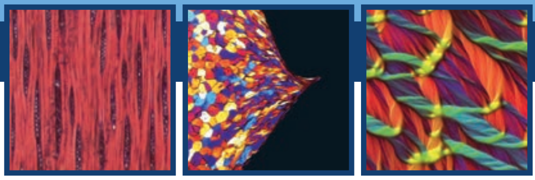
Cambridge materialeyes

Summer 2012 Issue 23



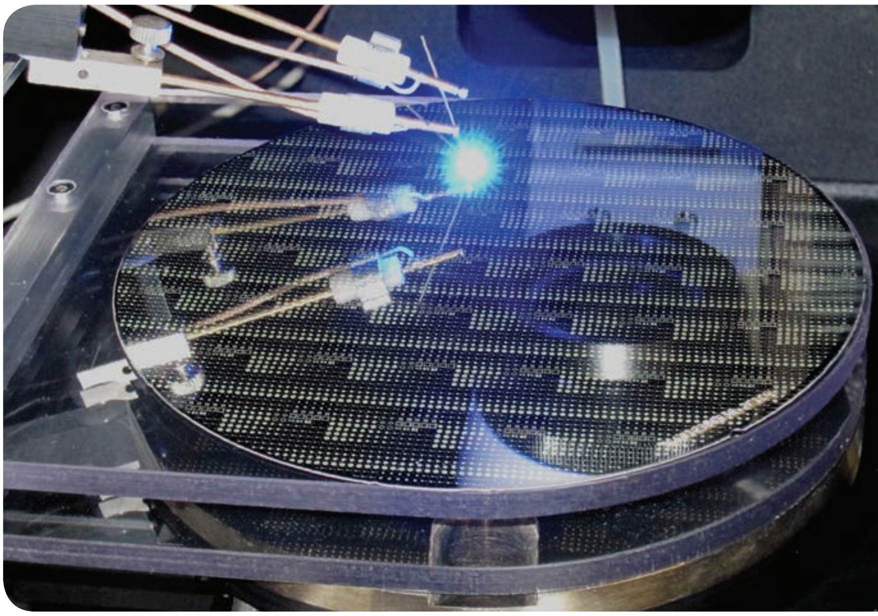
Gallium nitride LEDs go commercial

Research led by Colin Humphreys in the Cambridge Centre for Gallium Nitride goes from strength to strength. In 2010, Colin and his colleagues (post-doc Dandan Zhu and research student Lewis Liu) set up CamGaN in the St John's Innovation Centre with the aim of commercialising their research on light-emitting diodes based on gallium nitride. Andrew Lynn was recruited as CEO fresh from his success in commercialising Orthomimetic, a company that built on his doctoral research in the Department. Such was the promise of CamGaN that it was acquired by Plessey Semiconductors in February this year, and its technology will be developed by new subsidiary, Plessey Lighting. Plessey plans to manufacture millions of these LEDs per week at its factory in Plymouth. So, why the excitement?

High-brightness LED light sources offer significant benefits in at least two ways. Firstly, the efficiency with which electrical power is converted into visible light is already greater than the best competing sources (fluorescent tubes and compact fluorescent lamps) with further improvements in prospect. Secondly, the estimated lifetime of about 100,000 hours for an LED source is very much longer than for other sources.

GaN-based semiconductors for LEDs have usually been grown on 2- or 4-inch wafers of sapphire or silicon carbide. It has long been recognised that growth on the standard 6-inch silicon wafers so familiar in the semiconductor industry would be a lot less expensive. However, there are two major problems with growth on 6-inch silicon. Firstly, the GaN cracks when it is cooled from the 1000°C growth temperature because of a 50% difference in the thermal contraction of Si and GaN. Secondly, the dislocation density in the GaN is very high because of the large lattice-spacing mismatch between GaN and Si.

The CamGaN process solves both of these problems, so that a reduced-dislocation-density crack-free product can be obtained. This will reduce the cost of GaN LEDs by at least a factor of five, and will enable the widespread use of LED lighting in our homes and offices.



Testing of Cambridge-grown blue GaN LEDs on a 6-inch silicon wafer

Editorial

In February, it was with the greatest sadness that we learnt of the death of Sir Alan Cottrell. But Sir Alan's funeral, and even more so the Memorial Service in Great St Mary's on 9th June, were above all celebrations of a life well-lived. The tributes in the document distributed at the Service (and accompanying this issue) make it very clear that Sir Alan was not only supremely eminent, but also deeply loved – easily the Department's greatest member. A full report on our Cottrell Appeal will appear in the next issue.

