as the authoritative reference work on battery technology and the Fourth Edition, which is in preparation, will be published as *Linden's Handbook of Batteries* and is being edited by Dr. Reddy. Mr. Linden was also the author of numerous papers and articles in reference books and professional journals.

In 1947, Mr. Linden organized, and chaired until 1978, the Power Sources Symposium, an international conference devoted to battery, fuel cell, and related technologies and sponsored by U.S. government agencies.

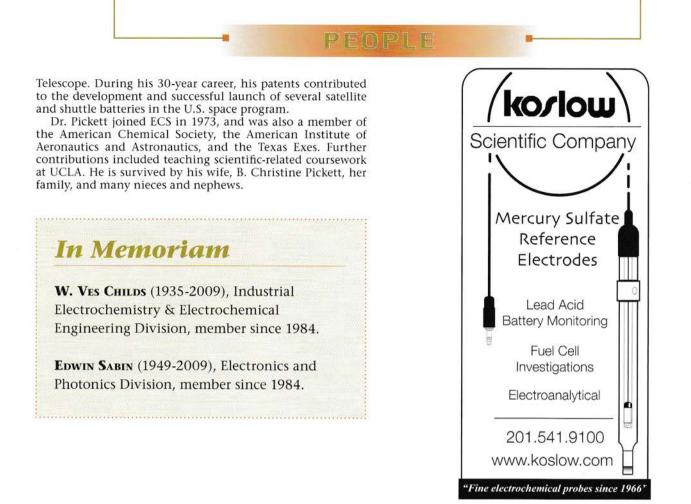
Mr. Linden received a BS degree in chemistry from the College of City of New York and an MS degree in chemistry from the Polytechnic Institute of Brooklyn. He was a member of the American Chemical Society.

David Franklin Pickett, Jr. 1936-2009

DAVID FRANKLIN PICKETT, JR., sprung from a humble birth on May 3, 1936, in Benjamin, Texas, to become a *bon vivant* and the toast of Corpus Christi, Texas. He was the son of the late David F. Pickett, Sr. and the late Dorothy "Dottie" Britton Pickett. After heroic service with the U.S. Navy (1956 to 1961), Dr. Pickett enrolled in an undergraduate program at the University of Texas in Austin. He Upon completion of his education, he began his working career at Wright -Patterson Air Force Base in Dayton, Ohio. He worked in the Air Force Aero Propulsion Laboratory and received the S.D. Heron Award for Exceptional Scientific Achievement in the Advancement of Aerospace Battery Technology in 1974. For several years, Dr. Pickett was listed in the "Who's Who in America."

Dr. Pickett was an internationally recognized independent consultant (AAAA Energy Enterprises Inc.) specializing in aerospace rechargeable batteries. While a scientist with the USAF at WPAFB, he invented the alcohol electrochemical impregnation process for the manufacture of nickel plated for rechargeable alkaline batteries (US Patent 3,827,911 - 1974). He joined Hughes S&CG in 1978 in order to integrate that technology into the recently developed Hughes Ni-H2 battery product. At Hughes, he became manager of the battery product area and was responsible for the establishment of the cell and battery manufacturing facility in Torrance, CA. While at Hughes, he participated in the development of the electric race car, the Sun Race, which won the race across Australia. After leaving HSC, he entered into a consulting career working with Eagle-Picher Technologies, Colorado Springs, and several other national and international battery developers and users.

In May, Dr. Pickett was invited by NASA to witness the space shuttle Atlantis' STS-125 mission to repair the Hubble Space



The Florida Solar Energy Center/University of Central Florida presents the 2010 SHORT COURSE in FUEL CELL TECHNOLOGY

February 7 - 11, 2010 Cocoa. Florida

Sponsored by: Scribner Associates, Inc. and ECS.

This popular course covers both basic and applied aspects of fuel cell technology through integrated lecture and laboratory sessions with a focus on polymer electrolyte and direct methanol fuel cells.

Lectures present the theory of fuel cell operation and outline the principles behind state-of-the-art diagnostic techniques.

This course is suitable for scientists and engineers working in or entering the fuel cell industry, employees of industries that have recently invested or plan to invest in fuel cell technology, and science and engineering graduate students desiring an understanding of fuel cell technology. It is also aimed at science and engineering faculty whose expertise lie in other fields and are looking to enter the field of fuel cells.



The course will be valuable to people who wish to acquire a quick working knowledge of fuel cells and utilize this information in their work. No prior knowledge of electrochemistry or fuel cell technology is required for participation. A B.S. degree in a science or engineering discipline is desirable but not required.

For details on course agenda, fees, instructors and other information: www.fsec.ucf.edu/go/fuelcellcourse







• TECH HIGHLIGHTS

Characteristics of Gadolinium Oxide Nanocrystal Memory with Optimized Rapid Thermal Annealing

The implementation of nanocrystalline into materials real-world device applications has taken a step forward with the recent discoveries of enhanced nonvolatile memory (NVM) characteristics of gadolinium oxide (Gd₂O₃) nanocrystals embedded within an amorphous Gd₂O₃ environment. Because of its large dielectric constant, Gd₂O₃ has been proposed to replace silicon dioxide in a variety of semiconductor devices applications. However, its use in NVM may show the most promise since amorphous Gd₂O₃ possesses a larger bandgap than its corresponding crystalline form. Thus, a Gd₂O₃ nanocrystal embedded within an amorphous Gd₂O₃ matrix can behave as a node for the storage of charge carriers within an NVM architecture. By exploring the annealing temperature that creates nanocrystals within amorphous environments, scientists from Chang-Gung University, National Cheng-Kung University, and Chung-Shan Institute of Science and Technology in Taiwan were able to optimize both the nanocrystal density and the capacitance-voltage (C-V) hysteresis window while minimizing the charge loss within the NVM. The observed nanocrystal densities, program/erase cycling tolerances, and extended memory window help inform the future progress of nanostructured Gd₂O₃ composites in memory device applications.

From: Electrochem. Solid-State Lett., 12, H202 (2009).

High-Capacity, Microporous Cu₆Sn₅-Sn Anodes for Li-Ion Batteries

The drive for higher volumetric and gravimetric energy densities for lithium ion batteries requires an alternative anode. The challenge with alternative anodes as a replacement for graphitic carbon is the large volume change upon charging and discharging, resulting in cell failure. Researchers at Argonne National Laboratory have developed a porous electrode structure, akin to the nickel current collector for the Na/NiCl₂ ("zebra") cells, to manage this volume change. The electrode fabrication consists of two separate electrochemical depositions. The first deposition produces the copper foam, which serves as the current collector, and the second deposition forms the active material. There is a sintering step between depositions and the final product is annealed to form the Cu6Sn5-Sn active material. Electrochemical testing with a lithium counter electrode shows a reversible capacity greater than 600 mAh/g for 30 cycles, followed by an onset of declining capacity. The authors identified possible causes for this capacity fade, including passive film formation, physical separation of active

material from current collector, and formation of inactive phases. This unoptimized electrode which incorporates a mechanically robust porous current collector is a promising alternative to a graphite anode on copper foil for lithium ion batteries.

From: J. Electrochem. Soc., 156, A385 (2009).

High-Performance Flexible Miniature Fuel Cell

Miniaturized fuel cells are the subject of research and development for possible applications in a variety of portable electronic devices. There are a number of approaches to miniaturization of polymer electrolyte fuel cells including several developed by researchers at the University of Minnesota's Corrosion Research Center. Here, Smyrl et al. have reported in past years on miniaturized fuel cells fabricated from silicon as well as others based on the use of anodized aluminum as a support material. In this publication, the Smyrl group describes design and fabrication of a flexible fuel cell manufactured with low-cost, readily available materials. They used a Nafion® catalyst membrane, Toray® carbon paper, gold-plated copper mesh, Parafilm[®], and overhead transparency sheets to fabricate a small (approximately 3 cm x 3 cm) fuel cell with a total material cost of about 7 U.S. dollars. The performance of the fuel cell was quite reproducible and very good, with maximum power densities as high as 57 mW/cm² at 0.35 V observed. The researchers conclude that this simple, flexible fuel cell can serve as an excellent laboratory vehicle to rapidly and effectively evaluate membranes. electrode catalysts, and other fuel cell components.

From: Electrochem. Solid-State Lett., 12, B86 (2009).

Effect of LiCoO₂ Cathode Nanoparticle Size on High-Rate Performance for Li-lon Batteries

Because of its high energy density, LiCoO₂ has been used extensively as a cathode material in commercial Li-ion batteries; however, these batteries traditionally have demonstrated a low power density due to extensive polarization at high currents. NanostructuredLiCoO₂electrodesexhibit both high power density and high energy density, primarily because the reduced dimension of LiCoO₂ nanoparticles results in shorter lithium-ion diffusion lengths and times. In an effort to quantify the relationship between nanoparticle size and high-rate performance, researchers in Korea studied 50 nm, 100 nm, 300 nm, and 1 µm LiCoO₂ nanoparticles, produced by annealing hydrothermallyprepared, oleylamine-capped 50 nm LiCoO₂ particles at 500°C, 700°C, and 900°C, respectively. While the smaller nanoparticles have shortened intraparticle lithium-ion diffusion lengths,

TEM images show that lithium ions must diffuse through a thicker solid electrolyte interphase (SEI) as the relative surface area of the particle is increased. LiCoO₂ particles of each size were assembled into separate electrodes and cycled at 2C, 4C, and 7C discharge rates. The authors report that the cathode utilizing 300 nm LiCoO₂ nanoparticles possessed the greatest high-rate discharge capacity and capacity retention—indicating that the 300 nm LiCoO₂ nanoparticle size was the most favorable compromise between particle size and SEI thickness.

From: J. Electrochem. Soc., 156, A430 (2009).

Relation Between the Semiconducting Properties of a Passive Film and Reduction Reaction Rates

The passive films formed on a commercial Ni-Cr-Mo-W engineering alloy, Alloy C22, and pure chromium were compared using a variety of electrochemical techniques in order to investigate relationships between the semiconducting properties of the oxide and the cathodic reaction rates, which could be supported as a function of applied potential. Mott-Schottky analyses of measured electrochemical impedance spectra were used to probe the semiconducting nature of the oxide films on both metals. The oxide lavers for both alloy C22 and pure chromium were found to be n-type semiconductors, and consequently, polarization of the materials to potentials more positive than each oxide's flatband potential resulted in the measurement of a negligible cathodic current density. Once polarized below the flatband potential, the measured cathodic current density increased sharply. At a given potential, larger currents were observed for allov C22 than for pure chromium, attributed to the more negative flatband potential of the pure metal. The flatband potentials measured via cathodic polarization were compared to a series of literature-based calculations, and found to agree most closely with those of Brug (1984). Based upon these results, it was concluded that for materials with an n-type semiconducting passive film, cathodic polarization represents a reliable method to corroborate the carrier identity and assess the accuracy of the calculated flatband potential.

From: J. Electrochem. Soc., 156, C154 (2009).

Tech Highlights was prepared by Aron Newman of Physical Sciences, Inc., David Enos and Mike Kelly of Sandia National Laboratories, Craig Walker of Valence Technology, Inc., James Dickerson of Vanderbilt University, and Donald Pile.

Increasing Efficiency with Conventional Fuels

by Eric D. Wachsman

S ir William Grove has been credited with inventing the fuel cell in 1839. That fuel cell, as with the majority of fuel cells developed since then, focused on the use of hydrogen as a fuel. As such, fuel cell technology has become synonymous with hydrogen technology in the public perception. As a result of this perception, the funding and advancement of fuel cell technology has risen and fallen with the popularity of a hydrogen-based economy replacing our current fossil fuel dependence.

However, the invention of the Nernst Glower later that century opened up the ability to consider fuels other than hydrogen. This discovery demonstrated that at high temperatures, oxygen-ions could be transported through a ceramic solid at rates comparable to hydrogenions in other (*e.g.*, acid and polymer) electrolytes at lower temperatures.

Solid oxide fuel cells (SOFCs) utilize the same basic high temperature oxygen-ion conducting ceramic for the electrolyte that Nernst used in his glower. This difference in conducting species allows for the potential use of almost any hydrocarbon fuel, since the oxygen-ion not only oxidizes hydrogen to H_2O , but can also oxidize carbon to CO_2 .

Therefore, while SOFCs can also operate on hydrogen, their fuel flexibility makes them attractive for numerous applications that require currently available fuels. Moreover, the inherent high efficiency of SOFCs provides the opportunity to produce more work with less greenhouse gas (CO₂) emissions than conventional technologies (*e.g.*, the Carnot limited internal combustion engine). Because of this the development and use of SOFCs for stationary and portable applications continues to grow.

Three articles in this issue of *Interface* explore some of the advancements and issues for SOFCs. The need for new materials, fabrication processes, and design and testing of

cell and stack components is summarized in the article "Solid Oxide Fuel Cell Commercialization, Research, and Challenges." Advancements in stationary applications are summarized in "The Role of Solid Oxide Fuel Cells in Advanced Hybrid Power Systems of the Future." In addition, advances toward portable applications are summarized in "Toward the Miniaturization of Solid Oxide Fuel Cells."

Finally, the growth of interest in SOFCs is reflected in the large and rapid growth of attendance in the ECS SOFC symposia. This symposium, first organized by Subhash Singhal in 1989 with the "First International Symposia on Solid Oxide Fuel Cells," has grown to be one of the largest symposia at ECS. The most recent symposium in Vienna, SOFC XI, has attracted almost 400 papers and has made this symposia *THE* place to be for anyone interested in the science and technology of SOFCs.

About the Author

ERIC D. WACHSMAN is the past Chair of the High Temperature Materials Division, Director of the University of Maryland Energy Research Center, and the William L. Crentz Centennial Chair in Energy Research at the University of Maryland (UMD). Prior to his recent move to UMD, Dr. Wachsman was the Director of the Florida Institute for Sustainable Energy at the University of Florida. Dr. Wachsman's research interests are in ionic and electronic conducting ceramics, from fundamental investigations of their transport properties and heterogeneous electrocatalytic activity, to the development of moderate temperature solid oxide fuel cells (SOFC), gas separation membranes, and solid state sensors. He is an ECS Fellow and Editor-in-Chief of *Ionics*. He may be reached at www.umerc.umd.edu.

Solid Oxide Fuel Cell Commercialization, Research, and Challenges

by Eric D. Wachsman and Subhash C. Singhal

orld wide interest in solid oxide fuel cells (SOFCs) has increased dramatically over the last ~20 years as indicated in part by the tremendous growth in attendance at the International Symposium on Solid Oxide Fuel Cells (see sidebar on page 43).

In the United States, the U.S. Department of Energy's (DOE) Office of Fossil Energy's (FE) National Energy Technology Laboratory (NETL), in partnership with private industry, educational institutions, and national laboratories, is leading the research, development, and demonstration of high efficiency, fuel flexible SOFCs and coal-based SOFC power generation systems for stationary market large central power plants.¹ This Fuel Cell Program has three focus areas under the Solid State Energy Conversion Alliance (SECA): cost reduction, coal-based systems, and research and development. The SECA cost reduction goal is to have SOFC stacks capable of being manufactured at \$170 per kilowatt (2007 basis) by 2010. Concurrently, the scale-up, aggregation, and integration of the technology will progress in parallel leading to prototype validation of megawatt (MW)-class fuel flexible products by 2015. The SECA coal-based systems goal is the development of large (greater than 100 MW) integrated gasification fuel cell power systems. Under this program, in February 2009, two fuel cell stacks (around 10 kWs each), developed by FuelCell Energy Inc. in partnership with Versa Power Systems achieved 5,000 hours of service. The stacks also exhibited an overall degradation of only 1.7 percent and 2.6 percent per 1,000 hours. Siemens' stack also surpassed 5,000 hours in April 2009. Another SECA Industry Team, Delphi, and the U.S. Navy, have made noteworthy development progress in early markets for truck auxiliary power units (APUs) and proof-of-concept for unmanned undersea vehicles (UUVs), respectively.

Using tubular (cylindrical) SOFCs, Siemens fabricated a 100 kW system for distributed power generation.^{2,3} This system has now operated for over four years in USA, The Netherlands, Germany, and Italy without any detectable performance degradation. It has provided up to 108 kW of ac electricity at an efficiency of 46%. Siemens tubular cells have also been used to fabricate and field test over a dozen 5 kW size CHP units, each about the size of a refrigerator. These units gave excellent performance and performance stability on a variety of hydrocarbon fuels. However, at present, their cost is high; future such units are expected to use higher power density alternate tubular geometry cells to drive down the cost.

Several hundred 1 kW size combined heat and power (CHP) units for residential applications were field tested by Sulzer Hexis of Switzerland; however, their cost and performance degradation was high and stack lifetime too short. With improved sealing materials and sealing concepts, planar SOFC prototype systems in the 1 to 5 kW sizes have recently been developed. Significant progress has now been made in producing and field testing about 1 kW size SOFC-based CHP (combined heat and power) systems for residential applications. In Japan, over 50 such prototype systems have been installed in homes to provide electricity and hot water and collect performance data for eventual commercialization within about a year. A photograph of one such unit is shown in Fig. 1. These systems are being built by Tokyo Gas, Osaka Gas, and Eneos in Japan using SOFCs produced by Kyocera Inc. The systems operate on natural gas and provide an electric conversion efficiency of about 45-50%.

Similar CHP systems are also being produced and field tested in Australia, New Zealand, and Europe by Ceramic Fuel Cells, Ltd. of Australia. Both the Japanese and the Australian CHP systems use SOFCs based on the conventional yttria-stabilized zirconia electrolyte and operate at about 750-800°C. On the other hand, Ceres Power Ltd. of UK is developing SOFCs based on a ceria-based electrolyte for operation at 550-600°C for use in wall-mountable residential CHP systems, also of about 1 kW size.

Another application of SOFC systems is in the transportation sector. The polymer electrolyte membrane (PEM) fuel cell is generally regarded as the fuel cell of choice for transportation applications. PEM fuel cells require pure H_2 , with no CO, as the fuel to operate successfully. However, presently no H₂ infrastructure exists, and on-board reformer systems to produce H₂ from existing fuel base (gasoline, diesel) are technically challenging, complex, and expensive. Furthermore, it is difficult to eliminate the CO entirely from the reformate stream. In contrast, SOFCs can use CO along with H₂ as fuel, and their higher operating temperature and availability of water on the anode side makes on-cell or in-stack reformation of hydrocarbon fuels feasible. Also,



Fig. 1. SOFC-based residential CHP system showing the SOFC unit (left) and the hot water tank (right).

no noble metal catalysts are used in SOFCs reducing cost of the cells. The initial application of SOFCs in the transportation sector will be for onboard auxiliary power units (APUs). Such APUs, operating on existing fuel base, will supply the ever increasing electrical power demands of luxury automobiles, recreational vehicles, and heavy-duty trucks. Delphi Corporation has developed a 5 kW APU using anodesupported planar SOFCs.⁴ This unit is intended to operate on gasoline or diesel, which is reformed through catalytic partial oxidation. The building blocks of such an APU consist of an SOFC stack, fuel reformation system, waste energy recovery system, thermal management system, process air supply system, control system, and power electronics and energy storage (battery) system. One of the most opportunistic applications for the SOFC is in APUs for transport trucks. This allows the drivers to turn the truck engines off while they're sleeping and use the much more efficient fuel cell APU to deliver power for environmental control of the driver's cab. There is an estimated 200,000 trucks per year that are produced that would need these APUs, which provides an attractive commercialization route for these fuel cells. By limiting idling time and running a SOFC instead of the main engine, emissions are reduced, noise is nearly eliminated, and operators realize significant fuel savings. The SOFC also has the capability of using a variety of fuels, including natural gas, diesel, bio-diesel, propane, gasoline, coal-derived fuel, and military logistics fuel. In 2008, Delphi Corporation and Peterbilt Motors Company successfully demonstrated a Delphi SOFC APU powering a Peterbilt Model 386 truck's "hotel" loads on diesel. During testing at Peterbilt's Texas headquarters, the Delphi SOFC provided power for the Model 386's electrical system and air conditioning and maintained the truck's batteries-all while the Model 386's diesel engine was turned off.

Residential CHP systems will, in all likelihood, be the first commercial products based on solid oxide fuel cells. Technological spinoffs of SOFCs into a variety of other applications areas, especially APUs, will add to market penetration, increase manufacturing production volume, and lower SOFC cost.

SOFC Research Challenges

The challenges for the fuel cell community are to reduce cost and increase reliability. These challenges extend from the cell itself, to the stack interconnect and seals, to the balance of plant.

There has been a tremendous effort to lower the operating temperature of SOFCs from ~1000°C to \leq 800°C, for cost and reliability considerations. Simultaneously there has been an even larger effort to increase the operating temperature of PEM fuel cells above 100°C, for performance and fuel poisoning considerations. Somewhere in between is the optimum operating temperature for a fuel cell, depending on fuel choice and degree of external fuel processing (vs. relying exclusively on internal reforming).

While there has been some success at developing high-temperature PEM fuel cells operating at temperatures around 140°C, the power densities and fuel flexibility of these systems are limited. Moreover, there is significant concern that the hydrogen infrastructure necessary for PEMFCs will make this a future technology with limited market penetration.

In contrast, SOFCs can operate on both current conventional fuels (*e.g.*, natural gas, gasoline, and diesel) and biofuels (biogas, ethanol, and biodiesel). As such, SOFCs offer great promise as a clean and efficient process for directly converting chemical energy to electricity while providing significant environmental benefits (they produce negligible CO, HC, or NO, and, as a result of their high efficiency, produce about one-third less CO, per kWh than internal combustion engines). Moreover, SOFC operation on biofuels is the most energy efficient means to utilize home grown carbon neutral fuels.

Unfortunately, current SOFC technology must operate in the region of ~800°C to avoid unacceptably high polarization losses. These high temperatures demand specialized (expensive) materials for the fuel cell interconnects and insulation; and significant time and energy to heat up to the operating temperature. Therefore, development of SOFCs to provide reasonable power output at lower temperatures would make SOFCs both more cost competitive with conventional technology, and significantly reduce start-up times which is critical to transportation and portable power applications.

Development of Anode Supported Cells

One of the biggest breakthroughs in lowering the SOFC operating temperature, while maintaining high power densities, was the development of anode supported cells. Techniques such as tape calendering⁵ and colloidal deposition⁶ allowed for the fabrication of anode supported thin (~10 μ m) electrolytes. An SEM cross section of a typical anode supported SOFC is shown in Fig. 2. With the advent of this technology the major polarization loss transitioned from the electrolyte to the cathode. This can be seen in Fig. 3 which shows the relative polarization losses in a typical anode supported SOFC.

Deconvolution of Cathode Polarization

Because of the dominance of cathode polarization, the recent major SOFC research emphasis has been on developing higher performance cathodes. Over the last several years, cathodes have progressed from p-type electronically conducting lanthanum manganate based (*e.g.*, $La_{1-x}Sr_xMnO_{3-\delta}$ - LSM) to composites of LSM with the electrolyte (yttria stabilized zirconia - YSZ) to both add ionic conduction and increase the triple phase boundary region (where the oxygen reduction

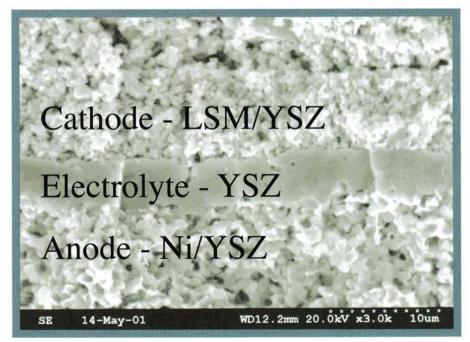


FIG. 2. Cross sectional SEM image of typical SOFC (Ref. 7).

