EDITORIAL

The state of research after 25 years of Nanotechnology

To cite this article: Anna Demming 2013 Nanotechnology 25 010201

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The state of research after 25 years of \textit{Nanotechnology}

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In 1990 the transistor was big—not just hugely prevalent in day-to-day devices but literally large in size compared with present day counterparts. Still, as Christoph Gerber describes in our latest \textit{Nanotechnology} Discussions podcast \cite{1}, with transistor footprints decreasing every two years as described in Moore’s law, by 1990 the electronics industry saw itself broaching new territory: nanotechnology. Atoms had made their debut as real-world observables with the first scanning probe microscopes only a few years previously, prompted by efforts to understand how physical systems behave at this scale. And in this heady climate of burgeoning nanoscale innovations \textit{Nanotechnology} published its first issue, the world’s first academic journal dedicated to nanoscale science and technology. This year the journal publishes its 25th volume and to celebrate we have commissioned a special issue presenting a snapshot of developments leading some of the most active areas in the field today \cite{2}.

As nanotechnology has matured both device-focused and fundamental research have placed high demands on improving fabrication processes to generate structures cheaply, efficiently and reliably. Since its discovery graphene has been under close scrutiny for the potential to exploit its optical transparency, mechanical flexibility and high carrier mobility. ‘However’, point out Ho Cho, Jong-Hyun Ahn and colleagues in Korea, ‘it is still significantly challenging to develop clean and simple fabrication procedures’. They demonstrate how photo-curable ion gel gate dielectrics can be used to produce self-aligned flexible graphene transistors and inverters \cite{3} simply without extra graphene-patterning steps. Sang Ouk Kim and colleagues at the Korea Advanced Institute of Science and Technology demonstrate another method for avoiding complex fabrication techniques, creating highly aligned graphene nanoribbon with their mussel-inspired block copolymer lithography and directed self-assembly \cite{4}. Porous anodic alumina structures are another recurring theme in nanoscale research, providing the starting point of many nanofabrication processes such as the Ta$_2$O$_5$ and Ta$_3$N$_5$ nanorod arrays demonstrated by researchers at the University of Tokyo. Applications of the array include solar-driven photoelectrochemical water splitting with a maximum solar energy conversion efficiency of 0.36\% \cite{5}.

Nanotechnology has had an enormous impact in catalysis where the high cross-sectional area and enhanced properties radically improve performance. In this issue Younan Xia and colleagues in the US focus their attention on sulfur, a damaging pollutant often present where catalysts are used \cite{6}. Their study provides evidence of site-selective sulfurization of catalytic palladium particles and suggests the underlying mechanism for this fast reaction. Reaction mechanism research in general continues to attract interest with its promise of efficiency and control in synthesis. Microstructure evolution and the nucleation dynamics of polymer-assisted deposition are examined by researchers in the US and China in a report on TiO$_2$ nanostructural thin films grown on (001) LaAlO$_3$ substrates. The work provides insights into the role of annealing temperature, and the topography of surface potentials \cite{7}.
There is also now increasing emphasis on ‘green’ nanotechnology and research that has potential to lessen man’s burden on the environment. In 2011 *Nanotechnology* launched a section dedicated to energy research in recognition of the mounting interest in this area. Organic photovoltaics have seen particularly significant progress in terms of efficiency [8] and in this issue Thompson and colleagues at the University of Southern California reveal ways to improve fabrication techniques for these systems [9]. As they explain, ‘Direct arylation polymerization (DArP) has emerged as a greener and more atom efficient alternative to Stille polymerization’. Their latest research tackling the selectivity of arylation techniques further empowers this approach.

While the electronics industry may have been the major driving force in nanotechnology research at the start, today the impact on research in medicine and biology is at least as significant. Nanofibrous networks provide invaluable tools in the development of tissue engineering techniques, and as demonstrated by Christman and colleagues at the University of California, San Diego, work in this field continues to progress [10]. Nanoparticles also have extraordinary potential as therapeutic agents not only as drug carriers but with a vast range of inherent properties that can mediate molecular processes and fight infection as reviewed by Kim and Hyeon in Korea [11]. Imaging and sensing are also important applications of nanoparticles in biology and medicine as well as other sectors. Observed surface enhanced Raman signal (SERS) enhancements of eight orders of magnitude have spurred numerous studies to effectively harness the effect. In this issue Xia and colleagues in the US present their study using 100-nm Ag nanocubes as the substrate [12]. ‘This work quantitatively evaluated, for the first time, some of the fundamental parameters of SERS imaging such as blur, spatial resolution, and penetration depth’, they explain.

As well as this special issue we are publishing a brochure of some of the top 25 papers over the past 25 years, accompanied by interviews with the authors describing how their research came about and what it has led to since. There is also an opportunity to listen in on James K Gimzewski, Christoph Gerber and Franz Gießibl as they discuss nanotechnology as it emerged, where it is today and where it may be heading [1]. However tempted we may be to speculate on the next 25 years for the field in general, there seems little room for doubt that the next 12 months in *Nanotechnology* promises to be a feast.

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