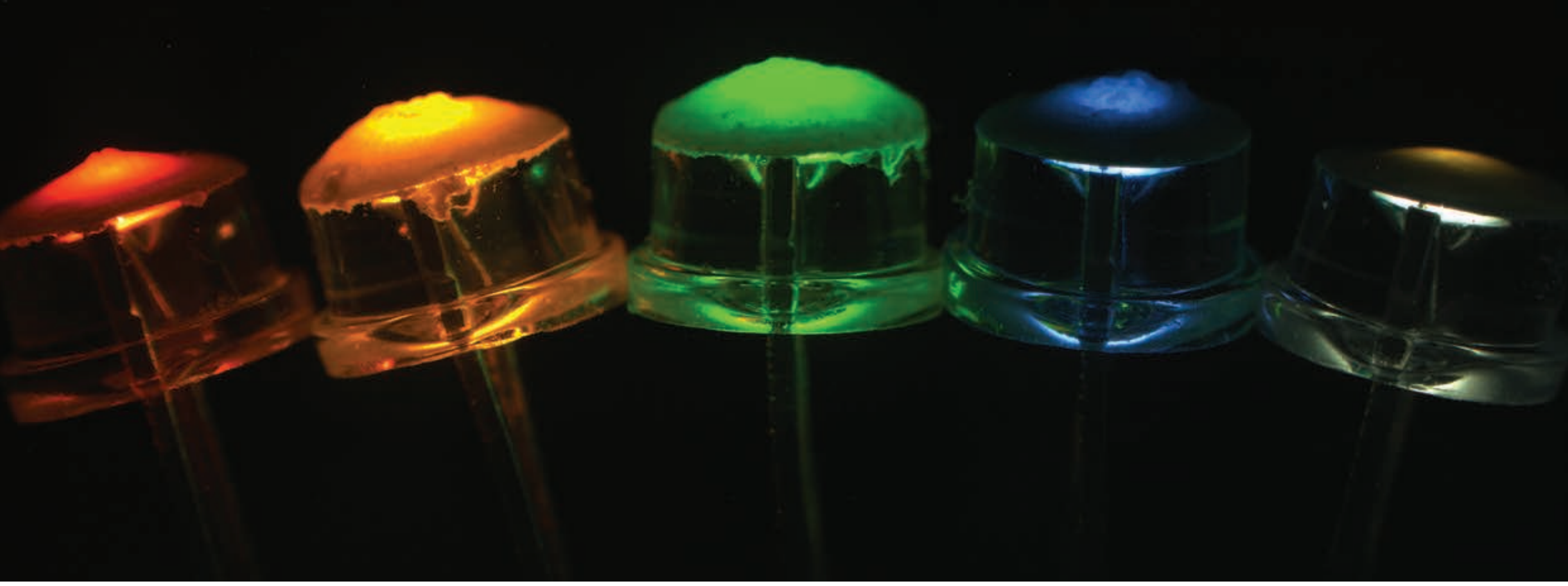
In connection with the topping-out ceremony for our new building (p. 3), it is a pleasure to record the substantial donation from Department alum, and my contemporary, Anne Glover. Anne's generosity will make possible the fitting out of the computer room for undergraduate teaching in our new quarters.

As I write, academic staff within the Department are developing an awareness that having such wonderfully high undergraduate numbers (reported in issue 20) brings painfully higher loads when marking examination scripts. A good problem to have …

Professor Lindsay Greer, Head of Department

UNIVERSITY OF CAMBRIDGE
Department of Materials Science and Metallurgy
Pembroke Street
Cambridge CB2 3QZ
01223 334300
www.msm.cam.ac.uk

Inside:



Daylight by design

Lighting accounts for almost 20% of world energy consumption. To reduce that fraction, while maintaining or improving the quality of lighting, is desirable as a potentially major contribution to reduction in greenhouse-gas emissions. It has been estimated that moving to solid-state lighting could halve that fraction. Page 1 outlined Colin Humphreys' work on light sources, now commercialised through CamGaN. In terms of the conversion of electrical power into visible light, such sources are already 100 times more efficient than the lamps invented by Edison in the 1870s, but light sources form only part of the effort. The human eye has evolved to function best when the spectral composition of the illumination corresponds to that of normal daylight. Artificial sources of illumination do not, as a rule, provide such illumination, and discomfort may follow. Therefore, the search is on for efficient ways of modifying the wavelengths of light from artificial sources to produce an overall spectrum more closely resembling daylight. One promising approach, being pursued by Goldsmiths' Professor Tony Cheetham and colleagues, is to develop suitable phosphors; their work has attracted substantial interest and support from the lighting business of Mitsubishi Chemicals.