Wachsman and Singhal

(continued from previous page)

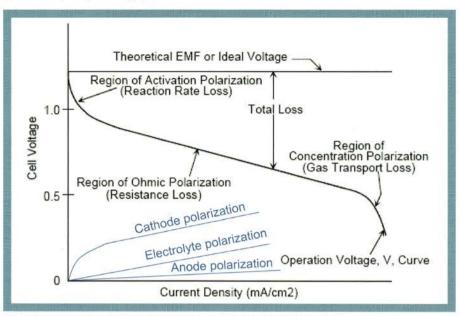


FIG. 3. SOFC current-voltage behavior indicating relative polarization losses.

reaction occurs); to the use of mixed ionic-electronic conducting oxide such as $La_{1-x}Sr_xCo_{1-y}Fe_yO_{3-\delta}$ (LSCF). More recently, impregnation techniques were employed to reduce the activation over-potential by depositing nano-dimensional catalyst in the cathode structure (see figure 4).⁸ The combination of these high performance cathodes with anode supported cell technology has resulted in power densities on the order of ~1W/cm² at 800°C.^{6,7}

These increases in cell performance, while impressive, have been to a large part Edisonian in nature. The fact is that the cathode process is extremely complex with multiple potential series and parallel mechanistic steps. An example of this is shown in Fig. 5 for the simple case of O2 reduction at a Pt/YSZ interface.9 In order to rationally design higher performance cathodes, a more fundamental understanding is necessary, and this requires the deconvolution and quantification of the various contributions to cathode polarization: electrocatalytic reduction (activation polarization), ionic and electronic conduction (ohmic polarization), and diffusion gas (concentration polarization).

The first important step is to quantify the effect of structure. Several groups

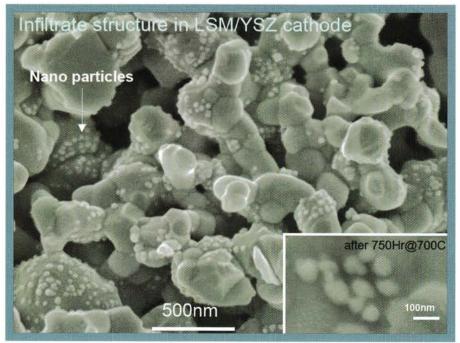


FIG. 4. SEM image of infiltrated cathode (Ref. 8).

have approached this by measuring the impedance of well-defined (circular or square) micro-electrodes.¹⁰ However, more recently analytic techniques have been developed with the ability to quantify the structure of cathodes with actual/real random structures. Using a focused ion beam (FIB)/SEM the 3D salient cathode features were quantified and directly related to electrochemical performance.¹¹⁻¹³

Figure 6 shows a FIB/SEM 3D reconstruction of a Siemens SOFC cathode, obtained from a series of sequential SEM images. Phase contrasting allows for identification of each phase: cathode (blue), electrolyte (orange), and pore (transparent). This allows for quantification of the critical microstructural parameters necessary to determine the sources of cathode polarization.

By quantifying phase boundaries we can calculate the triple phase boundary length (L_{TPB}) and surface area (S_v). These are the features where the oxygen reduction reaction occurs, and thus are the critical parameters for understanding activation polarization. Figure 7 shows the direct relationship between L_{TPB} and the charge transfer polarization, from impedance spectroscopy of LSM on YSZ.

With a quantified microstructure we can start to determine the fundamental reactions that occur at each feature of the microstructure. Independent measurement of the reaction rates of cathodematerialsbycatalytictechniques. e.g., O-isotope exchange,^{14,15} provide the necessary mechanistic information. integrating Bv measurements of fundamental rate constants, with quantified microstructures of the measured materials, and comparing to electrochemical measurements, a fundamental and rational based approach to cathode development can provide the framework for further reductions in cathode polarization and thus SOFC operating temperature.

Higher Conductivity Electrolytes

If cathode polarization is no longer the major loss in SOFC performance, then the ohmic contribution of the electrolyte will once again dominate. The problem is, the conductivity of the conventional YSZ electrolyte is insufficient at lower temperatures, even for a thin (~10 µm) electrolyte. Higher conductivity, alternative electrolytes will become necessary. Figure 8 compares the conductivity of YSZ with alternatives such as ceria and bismuth oxide based electrolytes.

Gadolinia doped ceria (GDC) has probably received the most attention as a lower temperature electrolyte due to its high conductivity,¹⁶ and recently an even more conductive ceria based

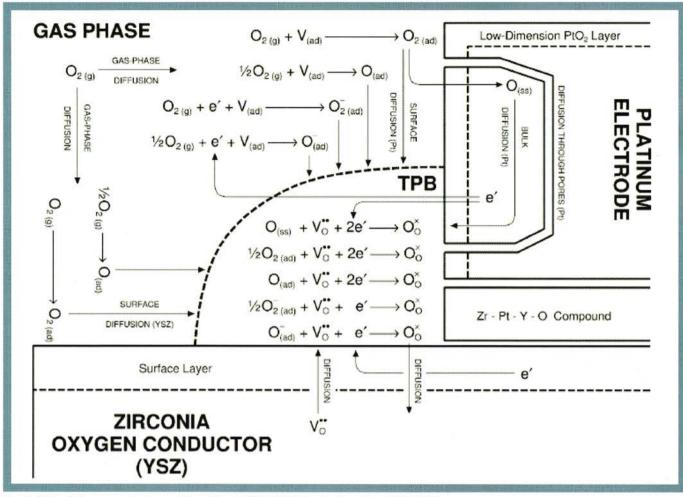


Fig. 5. Mechanistic oxygen reduction reaction at simple air/Pt/YSZ triple phase boundary (TPB) (Ref. 9).

electrolyte, samarium-neodymium doped ceria (SNDC) was developed.^{17,18} However, the highest conductivities have been obtained with bismuth oxide based electrolytes, such as erbia stabilized bismuth oxide (ESB),¹⁹ and recently a dysprosium-tungsten stabilized bismuth oxide (DWSB) was developed with even higher conductivity.^{20,21} At 500°C, the conductivity of SNDC is 20X that of YSZ, and the conductivity of DWSB is 100X that of YSZ; thus creating the opportunity for high power density low temperature SOFCs.

Unfortunately, high oxygen mobility is a result of weak metal-oxygen bonds, and thus these materials have lower stability under the low P_{02} at the anode (fuel side) resulting in mixed electronicionic conduction in CeO₂ electrolytes and decomposition to metallic Bi for Bi₂O₃ electrolytes. Addressing this issue is critical to future acceptance of these alternative electrolytes in practical SOFCs. Moreover, the use of a new electrolyte creates the need, and provides the opportunity, for a new compatible material set (cathode, anode, interconnect, etc.).

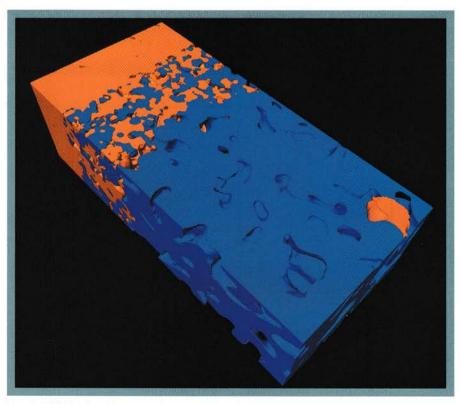


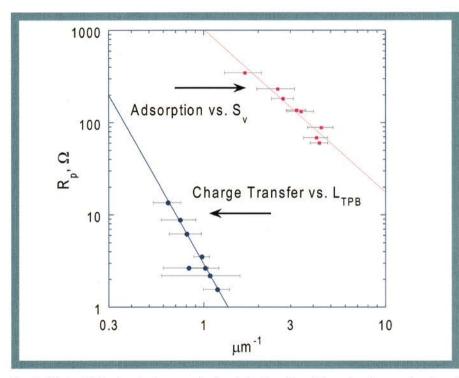
FIG. 6. FIB/SEM three dimensional reconstruction of SOFC cathode (Ref. 12).

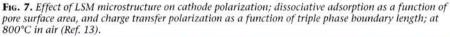
Wachsman and Singhal

(continued from previous page)

About the Authors

ERIC D. WACHSMAN is the past Chair of the High Temperature Materials Division, Director of the University of Maryland Energy Research Center, and the William L. Crentz Centennial Chair in Energy Research at the University of Maryland (UMD). Prior to his recent move to UMD, Dr. Wachsman was the Director of the Florida Institute for Sustainable Energy at the University of Florida. Dr. Wachsman's research interests are in ionic and electronic conducting ceramics, from fundamental investigations of their transport properties and heterogeneous electrocatalytic activity, to the development of moderate temperature solid oxide fuel cells (SOFC), gas separation membranes, and solid state sensors. He is an ECS Fellow and Editorin-Chief of *Ionics*. He may be reached at ewach@umd.edu.





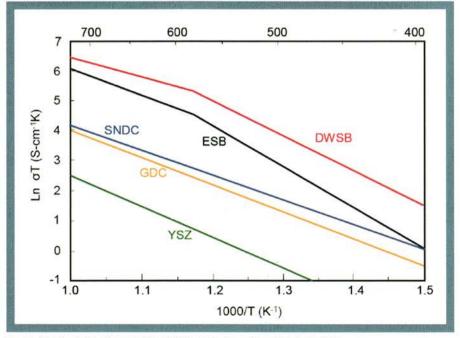


Fig. 8. Conductivity of conventional, YSZ, and alternative oxide electrolytes.

SUBHASH C. SINGHAL is a Battelle Fellow and Director of Fuel Cells at the Pacific Northwest National Laboratory (operated by Battelle for the U.S. Department of Energy), Richland, Washington. Prior to joining his present position in April 2000, he was manager of Fuel Cell Technology at the Siemens Westinghouse Power Corporation in Pittsburgh, Pennsylvania, for over 28 years. His research interests are in high temperature materials and advanced energy conversion systems. particularly solid oxide fuel cells. He is a member of the National Academy of Engineering and a Fellow of ECS, the American Ceramics Society, ASM International, and the American Association for the Advancement of Science. He has won several awards related to fuel cell technology including the Grove Medal, the Christian Friedrich Schoenbein Medal, and the Fuel Cell Seminar Award. He may be reached at singhal@pnl.gov.

References

- 1. W. A. Surdoval, "The Status of SOFC Programs in USA 2009," ECS Transactions, **25**, 2 (2009), in press.
- S C. Singhal, The Electrochemical Society Interface, 16(4), 24 (2007).
- M. C. Williams, J. P. Strakey, and S. C. Singhal, *J. Power Sources*, **131**, 79 (2004).
- 4. S. Mukerjee., K. Haltiner, *et al.*, *ECS Transactions*, **7**(1), 59 (2007).
- N. Q. Minh, et al., in Third International Symposium on Solid Oxide Fuel Cells, S. C. Singhal and H. Iwahara, Editors, PV 93-4, p. 801, The Electrochemical Society Proceedings Series, Pennington, NJ (1993).
- S. de Souza, S. J. Visco, and L. C. De Jonghe, *J. Electrochem. Soc.*, **144**, L35 (1997).
- J-W. Kim, A. V. Virkar, K-Z. Fung, K. Mehta, and S. C. Singhal, J. Electrochem. Soc., **146**, 69 (1999).
- K. Yamahara, C. P. Jacobson, S. J. Visco, X. F. Zhang, L. C. De Jonghe, Solid State Ionics, 176, 275 (2005).
- 9. J. Nowotny, et al., "Charge Transfer at Oxygen/Zirconia Interface at Elevated Temperature," Advances in Applied Ceramics, **104**, 154 (2005).
- 10. J. Fleig, Solid State Ionics, **161**, 279 (2003).
- D. Gostovic, J. R. Smith, K. S. Jones, and E. D. Wachsman, *Electrochem. Solid-State Lett.*, **10**, B214 (2007).
- 12. D. Gostovic, N. J. Vito, K. A. O'Hara, K.S. Jones, and E. D. Wachsman, "Microstructure and Connectivity Quantification of Complex Composite Electrode Three-Dimensional Networks," J. Am. Cer. Soc., submitted.
- J. R. Smith, A. Chen, D. Gostovic, D. Hickey, D. Kundinger, K. L. Duncan, R. T. DeHoff, K. S. Jones, and E. D. Wachsman, *Solid State Ionics*, **180**, 90 (2009).

- C. C. Kan, H. H. Kan, F. M. Van Assche, E. N. Armstrong, and E. D. Wachsman, J. Electrochem. Soc., 155, B985 (2008).
- 15. C. C. Kan and E. D. Wachsman, J. Electrochem. Soc., **156**, B695 (2009).
- B. C. H. Steele, Solid State Ionics, 129, 95 (2000).
- S. Omar, E. D. Wachsman, and J. C. Nino, *Solid State Ionics*, **178**, 1890 (2008).
- S. Omar, E. D. Wachsman, and J. C. Nino, *Appl. Phys. Lett.*, **91**, 1444106 (2007).
- M. J. Verkerk and A. J. Burggraaf, Solid State Ionics, 3-4, 463 (1981).
- N. Jiang, E. D. Wachsman, and S. H. Jung, *Solid State Ionics*, **150**, 347 (2002).
- 21. S. H. Jung, E. D. Wachsman, and N. Jiang, *Ionics*, **8**, 210 (2002).

International Symposium on Solid Oxide Fuel Cells

This continuing symposium series provides an international forum for the presentation and discussion of developments related to solid oxide fuel cells based on zirconia or another oxide electrolyte. Topics addressed include materials for cell components. (*e.g.*, electrolyte, electrodes, and interconnections); fabrication methods for complete cells and components; cell design, electrochemical performance and modeling; stacks and systems for residential and automotive applications; and field tests of SOFC demonstration systems.

This symposium series started in 1989 at the ECS fall meeting in Hollywood, Florida, and has since become the leading symposium in the field of solid oxide fuel cells. The symposium is held every two years, rotated among the U.S., Europe, and Japan, and is co-sponsored by the SOFC Society of Japan. S. C. Singhal has been the lead symposium organizer since its inception.

The eleventh symposium in this series (SOFC XI) is being held at the **216th ECS meeting in Vienna**, **Austria**, **October 4-9**, **2009**. At this symposium, 375 papers, a record number, covering all aspects of solid oxide fuel cells will be presented.





Interface is an authoritative yet accessible publication. With new ideas and products emerging at an overwhelmingly rapid pace—your product or service can stand out in a publication that will be read by over 9,000 targeted readers world-wide.

Your advertisement will be read by those hard-to-reach people in the field, actual users and purchasers of computers, both hardware and software; precision instruments, optics, laser technology, and other equipment; materials such as batteries, cells, chemistry, metals, etc.; semiconductor processing equipment; training and travel; outside laboratories; and other publications about computers, materials, and sources.

In today's environment of increasing competition for purchasers of goods and services, few publications can put your message in a more credible, respected editorial environment.



the society for solid-state and electrochemical science and technology

ECS • The Electrochemical Society

65 South Main Street, Bldg. D Pennington, New Jersey 08534-2839 USA

tel: 609.737.1902 • fax: 609.737.2743 interface@electrochem.org

www.electrochem.org

Electrochemical Society

▶ articles published online daily ▶ high impact factor* online backfile to 1948

> he Journal of the Electrochemical Society (JES) is a peerreviewed publication providing today's most authoritative research in solid-state and electrochemical science and technology. Articles are posted online as soon as they become available, with a monthly paper edition following electronic publication. A vear-end CD-ROM is also available.

HIGH QUALITY: In publication for over 60 years, JES bas a history of having the highest total cites by far of journals in the field of electrochemistry, and still holds the top spot today. ECS journals have consistently had impact factors among the top ten publications in the field of electrochemistry, according to the ISI Science Citation Index rankings.*

> ■ WIDE READERSHIP: The readership includes research scientists, engineers, technologists, and graduate students in solid-state and electrochemical science and technology.

To learn more, please contact ECS by calling 609.737.1902, or e-mail jes@electrochem.org, or visit the JES home page: www.ecsdl.org/JES.

*The 2008 impact factor for the Journal was 2.437 and the immediacy index was 0.432.

A Journal for Solid-State and Electrochemical Science and Technology

AREAS OF INTEREST

- Electrochemical Synthesis and Engineering
- Fullerenes, Nanotubes, and Carbon Nanostructures .
- Physical and Analytical Electrochemistry
- Sensors and Displays: Principles, Materials, and Processing
- Nanotechnology

Editor

Daniel A. Scherson Case Western Reserve University Cleveland, OH, USA

JOUP DE Marine Electrochemical

Society

105014V 152 (1)

2005 • Volume 152, Number

JES Editorial Board

Associate Editors Cor Claeys IMEC

Charles L. Hussey University of Mississippi University, Mississippi, USA

Yue Kuo Texas A&M University College Station, Texas, USA **Dolf Landheer** National Research Council, Canada Ottawa, Ontario, Canada

Mark E. Orazem

University of Florida

Gainesville, FL, USA

Ashok K. Shukla Indian Institute of Science Bangalore, India

Martin Winter University of Münster Münster, Germany

Leuven, Belgium

Biomedical Applications and Organic Electrochemistry

Dielectric and Semiconductor Materials, Devices, and Processing

Electrochemical/Chemical Deposition and Etching

D Corrosion, Passivation, and Anodic Films

Batteries, Fuel Cells, and Energy Conversion

Takavuki Homma Waseda University Tokyo, Japan

The Role of Solid Oxide Fuel Cells in Advanced Hybrid Power Systems of the Future

by David Tucker, Michael Shelton, and A. Manivannan

n pursuing the implementation of highly efficient, emission-free power, the U.S. Department of Energy (DOE) is looking to the development of hybrid power systems that make use of the coupling of an electrochemical device with a heat engine, or more specifically, a solid oxide fuel cell (SOFC) and a gas turbine.1-4 The synergies of coupling these systems in a hybrid configuration provide the potential for reaching the highest possible electric conversion efficiency ever realized.5 As such, advanced hybrid power systems that incorporate a fuel cell and a gas turbine represent fossil or renewable energy production technology that provide the opportunity for a significant improvement in generation efficiency.6 An example of a simplified process diagram of the power cycle in a hybrid fuel cell gas turbine is shown in Fig. 1.

While much of the DOE-sponsored research focuses on improving the performance of solid oxide fuel cells, a hardware simulation facility has been built by the Office of Research and Development at the National Energy Technology Laboratory (NETL) to explore both synergies and technical issues associated with integrated hybrid systems. The facility is part of the Hybrid Performance (Hyper) project, and is made available for public research collaboration with universities, industry, and other research institutions. The Hyper facility is capable of simulating high temperature fuel cell systems from 300 kW to 700 kW coupled with a 120 kW turbine. The purpose of the Hyper project is to specifically address this higher risk research by combining the flexibility of numerical simulation with the accuracy of experimental hardware.7 An illustration of the Hyper facility is shown in Fig. 2.

The Hyper facility makes use of pressure vessels and piping to simulate the volume and flow impedance of the cathode and a burner controlled by a real-time fuel cell model running on a dSpace hardware-in-the-loop simulation platform to simulate the fuel cell thermal effluent. The hardware used to simulate the fuel cell is integrated with a 120 kW Garrett Series 85 auxiliary power unit (APU) for turbine and compressor system. The APU consists of single shaft, direct coupled turbine operating at a nominal 40,500 rpm, a two-stage radial compressor, and gear driven synchronous generator. The electrical generator is loaded by an isolated, continuously variable 120 kW resistor

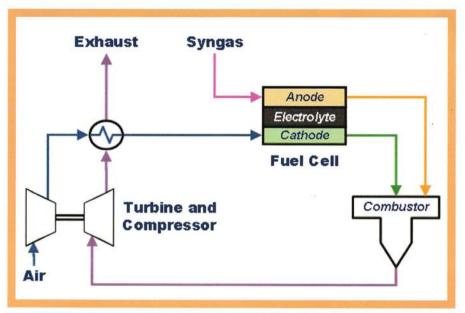


FIG. 1. Simplified flow diagram of a representative direct fired, recuperated fuel cell gas turbine hybrid system.

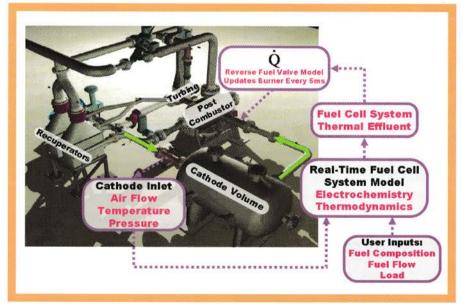


FIG. 2. Illustration of the Hybrid Performance (Hyper) simulation facility at NETL.

load bank. The compressor is designed to deliver approximately 2 kg/s of air at a pressure ratio of about four. The project facility makes use of two counter flow primary surface recuperators with a nominal effectiveness of 89% to preheat the air going into the pressure vessel used to simulate the fuel cell cathode volume.⁸ A more detailed description has been provided previously.^{7.9} A picture of the facility is shown in Fig. 3.

Fuel Cell Model

A real-time computational model is used to simulate the fuel cell portion of the hybrid. The model is used to dynamically calculate the thermal effluent of a stack based upon measured Hyper flow conditions and user set points, and assumes the use of coal syngas as a fuel, as shown in Fig. 4. In

Tucker, et al. (continued from previous page)

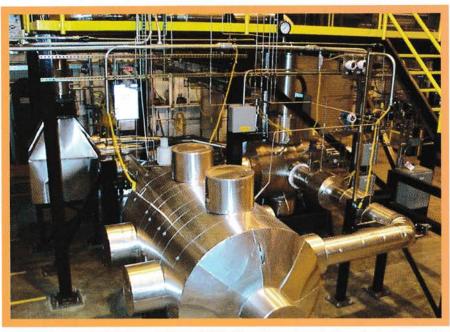


FIG. 3. A photograph of the Hyper facility at NETL (the cathode volume is shown in the foreground).

earlier studies, natural gas was used as a fuel source and was reformed to hydrogen and carbon monoxide before entering the fuel cell. For steady state system mapping studies, the model can be used off-line and driven to a steady condition that matches the corresponding steady state process conditions of the Hyper facility hardware for each valve position and specified turbine load. A more detailed description of the model is published elsewhere.¹⁰

As shown in Fig. 4, the numerically simulated section consists of the planar solid oxide stack, anode recycle, a precombustor, and an anode off gas postcombustor. For previous studies the stack size was fixed and composed of 3225 cells to target a range of electrical power generation varying between 228 kW and 687 kW. Computationally, only a single 20 cm x 20 cm cell is modeled with the inlet and outlet streams scaled by the 3225 factor. The range of fuel cell operating conditions used during the tests is specified in Table I.

To further expand the capabilities of the Hyper facility, a distributed 1D model of a solid oxide fuel cell capable of real-time operation has been developed at the Georgia Institute of Technology and implemented in the Hyper dSpace platform. This facilitates determination of dynamic temperature, species concentrations, and current density profiles along the cell during transient system events. Testing is currently underway to examine system response to fuel cell load changes and

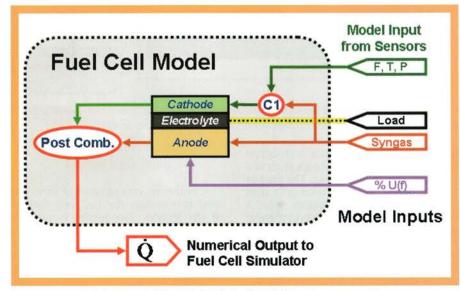


Fig. 4. Diagram of the Hyper facility real-time fuel cell model.

compressor dynamics resulting in fuel cell cathode airflow transients. The results are expected to be useful in developing control strategies to mitigate undesirable or damaging operating conditions.

Synergies

Efficiency.—The most apparent synergy of integrating a fuel cell and a gas turbine is the gain in total system efficiency. Quite simply, using a turbine to recover electricity from the waste heat of the fuel cell system allows for an increase in total system efficiency. The total system electric efficiency is shown by the lines in Fig. 5 for a combination of topping and bottoming cycle efficiencies. For hybrid systems, the fuel cell is generally used as the topping cycle with the turbine in a bottoming configuration, as shown for the direct fired case illustrated in Fig. 1.

However, a hybrid system generally has efficiencies that are greater than the simple sum of its parts (up to 60% HHV of coal). Cathode cooling airflow for thermal management in a solid oxide fuel cell represents a significant parasitic loss to the electrical efficiency in this component. Integration with a gas turbine provides this airflow reduction efficiency. without in The incorporation of exhaust gas recuperators can provide pre-heat for the fuel cell and still further improve the efficiency of the turbine cycle. In a similar fashion, the turbine cycle allows the fuel cell to be operated under pressure, improving fuel cell performance without a parasitic cost.

System Flexibility and Energy Security.— The need for preheating fuel cell cathode cooling flow is facilitated by the integration of a recuperated turbine cycle which operates at low pressure ratios and relatively low turbine inlet temperatures. Such lenient requirements preclude the need for complex turbine technologies such as turbine blade cooling associated with high temperature operation or even inter-stage compressor cooling required for high pressure ratios.

Gasification technologies are driven to more challenging operation at higher pressures by the requirement for a hydrocarbon rich syngas with a higher volumetric energy content for improved efficiencies in standard power cycles found in integrated gasifier combined cycles (IGCC), for example. An SOFC, on the other hand, is capable of achieving excellent performance using hydrogen (H_2) and carbon monoxide (CO) as a fuel source, eliminating the requirement for complicated gasification technology and opening up the possibility of fuel flexible systems operating at high efficiency.

Since high system efficiency can be achieved even if the turbine in the cycle does not produce electricity,

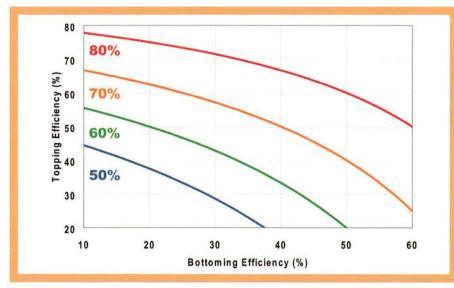


FIG. 5. Total system efficiency as a function of topping and bottoming cycle efficiencies.

there is the possibility of maintaining a low cost spinning power reserve and peaking demand. If the fuel cell is base loaded at a nominal condition without the turbine loaded to its maximum capacity, there exists the potential for handling peak load demands by auxiliary firing of the turbine without a significant reduction in total system efficiency. A spinning reserve could also be maintained without parasitic drain on fuel supplies. If sufficient turndown can be demonstrated, because the fuel cell is an electrochemical device, recovery from a full load reject could be accomplished in a matter of minutes instead of days. In recent studies using the Hyper facility to map fuel cell turbine operating envelopes, a system operating range representing a possible turndown of 69% was demonstrated.¹¹ The implementation of fuel cell turbine hybrid technology could result in more flexible power systems and a significant contribution to energy security in the U.S.

Parameter	Range	Nominal Value
Cell Voltage (V)	0.746 to 0.816	0.746
Load Current (Amps)	90 to 276	220
Stack Power (kW)	228 to 687	529
Stack Fuel Utilization	0.59 to 0.90	0.80
Single Pass Fuel Utilization	0.50	0.50
Stack Efficiency (% HHV)	34 to 44	40.4
Cell Temperature (K)	1,133	1,133
Stack Number of Cells	3,225	3,225
Total Stack Mass (kg)	4,515	4,515
Heat Capacity of Stack (kJ/K)	2,134	2,134
Syngas Fuel to Stack (kW)	534 to 1,631	1,310
Syngas to C1 Combustor (kW)	0 to 288	0

Control of Cathode Airflow.---If such systems are to be realized in stationary power generation in the near future, integration and control technology must be developed and proven. Recent work has shown management of cathode airflow to be critical to fuel cell performance and effective control of hybrid systems.^{12,13} Previous studies at NETL have shown that small transient changes in cathode airflow can have a dramatic effect on system performance.14 The effect of flow perturbation due to compressor dynamics or valve operation was shown to be more significant than fuel cell inlet temperature excursions resulting from load variations.14 It is likely off-design operation of hybrid systems will require careful management of cathode flow.

Compressor Stall and Surge.-The introduction of pressure losses between the compressor and turbine decreases the compressor surge margin and puts the fuel cell at risk for exposure to the pressure dynamics associated with compressor surge. This event represents the greatest risk to the fuel cell in the system because pressure variations are sufficient to damage the turbine and destroy the fuel cell. The use of compressor bleed air during startup was shown to be effective in increasing compressor mass flow and avoiding stall and surge during startup, and a base condition was established for future tests of other control strategies.¹⁵ Currently, the possibility of using the other bypass valves in the Hyper facility to increase surge margin is being examined.

Currently, plans are underway to expand the Hyper facility to include a gasifier capable of utilizing either fossil or renewable fuel sources, as shown in Fig. 6. A recent numerical simulation conducted at the lab showed that capturing the CO2 upstream of the fuel cell anode did not reduce system efficiency as would be expected.16 The energy requirement for steam and CO₂ capture was offset by an increase in fuel cell performance operating on a hydrogen-rich syngas without anode recycle (since carbon deposition is not an issue), and an increase in turbine performance due to elevated turbine inlet temperatures.

About the Authors

DAVID TUCKER is the Project Leader and principal investigator for the Hybrid Performance (Hyper) project at the U.S. Department of Energy, National Energy Technology Laboratory (NETL). Previous to his employment at NETL, Dr. Tucker had a diverse career in academia and industry. His research interests and experience include fuel cell turbine hybrid systems, solid oxide fuel cell cathode development, coal structure and catalytic liquefaction, flash pyrolysis of

Tucker, et al. (continued from previous page)

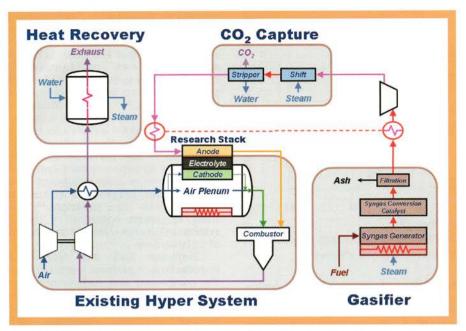


FIG. 6. *Proposed modifications to the Hyper facility for expanding the scope of hybrid system exploration.*

lignite and biomass, and heterogeneous catalysis in gasification. Dr. Tucker maintainsseveral research collaborations, and participates as an adviser in the NRC Research Associateship Programs. He may be reached at david.tucker@netl. doe.gov.

MICHAEL S. SHELTON is a professional engineer and CEO of SpectraCADD, LLC. Previously, as the senior engineer for Trans-Alaska Pipeline System, Mr. Shelton focused his efforts in Alaska on arctic engineering and the special engineering issues faced daily by the Alaskan people. Mr. Shelton has research interests in fuel cell turbine hybrids and the application of high temperature structural materials and computational fluid dynamics to this field. Mr. Shelton also serves on several professional engineering committees responsible for developing industry codes standards. He may be reached at michael.shelton@ jacobs.com.

A. MANIVANNAN is a materials scientist at the U.S. Department of Energy, National Energy Technology Laboratory (NETL). Prior to joining U.S. DOE, Dr. Manivannan was a faculty member of the Physics Department, West Virginia University, where he currently serves as an adjunct professor. He has carried out research in multidisciplinary areas in materials science for more than 25 years in academia. His research interests and expertise include materials for energy conversion and storage involving photoelectrochemical cells, solid oxide electrochemical energy fuel cells, storage devices such as Li-ion batteries, and thermoelectric supercapacitors,

materials, catalysts, etc. Dr. Manivannan has been active in performing several international research collaborations and participates as an adviser in the NRC Research Associateship Programs. He may be reached at manivana@netl. doe.gov.

References

- 1. Report to Congress, "FutureGen Integrated Hydrogen, Electric Power Production and Carbon Sequestration Research Initiative," U.S. DOE, Office of Fossil Energy, March 2004.
- M. C. Williams, J. Strakey, and W. Surdoval, J. Power Sources, 159, 1241 (2006).
- 3. U.S. Department of Energy, "Fuel Cell-Coal Based Systems," U.S. DOE Funding Opportunity Announcement, DE-PS26-05NT42346 (2005).
- R. A. Dennis, G. S. Samuelsen, M. C. Williams, N. T. Holcombe, and A. W. Layne, "The National Energy Technology Laboratory's Hybrid Power Systems Program," 2002 ASME Turbo Expo, Amsterdam, The Netherlands (GT-2002-30668).
- 5. W. Winkler, P. Nehter, M. C. Williams, D. Tucker, and R. S. Gemmen, *J. Power Sources*, **159**, 656 (2006).
- Systems Analysis of an Integrated Gasification Fuel Cell Combined Cycle; http://www.netl.doe.gov/ energy-analyses/pubs/IGFC%20 Combined%20Cycle%20Final% 20Report.pdf

- D. Tucker, E. Liese, J. G. Van Osdol, L. O. Lawson, and R. S. Gemmen, "Fuel Cell Gas Turbine Hybrid Simulation Facility Design," 2003 ASME International Mechanical Engineering Congress and Exposition, New Orleans, LA.
- 8. M. E. Ward and M. D. Stephenson, "The Primary Surface Recuperator - Durability and Applications," International Gas Turbine Congress, Kobe, Japan (1999).
- 9. D. Tucker, L. O. Lawson, and R. S. Gemmen, "Characterization of Air Flow Management and Control in a Fuel Cell Turbine Hybrid," Proceedings of the ASME Power Conference, PWR2005-50127 (April 2005).
- E. A. Liese, T. P. Smith, C. L. Haynes, and R. S. Gemmen, "A Dynamic Bulk SOFC Model Used in a Hybrid Turbine Controls Test Facility," 2006 ASME Turbo Expo, Barcelona, Spain, GT2006-90383.
- 11. D. Tucker, É. A. Liese, and R. S. Gemmen, "Determination of the Operating Envelope for a Direct Fired Fuel Cell Turbine Hybrid Using Hardware Based Simulation," 2009 International Colloquium Environmentally Preferred on Generation, Advanced Power Newport Beach, California, ICEPAG2009-1021 (February 2009).
- A. Traverso, A. F. Massardo, R. A. Roberts, J. Brouwer, and G. S. Samuelsen, "Gas Turbine Assessment for Air Management of Pressurized SOFC/GT Hybrid Systems," First European Fuel Cell Technology and Applications Conference, Rome, Italy, EFC2005-86228 (December 2005).
- 13. C. Stiller, B. Thorud, O. Bolland, R. Kandepu, and L. Imsland, *J. Power Sources*, **158**, 305 (2006).
- D. Tucker, T. P. Smith, L. O. Lawson, and C. Haynes, "Evaluation of Cathodic Air Flow Transients in a Hybrid System Using Hardware Simulation," Proceedings of the 4th International Conference on Fuel Cell Science, Engineering, and Technology, FUELCELL2006-97107 (June 2006).
- D. Tucker, L. O. Lawson, and R. S. Gemmen, "Evaluation of Hybrid Fuel Cell Turbine System Startup with Compressor Bleed," 2005 ASME Turbo Expo, GT2005-68784.
- E. A. Liese, "Comparison of Pre-Anode and Post-Anode Carbon Dioxide Separation for IGFC Systems," 2009 ASME/IGTI Turbo Expo, GT2009-59144.

Have you moved or are you planning to move?

Please take a moment to fill out this form with your updated contact information and return it to ECS.

(Please print clearly) Name	Membership No
Old address	New address
Organization	Organization
Address	Address
City	City
State/Province	State/Province
Postal Code	Postal Code
Country	Country
E-Mail	Phone
	Fax
	E-Mail

Place First Class Postage here. Post office will not deliver without proper postage.

ECS-The Electrochemical Society

65 S Main St Ste D1 Pennington, NJ 08534–2839

Միսիսիսիվութիվութինիսիսինիսիսիսիսի

Toward the Miniaturization of Solid Oxide Fuel Cells

by Enrico Traversa

ustainable energy production, compatible with environment preservation, is one of the major problems to be tackled in the near future. The search for new energy production technologies as alternatives to fossil fuel combustion need to consider renewable sources. Fuel cells show potential because, depending on the type of fuel cells, they can be used not only for the production of stationary energy (mainly solid oxide fuel cells, or SOFCs), but also for mobile applications for vehicles and portable electronics (mainly polymer electrolyte fuel cells, or PEFCs). However, recently it has been demonstrated that SOFCs can be also used for mobile applications and are expected to produce energy densities per volume and specific energy per weight significantly larger than PEFCs and state-of-the-art rechargeable Li-ion and Ni metal hydride batteries. This article focuses on recent developments in the miniaturization of SOFCs, with a critical review of the obstacles to be overcome.

Scaling-Down SOFCs

Solid oxide fuel cells (SOFCs) find their main exploitation in stationary energy production applications with power output in the 1 kW to 1 MW range, as described in a companion article in this issue, which require a scale-up of their features. However, the large energy densities of SOFCs and the versatility in fuel use, not limited to hydrogen, generated interest in the deployment of micro-SOFCs (µ-SOFCs) for mobile power generation in the lower 1-500 W range. Foreseable applications include portable electronic devices (which are now powered by rechargeable batteries), vehicle power supplies, and auxiliary power units.1-3

Fuel cell systems for compact, have great portable applications potential to achieve significant market penetration because of the high cost of the batteries they will replace on a \$/W-hr/kg basis. Moreover, SOFCs are expected to produce energy densities per volume and specific energy per weight significantly larger than stateof-the-art rechargeable Li-ion and Ni metal hydride batteries, and larger also than polymeric electrolyte membrane fuel cells (PEMFCs), especially when hydrocarbon fuels will be used.4 This feature is crucial because the ever increasing functionalities offered by modern portable electronic devices soon will increase energy requirements to a level that cannot be sustained by rechargeable batteries without increasing

their size or sharply reducing their running time.^{5,6} A further advantage with respect to rivaling batteries is the continuous SOFC operation when fed with fuel and oxidant, compared to the charge-discharge cycling operating mode of batteries.

Because direct conversion of chemical energy into electrical energy does not suffer from the thermodynamics efficiency restrictions of conventional thermo-mechanical energy production methods, in principle it is possible to scale down to the micrometer level the size of the whole device without affecting the SOFC overall efficiency.

Reduction of SOFC operating temperatures is a prerequisite for their use in portable devices, targeting the 300-600°C temperature range.7-9 To achieve the objective of these low operating temperatures, new materials, processing, and unique architectures must be developed and re-examined. Two are the most successful designs so far, which will be described in the following paragraphs, for fabricating SOFCs for portable applications at lower operating temperatures. These are the micro-tubular SOFC design, which allows scaling down the SOFC size at the millimeter range, and the thin-film design of SOFCs prepared on silicon substrates using microfabrication technologies, which allows scaling down the SOFC size at the sub-millimeter range.

Micro-Tubular SOFCs

Micro-tubular SOFCs have been reviewed in a very recent paper.10 The main limiting factor for using SOFCs in portable power production was the high operating temperature and the bulky design, which hindered a fast startup, indeed a necessary requirement to compete with engines and batteries. The development of a micro-tubular SOFC stack based on extruded zirconia tubes with a wall thickness of 0.2 mm and an internal diameter of 2 mm circumvented this limit, allowing rapid thermal cycling between 400 and 800°C at a rate of 200°C min⁻¹ without failing, due to the cell robustness.11 Later, tolerance to thermal cycling at a much faster heating rate of 4000°C min-1 has been demonstrated.12 Despite limited power generated, these promising findings boosted research activity to improve micro-tubular SOFC materials performance, processing, and cell and stack design.

The most customary stack design of micro-tubularSOFCs is a heat exchangerlike design, with a bundle of microtubular SOFCs with hydrogen flowing inside each cell and air flowing outside the cells. Therefore, whereas in planar SOFCs where sealing is critical, tubular SOFCs only need sealing at the junction with cells and manifolds. However, due to their tiny dimensions, micro-tubular SOFC sealing needs to be more accurate than for the larger counterparts, even though the literature on this topic is scarce.¹³

The research in the field of microtubular SOFCs has followed the same patterns pursued for reducing the operating temperature of large-scale SOFCs.¹⁴ Micro-tubes of alternative electrolytes, such as Gd-doped ceria (GDC) and Sr- and Mg-doped lanthanum gallate (LSGM) have been extruded,15 but their mechanical properties are inferior to those of vttria-stabilized zirconia (YSZ) tubes, in particular their toughness. A critical factor in reducing the Ohmic resistance is the reduction of electrolyte thickness using anodesupported thin film electrolytes in tubular configuration,16 following the research trends of planar SOFCs. Ni-YSZ tubes were extruded and YSZ electrolyte layers were deposited by dip-coating in a YSZ slurry in the approach followed at the University of Connecticut. They have also developed an original stack design, where single micro-tubular SOFCs are aligned to form planar multicells arrays, which can be subsequently stacked as they were planar cells.17 The cells were connected to the current collectors by brazing with silver. The power density output for the stack at 850°C fueled with hydrogen was almost 60 mW cm⁻², showing that further progresses are possible.

A different processing procedure using electrophoretic deposition (EPD) has been proposed by the Alberta Research Council in Canada to fabricate one-end-closed anode-supported single cells.18 EPD is a very versatile technique that shows advantages for the fabrication of ceramic multilayers for SOFCs.^{19,20} A graphite rod was used as a substrate to sequentially deposit by EPD anode (Ni-YSZ), electrolyte (YSZ), and cathode (LSM) layers. However, large overpotential losses at the cathode avoided to obtain a large power density output.18

In an approach proposed by the National Institute of Advanced Industrial Science and Technology (AIST) and the Fine Ceramics Research Association (FCRA) of Nagoya, Japan, under the frame of their joint research funded by NEDO, anode-supported electrolyte YSZ was substituted with GDC.²¹ NiO-GDC tubes were prepared by extrusion and

Traversa

(continued from previous page)

the GDC electrolyte layer was prepared by dip-coating.22 This group developed a completely different design for the stack, consisting of a cube-shaped array of micro-tubular cells distributed in a porous matrix made of the cathode material.23 The first demonstration showed the fabrication of a 3 cm x 3 cm x 3 cm cathode matrix cube with 36 micro-tubular cells 2 mm in diameter. arranged in a 6 x 6 configuration.²³ The group has worked intensively toward the reduction in size of the microtubular SOFCs, reaching needle-type cells where the tube diameter was 0.4 mm.²⁴ Figure 1 shows a photo of a micro-tubular SOFC bundle with the size of 1 cm3 made of 25 micro-tubular cells with the diameter of 0.8 mm in a 5 x 5 configuration. The tubular cells are based on anode-supported GDC electrolyte and were stored in a porous LSCF matrix. The electrode area of the single bundle reaches over 5 cm². The electrochemical performance has been also improved with time; the power density obtained for a single micro-tubular cell 0.8 mm in diameter increased from 350 mW cm-2 at 550°C with hydrogen as a fuel²¹ up to more than 1 W cm-2 upon improvement of the anode microstructure.25 This led to an overall volumetric power density output of 2 W cm-3 at 550°C with hydrogen for a module of the size of 0.2 x 1 x 3 cm, consisting of a stack of three bundles with fuel manifolds, each bundle having five micro-tubular cells.²⁶ Further improvement has being searched through the use of bilayer electrolytes,^{27,28} to block the electronic conductivity of GDC.29,30

In summary, even though there are already a few commercial products based on micro-tubular SOFCs in the market, there is still a lot of space for improvement of electrochemical performance through study and design of materials and their processing,³¹ in particular to reduce polarization losses at the electrodes, and on stack design.

Thin Film µ-SOFCs

Thin film µ-SOFCs based on silicon substrates with lateral dimensions in the sub-millimeter scale are very promising for use in portable electronic devices operating at low temperatures. The integration of thin film SOFC materials with silicon technology takes advantage of recent progresses in creating complex structures utilizing a variety 3D techniques.32 micromachining of Moreover, a microfabricated fuel cell could, in principle, be integrated onto a single chip with other electronic circuits, enabling extended, remote operation of electronic devices.33

While several papers have been reported on the investigation of thin film materials for μ -SOFCs, which have been recently reviewed,^{34,35} less numerous works have been reported on the fabrication of the entire μ -SOFC device, being the market still far. Nonetheless, the reported preliminary results are very promising.