A combination of red, green and blue LEDs is excellent for point sources of illumination, and is the basis of most solid-state lighting devices, but the quantum efficiency of green LEDs is appreciably less than that of red or blue, and green is the spectral region to which the human eye is most sensitive. Instead of using LEDs of several colours, a more acceptable overall spectrum may be produced using a blue or near-UV LED and suitable phosphors with broad emissions. Of course, these phosphors must have high quantum efficiencies and long lifetimes, and be easy and inexpensive to manufacture – to mention only some of the requirements! At present, a blue LED with a cerium-doped yttrium aluminium garnet (Ce^{3+}-YAG) phosphor is often used, but other doped garnets offer additional prospects. Tuning of the emission spectrum is achieved through choice of dopant and by tailored modifications of the crystal structure (e.g.) to alter deviations from cubic symmetry at the cerium site. Not all the substances under investigation are oxides; some nitrides also show promise. And rare-earth doping may not be essential.

The phosphors described above work by absorbing a relatively high energy photon and emitting one of lower energy. Another interesting class of phosphor functions by absorbing two lower-energy photons and emitting one of higher energy by 'up-conversion' for which a number of basic crystal structures, again with rare-earth doping, show promise. The picture (top) illustrates the output from a range of up-conversion phosphors excited by infra-red LEDs. This work was supported by Saint-Gobain.

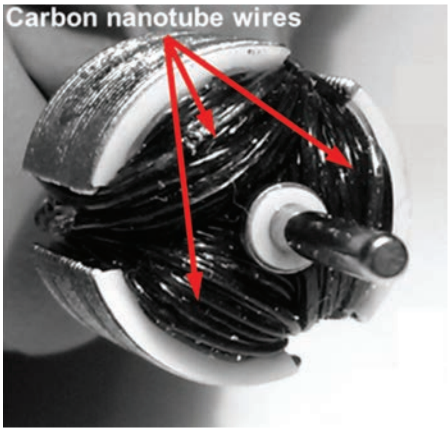
In short, work in the Department not only seeks to optimise the efficiency with which electrical power is converted to visible light but also the acceptability of the spectrum of that light.

Conductors, but not as we know them …

Electrical connections are generally made with metallic conductors. Is the end of this era now in sight?

That some carbon nanotubes (CNTs) can carry a high current density is not news, nor is their low mass-density, but it is news that CNTs can be used to make metres (even kilometres) of wire containing continuous high-conducting paths. Now Krzysztof Koziol, a Royal Society University Research Fellow, and his colleagues can make such macroscopic wires with a potential current-carrying capacity of the order of 100,000 A cm^{-2} (10^9 A m^{-2}) and with a weight only one tenth that of the equivalent copper wire.

They have developed, and are now optimising, continuous direct-spinning to produce electrically conducting wires composed of aligned CNTs with well-defined chirality (in other words precise molecular control of the material at the macroscopic scale) – a very compact process that is also environmentally friendly. The process starts by forming a CNT aerogel in the gas phase at around 1200°C in a reactor. Next, this aerogel is pulled out of the reactor and densified using a low-boiling-point solvent bath, giving CNT fibres with a diameter of about 10 micrometres. Finally, these fibres are coated with suitable insulation to produce CNT-based wires. The entire set-up is less than 4 m long. With each step taking only a few seconds, wire production at up to 50 m min^{-1} can be achieved.



It is confidently expected that this method can be scaled up to produce kilogrammes in each run. Furthermore, being based on methane (or CO_2), the process consumes a 'greenhouse gas'! As well as electrical conductivity, the wires have good mechanical strength (currently 10 times higher than copper) and flexibility, and can operate in air up to about 500°C. If such wires are to find use in electrical circuits, reliable, robust connections to the components will be essential, as will robust insulation around the fibres. Krzysztof's group has addressed these issues: soldering and crimping for termination have already been developed, along with a range of insulating materials. Also being investigated is the interesting response of these wires to radio-frequency signals. Practical uses of the wires already demonstrated include the first examples of a fully operational transformer, a mini-motor (illustrated, page 2) and a mini generator.