The first example of a thin film µ-SOFC was probably reported by the University of Houston.³⁶ The development of the fuel cells followed an original strategy: a thin-film electrolyte, either YSZ or Sm-doped ceria (SDC), was grown by pulsed laser deposition (PLD) on a nickel foil substrate and then photolithographic patterning and chemical etching were used to develop pores in the anode for gas transport. A porous LSC cathode layer on the electrolyte side and a porous NiO-YSZ layer on the porous Ni side to boost the anode triple phase boundary were deposited by PLD to complete the

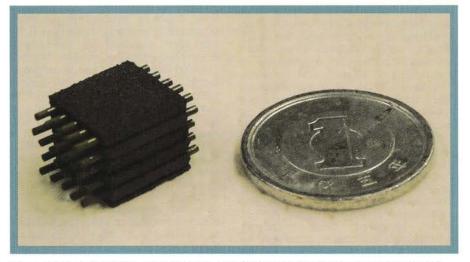


FIG. 1. Micro-tubular SOFC bundle with a size of 1 cm³, jointly developed by the National Institute of Advanced Industrial Science and Technology (AIST) and the Fine Ceramics Research Association (FCRA) of Nagoya, Japan; 25 micro-tubular cells, each with a diameter of 0.8 mm and based on anode-supported GDC electrolyte, were housed in a porous LSCF matrix. The electrode area of the single bundle reaches over 5 cm^2 . (Photo courtesy of Toshio Suzuki, AIST, Advanced Manufacturing Research Institute, Functional Assembly Technology Group, Nagoya, Japan.)

cells. The maximum power density of 140 mW cm⁻² at 575°C was obtained for cells with YSZ electrolyte, using hydrogen as fuel.³⁷ The approach of using Ni substrates for the μ -SOFC fabrication has been reported also by other groups, achieving lower power density outputs.^{32,38,39}

A research effort at MIT showed the first example of using silicon processing technologies developed for microelectromechanical systems (MEMS) applied to the fabrication of freestanding SOFC electrolyte membranes.40 As shown in the schematics in Fig. 2, the design is based on a conventional dualchamber configuration where the dense, free-standing electrolyte membrane acts as air/fuel barrier and mechanical support for anode and cathode layers. Figure 2 reports also an example of a cell fabricated at the University of Rome Tor Vergata, with SEM-micrographs of a bottom view of the free-standing cell and of the cross-section.41 One of the most important problems to be tackled for µ-SOFC fabrication is their thermal-mechanical stability. Residual tensile or compressive stresses deriving from thermal expansion mismatch with the substrate (SiN_x, for instance) can result in buckling and/or failure of the free-standing membrane, even relatively low temperatures. It at has been found that the deposition technique affected the residual stress in the electrolyte films.40 Only µ-SOFCs with larger thickness/area ratios, thus with an unfavorable electrochemical design, achieved an average fracture temperature significantly above their operating temperature.40

The use of Foturan, a photo-curable glass ceramic that can be micromachined by HF etching, has been proposed by ETH Zurich as a μ -SOFC substrate alternative to silicon, since its thermal expansion coefficient match well with the SOFC materials used.⁴ The maximum power density of 150 mW cm⁻² with open circuit voltage of 1.06 V was measured at 550°C using hydrogen as fuel on a cell with a sputtered platinum anode, an electrolyte prepared by TLD and the other by spray pyrolysis, and a platinum paste cathode.⁴

Ultrathin µ-SOFCs were fabricated at Stanford University using microfabrication techniques (lithography and etching), made of a YSZ electrolyte film as thin as 50 nm deposited by rf sputtering on a silicon wafer, with porous Pt films both for anode and cathode prepared by dc sputtering.⁴² The power density obtained was outstanding: the power output using hydrogen as fuel of a cell with a 50 nm-thick YSZ electrolyte was 130 mW cm⁻² at 350°C. Moreover, the addition of a supplementary layer of GDC between the YSZ and cathode films increased the power output up to 200 mW cm-2 at 350°C, reaching 400 mW cm⁻² at

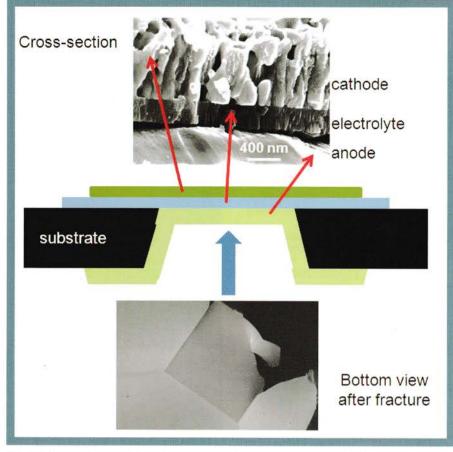


Fig. 2. Schematic diagram of the design of microfabricated μ -SOFCs based on a free-standing electrolyte membrane with anode and cathode layers, together with SEM micrographs of the bottom view and the cross-section of a SOFC, fabricated at the University of Rome Tor Vergata. The electrolyte is SDC and the electrodes are made of Pt. The size of the cell is 0.25 mm (bottom view).

400°C. Other groups fabricated similar µ-SOFC devices, but the power output was unrivaled. For instance, at Harvard, using a cell of similar configuration with a 100 nm-thick YSZ electrolyte. the maximum power density was 90 mW cm-2 measured at 500°C, and even substituting Pt at the cathode with $La_{0.6}Sr_{0.4}Co_{0.8}Fe_{0.2}O_3$ (LSCF) led to a maximum power density of 60 mW cm-2 at the same temperature.43 LSCF should have much lower overpotentials than Pt at low temperatures, although recent findings showed that removing Si at the Pt/YSZ interface dramatically improve the electrochemical performance,44 and this might be a possible explanation for the Stanford results.

Simulation studies have determined that thermal-mechanical reliability of μ -SOFCs can be improved using corrugated membranes that can reduce thermal stresses.⁴⁵ The group of Stanford was able to fabricate a μ -SOFC with a corrugated electrolyte membrane almost doubling indeed the power output: both flat and corrugated Pt/YSZ/Pt cells had a projected area of 0.0036 cm² (600 μ m × 600 μ m), and the depth of cups in the corrugated membrane was 20 μ m, showing a maximum power density of 680 mW cm⁻² at 400°C, with respect to that of 360 mW cm⁻² for the flat membrane.⁴⁶

A further step forward is represented by the μ -SOFC system developed under the frame of the ONEBAT Swiss project, which consists not only in a μ -SOFC device,⁴ but also in the gas-processing unit for fuel reforming and postcombustion, together with a suitable thermal management system.³ The most important output of this work is the demonstration of the technical feasibility of such kind of a system, which can become competitive once the SOFC performance will be enhanced through materials improvement.

Materials Challenges for Thin Film µ-SOFC Development

The progress that has to be made for boosting the performance of thin film μ -SOFCs concern both electrolyte membranes and electrodes with low overpotentials, especially the cathode. For instance, depositing epitaxiallyordered electrolyte films will improve their ionic conductivity with respect to polycrystalline films and will have also a beneficial effect on thermal-mechanical reliability. We recently discovered that epitaxially-grown SDC single crystals are stable in low oxygen partial pressure environments, while the equivalent polycrystalline films were dramatically unstable.⁴⁷ This is a caution for use in μ -SOFCs and the ability to produce crystalline-ordered electrolyte films might be advantageous for practical applications. The cathode selection and fabrication can be the real crucial point for μ -SOFC development. However, a recent paper demonstrated that PLD can be used to fabricate nanoporous perovskite-type cathodes having low area specific resistance, and this is very promising for further development.⁴⁸

About the Author

ENRICO TRAVERSA is Principal Investigator at the International Research Center for Materials Nanoarchitectonics (MANA) at the National Institute for Materials Science (NIMS), Tsukuba, Japan, leading a group on Nanomaterials for Fuel Cells since January 2009. He joined the University of Rome Tor Vergata in 1988 where he is currently Professor of Materials Science and Technology. He is Senior Vice-Chair of the ECS High Temperature Materials Division. Dr. Traversa's research interests are in nanostructured materials for environment, energy, and healthcare, with special attention to solid oxide fuel cells. He is author or co-author of seven patents, more than 400 scientific papers (more than 230 of them published in refereed international journals), and edited sixteen books or special issues of journals. Elected in 2007 in the World Academy of Ceramics, he is currently Associate Editor for the Journal of Nanoparticle Research and Science and Technology of Advanced Materials. He may be reached at traversa.enrico@ nims.go.jp.

References

- G. A. Tompsett, C. Finnerty, K. Kendall, T. Alston, and N. M. Sammes, J. Power Sources, 86, 376 (2000).
- S. Mukerjee, M. J. Grieve, K. Haltiner, M. Faville, J. Noetzel, K. Keegan, D. Schumann, D. Armstrong, D. England, and J. Haller, in *Solid Oxide Fuel Cells VII*, S. C. Singhal and H. Yokokawa, Editors, PV 2001-16, p. 173, The Electrochemical Society Proceedings Series, Pennington, NJ (2001).
- A. Bieberle-Hütter, D. Beckel, A. Infortuna, U. P. Muecke, J. L. M. Rupp, L. J. Gauckler, S. Rey-Mermet, P. Muralt, N. R. Bieri, N. Hotz, M. J. Stutz, D. Poulikakos, P. Heeb, P. Müller, A. Bernard, R. Gmür, and T. Hocker, J. Power Sources, 177, 123 (2008).
- U. P. Muecke, D. Beckel, A. Bernard, A. Bieberle-Hütter, S. Graf, A. Infortuna, P. Müller, J. L. M. Rupp, J. Schneider, and L. J. Gauckler, *Adv. Funct. Mater.*, **18**, 3158 (2008).
 C. K. Dvor, J. Bouge Sources, **106**, 21
- 5. C. K. Dyer, J. Power Sources, **106**, 31 (2002).

Traversa

(continued from previous page)

- 6. D. Nikbin, Fuel Cell Rev., 4/5, 21 (2006).
- K. Kendall and M. Palin, J. Power Sources, 71, 268 (1998).
- N. M. Sammes, R. J. Boersma, and G. A. Tompsett, *Solid State Ionics*, 135, 487 (2000).
- 9. D. Perednis and L. J. Gauckler, Solid State Ionics, **166**, 229 (2004).
- V. Lawlor, S. Griesser, G. Buchinger, A. G. Olabi, S. Cordiner, and D. Meissner, *J. Power Sources*, **193**, 387 (2009).
- T. Alston, K. Kendall, M. Palin, M. Prica, and P. Windibank, J. Power Sources, 71, 271 (1998).
- 12. W. Bujalski, C. M. Dikwal, and K. Kendall, *J. Power Sources*, **171**, 96 (2007).
- S. Hashimoto, H. Nishino, Y. Liu, K. Asano, M. Mori, Y. Funahashi, and Y. Fujishiro, *J. Fuel Cell Sci. Technol.*, 5, 031208 (2008).
- A. Boudghene Stambouli, E. Traversa, *Renewable and Sustainable Energy Rev.*, 6, 433 (2002).
 Y. Du, N. M. Sammes, G. A.
- Y. Du, N. M. Sammes, G. A. Tompsett, D. Zhang, J. Swan, and M. Bowden, *J. Electrochem. Soc.*, **150**, A74 (2003).
- 16. Y. Du and N. M. Sammes, J. Power Sources, **136**, 66 (2004).
- 17. N. M. Sammes, Y. Du, and R. Bove, J. Power Sources, **145**, 428 (2005).
- P. Sarkar, L. Yamarte, H. Rho, and L. Johanson, *Int. J. Appl. Ceram. Technol.*, 4, 103 (2007).
- 19. F. Bozza, R. Polini, and E. Traversa, *Fuel Cells*, **8**, 344 (2008).
- 20. M. Zunic, L. Chevallier, F. Deganello, A. D'Epifanio, S. Licoccia, E. Di Bartolomeo, and E. Traversa, J. Power Sources, **190**, 417 (2009).
- 21. T. Suzuki, Y. Funahashi, T. Yamaguchi, Y. Fujishiro, and M. Awano, J. Power Sources, **171**, 92 (2007).
- T. Suzuki, T. Yamaguchi, Y. Fujishiro, and M. Awano, J. Power Sources, 160, 73 (2006).
- Y. Funahashi, T. Shimamori, T. Suzuki, Y. Fujishiro, and M. Awano, *J. Power Sources*, **163**, 731 (2007).
- T. Suzuki, Y. Funahashi, Z. Hasan, T. Yamaguchi, Y. Fujishiro, and M. Awano, *Electrochem. Comm.*, 10, 1563 (2008).
- 25. T. Suzuki, Y. Funahashi, T. Yamaguchi, Y. Fujishiro, and M. Awano, *Electrochem. Solid-State Lett.*, **10**, A177 (2007).
- T. Suzuki, Y. Funahashi, T. Yamaguchi, Y. Fujishiro, and M. Awano, J. Electrochem. Soc., 156, B318 (2009).
- 27. T. Yamaguchi, S. Shimizu, T. Suzuki, Y. Fujishiro, and M. Awano, *J. Electrochem. Soc.*, **155**, B423 (2008).

- T. Suzuki, Z. Hasan, Y. Funahashi, T. Yamaguchi, Y. Fujishiro, and M. Awano, *Electrochem. Solid-State Lett.*, **11**, B87 (2008).
- E. D. Wachsman, P. Jayaweera, N. Jiang, D. M. Lowe, and B. G. Pound, J. Electrochem. Soc., 144, 233 (1997).
- 30. J. S. Ahn, D. Pergolesi, M. A. Camaratta, H. Yoon, B. W. Lee, K. T. Lee, D. W. Jung, E. Traversa, and E. D. Wachsman, *Electrochem. Comm.*, **11**, 1504 (2009).
- H. Luebbe, J. Van herle, H. Hofmann, P. Bowen, U. Aschauer, A. Schuler, F. Snijkers, H. J. Schindler, U. Vogt, and C. Lalanne, *Solid State Ionics*, 180, 805 (2009).
- 32. S. Rey-Mermet and P. Muralt, Solid State Ionics, **179**, 1497 (2008).
- 33. J. L. Hertz and H. L. Tuller, J. *Electroceram.*, **13**, 663 (2004).
- D. Beckel, A. Bieberle-Hütter, A. Harvey, A. Infortuna, U. P. Muecke, M. Prestat, J. L. M. Rupp, and L. J. Gauckler, J. Power Sources, **173**, 325 (2007).
- S. J. Litzelman, J. L. Hertz, W. Jung, and H. L. Tuller, *Fuel Cells*, 5, 294 (2008).
- X. Chen, N. J. Wu, L. Smith, and A. Ignatiev, *Appl. Phys. Lett.*, **84**, 2700 (2004).
- A. Ignatiev, X. Chen, N. J. Wu, Z. Lu, and L. Smith, *Dalton Trans.*, 5501 (2008).
- S. Kang, P. C. Su, Y. I. Park, Y. Saito, and F. B. Prinz, *J. Electrochem. Soc.*, 153, A554 (2006).
- 39. J. H. Joo and G. M. Choi, J. Power Sources, **182**, 589 (2008).
- C. D. Baertsch, K. F. Jensen, J. L. Hertz, H. L. Tuller, S. T. Vengallatore, S. M. Spearing, and M. A. Schmidt, *J. Mater. Res.*, **19**, 2604 (2004).
 D. Pergolesi, V. Esposito, A. Tebano,
- D. Pergolesi, V. Esposito, A. Tebano, P. G. Medaglia, S. Sanna, S. Licoccia, G. Balestrino, and E. Traversa, *ECS Trans.*, 7(1), 891 (2007).
- 42. H. Huang, M. Nakamura, P. C. Su, R. Fasching, Y. Saito, and F. B. Prinz, J. Electrochem. Soc., **154**, B20 (2007).
- A. C. Johnson, B. K. Lai, H. Xiong, and S. Ramanathan, J. Power Sources, 186, 252 (2009).
- 44. J. L. Hertz, A. Rothschild, and H. L. Tuller, J. Electroceram., 22, 428 (2009).
- 45. Y. Tang, K. Stanley, J. Wu, D. Ghosh, and J. Zhang, *J. Micromech. Microeng.*, **15**, S185 (2005).
- P. C. Su, C. C. Chao, J. H. Shim, R. Fasching, and F. B. Prinz, *Nano Lett.*, 8, 2289 (2008).
- S. Sanna, V. Esposito, D. Pergolesi, A. Orsini, A. Tebano, S. Licoccia, G. Balestrino, and E. Traversa, *Adv. Funct. Mater.*, **19**, 1713 (2009).
- J. Yoon, R. Araujo, N. Grunbaum, L. Baqué, A. Serquis, A. Caneiro, X. Zhang, and H. Wang, *Appl. Surf. Sci.*, 254, 266 (2007).

Future Technical Meetings



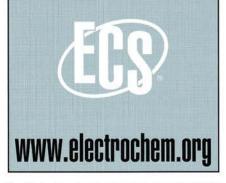
April 25-30, 2010 Vancouver, Canada

Oct. 10-15, 2010 Las Vegas, NV

May 1-6, 2011 Montreal, Canada

Oct. 9-14, 2011 Boston, MA

For more information on these future meetings, contact ECS Tel: 609.737.1902 Fax: 609.737.2743



From Laboratory Breakthrough to Technological Realization: The Development Path for Solid Acid Fuel Cells

by Calum R.I. Chisholm, Dane A. Boysen, Alex B. Papandrew, Strahinja Zecevic, SukYal Cha, Kenji A. Sasaki, Áron Varga, Konstantinos P. Giapis, and Sossina M. Haile

pen up any textbook on fuel cells and the reader finds a list of five classic types of fuel cells, each differentiated by the nature of the electrolyte: polymer electrolyte membrane (or sometimes proton exchange membrane), phosphoric acid, alkali, molten carbonate, and solid oxide. This article deals with a newcomer on the scene of fuel cell science and technology-the superprotonic solidacid fuel cell^{1,2}—that expands this list from five to six. Like its cousins, the solid-acid fuel cell, or SAFC, offers tremendous environmental benefits in the generation of electricity (and mechanical work) from chemical fuels.3 These include zero regulated emissions, high efficiency leading to reduced carbon dioxide emissions, suitability to hydrogen, and low noise and mechanical vibrations. Unlike other fuel cells, however, SAFCs operate at warm temperatures using a truly solid electrolyte. The occurrence of liquid-like proton transport in a noncorrosive, solid material implies unique opportunities for new approaches to fuel cell design, construction, and operation.

Which Solid Acid?

The solid acids of interest for fuel cell application are those whose chemistry is based on oxyanion groups (SO42 PO_4^{3-} , SeO_4^{2-} , AsO_4^{3-}), in turn, linked together by hydrogen bonds and charge balanced by large cation species (Cs⁺, Rb+, NH4+, K+). A select few among these compounds undergo a polymorphic, structural transition from an ordered state (with oxyanion groups in fixed orientation) to a highly disordered one, in which the oxyanion groups undergo almost free reorientation. Despite the high degree of disorder, the materials display sharp crystalline diffraction patterns as a consequence of the fixed position for the heavy metal cations and the fixed center of mass of the oxyanion groups. Accompanying this order-disorder transition is a dramatic increase in proton conductivity, by as much as 4 orders of magnitude in the case of CsHSO₄. Above the transition, the conductivity is typically ~ 10^{-2} S/cm, approaching the value of the best aqueous systems, and the activation energy for proton transport is ~ 0.35 eV.1 This combination of features has led to the term superprotonic to describe the nature of both the high

conductivity phase and the transition itself. As an aside, we note that despite the overwhelming evidence to the contrary, there are those who continue to hold that the rise in conductivity at the superprotonic transition is due merely to a transient dehydration phenomenon rather than a true polymorphic transformation.⁴ This unfortunate position has had no bearing on the progress of SAFC development.

Superprotonic behavior has been confirmed under atmospheric pressures in the solid acid compounds CsHSO4.5 CsHSeO₄,⁵ CsH₂PO₄,⁶ Cs₃H(SeO₄)₂,⁷ Rb₃H(SeO₄)₂,⁷ (NH₄)₃H(SO₄)₂,⁸ among others, and several mixed cesium sulfate-phosphates.⁹ The transition temperature ranges from as low as 91°C in $Cs_2(HSO_4)(H_2PO_4)^{10}$ to as high as 228°C in CsH_2PO_4 .^{4,6} The conductivity in the superprotonic phase is sufficiently high for each of these materials to warrant consideration for fuel cell implementation. However, criteria beyond simply conductivity must be considered. An examination of the list of superprotonic compounds indicates that almost every single one is based on oxyanions of column 16 elements: S and Se. Careful studies of acid sulfates and selenates have revealed that these compounds undergo a detrimental reaction with hydrogen as would be present in the fuel cell anode11

$$2MHXO_4 + 4H_2 \rightarrow M_2XO_4 + H_2X + 4H_2O$$
(1)

 $\begin{array}{ll} 2M_{3}H(XO_{4})_{2}+7H_{2}\rightarrow\\ 3M_{2}XO_{4}+4H_{2}X+4H_{2}O \quad (2) \end{array}$

where M = Cs, Rb, etc. and X = S, Se. Furthermore, the reduction reaction catalyzed is by typical anode electrocatalysts (Pt, etc.) and even the mixed sulfate-phosphate compounds are not immune. Worse, the byproduct of the reaction product, H₂S or H₂Se, is an extreme poison to the fuel cell anode catalyst and, as a consequence, even a modest extent of reaction severely degrades the fuel cell power output. With this appreciation of the transport properties and thermodynamics of solid acids, only one candidate amongst known compounds remains a viable fuel cell electrolyte: CsH₂PO₄.

Understanding CsH₂PO₄

But CsH₂PO₄ is not without its own challenges. A key disadvantage of this phosphate is the relatively high superprotonic transition temperature, 228°C under ambient pressures. All compounds in which protons are incorporated are subject to thermodynamic driving forces favoring dehydration at high temperature. Specifically, the reaction

$$CsH_2PO_4 \rightarrow CsPO_3 + H_2O$$
 (3)

is increasingly favored as the temperature is increased to achieve the superprotonic state. Fortunately, chemical thermodynamics can also be called upon to rescue the situation. Under application of a suitable water partial pressure, Reaction 3 can be driven toward the left and the dehydration reaction suppressed. A complete study of the temperature and water partial pressure dependence of the dehydration behavior has provided a road map for identifying safe conditions for fuel cell operation (Fig. 1a).^{12,13}

A second challenge in working with CsH₂PO₄ is the high plasticity or ductility that emerges in the superprotonic state. In the case of CsHSO₄, it has been shown that perfect single crystals can be literally twisted into the shape of breakfast pastries without fracture.14 In a fuel cell, application of pressure to isolate the anode and cathode chambers implies that ductile behavior is highly undesirable and indeed the electrolyte can be completely expelled and an electrical short circuit encountered. However, a remarkably simple solution exists to this plasticity problem. By introducing 10 wt% SiO₂ (15 vol%, 2 um average particle size) and forming a composite electrolyte, the steady state strain rate is lowered from 8.1 to 1.7 cm/cm·min (Fig. 1b).14 The impact on conductivity is minimal, lowering by it by just 20% in the superprotonic phase.

Fuel Cell Operation

With these challenges understood, one can then begin to design fuel cells that take advantage of the benefits inherent in moderate temperature operation in conjunction with a truly solid electrolyte. Using mechanically mixed, composite electrodes of Pt + CsH₂PO₄, pre-commercial SAFCs

Chisholm, et al.

(continued from previous page)

routinely draw peak power densities of 180 mW/cm² when operated on hydrogen / air at 250°C under ambient pressures; they display degradation rates of tens of microvolts per hour in constant current operation over periods of several hundred hours. Furthermore, these values of power output and stability of single membrane-electrode assemblies (MEAs) are almost directly replicated in 20-cell stacks (Fig. 2). Standard MEAs at Superprotonic, Inc. are 2 inches in diameter (15 cm² active area) with electrolyte thicknesses of 50 µm and Pt loadings of 4 mg/cm², and these MEAs serve as the basis for stacks with net 50 W power output. Larger cells up to 5 inches (105 cm² active area), with similar physical characteristics, have also been successfully fabricated. In all cases, comparison of the fuel cell polarization curves with the electrolyte area specific resistance (0.2 Ω cm² at 50 um, 250°C) indicates that the bulk of the voltage losses are due to the electrodes, and of these, the cathode is the limiting component.^{4,16} Furthermore, degradation is largely limited to the chemical and microstructural evolution of the cathode. Before turning toward efforts to improve durability and enhance cathode electrocatalysis rates, it is valuable to consider some additional milestones that have been reached with SAFCs.

The temperatures at which SAFCs are operated, ~ 250°C, suggest both a high degree of fuel stream impurity tolerance and suitability to operation on fuels more complex than hydrogen. Indeed, tolerance to CO levels as high as 20% has been demonstrated even in the absence of Ru as an alloving agent for the Pt anode catalyst (Fig. 3a), as has tolerance to H_2S , NH_3 , CH_3OH , C_3H_8 , and CH_4 to levels of 100 ppm, 100 ppm, 5%, 3%, and 5%, respectively. For operation on reformed hydrocarbons, this characteristic greatly simplifies the reforming system by largely eliminating the need for gas clean-up. In the case of methanol, it is possible to simplify the system even further by incorporating reforming catalysts, which, like the SAFC, operate optimally at ~ 250°C,17 directly into the fuel cell anode. The integration is particularly attractive because the heat released during fuel cell operation can be absorbed by the endothermic reforming reaction,18 overcoming the tremendous challenge of heat removal encountered in conventional, large-scale fuel cell systems. We have operated SAFCs with suitably modified anodes, using the base metal reforming catalyst, Cu/Zn/ Al₂O₃,¹⁷ on vaporized methanol-water mixtures and measured power densities that are within 90-95% of those obtained from equivalent hydrogennitrogen mixtures, for current densities

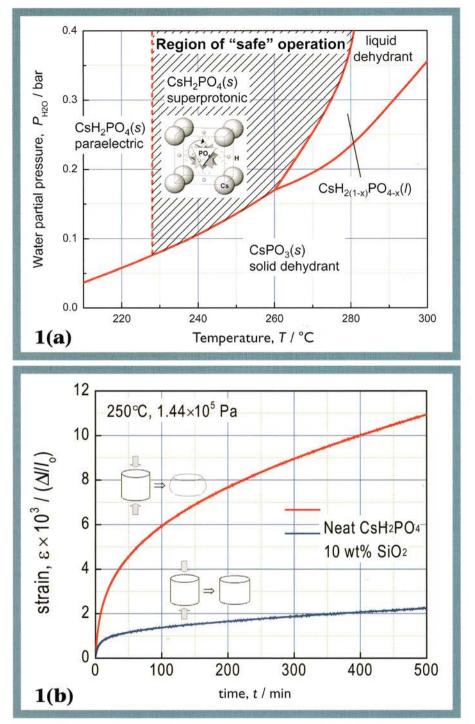


Fig. 1. Operational considerations for solid acid fuel cells based on CsH_2PO_4 . (a) Phase stability diagram, and (b) mechanical deformation behavior under constant stress.

as large as 0.5 A/cm^2 (Fig. 3b). Thus, the expectations of fuel stream flexibility due to moderate temperature operation are indeed fulfilled in SAFCs.

Challenges and Opportunities for SAFCs

Despite the impressive improvement in performance of SAFCs from their inception a decade ago, significant additional progress must be made before they can enter a broad range of commercial applications. The key barriers are summarized as durability and cost, both of which are connected to the characteristics of the cathode.

For most applications requiring kilowatts of power, fuel cell operation for thousands of hours (auxiliary, back-up, remote) to tens of thousands of hours (distributive and automotive) is necessary, where power output must remain at typically 80% of rated power. By this metric, state-of-the-art SAFCs have lifetimes only on the order of 1000-2000 h. In terms of costs, the acceptable entry price point for fuel cell systems to achieve mass adoption

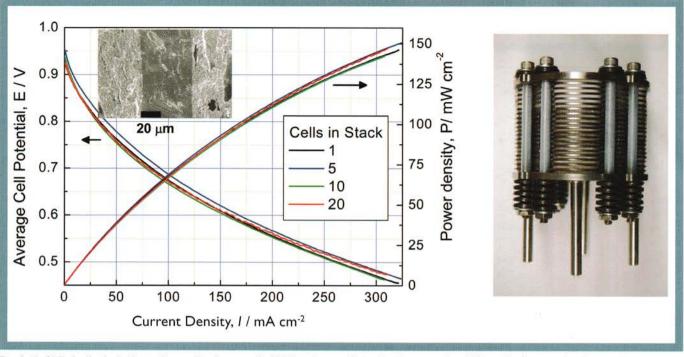


Fig. 2. (Left) Fuel cell polarization and power density curves for SAFC stacks manufactured at Superprotonic with inset showing scanning electron microscope image of a typical MEA; and (right) a 50W net stack constructed from such MEAs. Morphologically, solid acid fuel cells are similar to solid oxide fuel cells, with a dense ~ 50 µm electrolyte supported on a porous anode. Here, however, the components of the thin, porous cathode are identical to those of the anode. The planar power densities are retained on increasing the number of cells in the stack indicating negligible electrical resistance in the interconnect metals.

in early commercial markets is often quoted at ~ \$1000/kW.19 Even with the stack advantages (metal parts, polymer seals) and system level simplification attainable using SAFCs (ease in reforming, gas clean-up, cooling, and hydration/water management), today's system costs are estimated to exceed this target number for system price by a factor of 2-3. What follows is a discussion of the source of these challenges and the efforts underway to address them.

We have several indications that SAFC degradation is almost entirely due to changes at the cathode. Key among these is the observation that, when operated as a hydrogen pump at 0.5 A/cm², a standard SAFC cell displays negligible changes in cell voltage for periods up to 500 h. Microstructural examination of SAFC electrodes operated in conventional fuel cell mode reveals that the anode retains the as-prepared, high-porosity microstructure, whereas regions of the cathode appear densified and penetrated by the previously distinct electrolyte layer. Our interpretation is that the high overpotential at the cathode generates heat, accelerating the rate of creep of the electrolyte into the electrode and inducing densification. In turn, this decreases triple point density (the contact points between the electrolyte, the catalyst, and the phase), limits gas diffusion pathways, and, in severe instances, also deteriorates electrical connectivity. Our initial attempts to enhance microstructural stability through the introduction of additional components

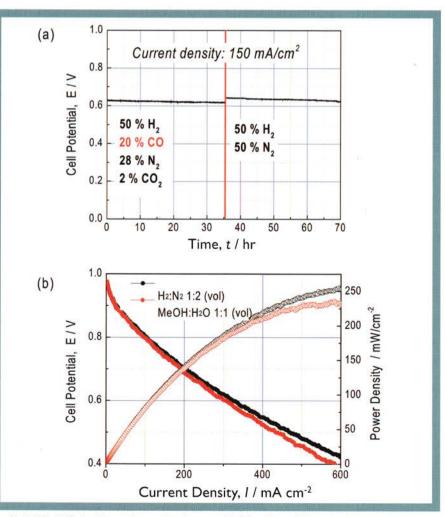


Fig. 3. Solid-acid fuel cell operation on (a) reformate with 20% CO; and (b) methanol supplied as vapor in a 1:1 molar ratio with H_2O .

Chisholm, et al. (continued from previous page)

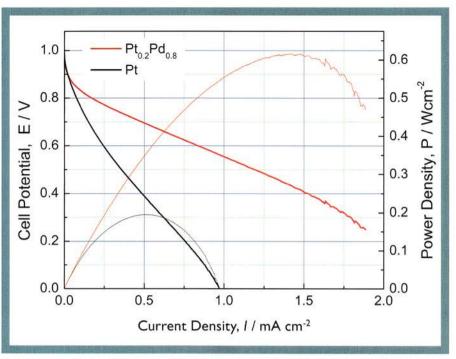


Fig. 4. Comparison of polarization and power density curves for SAFCs operated on Pt and on $Pt_{0,2}Pd_{0,8}$ cathode catalysts. Anode catalyst is Pt in both cases.

to the composite cathode have, in some cases, improved SAFC lifetimes, but have generally been accompanied by decreases in performance. Specifically, while hydrophilic materials like silica can impede the creep of the electrolyte by binding to it, such materials typically also decrease the protonic conductivity in the electrode. On the other hand, hydrophobic materials such as carbon and Teflon can repel the advance of the electrolyte, but these tend to decrease the electrolyte-catalyst interaction and therefore the triple phase boundary density. An alternative approach is then to enhance the catalytic activity of the cathode so as to lower the overpotential ideally, and, obtain durability comparable to that observed for the anode.

With respect to cost, the key metric is not the absolute cost of any fuel cell system, but, as is widely appreciated, the cost per unit power output. Decreasing the cost/power ratio can be achieved either by decreasing the materials costs (per unit area of MEA) or increasing the fuel cell power density, or both. At present, the precious metals loading in the SAFC stack are cost-prohibitive (22 mg Pt/W), and attaining higher power densities with materials less costly than Pt can ideally address both the numerator and denominator in the cost/ power ratio. By exploring alternatives to Pt in combination with a reduction to the thickness of the electrolyte layer (from 50 to 25 µm), we have recently achieved SAFC power densities of over 0.5 W/cm² at operational voltages (0.6

V) and with total platinum group metal (PGM) loadings of less than 4 mg/cm² (Fig. 4), under conditions suitable for most applications (80% and 50% H₂ and air utilization, respectively, at ambient pressures). The results are achieved by replacing the Pt cathode catalyst with a Pt_{0.2}Pd_{0.8} alloy, where this particular composition was found most effective across the Pt_xPd_{1-x} system. Remarkably, at very low current densities (< 0.03 mA/ cm²), the Pt and Pt_{0.2}Pd_{0.8} alloy display similar overpotential and it is at higher current densities that the impact of the Pd is manifested. At this performance level, the SAFC stack costs would be about \$500/kW (assuming PGM costs are 50% of total stack), and in order to be profitable at a system price of \$1000/ kW, additional development is clearly necessary. It should be noted that despite the higher cathode performance using Pd-based catalysts, the challenge of durability remains. Furthermore, the reason for the enhanced activity is as yet unknown, although it may be relevant that analogous enhancements have also been observed for hydrogen electro-oxidation.20

Another strategy for enhancing power density is to increase the number density of catalyst sites (triple phase boundaries). As SAFC electrodes contain solid electrolyte particles, the most direct path to this goal is to decrease the electrolyte particle size and thereby increase the electrode-electrolyte contact area. This is a fundamental distinction from liquid or polymeric electrolyte systems, in which the catalyst surface area limits performance because the electrolyte can contact almost all catalyst particles. With this in mind Superprotonic spent considerable efforts to synthesize nano-sized solid acid particles and incorporate them into SAFC electrodes. These efforts were successful (Fig. 5), and indeed, the increase in catalysis for particles in the range of 100 to 200 nm agrees with the square root dependence of the effective charge transfer resistance on average particle size $(R_{ct}^{eff} \propto \sqrt{L})$ determined for solid oxide fuel cell cathodes.²¹ However, this same dependence suggests that to lower the cathode overpotential to a target value of 300 mV at 500 mA/cm², will require decreasing the solid acid particle size by another order of magnitude to 10 nm, although the requirement may be relaxed if one simultaneously takes advantage of the high activity of Pt-Pd alloys. Nevertheless, in light of the plasticity of the electrolyte, small electrolyte particles (even 100 nm particles), or equivalently high surface-area structures, require support on or by another material that will maintain both the high surface area and interconnectivity of the electrolyte. Doing both simultaneously challenging, but initial work at Caltech using an electrospray process shows promise. Here, all three phases in the electrode (catalyst, electrolyte, support material) are simultaneously deposited with nanoscale features (Fig. 6a).

In addition to decreasing the electrolyte particle size, the triple phase boundary in SAFC electrodes can be enhanced through judicious placement of the catalyst material. To this end, Superprotonic has developed a metalorganic chemical vapor deposition (MOCVD) process for deposition of Pt catalyst particles directly onto high surface area CsH₂PO₄ (Fig. 6b). The highly tunable process, in which the surface density of nanometric Pt particles can be easily adjusted, allows for nearly all the electrolyte surface to be active for catalysis, while providing nearly 100% Pt yield from the input precursor. Furthermore, there is strong evidence that the Pt particles act as inhibitors to electrolyte sintering. Accordingly, this process enables preparation of electrodes from only MOCVD coated electrolyte particles, and it is from such optimized structures that we have obtained the results shown in Figure 5.

These directions in SAFC research all center on cathode development for the reasons already highlighted: cost and durability. Continued progress along the present development path may ultimately enable SAFCs to attain platinum group metal (PGM) loadings of less than 1 mg/cm² as is required for cost competitiveness against either other fuel cell or incumbent technologies. Even more tantalizing, however, is the prospect of eliminating

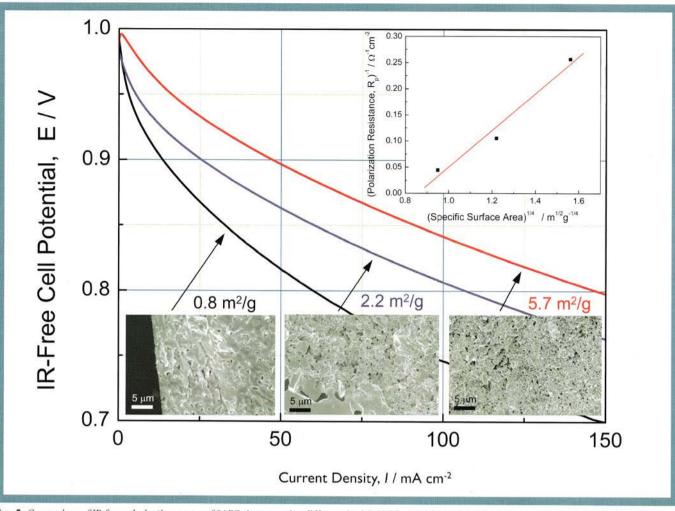


FIG. 5. Comparison of IR-free polarization curves of SAFCs incorporating different sized CsH₂PO₄ particles in the cathode. Scanning electron micrographs of the electrodes are shown and the inset presents the correlation between effective charge transfer resistance and average particle size, L (of the electrolyte component of the cathode). IR correction was performed by subtracting out the ohmic resistance of the electrolyte.

PGMs entirely, a plausible scenario given the temperature of operation. Such an achievement, if attained without performance penalties, would render SAFCs extremely attractive from a raw materials cost basis, as the electrolytes themselves are extremely inexpensive.

In terms of systems development, no obviously insurmountable barriers have been identified, but some constraints have emerged from the experience gained at Superprotonic in prototyping the first SAFC power units. First, because the electrolyte is essentially protonically insulating below the superprotonic transition temperature, the system must heat the stack above the phase transition temperature (~ 230°C) before the stack is operable. At present, this is achieved using a heating sub-system similar to those employed in PAFCs systems. Second, the fact that the electrolyte is water soluble demands that the stack not fall below the dew point and condense liquid water within the MEAs. This is not particularly difficult to ensure given

the stack inoperability below ~ 230° C; on either heat-up or cool-down, water generated in the stack at high temperatures is in the vapor form and hence can be easily purged. Third, due to the possibility CsH₂PO₄ dehydration at operational temperatures, both anode and cathode gas streams must be humidified to greater than 0.2 atm of water for safe operation of the stack. This is by far the most demanding systems level requirement for SAFCs as the energy required to heat the water

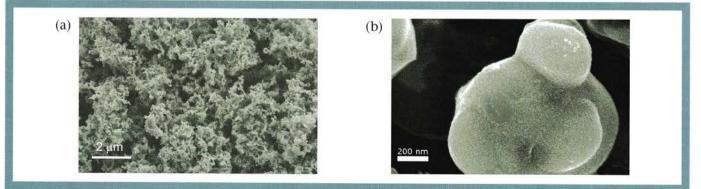


Fig. 6. Advanced electrode fabrication routes: (a) composite $CsH_2PO_4 - Pt - carbon electrodes prepared by electrospray; and (b) ultrafine-Pt coating on porous, nanoscale <math>CsH_2PO_4$ obtained by metal-organic chemical vapor deposition (MOCVD).

Chisholm, et al.

(continued from previous page)

for humidification must be recovered in order to achieve reasonable overall efficiencies. Moreover, for applications in which water neutrality is necessary (*e.g.*, remote and portable power), water recovery from outgoing gas streams becomes an additional requirement and standard passive condensers may not be sufficient. While these constraints place engineering demands on SAFC power systems, the operation remains relatively simple, particularly in comparison to the complexity of PEMFC operation on reformed hydrogen.

Conclusions

Taken in total, the durability, power densities, precious metal loadings, and MEA active areas of state-of-the-art SAFCs render this nascent technology ready for immediate implementation in applications requiring hundreds of watts or less and for which high purity hydrogen may not be readily available. Typically, such applications are in small portable power for which methanol is often the fuel of choice and hence SAFCs are particularly attractive. To penetrate a broader range of markets, the remaining challenges in cost and durability, both of which are connected to cathode electrocatalysis rates, must be addressed. As outlined here, several opportunities for achieving competitive cost and performance targets appear viable. Success in this arena may enable the realization of the enormous environmental benefits that fuel cells continue to offer.

About the Authors

DANE A. BOYSEN is a co-founder of Superprotonic, Inc., in Pasadena, California, and served as the team lead for stack development. Dr. Boysen has investigated the transport properties, phase transitions, and atomic structure of solid acid proton conductors for more than 14 years. He carried out his doctoral studies in materials science at the California Institute of Technology, focusing on the phase behavior of a particular solid acid compound, CsH₂PO₄. Dr. Boysen went on to show that this compound is the most suited for real-world fuel cell applications of all the known solid acid compounds. After leading the highly successful stack development effort at Superprotonic, Dr. Boysen spent time studying nanoparticle synthesis at Iowa State University, and is now a Staff Scientist in Materials Science and Engineering at the Massachusetts Institute of Technology as part of a battery research team. He may be reached at dane.boysen@gmail. com.

SUKYAL CHA is Director of Electrode Development at Superprotonic Inc.

Prior to joining Superprotonic, he was Director of Technology at PolyFuel Inc, Mountain View, California and Ooria Protonics Inc. Fremont, California; and a researcher at SRI International, Menlo Park, California and KIST, Seoul, Korea, for over 10 years. His research interests are micro and macro electrode structures, interface between ionic and electronic conducting materials, hydrogen generation, advanced conversion electrochemical energy systems, especially H₂/air fuel cells, direct methanol fuel cells, and supercapacitors. He may be reached at sukyal. cha@superprotonic.com.

CALUM R.I. CHISHOLM is a co-founder and Vice-President of Superprotonic, Inc., an energy technology company established to develop and commercialize solid acid fuel cells. As a graduate student and then postdoctoral scholar in materials science at the California Institute of Technology, Dr. Chisholm investigated the fundamental properties of a class of materials known as superprotonic solid acids, named such for their ability to transform into highly conductive solidstate proton conductors under specific temperature/pressure conditions. In 2003, Dr. Chisholm co-founded Superprotonic with the goal of developing these scientifically fascinating materials into a commercially viable fuel cell technology for a wide range of power applications. Working with many exceptional collaborators, Dr. Chisholm has published 17 scientific papers in peer review journals and holds, or has applied for, eight patents. He may be reached at calum.chisholm@superprotonic.com.

KONSTANTINOS P. GIAPIS is an associate professor of chemical engineering in the Division of Chemistry and Chemical Engineering at the California Institute of Technology. He received his PhD in chemical engineering from the University of Minnesota and continued as a postdoctoral member of the technical staff at AT&T Bell Laboratories (Murray Hill, NJ) before joining Caltech. His research interests include ion-surface dynamics, plasma processing, and nanotechnology. He may be reached at giapis@caltech.edu.

Sossina M. HAILE is a professor of materials science and of chemical engineering at the California Institute of Technology. Before assuming her present position at Caltech in 1996, Haile was a member of the faculty at the University of Washington. Her research broadly encompasses solid state ionic materials and devices, with particular focus on fuel cells and thermochemical fuel production. In 2008 Haile was awarded an American Competitiveness and Innovation (ACI) Fellowship from the National Science Foundation in recognition of "her timely and transformative research in the energy field and her dedication to inclusive mentoring, education, and outreach across many levels." Since 2005 Haile has been a member of the National Materials Advisory Board, a committee serving the National Academies of Sciences and of Engineering. She may be reached at smhaile@caltech.edu.

ALEXANDER B. PAPANDREW is a Senior Scientist at Superprotonic, Inc. Prior to his employment at Superprotonic, Dr. Papandrew received his PhD from the California Institute of Technology under the supervision of Brent Fultz. While at Caltech, he was a recipient of a National Defense Science and Engineering Grant fellowship. His research interests are in electrode development for solid acid fuel cells, artificial nanostructures, transition metal chemical vapor deposition, and X-ray and neutron scattering. He may be reached at alex. papandrew@superprotonic.com.

KENJI A. SASAKI is currently a graduate student in materials science at the California Institute of Technology. His research interests include heterogeneous catalysis and facile microstructural engineering for energy storage and conversion applications. Kenji's present focus is on electrocatalytic pathways in solid acid fuel cells, and his past studies include thermoelectric materials and electrochemical hydrogen pumps. He may be reached at kenji.sasaki@gmail. com.

ARON VARGA received his BS and MS in materials science and engineering from the University of Cambridge, UK. He is currently a PhD candidate at the California Institute of Technology working under the supervision of Sossina M. Haile. His work focuses on fabricating composite nanostructured fuel-cell electrodes. In solid-acid addition to his experience as graduate research assistant, Aron has worked on modeling the oxygen reduction reaction at solid oxide fuel cell cathodes at MIT. He may be reached at avarga@caltech. edu.

ZECEVIC is a Senior STRAHINJA Electrochemist at Superprotonic, Inc. He received his PhD in electrochemistry from the University of Belgrade, Yugoslavia, in 1983. He has broad experience in both university (1976-1995) and corporate R&D (1995-present) type research. He was a professor of electrochemical engineering and physical chemistry at the University of Belgrade; Senior Research Associate at Case Western Reserve University, Cleveland, OH; Senior Scientist at Ceramatec Inc. and SARA Inc.; and Senior Fuel Cell Engineer at GE. His interest in electrochemistry involves electrode processes, particularly oxygen reduction electrochemistry, deposition, dissolution and corrosion of metals, batteries, fuel cells, sensors, low and high temperature systems based on

The Electrochemical Society Interface • Fall 2009

use of ceramic membranes, and fluid delivery devices. He has 49 publications in scientific journals, ten patent disclosures, and four scholarly books. He may be reached at zeka.zecevic@ superprotonic.com.