Krzysztof sees the most important short-term target in this fast-developing technology as the conversion yield from carbon precursor to CNT fibre (currently around 10%), as this will control future scale-up strategies. Length control of individual CNTs presents another challenge. The fibres can be produced in lengths of metres or kilometres, but actual CNTs are around a millimetre long. This has implications for the mechanical and electrical properties of the macroscopic materials.

The major funding for this work is from the European Research Council. For further information, see: **www.msm.cam.ac.uk/department/profiles/koziol.php**

The Naked Scientist

Dr Chris Smith, nationally famous as the Naked Scientist, regular commentator on developments in the world of science, has recently been taking a keen interest in the Department, particularly in the work of the Rolls Royce UTC. See for example: **www.thenakedscientists.com/HTML/articles/article/the-superalloys**

Debashish Bhattacharjee

Group Director, Research Development and Technology, Tata Steel Group

As the Tata Steel Group has expanded across an international stage, so its contacts with the Department have increased. In 2008, Tata Steel generously endowed a Chair of Metallurgy in the Department, with Harry Bhadeshia becoming the first Tata Steel Professor. Meanwhile, Tata Steel's current Group Director, Research Development and Technology, is Dr Debashish Bhattacharjee, who gained his PhD in the Department. The picture of Debashish (above, on right) with Harry records a recent visit to Cambridge.

Stationed in IJmuiden in the Netherlands, Dr Bhattacharjee is leading the transformation of the research of Tata Steel Europe (previously Corus RD&T) and Tata Steel India & Asia (based in Jamshedpur) into a global Tata Steel Research organisation with focus on alignment with corporate strategy and speed of delivery. Altogether there are five technology centres in Tata Steel, three in the UK, one in the Netherlands and one in India.

Before coming to Cambridge, Debashish graduated with a BTech from Jadavpur University and MTech from the Indian Institute of Technology, Kanpur. He came to Cambridge in 1989, becoming a member of Churchill College. For his PhD, he worked on micromechanisms of mixed-mode fracture supervised by John Knott. He then carried out post-doctoral research in the Rolls-Royce University Technology Centre, working with Julia King. In 1996, he joined the Tata Steel Group, steadily rising to his present post. In 2000-01, he took sabbatical leave from the company to rejoin John Knott, by then at the University of Birmingham.

Dr Bhattacharjee's areas of expertise include fracture and fatigue of materials, physical metallurgy of rolling, and application of artificial neural networks in industry. His personal technical contributions span a wider area, from mineral beneficiation, to development of new technology for generating hydrogen at low cost and development of advanced coolants using nanofluids. All this has created a significant list of publications and patents, and some notable distinctions. He was honoured by the Metallurgist of the Year award from the Government of India in 2004. In 2008, his contribution to engineering was nationally recognised through Fellowship of the Indian National Academy of Engineering (FNAE), and in 2011 he was elected to Fellowship of the Bengal Academy of Science. Since 2010, he has been an Industrial Professor at the University of Warwick here in the UK, delivering periodic lectures and helping to set the direction for teaching and research.

A senior position such as his inevitably attracts other responsibilities on an international scale within and beyond Tata. Dr Bhattacharjee is a member of the Governing Council of the Welding Institute (TWI) in the UK and chairs the Flat & Long Steel Sectional Committee of the Bureau of Indian Standards. He has been Chairman of the Jamshedpur chapters of the Indian Institute of Metals, the Indian Institute of Mineral Engineers and the Indian Institute of Welding, and he was a Director of Tata Advanced Materials Ltd.

As a graduate student and post-doc, Debashish was an avid squash and cricket player, captaining the Department cricket team for a spell. These days his hobbies include aeromodelling (fabricating and flying model aeroplanes) and studying the ancient history of India. He is a founder member of the Jamshedpur Aeromodelling Club and an expert on control-line aerobatics.

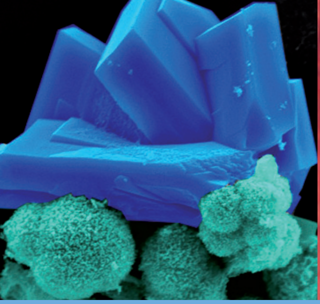
New Books

Three books have recently been published by members of the Department.

The classic text *Crystallography and Crystal Defects* by Kelly and Groves was first published over 40 years ago, and a second edition (by Kelly, Groves and Kidd) followed in 2000. Now, for a thoroughly revised and updated edition, Anthony Kelly has been joined by Kevin Knowles. They explain the basic concepts of crystallography and demonstrate applications to linear and planar defects within crystalline materials, at the interfaces between such materials, and in quasicrystals.