References

- S. M. Haile, D. A. Boysen, C. R. I. Chisholm, and R. B. Merle, *Nature*, **410**, 910 (2001).
- D. A. Boysen, T. Uda, C. R. I. Chisholm, and S. M. Haile, *Science*, 303, 68, (2004).
- 3. T. Norby, Nature, 410, 877 (2001).
- S. M. Haile, C. R. I. Chisholm, K. Sasaki, D. A. Boysen, and T. Uda, *Faraday Discussions*, **134**, 17 (2007).
- A. I. Baranov, L. A. Shuvalov, and N. M. Shchagina, *JETP Lett.*, 36, 459 (1982).
- A. I. Baranov, V. P. Khiznichenko, V. A. Sandler, and L. A. Shuvalov, *Ferroelectrics*, 81, 1147 (1988).
- A. Pawlowski, C. Pawlaczyk, and B. Hilzcer, *Solid State Ionics*, 44, 17 (1990).
- M. Polomska, L. F. Kirpichnikova, T. Pawlowski, and B. Hilczer, *Ferroelectrics*, **290**, 51 (2003).
- 9. C. R. I. Chisholm, PhD Thesis, California Institute of Technology, Pasadena, CA (2003).
- C. R. I. Chisholm and S. M. Haile, Acta Crystallographica B, 55, 937 (1999).
- R. B. Merle, C. R. I. Chisholm, D. A. Boysen, and S. M. Haile, *Energy Fuels*, **17**, 210 (2003).
- Y. Taninouchi, T. Uda, and Y. Awakura, Solid State Ionics, 178, 1648 (2008).
- Y. K. Taninouchi, T. Uda, Y. Awakura, A. Ikeda, and S. M. Haile, *J. Mater. Chem.*, **17**, 3182 (2007).
- 14. J. Wu, personal communication.
- L. F. Kirpichnikova, A. A. Urusovskaya, and V. I. Mozgovoi, *JETP Lett.*, 62, 638 (1995).
- 16. T. Uda and S. M. Haile, *Electrochem. Solid-State Lett.*, **8**, A245 (2005).
- B. A. Peppley, J. C. Amphlett, L. M. Kearns, and R. F. Mann, *Applied Catalysis A*, **179**, 21 (1999).
- T. Uda, D. A. Boysen, C. R. I. Chisholm, and S. M. Haile, *Electrochem. Solid-State Lett.*, 9, A261 (2006).
- H. Stone, K. Mahadevan, K. Judd, H. Stein, V. Contini, J. Myers, J. Sanford, J. Amaya, J. Upton, and D. Paul, DOE Contract No. DE-FC36-03GO13110; Economics of Stationary Proton Exchange Membrane Fuel Cells, Battelle (2006).
- 20. M. Louie, K. Sasaki, and S. M. Haile, ECS Trans., **13**(28), 57 (2008).
- 21. C. W. Tanner, K. Z. Fung, and A. V. Virkar, *J. Electrochem. Soc.*, **144**, 21 (1997).

THE ELECTROCHEMICAL SOCIETY MONOGRAPH SERIES

The following volumes are sponsored by ECS, and published by John Wiley & Sons, Inc. They should be ordered from: ECS, 65 South Main St., Pennington, NJ 08534-2839, USA or www. electrochem.org/dl/bookstore.htm

Just Published!

Fuel Cells: Problems and Solutions by V. Bagotsky 320 pages. ISBN 978-0-470-23289-7

Electrochemical Impedance Spectroscopy

by M. E. Orazem and B. Tribollet (2008) 524 pages. ISBN 978-0-470-04140-6

Fundamentals of Electrochemical Deposition (2nd Edition)

by M. Paunovic and M. Schlesinger (2006) 373 pages. ISBN 978-0-471-71221-3

Fundamentals of Electrochemistry (2nd Edition)

Edited by V. S. Bagotsky (2005) 722 pages. ISBN 978-0-471-70058-6

Electrochemical Systems (3rd edition)

by John Newman and Karen E. Thomas-Alyea (2004) 647 pages. ISBN 978-0-471-47756-3

Modern Electroplating (4th edition)

Edited by M. Schlesinger and M. Paunovic (2000) 888 pages. ISBN 978-0-471-16824-9

Atmospheric Corrosion

by C. Leygraf and T. Graedel (2000) 3684 pages. ISBN 978-0-471-37219-6

Uhlig's Corrosion Handbook (2nd edition)

by R. Winston Revie (2000). paperback 1340 pages. ISBN 978-0-471-78494-4

Semiconductor Wafer Bonding

by Q. -Y. Tong and U. Gösele (1999) 297 pages. ISBN 978-0-471-57481-1

Corrosion of Stainless Steels (2nd edition)

by A. J. Sedriks (1996) 437 pages. ISBN 978-0-471-00792-0

Synthetic Diamond: Emerging CVD Science and Technology

Edited by K. E. Spear and J. P. Dismukes (1994) 688 pages. ISBN 978-0-471-53589-8

Electrochemical Oxygen Technology

by K. Kinoshita (1992) 444 pages. ISBN 978-0-471-57043-1

ECS Members will receive a discount. All prices subject to change without notice.

www.electrochem.org

ith the new ECS Bylaws in place, some changes have been made to the governance of the Sections program. A representative from each of the Divisions and Sections is invited to attend the Individual Membership Committee meeting, which is held at the ECS biannual meetings, to share their activities and challenges. Topics to be included on the meeting agenda should be forwarded to Karla T. Stein, Director of Membership and Development, at karla.stein@ electrochem.org one month prior to the ECS meeting.

Canada

The Canadian Section's 2009 spring meeting, "Frontier in Electrochemistry," organized by Jacek Lipowski and Gregory Jerkiewicz, was held at the Hamilton Convention Center from May 31 to June 1, and included the Canadian Society of Chemistry (CSC). The invited international speakers were Dieter M. Kolb from Germany, who spoke on "Structure-Reactivity Relations in Electrochemistry," and Hector Abruña from the U.S., who spoke on "Surfaces, Interfaces, and Morphology Effects in Electrocatalvsis."

At the annual general meeting held on June 1 in Hamilton, Ontario, the following officers were elected:

- Chair: Aicheng Chen, Lakehead University
- First Vice-Chair: Sylvie Morin, York University
- Second Vice-Chair: Alexandre Brolo, University of Victoria

Secretary: Janine Mauzeroll,

Université du Québec at Montréal Treasurer: Ian Burgess, University of Saskatchewan

- Councilor: Dan Bizzotto, University of British Columbia
- Incumbent Councilor: Gregory

Jerkiewicz, Queens

The Section reported that the 2009 recipient of the Lash Miller Award is Aicheng Chen from Lakehead University in Ontario. The Canadian Section Student Award winner for 2008 is Arash Shahryari from McGill University in Montréal and the winner for 2009 is Mohamed Naser from McMaster University in Hamilton.

Detroit

Christian Fierro from Energy Conversion reported that the Detroit Section met on May 14 at Lawrence Technological University, in Southfield, Michigan. Benny Reichman from Ovonic Battery Company gave a well-attended talk entitled, "Ovonic Renewable Hydrogen Temperature (ORH)-Low Hydrogen Production from Renewable Fuels." hydrogen production Conventional technology today is steam reformation of natural gas. The process requires steam at high temperatures and significant amount of heat for operation. He presented a one-step process that operates at significant lower temperatures (130-300°C) than conventional steam reforming or gasification processes (800-1000°C). ORH uses alkaline materials as reactants to facilitate the reforming of organic matters to hydrogen. He reported that, unlike conventional reforming process, the ORH process does not form CO or CO_2 gases. Instead, pure hydrogen is formed at high yields with carbonate salt as the only byproduct of the reaction. He mentioned that the ORH reactor can be scaled down for production of hydrogen in a distributed manner with a projected cost of hydrogen lower than conventional technology.

On June 17, Dawn Bernardi, from Ford Motor Company, closed a vey busy year of the Detroit Section with a wellattended talk entitled, "Mathematical Modeling of Pulse and Relaxation Behavior in Lithium-ion Batteries." She presented results from a mathematical model of a Li-ion cell derived from first-principles of electrochemical kinetics, ionic, electronic transport, and thermodynamics. Her model results compared favorably with experimental behavior of cells designed for hybridapplications. electric-vehicle She showed that model results suggest that the behavior of the cell overvoltage is dominated by solid-state diffusion of lithium in the positive electrode. She stated that the elucidation of the factors dominating cell overvoltage can aid in the development of optimized systems that deliver maximized fuel-economy.

Overall the Detroit session held nine interesting talks over the past year in the areas of fuel cell batteries, supercapacitors, and hydrogen energy. The speakers were from both industry and academia and the average attendance at each talk was around 25-30.



www.electrochem.org

65 South Main Street Pennington, NJ 08534-2839, USA

2009 Oronzio de Nora Industrial Electrochemistry Award Recipient



VIJAVASEKARAN BOOVARAGAVAN is the 2009 recipient of the Oronzio de Nora Industrial Electrochemistry Fellowship of ECS. This year's fellowship is the third time he has received this prestigious international award. (See his report on page 64 of the winter 2008 issue of *Interface*; his 2009 report will be published in an upcoming issue.)

Dr. Boovaragavn (Vijay) received his Master of Engineering degree in chemical engineering from Annamalai

University, India, in 2002 and his PhD in chemical engineering from Central Electrochemical Research Institute (CECRI), India, in 2005. He is involved in studying electrochemical processes namely electro-organic synthesis, electrochemical power sources, and electroplating using mathematical models with novel simulation schemes and dynamic optimization procedures. He did his doctoral research under the supervision of Dr. Ahmed Basha, scientist and Dean. It included the evaluation of exact optimal control strategy for electrochemical reactors, successful development of simple mathematical model for lead-acid batteries, and formulation of a novel simulation scheme for elucidating tertiary current distribution in electrochemical cells for different geometries. He was a Junior and Senior Research Fellow at the Council for Scientific and Industrial Research (CSIR), India, which supported his entire doctoral research. He received the Young Scientist Award at CECRI twice in a row for the years 2003 and 2004 for his outstanding research output. His work on dynamic optimization of electrochemical reactors gained him international recognition through the 2006 Oronzio de Nora foundation's young author award of the International Society of Electrochemistry

In the spring of 2006, Vijay joined the research group of Venkat Subramanian in the department of Chemical Engineering at Tennessee Technological University (TTU) in Cookeville, Tennessee as a postdoctoral associate. At TTU, he has coauthored ten research articles focusing mainly on the development of a novel reformulated model for lithium-ion batteries that can predict the battery behavior in milliseconds. At TTU, he has helped three graduate students in their thesis and research, and has taught a course for undergraduates entitled Chemical Engineering Operations. He is currently working on modeling corrosion in electrodes, cycling/capacity-fade analysis of lithium-ion batteries using a reformulated real-time model, and overcoming the numerical and computational difficulty associated with different electrochemical models like impedance and fuel cell models. The successful development and implementation of an efficient reformulated model and computational schemes will help pave the way for using electrochemical power sources in niche applications such as hybrid vehicles, satellites, online control, and monitoring. He has 19 peer-reviewed journal publications, two book chapters and 23 scientific presentations to his credit.

The Oronzio de Nora Industrial Electrochemistry Fellowship was established in 2003 to assist a postdoctoral scientist or engineer in the research of the field of industrial electrochemistry. The award, funded by the Oronzio de Nora Foundation, is in the amount of \$25,000 for one year, twice renewable based on successful research progress as judged by the award's committee.

2008 Young Author Award Winners

The Society is pleased to announce the recipients of the 2008 Norman Hackerman Young Author Awards. The awards are given annually for the two best papers published in the *Journal of The Electrochemical Society* (JES) by authors under 31 years of age. The awards were established in 1928 and renamed for Dr. Norman Hackerman, former Editor of JES. (**Ed. Note**: See the ECS Classics piece on Dr. Hackerman in the summer 2008 issue of *Interface*, p. 23.) The selection subcommittees were chaired by Randy Leising, Greatbatch, Inc., for the Electrochemical Science and Technology Subcommittee; and Mike Kelly, Sandia National Laboratory, for the Solid-State Science and Technology Subcommittee.

(continued on next page)

Call for Nominations

For details on each award, including a list of requirements for award nominees, and in some cases, a downloadable nomination form, please go to the ECS website (www.electrochem.org) and click on the "Awards" link. This will take you to a general page that will then lead to the individual awards. The awards are grouped in one of four categories: Society Awards, ECS Division Awards, Student Awards, and ECS Section Awards. Click on one of these sub-links to find the individual award. Please see each for information about where nomination materials should be sent; or you may contact the ECS headquarters office by using the contact information on the awards Web page. For student awards, please see the Student News Section in this issue.

Visit w w w . e l e c t r o c h e m . o r g

and click on the "Awards" link.

(continued from previous page)



KEVIN RALSTON was awarded the 2008 Young Author Award in the category of Electrochemical Science & Technology for his paper, "Corrosion Inhibition of Aluminum Alloy 2024-T3 by Aqueous Vanadium Species" (JES, **155**, C350, 2008).

Dr. Ralston received his doctorate this past December from The Ohio State University where he worked in the Fontana Corrosion Center within the Department of Materials Science and Engineering. He also earned his

Bachelor's degree in 2003 and Master's degree in 2007 from the same department. Dr. Ralston's research interests have been focused on the corrosion of light alloys, most specifically aluminum. His graduate work focused on the use of vanadatebased inhibitors in conjunction with anion-exchange clay pigments to inhibit corrosion of aircraft grade aluminum.

Dr. Ralston is currently a research fellow in the ARC Centre of Excellence for Design in Light Metals at Monash University located near Melbourne, Australia. His current projects on aluminum and other light alloys include the exploration of the relationships between grain size and corrosion resistance, and the possible role of processing on corrosion; and the development and evaluation of highly corrosion resistant medium strength Al-Cu-Mg alloys through microstructure manipulation.



YUDI SETIAWAN and **EU JIN TAN** were awarded the 2008 Young Author Award in the category of Solid-State Science & Technology for their paper, "Materials and Electrical Characterization of $Er(Si_{1-x}Ge_x)_{2-y}$ Films Formed on $Si_{1-x}Ge_x(001)$ (x = 0.0.3) via Rapid Thermal Annealing" (JES, **155**, H26, 2008).

Yudi Setiawan received his BEng and PhD in materials science and engineering from Nanyang Technological University (NTU), Singapore, in 2004

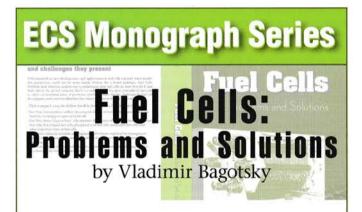
and 2008, respectively. In 2004, he obtained a scholarship sponsored by Chartered Semiconductor Manufacturing Ltd to pursue his PhD studies at NTU. His doctoral topic was "Pulsed-Laser Annealed Silicides for Advanced MOS Applications." His doctoral work focused on the thermodynamic and kinetic investigation on metal-semiconductor compound (silicide) formation during nano-second high-energy laser annealing, thermal and mechanical properties of laser-annealed silicides, and electrical properties of silicide/semiconductor interfaces.

Dr. Setiawan was the recipient of the "E-MRS 2007 Young Scientist Award" for his paper on a novel method to form an atomically abrupt silicide/silicon interface using laser annealing. He has authored or co-authored more than 20 technical papers and conferences. Since September 2008, he has been working as a Senior Engineer at Chartered Semiconductor Manufacturing Ltd and is working on development of sub 32 nm technology nodes.



Eu Jin Tan received his doctorate from the Nanyang Technological University (NTU), Singapore in 2009. He majored in electrical and electronic engineering, and his thesis is entitled, "Study of Erbium Disilicide and Its Application in Schottky Source/Drain Silicon Nanowire MOSFETs." In 2004, he obtained a scholarship sponsored by the Institute of Materials Research Engineering (IMRE) to pursue his PhD studies for the subsequent four years. His work included the investigation of

Si based metal semiconductor contacts and nanodevices. From 2002 to 2004, he worked as a Product Engineer with DenseLight Semiconductors Pte Ltd. His job scope included the testing and development of distributed feedback lasers for optical communication applications. Since April 2008, he has been working as an engineer at Chartered Semiconductors Manufacturing Ltd.



With hundreds of new developments and applications in fuel cells reported every month, this publication could not be timelier. Written for a broad audience, *Fuel Cells: Problems and Solutions* lets the reader understand what fuel cells do, how they do it, and discusses their role in the global economy. Readers will not only discover the great potential of fuel cells to solve a tremendous array of problems, but will also learn the key challenges in fuel cell development and commercialization that researchers are seeking to overcome. This compact, easyto-follow book is divided into four logical parts:



Special discount for ECS members!

Order your copy from ECS E-mail: customerservice@electrochem.org Tel: 609.737.1902 Fax: 609.737.2743

> ISBN: 978-0-470-23289-7, 320 pages Hardcover, Sponsored by ECS

(W) WILEY Published by John Wiley & Sons, Inc.





The Edward Goodrich Acheson Award was established in 1928 for distinguished contributions to the advancement of any of the objects, purposes, or activities of ECS. The award consists of a gold metal, wall plaque, and a prize of \$10,000. The next award will be presented at the ECS fall meeting in Las

Vegas, Nevada, October 10-15, 2010.

Nominations and supporting documents should be sent to Paul Kohl, Georgia Tech, School of Chemical & Biomolecular Engineering, 311 Ferst Drive, Atlanta, GA 30331-0100, USA; e-mail: paul.kohl@chbe.gatech.edu. Materials are due by March 1, 2010.



The Gordon E. Moore Medal for Outstanding ACHIEVEMENT IN SOLID STATE SCIENCE AND **TECHNOLOGY** was originally established in 1971 (as the Solid State Science and Technology Award) for distinguished contributions to the field of solid state science. The award recognizes outstanding contributions to the fundamental understanding and technological

applications of solid state materials, phenomena, and processes. The award consists of a silver medal, a wall plaque, and prize of \$7,500. The next award will be presented at the ECS fall meeting in Montreal, Canada, May 1-6, 2011.

Nominations and supporting documents must be submitted electronically (additional hard copy submissions are optional) to Jerzy Ruzyllo, Penn State University, 214 Electrical Engineering West, University Park, PA 16802-2701, USA; e-mail: jruzyllo@ psu.edu. Materials are due by May 1, 2010.



The award of ECS FELLOWS was established in 1989 for individual contribution and leadership in the achievement of science and technology in the area of electrochemistry and solid-state sciences and current active

participation of the affairs of ECS, and consists of a scroll, lapel

pin, and announcement in a Society publication. The next Fellows will be presented at the ECS fall meeting in Las Vegas, Nevada, October 10-15, 2010. Nominations and supporting documents should be sent to

Andrzej Wieckowski, University of Illinois, Chem/RAL 58B Box 56-5, 600 S. Mathews Ave., Urbana, IL 61801-3602, USA: email: andrzej@scs.uiuc.edu. Materials are due by January 15, 2010.



The 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 certificate, a prize of \$5,000, ECS Life Membership, and travel assistance to the meeting of the award presentation (up to \$1,000). The next award will be presented at the ECS fall meeting in Las Vegas, Nevada, October 10-15, 2010.

Nominations and supporting documents should be sent to Krishnan Rajeshwar, University of Texas, 700 Planetarium Place CPB 130, PO Box 19065, Arlington, TX 76019-0065, USA; e-mail: rajeshwar@uta.edu. Materials are due by January 15, 2010.



The ORONZIO NORA INDUSTRIAL DE ELECTROCHEMISTRY FELLOWSHIP OF THE ELECTROCHEMICAL SOCIETY was established in 2003 to assist a postdoctoral scientist or engineer in the research of the field of

industrial electrochemistry, and consists of a \$25,000 scholarship for one year, twice renewable based on successful research progress as judged by the award's committee. The next award will be announced April 1, 2010.

Nominations and supporting documents should be sent to Albert L. Barnes, Eltech Systems Corp., 625 East Street, Fairport Harbor, OH 44077-5668, USA; e-mail: al.barnes@denora.com. Materials are due by January 1, 2010.

ECS Division Awards



The BATTERY DIVISION RESEARCH AWARD was established in 1958 to recognize outstanding contributions to the science and technology of

primary and secondary cells and batteries and fuel cells. The award consists of a scroll, a prize of a \$2,000, travel assistance to the meeting if required, and membership in the Battery Division for as long as the winner is an ECS member. The next award will be presented at the ECS fall meeting in Las Vegas, Nevada, October 10-15, 2010.

Nominations and supporting documents should be sent to KM Abraham, E-Kem Sciences, 57 Colonial Rd., Needham, MA 02492-1612, USA; tel. 781.444.8453; e-mail: kmabraham@ comcast.net. Materials are due by March 15, 2010.



The Technology Award of the Battery Division was established in 1993 to encourage the development of battery and fuel cell technology. The award consists of a scroll, prize of \$1,000 and membership in the Battery Division for as long as the winner is a Society member. The next award will be presented at the ECS fall meeting in Las Vegas, Nevada, October 10-15, 2010.

Nominations and supporting documents should be sent to Martin Winter, Westfaelische Wilhelms Univ., Institute for Physical Chemistry, Muenster Corrensstrasse 28/30, D-4819 Muenster, Germany; tel. +49.251.83.36033; e-mail: martin. winter@uni-muenster.de. Materials are due by March 15, 2010.



The 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. The award consists of a scroll, a prize of \$1,500, and travel assistance

(continued from previous page)

to the meeting of the award presentation (if required). The next award will be presented at the ECS fall meeting in Las Vegas, Nevada, October 10-15, 2010.

Nominations and supporting documents should be sent to Robert Kelly, University of Virginia, 860 Charter Oaks Dr., Charlottesville, VA 22901-0630, USA; e-mail: rgk6y@virginia. edu. Materials are due by December 15, 2009.



The HIGH TEMPERATURE MATERIALS DIVISION **OUTSTANDING ACHIEVEMENT AWARD** was established in 1984 to recognize excellence in high temperature materials research and outstanding technical contributions to the field of high temperature

materials science. The award shall consist of a scroll, prize of a \$1,000, complimentary meeting registration, and travel assistance to meeting of award presentation (up to \$1,000). The next award will be presented at the ECS fall meeting in Las Vegas, Nevada, October 10-15, 2010.

Nominations and supporting documents should be sent to the award chair, Timothy R. Armstrong, Carpenter Technology, Corp. Res. & Dev., PO Box 14662, Reading, PA 19612, USA; tel: 610.208.3923; e-mail: tarmstrong@cartech.com. Materials are due by January 1, 2010.



The CENTENNIAL OUTSTANDING ACHIEVEMENT AWARD OF THE LUMINESCENCE AND DISPLAY MATERIALS DIVISION was established in 2002 to encourage excellence in luminescence and display materials research and outstanding contributions to the field of luminescence

and display materials science. It consists of a scroll and a prize of \$1,000. The next award will be presented at the ECS meeting in Las Vegas, Nevada, October 10-15, 2010.

Nominations and supporting documents should be sent to Anant A. Setlur, GE Global Research Center, 1 Research Circle, Room K1-4A41, Niskayuna, NY 12309, USA; tel. 518.387.6305; e-mail: setlur@research.ge.com. Materials are due by January 1, 2010.



The MAX BREDIG AWARD IN MOLTEN SALT CHEMISTRY OF THE PHYSICAL AND ANALYTICAL ELECTROCHEMISTRY DIVISION was established in1984 to recognize excellence in molten salt chemistry research and

consists of a scroll and a prize of \$1,500. The next award will be presented at the ECS fall meeting in Las Vegas, Nevada, October 10-15, 2010.

Nominations and supporting documents should be sent to Paul C. Trulove, Chemistry Department, US Naval Academy, 572M Holloway Rd., Stop 9B, Annapolis MD, 21402-5026, USA; tel. 410.293.6622, e-mail: trulove@usna.edu. Materials are due by January 31, 2010.



The Outstanding Achievement Award of the Sensor DIVISION was established in 1989 to recognize outstanding achievement in the science and or technology of sensors and to encourage excellence of work in the field. It consists of a scroll and a prize of \$1,000.

The next award will be presented at the ECS meeting in Las Vegas, Nevada, October 10-15, 2010.

Nominations and supporting documents should be sent to Girish M. Kale, Univ. of Leeds, Inst. for Materials Research, Leeds, West Yorkshire LS29JT, UK; tel. +44.113.343.2805; email: g.m.kale@leeds.ac.uk. Materials are due by January 1, 2010.

ECS Section Awards

The Allesandro Volta Medal of the European Section was established in 1998 to recognize excellence in electrochemistry and solid-state science and technology research, and consists of a silver medal and a check for \$500. The next award will be presented at the ECS meeting in Las Vegas, Nevada, October 10-15, 2010.

Nominations and supporting documents should be sent to Pawel J. Kulesza, University of Warsaw, Department of Chemistry, Pasteura 1, PL-02-093 Warsaw, Poland; tel. of 48.228220211, ext. 289 (office) or 277 (lab), fax: +48.22 8225996, e-mail: pkulesza@alfa.chem.uw.edu.pl. Materials are due by March 15, 2010.

ECS Monograph Series

Electrochemical Impedance Spectroscopy

by Mark E. Orazem & Bernard Tribollet



MARK E. ORAZEM, University of Florida and BERNARD TRIBOLLET, Centre National de la Recherche Scientifique (CNRS) and Pierre and Marie Curie University: 524 pages. ISBN 978-0-470-04140-6

This book provides the background and training suitable for application of impedance spectroscopy to varied applications, such as corrosion, biomedical devices, semiconductors and solid-state devices, sensors, batteries, fuel cells, electrochemical capacitors, dielectric measurements, coatings, electrochromic materials, analytical chemistry, and imaging. The emphasis is on generally applicable fundamentals rather than on detailed treatment of applications. With numerous illustrative examples showing how these principles are applied to common impedance problems, Electrochemical Impedance Spectroscopy is ideal either for course study or for independent self-study, covering:

A Special discount for ECS members! Order your copy from ECS E-mail: customerservice@electrochem.org Tel: 609.737.1902 Fax: 609.737.2743

WILEY Published by John Wiley & Sons, Inc.

The Electrochemical Society Interface • Fall 2009

NEW MEMBERS

ECS is pleased to announce the following new members for April, May, and June 2009.

-88

Active Members

Esta Abelev, Hillsboro, OR Jeremiah Abiade, Blacksburg, VA Rohan Akolkar, Hillsboro, OR Faisal Alamgir, Atlanta, GA Antoine Allanore, Lorraine, France Narayan Aluru, Urbana, IL Travis Anderson, Alexandria, VA Matthias Arenz, Garching, Germany Neal Armstrong, Tucson, AZ Michael Aziz, Cambridge, MA Jean-Claude Badot, Paris, France Vincenzo Baglio, Messina, Italy Francis Balestra, Grenoble, France Amit Bansiwal, Nagpur Maharashtra, India

Jianer Bao, Menlo Park, CA Sajid Bashir, Kingsville, TX Indra Basumallick, Bolpur, India Christine Beavers, Berkeley, CA Amr Beltagi, Kafr El-Sheikh, Egypt Haluk Beyenal, Pullman, WA Renata Bilewicz, Warsaw, Poland Govoreanu Bogdan, Leuven, Belgium Mary-Elizabeth Bolster, Mount Airy, MD Roger Bonnecaze, Austin, TX Florina Branzoi, Bucharest, Romania Valerie Butterhof, Rockville, MD Stephane Campidelli, Gif sur Yvette, France Christopher Campion, West Groton, MA Jeannette Chantalat, Skillman, NJ Greg Chase, Nashua, NH Sumit Chaudhary, Ames, IA Min-Hua Chen, Koshiung, Taiwan Bei Chen, Sunnyvale, CA Bruce Claflin, Dayton, OH Cedric Coia, Bromont, QC, Canada Fabrice Courtel, Ottawa, ON, Canada

Felice Crupi, Arcavacat di Rende, Italy Ismaila Dabo, Paris, France Tulika Dalavoy, Albany, NY Nimai Datta, Thane, Maharashtra, India James Davis, Nottingham,

Nottinghamshire, United Kingdom Jin-Pei Deng, Tamsui, Taipei, Taiwan Sheba Devan, Cupertino, CA Abhishek Dhanda, Mission Viejo, CA Ravi Droopad, San Marcos, TX Arwind Dubey, Ruwi Muscat, Oman Teresa Duncan, Fairfax, VA Oguz Elibol, Santa Clara, CA Ionut Enculescu, Magurele, Romania Geert Eneman, Heverlee, Vlaams-Brabant, Belgium Craig Evans, Portland, OR Emiliana Fabbri, Tsukuba, Ibaraki, Japan

William Fahrenholtz, Rolla, MO Christian Fau, Southfield, MI Jon Ferencuha, Midland, PA Eugen Foca, Radebeul, Saxony, Germany Michael Fuhrer, College Park, MD Juan-Carlos Galvan, Madrid, Spain

Stephen Garofalini, Piscataway, NJ Javier Gazzarri, Vancouver, BC, Canada William Gemmill, Phillipsburg, NI Rosalba Gerbasi, Padova, Italy Serguei Goupalov, Jackson, MS Miklos Gratzl, Mayfield Heights, OH Lorenz Gubler, Villigen PSI, Switzerland Pradeep Guduru, Walnut Creek, CA Liang Guo, East Lansing, MI Evgeni Gusev, San Jose, CA Christopher Gwenin, Bangor, United Kingdom Otto Haas, Minusio, Switzerland Selma Hansal, Markt Peisting, Austria Charles Hays, Pasandena, CA Russell Heathcote, Althofen, Austria Seiichiro Higashiya, Albany, NY Christopher Hinkle, Richardson, TX Shifeng Hou, Montclair, NJ Pei-Huan Hsieh, Koahsiung, Taiwan Chen-Peng Hsu, Hsinchu County, Taiwan Li-Hsien Huang, Tainan, Taiwan Gunnar Hultquist, Stallarholmen, Sweden Supat leamsupapong, Bangkok, Thailand Hiroki Imoto, Kobe, Japan Shinsuke Inagi, Yokohama, Japan Benjamin Jacobs, Livermore, CA Hosen Jawan, Alkhoms, Libya Meng Jiang, Berkeley, CA Luhua Jiang, Indianapolis, IN Antonia Jimenez-Morales, Leganes, Spain Jan-Fong Jue, Idaho Falls, ID Toshihiko Kanayama, Tsukuba, Ibaraki, Japan Steven Kaye, San Diego, CA Boris Kiefer, Las Cruces, NM Dae Sik Kim, Los Alamos, NM Haekyoung Kim, Gyeongsan, Gyeongbuk, South Korea Doo Young Kim, Okemos, MI Heesan Kim, Vestavia Hills, AL Adam Kisor, Pasadena, CA Refik Kortan, Warren, NJ Joseph Kowal, Aberdeen Proving Ground, MD Charoenkwan Kraiya, Bangkok, Thailand Jaideep Kulkarni, London, United Kingdom Peter Kurunczi, Cambridge, MA Erkan Kuzeci, Rozzano, Milan, Italy Se-Hun Kwon, Busan, South Korea Shuo-Jen Lee, Chung-Li, Taiwan Won-Gyu Lee, Chunchon, Kangwon, South Korea Sungwon Lee, Lemont, IL Vladislav Levenets, Medford, MA A Lewenstam, Abo, Finland Guofeng Li, Fairfax, VA Yanli Li, Paris, France Chenzhong Li, Miami, FL Ray-Ming Lin, TaoYuan, Kwei-Shan, Taiwan Wing Liu, Mountain View, CA Ying Liu, Saint Paul, MN Frank Liu, Troy, MI

Carmen Lopez, Wheaton, IL Herman Lopez, Sunnyvale, CA Olivier Lottin, Vandoeuvre, Nancy, France Melanie Loveridge, Culham, Oxfordshire, United Kingdom Ben Luan, London, ON, Canada Paolo Magnone, Rende (CS), Italy Edoardo Magnone, Ibaraki, Japan Rabindra Mahapatra, Patuxent River, MD Christopher Marrows, Leeds, United Kingdom Ryouji Marubayashi, Tsu-shi, Mie, Japan Sharon Marx, Pittsburgh, PA Takuya Masuda, Sapporo, Japan John Matachek, St. Paul, MN Kazuhiko Matsumoto, Kyoto, Japan Toyoaki Matsuura, Ann Arbor, MI Rashid Mavliev, Campbell, CA Patrick McGrath, Arlington, VA Lamartine Meda, New Orleans, LA Robert Miller, Delmar, NY Hiroaki Misawa, Sapporo, Japan Toshinori Miura, Numazu, Shizuoka, Japan Takaaki Mizukami, Hitachi, Ibaraki, Japan Hugo Mosqueda Altamirano, Nantes, France Bill Murray, Alpharetta, GA Tomio Nagayama, Kyoto, Japan Udayabhanu Nair, Dhanbad, Jharkhand, India Kazu Nakajima, San Jose, CA Patcheammalle (Pat) Nandakumar, Odessa, TX Linda Nazar, Waterloo, ON, Canada Trung Nguyen, Lawrence, KS Shinji Nohara, Yamanashi, Japan Gottlieb Oehrlein, College Park, MD Hiroaki Okamoto, Ube, Japan Alejandro Oyarce, Stockholm, Sweden Fu-Ming Pan, Hsinchu, Taiwan Yong Joon Park, Suwon-si, South Korea Jung Park, Yongin-si, South Korea Dae Bong Park, Seoul, South Korea Jong Il Park, Gyeong-buk, South Korea Andre A. Pasa, Florianopolis, SC, Brazil Mary Patterson, Carmel, IN Robert Payne, Joplin, MO Kanala Phani, Tamil Nadu, India Luisa Pilan, Bucharest, Romania Steven Policastro, Odenton, MD Estelle Potvin, Varennes, QC, Canada Sung Gyu Pyo, Cheongju-Si Chungcheongbuk-Do, South Korea Baixin Qian, Palo Alto, CA Rui Qiao, Clemson, SC Aleksandar Radu, Dublin, Ireland Ramaraja Ramasamy, Panama City, FL John Robertson, Cambridge,

Cambridgeshire, United Kingdom David Robinson, Livermore, CA Israel Rodriguez, San Luis Potosi, Mexico

Maia Romanes, Denton, TX Kevin Ryan, Limerick, Ireland

NEW MEMBERS

-81

Bruce Sabacky, Reno, NV Leonardo Salgado, Distrito Federal, Mexico Hirotaka Sato, Albany, CA Molly Scheffe, Carlisle, MA Julian Schwenzel, Bremen, Germany David Seidman, Evanston, IL Siegfried Selberherr, Tulln, Austria Bert Sels, Heverlee, Belgium Inseok Seo, Ames, IA Jeffrey Shallenberger, Phoenix, AR Paul Shen, Adelphi, MD Satoru Shinzaki, Southfield, MI Ashok Shukla, Bangalore, India Lidija Siller, Newcastle upon Tyne, United Kingdom Premkumar Sivasubramanian, Aiken, SC Matt Smith, Los Gatos, CA Karel Stulik, Prague, Czech Republic Yuh-Fan Su, Taichung, Taiwan Haoran Sun, Vermillion, SD Svein Sunde, Trondheim Sor-Trondelag, Norway Taison Tan, Indianapolis, IN Jason Tang, Hillsboro, OR Ji Yue Tang, Pudong New Area, Shanghai, China Thomas Thomberg, Tartu, Estonia Indrajeet Thorat, Bartlesville West, OK Z. Rvan Tian, Favetteville, AR Osamu Tonomura, Odawara, Kanagawa, Japan Katsuhiko Tsunashima, Gobo, Wakayama, Japan Avi Ulus, Kiryat Ekron, Israel Nicole van der Laak, Pokfulam, Hong Kong Parichatr Vanalabhpatana, Bangkok, Thailand Anabela Veloso, Leuven, Belgium Branzoi Viorel, Bucharest, Romania Siegfried Waldvogel, Bonn NRW, Germany Shiunchin Wang, Brooklyn, NY George Wang, Albuquerque, NM Robert Wang, Berkeley, CA Xiaojian Wang, Upton, NY Chung-Yih Wang, Irvine, CA Christoph Wannek, Juelich, North Rhine-Westphalia, Germany David Williams, Auckland, New Zealand C. Willson, Austin, TX Jamie Wilson, Tonawanda, NY Liqi Wu, Santa Clara, CA Gang Wu, Los Alamos, NM Huiming Wu, Lemont, IL Shich-Chuan Wu, Hsinchu, Taiwan Deyuan Xiao, Shanghai, China Xinzhong Xue, Ottawa, ON, Canada Naoki Yamamoto, Kochi, Japan Michael Yang, Palo Alto, CA Chien-Hsin Yang, Kaohsiung City, Taiwan Gowri Yeduvaka, Athens, GA Ying Zhang, Yorktown Heights, NY Enxia Zhang, Nashville, TN Jian Zhou, Potsdam, NY

Member Representatives

Martin Schuster, Kamenz, Germany Max Yaffe, Warminster, PA Joel Zazyczny, Morrisville, PA

Student Members

Hina Abid, Lahore Punjab, Pakistan Tahmina Akter, Toronto, ON, Canada Nabeel Amir, Bahwalpur, Punjab, Pakistan Salzitsa Anastasova, Dublin, Ireland Toyli Anniyev, Menlo Park, CA Pendar Ardalan, Stanford, CA Roy Arnab, Storrs, CT Christelle Arnould, Namur, Belgium Muhammad Ashraf, Lahore, Pakistan Banfsheh Babakhani, Edmonton TGV, Alberta, Canada Kang Bae, Gyeongsan, South Korea Andrew Bak, Scaggsville, MD Katharina Becker-Steinberger, Ulm, BW, Germany Keith Beers, Berkelev, CA Hadar Ben-Yoav, Tel-Aviv, Israel David Bierschenk, Evanston, IL Kyle Braam, Berkeley, CA Neil Brahma, San Diego, CA Eric Broaddus, Ruston, LA Jiaving Cai, Tempe, AZ Eric Carlson, Albany, CA Partha Chakraborty, Atlanta, GA Jeng-Kuei Chang, Tainan, Taiwan Chetan Chaudhari, Tempe, AZ Bwo-Ning Chen, Keelung City, Taiwan Yi-Hsin Chen, Durham, NH Ke-Hung Chen, Gainesville, FL Dao-Sheng Chen, Taichung, Taiwan Haiyan Chen, Amiens, France Sin-An Chen, Hsinchu, Taiwan Tian-Hao Cheng, Taichung, Taiwan Andrew Chien, Akron, OH Ya-Lan Chiou, Tainan, Taiwan Hyoup Je Cho, Pohang, South Korea Dae-Jin Choi, Laramie, WY Byung-Hwan Chu, Gainesville, FL Gustavo Ciniciato, San Carlos, Brazil Laurie Clare, El Cajon, CA Richard Connolly, Riverview, FL Thomas Conry, Berkeley, CA Christopher Corcoran, Tampa, FL Nathan Craig, Berkeley, CA Damien Dambournet, Chicago, IL Robert Daniel, Cambridge, MA Mahdi Darab, Trondheim, Norway Hari Prasad Dasari, Seoul, South Korea Kathryn Davis, Pittsburgh, PA Michelly de Souza, Sao Paulo, Brazil Lisa Deleebeeck, Calgary, Alberta, Canada Sebastien Devillers, Namur, Belgium Wayne Doherty, Louth, Ireland Lior Elbaz, Beer Sheva, Israel Yoichi Endo, Bunkyo-ku, Tokyo, Japan Erika Engstrom, Tempe, AZ Kara Evanoff, Atlanta, GA Zeng Fan, Palo ALto, CA Mohammad Farooque, Danbury, CT Ileana Feliciano, Isabela, PR Guang Feng, Clemson, SC

Rodrigo Ferreira de Morais, Grenoble, France

Gragory Fonder, Namur, Belgium Richard Fu, Storrs Mansfield, CT Yan Gao, Lawrence, KS Federico Garcia-Galvan, Madrid, Spain Debra Gilbuena, Corvallis, OR Puneet Kamal Gill, Miami, FL Dincer Gokcen, Houston, TX Mohammad Haider, Charlottesville, VA Dionne Hernandez-Lugo, Ceiba, PR Michael Hess, Cambridge, MA Justin Hill, Gainesville, FL Megan Hoarfrost, Berkeley, CA Rvan Hsu, Toronto, ON, Canada Chia-Wei Hsu, Hsinchu, Taiwan Liangbing Hu, Mountain View, CA Liudmila Ilyukhina, Trondheim, Sor-Trondelag, Norway Noriko Izumi, Nagoya City, Aichi, Japan Xiu Jiang, Athens, OH Yingqi Jiang, Berkeley, CA Ashish Kamat, Braunschweig, Germany Ainnur Kamisan, Shah Alam, Malaysia Young Jin Kang, Pohang, South Korea Keon Hyeong Kim, Seoul, South Korea JongGi Kim, Seoul, South Korea Ji-Young Kim, Seoul, South Korea Bohye Kim, Gwangju, South Korea Hyun-Kyung Kim, Seoul, South Korea Ji-hwan Kim, Gyeongsan, South Korea Taek-Soo Kim, Stanford, CA Kyle Kotaich, Salem, OR Denis Kramer, Cambridge, MA Joern Kulisch, Bonn, NW, Germany Ou Jung Kwon, State College, PA John LaBarba, Berkeley, CA Michael Lang, Madison, NJ Bongki Lee, Richardson, TX YongJian Li, Chongqing, China Yunsong Li, Xiamen, China Wun-Shan Li, Hsinchu City, Taiwan Liang Li, Boston, MA Wei-Chih Li, Taipei, Taiwan Zhan Lin, Raleigh, NC Ching Chun Lin, Hsinchu, Taiwan Chun Yi Liu, Hsinchu, Taiwan Yihua Liu, Johnson City, NY Paula Lopes, Durham, United Kingdom De-En Lu, Tainan, Taiwan Sonia Maciejewski, Chula Vista, CA Maciej Marczewski, Warsaw, Poland Maria Marti Villalba, Nottingham, Notts, United Kingdom Elena Matei, MAgurele, Romania Taku Matsuzaka, Nosa, Chiba Japan Laurence Mayrand-Provencher, Montreal, QC, Canada Kirk McGuire, Ortonville, MI

Christopher McTiernan, Val Caron, ON, Canada

Brandon Mercado, Davis, CA Craig Metcalfe, Toronto, ON, Canada Rene Meyer, Mountain View, CA Tumaini Mkwizu, Pretoria, South Africa Ahmed Moghieb, Gainesville, FL Vanessa Monier, Grenoble, France Scott Mullin, Berkeley, CA Ryo Nakanishi, Nagoya, Japan Amir Nakash, Brooklyn, NY Vasily Nakostenko, Freiberg, Germany

NEW MEMBERS

Johnpeter Ngunjiri, Baton Rouge, LA Leszek Niedzicki, Mazowiecke, Poland Nick Norberg, Berkeley, CA Yuki Nozaki, Kyoto, Kyoto Japan Shih-Fu Ou, Taipei, Taiwan Marcela Ovalle, Mexicali, Baja California, Mexico Ashish Pande, Atlanta, GA Boumyoung Park, Albany, CA Shrayesh Patel, Berkeley, CA Devproshad Paul, Kingston, ON, Canada Christina Peabody, Princeton, NJ Blaise Pinaud, Stanford, CA William Pinc, Rolla, MO Elad Pollak, Albany, CA Benedict Portillo, Clint, TX Antonin Prevoteau, Bordeaux, France Ping Qui, Stockholm, Sweden Md. Mokhlesur Rahman, Wollongong, NSW, Australia Cesar Ramos, Tabasco, Mexico Gayathri Rao, Albany, NY Steve Rhieu, Providence, RI

Steve Rhieu, Providence, RI Amy Richards, Edgewater, CO Leah Riley, Boulder, CO Mason Risley, Socorro, NM Jason Rugolo, Boston, MA Roshidah Rusdi, Selangor, Malaysia

Robert Sacci, Victoria, Canada Sonny Sachdeva, Golden, CO Michael Sanders, Golden, CO Emeline Saracco, Grenoble, France Justin Scott, Chicago, IL Michael Shaltry, Idaho Falls, ID Shuanglin Shen, Xingtai, China Disha Sheth, Cleveland Heights, OH Zhongving Shi, Walled Lake, MI Qian Shi, Guangzhou, Guangdong, China Fiona Sillars, Glasgow, United Kingdom Tamiru Simano, Adama, Ethiopia Mitsuru Sometani, Tsukuba, Ibaraki, Japan Dong Chan Suh, South Korea Matthew Suss, Stanford, CA V. Swope, East Lansing, MI Shuhei Takashima, Kyoto, Japan Chihiro Tamura, Tsukuba, Ibaraki, Japan Hongjin Tan, Pasadena, CA Alexander Teran, Berkeley, CA Qifeng Tian, Toronto, ON, Canada Takane Usui, Stanford, CA Ana Valenzuela, Chihuahua, Mexico Jasper Van Noven, Heverlee, Belgium

Sri Sai Sivakumar Vegunta, Baton Rouge, LA Jeyavel Velmurugan, Jamaica, NY Luciano Vieceli Taveira, Porta Alegre, RS, Brazil

Nicholas Vito, Gainseville, FL Fred Wafula, Johnson City, NY Nisita Wanakule, Berkeley, CA Deyu Wang, Richland, WA Chun Chieh Wang, Tainan, Taiwan Takashi Watanabe, Kyoto, Japan Siyu Wei, Nashville, TN Stephane Werwinski, Southampton,

Hampshire, United Kingdom Colin Wessells, Palo Alto, CA Ryan West, Atlanta, GA James Wilson, Chicago, IL David Wong, Berkeley, CA Jessica Woods, Davis, CA James Woodworth, Cleveland, OH Li Xiao, Wuhan, China Qinqin Xu, Bern, Switzerland Nai Yang, Taichung, Taiwan Jie Yang, Oslo, Norway Sung-Hun Yu, Seoul, South Korea Mehdi Zamanpour, Boston, MA Kan Zhang, Madison, WI Yongning Zhou, Upton, NY Haihui Zhou, Hong Kong, China



Student Grants and Awards Student awards and support for travel available from ECS Divisions

Student Poster Sessions

Present papers and participate in student poster sessions at ECS meetings

ECS Member Article Pack

100 full-text downloads from the Journal of The Electrochemical Society (JES), Electrochemical and Solid-State Letters (ESL), and ECS Transactions (ESCT)

Interface - Members Magazine Contains topical issues, news, and events

Discounts on ECS Meetings Valuable discounts to attend ECS spring and fall meetings

Discounts on ECS Transactions, Monographs, and Proceedings Volumes ECS publications are a valuable resource for students

ECS is an international, educational organization with more than 8,000 scientists and engineers in over 70 countries, engaged in a broad range of technical interests including: Batteries, Corrosion, Dielectric Science & Technology, Electrodeposition, Electronics & Photonics, Energy Technology, Fullerenes, Nanotubes, and Carbon Nanostructures, High Temperature Materials, Industrial Electrochemistry & Electrochemical Engineering, Luminescence & Display Materials, Organic & Biological Electrochemistry, Physical and Analytical Electrochemistry, and Sensors.

The Electrochemical Society 65 South Main Street, Building D Pennington, New Jersey 08534-2839 USA Tel 609.737.1902 • Fax 609.737.2743

AGSTANSACTIONS Volume 16-Honolulu, Hawaii

from the PRiME Honolulu meeting, October 12-October 17, 2008

The following issues of ECS Transactions are from symposia held during the Honolulu PRIME meeting. All issues are available in electronic (PDF) editions, which may be purchased by visiting http://ecsdl.org/ECST/. Some issues are also available in hard cover (HC) editions. Please visit the ECS website for all issue pricing and ordering information. (All prices are in U.S. dollars; M = ECS member price; NM = nonmember price.)