For The Future of Helium as a Natural Resource, which is part of the series Routledge Explorations in Environmental Economics, Bartek Glowacki has teamed up with William Nuttall of the Judge Business School and Richard Clarke of the Culham Centre for Fusion Energy to edit this timely survey of the world's limited sources of helium, of its ever-increasing usefulness and of the economics of helium supply, coupled with a look back at the history of the helium industry.

In *Nucleation in Condensed Matter: Applications in Materials and Biology* Ken Kelton, from Washington University, St Louis, and a familiar visitor to the Department, and Lindsay Greer have collaborated to produce a thorough survey of this wide area, including theoretical approaches, experimental measurements and computer modelling, as well as a treatment of many applications and other topics ranging from the microstructure of castings through biomineralization to chocolate.




The quest for quantum dots: Rachel Oliver

The search for new ways to make very small structures, and to characterise those structures, began to take over Rachel's life when she embarked on her undergraduate project in the Department of Materials at Oxford, and continued through her DPhil with Andrew Briggs on 'Growth and Characterisation of Nitride Nanostructures'. Come the third year, it turned out to be advantageous to grow samples covered by many quantum dots here in Cambridge using an MOVPE (metal-organic vapour phase epitaxy) technique she developed in collaboration with Menno Kappers. She also spent two periods working in the Quantum Structures Research Initiative at Hewlett-Packard in Palo Alto, California. In 2003, she came to the Cambridge Centre for Gallium Nitride upon winning support from the Royal Commission for the Exhibition of 1851 combined with a Research Fellowship at Peterhouse. She moved onto a Royal Society University Research Fellowship from 2006 to 2011, after which she took up the University Lectureship in the Department to which she had been appointed in 2009. She is now a Fellow and Director of Studies at Robinson College.

Nanoscale nitrides continue to fascinate Rachel. She employs three-dimensional atom-probe tomography (with the world-leading group in her former department in Oxford), atomic-force microscopy and luminescence in the SEM to investigate nitrides' secrets, for example studying exactly the same dot in several different ways. The aim of all this is to improve understanding of the structural and electronic properties of nitride quantum dots, leading, it is hoped, to the creation of a practical single-photon source. This multi-microscopy approach has recently won major support from the European Research Council (see *Material Eyes* no. 22).

The integration of research and teaching is important, and Rachel's involvement with teaching has steadily grown. She contributes to the Functional Nanomaterials course in Part III and to the graduate course on Characterisation Techniques on the Nanometre Scale, and has recently begun teaching the Microstructure course in Part IA. In addition, she shares with Cate Ducati the directorship of the MPhil in Micro- and Nanotechnology Enterprise, a course that attracts 15-20 students a year.

Away from the Department, Rachel enjoys demanding physical activities with cardiologist husband Dave when time permits; a half-marathon is in prospect later this year, while lengthy mountain-biking endurance events featured in the past. The arrival of son Jamie in 2010 has of late added a different range of time-consuming activities!

Congratulations

Bartek Glowacki, Personal Professorship from 1st October 2012
James Elliott, Readership from 1st October 2012
Tony Cheetham, Honorary Fellowship, Jawaharlal Nehru Centre, Bangalore, India; the 2012 RSC Nyholm Prize for Inorganic Chemistry, Royal Society of Chemistry
Harry Bhadeshia, NIMS Award 2012, National Institute for Materials Science, Tsukuba, Japan
Sir John Meurig Thomas, Honorary Degree, University of St Andrews
Talia Gershon, Winner of AkzoNobel's *Tomorrow's Answers Today* 2012 UK Poster Competition
Rowan Leary, Poster Prize, 2nd Int. Symp. on Advanced 'Electron Microscopy for Catalysis & Energy Storage, Berlin
Neville Greaves, George Morey Award, American Ceramic Society.
Giorgio Divitini and **Najeeb Ullah** 2nd prize, Cambridge / Dow Sustainability Innovation Student Challenge Award

Editorial team: John Leake, Lindsay Greer and Rachel Hobson. **Comments to:** rjh24@cam.ac.uk

The Department has networking groups on Linkedin and Facebook sites.
If you would prefer to receive your copy of *Materials Eyes* electronically please e-mail **rjh24@cam.ac.uk.**