Available Issues—Hard Cover (HC) & Electronic (PDF)

Vol. 16

Vol. 16

No 40

Solid State (General)

PDF

214th ECS Meeting/PRIME 2008

...M \$35.00, NM \$43.75

- Vol. 16 Electrochemical Capacitors and Hybrid Power Batteries 2008 HC......M \$85.00, NM \$107.00 PDF......M \$58.20, NM \$72.75
- Vol. 16
 Proton Exchange Membrane Fuel Cells 8

 No. 2
 HC
 M \$154.00, NM \$191.00

 PDF
 M \$135.20, NM \$169.00
- Vol. 16 No. 3 Held in Memory of Vitali Parkhutik and Volker Lehmann HC.......M \$85.00, NM \$107.00 PDF......M \$97.60, NM \$97.00
- Vol. 16 Atomic Layer Deposition Applications 4 HC......M \$71.00, NM \$89.00 PDF......M \$66.80, NM \$83.50

- Vol. 16 State-of-the-Art Program on Compound No. 7 Semiconductors 49 (SOTAPOCS 49) - and- Nitrides and Wide-Bandgap Semiconductors for Sensors,
- Photonics, and Electronics 9 HC......M \$76.00, NM \$95.00 PDF......M \$54.00, NM \$67.50
- Vol. 16 Semiconductor Wafer Bonding 10: No. 8 Science, Technology, and Applications HC.......M \$93.00, NM \$117.00 PDF.......M \$93.80, NM \$117.25

Micro Power Sources

- Thin Film Transistors 9 (TFT 9) HC.....M \$94.00, NM \$118.00 Vol. 16 No. 9 HC..... PDF M \$86.40, NM \$108.00 SiGe, Ge, and Related Compounds 3: Vol. 16 Materials, Processing, and Devices HC.....M \$135.00, NM \$168.00 No. 10 M \$115.20, NM \$144.00 PDF Chemical Sensors 8: Chemica (Gas. Ion Vol. 16 Bio) Sensors and Analytical Systems HC......M \$105.00, NM \$131.00 No. 11 ..M \$95.00, NM \$118.75 PDF. ZnO Based Thin Films, Nano-Wires, and Vol. 16 Nano-Belts for Photonic and Electronic Devices No. 12
 - and Sensors HC.......M \$66.00, NM \$82.00 PDF......M \$34.80, NM \$43.50

Available Issues-Electronic (PDF) Only

- Vol. 16 Tutorial Symposium on Electrochemical No. 13 Engineering, in Honor of Professor John Newman's 70th Birthday PDF M \$34.80, NM \$43.50
- Vol. 16 Microfabricated and Nanofabricated No. 14 Systems for MEMS/NEMS 8 PDF......M \$36.60, NM \$45.75
- Vol. 16 Tutorials in Nanotechnology: No. 15 Focus on Sensors PDF......M \$16.71, NM \$20.89
- Vol. 16 High Power Batteries for Hybrid EV and No. 16 Portable Power
- PDF......M \$14.61, NM \$18.26 Vol. 16 Challenges to Single-Cell Engineering
- No. 17 and Imaging Technology PDFM \$16.71, NM \$20.89
- Vol. 16 New Frontiers of Synthetic and Mechanistic Organic Electrochemistry PDF......M \$14.61, NM \$18.26
- Vol. 16 Copper Interconnects, New Contact Metallurgies/ No. 19 Structures, and Low-k Inter-level Dielectrics PDF......M \$20.92, NM \$26.15
- Vol. 16 Science and Technology of Dielectrics for No. 21 Active and Passive Devices
- PDF...... M \$18.82, NM \$23.52 Vol. 16 Electronics Packaging 3
- Vol. 16
 Bioelectroanalysis

 No. 23
 PDF......M \$10.40, NM \$13.00
- Vol. 16 Student Posters (General) -No. 24 214th ECS Meeting/PRiME 2008 PDF......M \$58.52, NM \$73.15
- Vol. 16 Nanotechnology (General) -No. 25 214th ECS Meeting/PRIME 2008 PDF......M \$51.16, NM \$63.95
- No. 26 PDF......M \$27.23, NM \$34.04 Environmental Electrochemistry Vol. 16 No. 27 PDFM \$12.50, NM \$15.63 Physical, Analytical, and Spectro-Electrochemistry (General) - 214th ECS Meeting/ Vol. 16 No. 28 **PRIME 2008** PDF ..M \$27.23, NM \$34.04 **Rechargeable Lithium and Lithium** Vol. 16 No. 29 Ion Batteries PDF ...M \$52.63. NM \$65.79 **Phosphors for New-Generation Lighting** Vol. 16 No. 30 PDF......M \$27.23, NM \$34.04 Vol. 16 Physics and Chemistry of Luminescent Materials, including the 4th Symposium on Persistent No. 31 Phosphors PDFM \$48.22, NM \$60.27 Vol. 16 Corrosion and Electrochemical Properties of Bulk Metallic Glasses and Nano-Crystalline No. 32 Materials .M \$25.13 NM \$31.41 PDF One-Dimensional Nanoscale Electronic and Vol. 16 **Photonic Devices 2** No. 33 PDF .. M \$18.82, NM \$23.52 Vol. 16 Large Scale Energy Storage SystemsM \$25.13, NM \$31.41 No. 34 PDF Vol. 16 Non-Aqueous Electrolytes for Lithium Batteries .M \$48.22, NM \$60.27 No. 35 PDF. Vol. 16 Green Electrodeposition 2 No. 36 PDF.....M \$27.23, NM \$34.04 Vol. 16 **Electrocatalysis**M \$12.50, NM \$15.63 No. 37 PDF ... Vol. 16 Biological Nanostructures, Materials, and No. 38 Applications PDF. M \$27.23, NM \$34.04 **Electrodes for Industrial Electrochemistry** Vol. 16 No. 39 ..M \$23.02, NM \$28.78 PDF.
- Vol. 16 **Integrated Optoelectronics 4** No. 41 PDF Intercalation Compounds for Energy Conversion Vol 16 and Storage Devices No. 42 PDF.....M \$31.22, NM \$39.03 Vol. 16 **Corrosion in Marine and Saltwater** No. 43 **Environments 3** PDFM \$42.55, NM \$53.19 High Temperature Corrosion and Vol. 16 Materials Chemistry 7 No. 44 PDF......M \$49.69, NM \$62.11 Vol. 16 Magnetic Materials, Processes, and Devices 10 No. 45 PDF......M \$57.05, NM 71.31 Vol. 16 Molecular Structure of the Solid-Liquid Interface No. 46 and its Relationship to Electrodeposition 6 ...M \$33.11, NM \$41.39 PDF Vol. 16 Nanostructure and Function of Fullerenes, Carbon Nanotubes, and Related Materials No. 47 PDF M \$16.71 NM \$20.89 Vol. 16 **Corrosion Posters (General)** No. 48 214th ECS Meeting/PRIME 2008 PDFM \$25.13, NM \$31.41 Vol. 16 Molten Salts and Ionic Liquids 16M \$96.35 NM \$120.44 No. 49 PDF Battery and Energy Technology (General) -214th ECS Meeting/PRiME 2008 Vol. 16 No. 50 ...M \$46.33, NM \$57.91 PDF Vol. 16 Solid State Ionic Devices 6 - Nano IonicsM \$82.91. NM \$103.64 PDF No. 51 Critical Factors in Localized Corrosion 6, Vol. 16 in Honor of Professor Shibata No. 52 PDF.....M \$65.46, NM \$81.83

Ordering Information

To order any of these recently-published titles, please visit the ECS Digital Library, http://ecsdl.org/ECST/

ECS 2009 Summer Fellowship Winners

Each year ECS gives up to five Summer Fellowships to assist students in continuing their graduate work during the summer months in a field of interest to the Society. Congratulations to the following 2009 Summer Fellowship recipients. The reports of the 2009 Summer Fellows will appear in the winter issue of *Interface*.



SHULEI CHOU is the recipient of the 2009 ECS Edward G. Weston Summer Fellowship. Mr. Chou is a PhD student under the supervision of Prof. Huakun Liu, Prof. Shixue Dou, and Dr. Jiazhao the Institute Wang at for Superconducting & Electronic Materials (ISEM) and the ARC Centre of Excellence for Electromaterials Science (ACES), University of Wollongong, Australia. His PhD project is mainly focused on novel nanomaterials and composite materials fabrication.

characterization, and electrochemical measurements and analysis. The novel materials, such as V_2O_5 nanomaterials, SnO_2 nanotubes, PPy-LiFePO₄ composites, and MnO₂ nanowires/CNT composites were used in Li-ion rechargeable batteries or supercapacitors showing enhanced performance. The successful results have been published or accepted in 12 papers and seven as first author in well-known international journals: *J. Electrochem. Soc., Electrochem. Solid-State Lett., Chem. Mater., Electrochem. Commun.*, and *J. Power Sources*. This summer, Mr. Chou will continue his research work by visiting to Prof. Jeff Dahn's group in Dalhousie University, Canada.



HyeA KIM is the recipient of the 2009 ECS Colin Garfield Fink Summer Fellowship. Ms. Kim received her bachelor's degree in chemical engineering from Yonsei University in Korea in 2003. After graduation, she was employed as an engineer in the fuel cell division of the energy lab at Samsung SDI Corporate R&D Center. She was involved in optimizing the catalyst layers of proton exchange membrane electrodes. In 2006, she entered the PhD program at the Georgia

Institute of Technology. Currently, she is a PhD candidate in chemical engineering at Georgia Tech under the supervision of Dr. Paul Kohl. Her research is focused on producing high energy density, inorganic membrane fuel cells for wireless applications.



HAIZHOU LIU is the recipient of the 2009 ECS Joseph W. Richards Summer Fellowship for 2009. He received his bachelor's degree from Sichuan University in China (2006) and master's degree from University of Washington, Seattle (2007), both majoring in environmental engineering. Haizhou is working toward a PhD in environmental science and engineering under the supervision of Profs. Gregory Korshin and John Ferguson at the University of Washington, Seattle. His research

focuses on the lead release from drinking water distribution system with corroded pipes, specifically the mechanisms and kinetics of Pb(II) solid oxidation by chlorine and the interactions of Pb(II)/Pb(IV) solids with chloramine and natural organic matter in drinking water. He is currently applying advanced electrochemical methods to probe these environmental chemical processes. Mr. Liu has coauthored several referred journal publications and received a graduate student paper award from American Chemical Society, division of environmental chemistry, in 2009.



STEVE RHIEU is the recipient of the 2009 ECS F. M. Becket Summer Fellowship. Mr. Rhieu graduated with a BS degree in bioengineering from the University of California at Berkeley in 2004. In fall 2005, he joined G. Tayhas R. Palmore's group at Brown University where he is currently finishing his PhD. During the first two years of his studies, he concentrated on studying laccase, a multi-copper oxidoreductase, which can be used as a biocatalyst in biofuel cells under benign physiological

conditions. During the past two years, the main focus of his research has been the development of an electrochemical biosensor for vitamin D3 using an electrode coated with cytochrome P450 27B1 (CYP27B1), which selectively hydroxylates 25-hydroxycholecalciferol to give 1α ,25-dihydroxycholecalciferol, the biologically active form of vitamin D3. Some of the other projects in which he has participated include the development of a method to measure molecular diffusion coefficients using nanofluidic channels and HPLC-GC/MS based vitamin D drugs metabolism. He is the recipient of the NASA Rhode Island Space Grant Fellowship (fall 2006-fall 2007) and the NSF GK-12 Graduate Teaching Fellowship (fall 2009-spring 2010).



VENKAT VISWANATHAN is the recipient of the 2009 ECS Herbert H. Uhlig Summer Fellowship. He is a PhD candidate in mechanical engineering at Stanford University. He graduated with a bachelor's and a master's degree in mechanical engineering from the Indian Institute of Technology, Madras. His research, under the guidance of Prof Heinz Pitsch and Prof Thomas laramillo. involves developing theoretical molecular methods for understanding electrochemical

reactions on catalyst surfaces. The recent focus of his research has been on applying a combination of quantum calculations and Monte Carlo based methods to study electrocatalysis of reactions relevant to fuel cells, namely oxygen reduction reaction.

(continued on next page)

2009 Summer Fellowship Committee Vimal Desai, Chair New Mexico State University Scott Lillard Los Alamos National Laboratory Kalpathy Sundaram University of Central Florida

Enrico Traversa University of Rome "Tor Vergata"

(continued from previous page)



Battery Division 2009 Student Research Award



NONGLAK MEETHONG has been named the Battery Division's 2009 Student Research Award recipient. In 2000, Dr. Meethong was awarded a full scholarship from the Royal Thai Government to study in the United Stated. She received her BS degree in ceramic engineering from Alfred University, Alfred, NY in 2004 working with Prof. Doreen Edwards, and her PhD in materials science and Massachusetts engineering from Institute of Technology, Cambridge,

MA in June 2009, working with Professor Yet-Ming Chiang. Currently, she is a junior faculty member in the Department of Physics, Faculty of Science at Khon Kaen University, Thailand.

Her doctoral work at MIT was on understanding the correlation between particle size, composition (doping), phase behavior, and phase transformation kinetics, and their relation to practical properties for the LiMPO₄ olivine cathode compounds for Li-ion batteries. Her current research interests are in the fields of ceramic science, solid-state electrochemistry, and nanotechnology focusing on using nanomaterials for energy storage and environmental applications.

Dr. Meethong has co-authored eight scientific articles (*Science, Adv. Funct. Mater., Chem. Mater., Solid State Ionics, Electrochem. Solid-State Lett., Mater. Res. Soc. Symp. Proc.*) and two world patents so far. Among other honors, she has won two travel grant awards from ECS (2007, 2008), the "Most Excellent Paper Award" at the International Meeting on Lithium Batteries, held June 2008 in Tianjin, China, and the "Best Poster Presentation Award" for "Nanoscale Olivine Compounds as High-Power Li-ion Battery Positive Electrodes for Transportation Applications" on Materials Day 2008 at MIT. She may be reached at nmpuye@alum.mit.edu.



Corrosion Division 2009 Morris Cohen Graduate Student Award



MARIANO IANNUZZI has been named the recipient of the Corrosion Division's 2009 Morris Cohen Graduate Student Award. Dr. Iannuzzi completed his BS degree in materials engineering in 2002. He joined the Fontana Corrosion Center (FCC) at The Ohio State University (OSU) in fall 2002, and obtained his PhD in materials science and engineering in the fall of 2006 with Professor Jerry Frankel as adviser. While at the FCC, Dr. Iannuzzi helped in the organization of both the NACE

and ECS student chapters. In October 2006 he joined the Corrosion and Materials Technology Laboratory (CAMT) at Det Norske Veritas (DNV)-Columbus. He has recently moved to Norway to work for the Materials and Sensors program at the DNV Research and Innovation (DNVRI) department, lead by Dr. Narasi Sridhar. Dr. Iannuzzi's dissertation focused on the mechanisms of corrosion inhibition of high strength aluminum alloys by vanadates. His work provided a better understanding on the effects of metavanadate and decavanadate speciation on inhibition performance. While at DNV-Columbus, he worked in numerous materials compatibility issues with focus on the oil and gas industry. His current work includes corrosion and degradation issues in biofuels as well as materials compatibility in deep wells.

Dr. Iannuzzi's professional interest include materials issues in biofuel technologies, advanced coatings, and sensors for real-time localized corrosion detection. He is an active NACE and ECS member and is also the Vice-Chair of the NACE Biofuels Task Group (STG 035).

Start a Student Chapter!

ECS currently has 20 student chapters around the world, which provide students an opportunity to gain a greater understanding of electrochemical and solid-state science, to have a venue for meeting fellow students, and to receive recognition for their organized scholarly activities. Students interested in starting a student chapter may contact karla.stein@electrochem.org for details.



ECS takes an active interest in the affairs of its Student Members, and is always interested in hearing from you about your interests, activities, and accomplishments.

www.electrochem.org

The ECS SUMMER FELLOWSHIPS were established in 1928 to assist students during the summer months in pursuit of work in the field of interest to ECS. The next fellowships will be presented in 2010.

Nominations and supporting documents should be sent to Vimal H. Desai, New Mexico State University, Office of the VP for Research, MSC 3RES - Box 30001, Las Cruces, NM 88033-8001, USA, e-mail: vimalc@nmsu.edu. **Materials are due by January 1, 2010.**

The **STUDENT RESEARCH AWARD OF THE BATTERY DIVISION** was established in 1962 to recognize promising young engineers and scientists in the field of electrochemical power sources and consists of a scroll, a prize of \$1,000, and membership in the Battery Division as long as a Society member. The next award will be presented at the ECS fall meeting in Las Vegas, Nevada, October 10-15, 2010.

Nominations and supporting documents should be sent to Robert Kostecki, Lawrence Berkeley National Laboratory, 1 Cyclotron Rd., MS 70R0108B, Berkeley, CA 94720-8168, USA; tel. 510.486.6002, e-mail: r_kostecki@lbl.gov. Materials are due by March 15, 2010.

The MORRIS COHEN GRADUATE STUDENT AWARD OF THE CORROSION DIVISION was established in 1991 to recognize outstanding graduate research in the field of corrosion science and/or engineering. The award consists of a scroll, a prize of \$1,000, and travel assistance to the meeting where the award will be presented (up to \$1,000). The next award will be presented at the ECS fall meeting in Las Vegas, Nevada, October 10-15, 2010.

Nominations and supporting documents should be sent to Shinji Fujimoto, Osaka University Department MSP, 2-1 Yamada-oka, Suita, Osaka 565-0871 Japan; e-mail: fujimoto@ mat.eng.osaka-u.ac.jp. **Materials are due by December 15, 2009.**

Travel Grants

Several of the Society's Divisions offer travel assistance to students and young faculty members presenting papers at ECS meetings. For details about travel grants for 217th ECS Meeting in Vancouver, Canada, (April 25-30, 2010), please see the Vancouver, Canada Call for Papers in the summer 2009 issue; or visit the ECS website: www.electrochem.org/student/ travelgrants.htm. Please be sure to e-mail the student travel grant contact as each Division requires different materials for approval. **The deadline for submission for the spring 2010 travel grants is November 16, 2009.**

Awarded Student Memberships Available

ECS Divisions are offering Awarded Student Memberships to qualified full-time students. To be eligible, students must be in their final two years of an undergraduate program or enrolled in a graduate program in science, engineering, or education (with a science or engineering degree). Postdoctoral students are not eligible. Awarded memberships are renewable for up to four years; applicants must reapply each year. Memberships include article pack access to the *Journal of The Electrochemical Society* online, *Electrochemical and Solid-State Letters* online, *ECS Transactions* online, and a subscription to *Interface*. To apply for an Awarded Student Membership, use the application form on page 72 or refer to the ECS website at: www.electrochem. org/awards/student/student_awards.htm#a.

call for nominations

For details on each award—including a list of requirements for award nominees, and in some cases, a downloadable application form—please go to the ECS website (www.electrochem.org) and click on the "Awards" link. Awards are grouped in the following sub-categories: Society Awards, ECS Division Awards, Student Awards, and ECS Section Awards. Please see the individual award call for information about where nomination materials should be sent; or contact ECS headquarters.

Visit www. electrochem.org and click on "Awards" link.

Advertisers INDEX

nton Paar1	Ľ
o-Logic back cove	r
33.33.31.21.21.21.21.21.21.21.21.21.21.21.21.21	3
orida Solar Energy Center3	5
amry2, 4	ł
slow Scientific3	5
etrohm USA	5
inceton Applied Research	þ
lartron Analyticalinside back cove	r
ribner	3

ECS Awarded Membership Application

ECS Divisions are offering Awarded Student Memberships to qualified full time students. To be eligible, students must be in their final two years of an undergraduate program or be enrolled in a graduate program in science, engineering, or education (with a science or engineering degree). Postdoctoral students are not eligible. Awarded memberships are renewable for up to four years; applicants must reapply each year. Memberships include article pack access to the *Journal of The Electrochemical Society* online, *Electrochemical and Solid-State Letters* online, a subscription to *Interface*, and a CD-ROM of the *Journal* and *Letters*.

Personal Information		Divisions (please select only one):
Name:	Date of Birth:	🗆 Ba	
Humon			electric Science &
			chnology
Home Address:		EI EI	ectrodeposition
			ectronics and Photonics
			iergy Technology
		D Fi ar	llerenes, Nanotubes, Id Carbon Materials
		🗆 Hi	gh Temperature Materials
	Phone: Fax:	ln El	dustrial Electrochemistry & ectrochemical Engineering
	Email:		iminescence & Display aterials
		0	ganic & Biological ectrochemistry
<u>School Information</u>			ysical and Analytical ectrochemistry
School:			
	(close inducts Division and Dependence)		California California de la
	(please include Division and Department)		
Address:			
Undergraduate Year	(U) or Graduate Year (G) - circle one: U3 U4 G1 G2 G3 G4 G5		on 2011 and Hubble Proven
Major Subject:	Grade Point Average: out of possible:		
	Have you ever won this award before? YESNO If yes, how many times?		
	Have you even won this award before? TESNO in yes, now many times?		
Signatures		Seath Se	
Rigulatini yy	contract a protocol part for the state of the second part of the second part of the second part of the second p	10 10 100	
Student Signature:	Date:		
Equility member atte	sting to eligibility of full time student:		
Faculty member alle			
Faculty Member:	Dept.:		
E mail A LL			
E-mail Address:	Date:		

Not so much an instrument...

...more an orchestra.

solartron analytical

US: Tel: 1-865-425-1360 Fax: 1-865-481-2410 UK: Tel: +44 (0)1252 556800 Fax: +44 (0)1252 556899 Email: solartron.info@ametek.com www.solartronanalytical.com



modulob the new gold standard for electrochemical instrumentation

sion and cos

8

۲

0

To compose an electrochemical test system that's totally in tune with your research requirements, contact Solartron today.

The definitive modular system for electrochemical research, ModuLab delivers sublime performance for a vast repertoire of applications...

High performance 'Plug & Play' modules 64 MS/s smooth scan - LSV, LSP, CV Up to 1 MS/s data acquisition - pulse, CV 100 aA current resolution Up to ±25 A current - scan / pulse ±100 V compliance and polarization 10 $\mu\Omega$ impedance measurement >100 T Ω impedance measurement Multiple high-speed EIS techniques



NISM













FCT-150S/Z





Designed by Electrochemists...for Electrochemists Electrochemical Measurement Instrumentation Potentiostats, Software and Accessories

Modular Systems... World Class Performance



.....

Breakthrough Technology

A New Generation of Super-Potentiostats

SP-300

Fast, Sensitive, Stable... All This, and Exceptional Power, too! A Remarkable Combination!

EC-Lab Electrochemical Instruments... Growing to Meet Your Needs

Single and Multi-Channel Potentiostats Current Boosters · Fuel Cell Testers Electronic Loads · Accessories



Tel: +33 476 98 68 31 Web: www.bio-logic.info



BioLogic USA

NEW

Phone: 865.769.3800 Web: www.bio-logic.us