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UNIVERSITY OF CAMBRIDGE 800 YEARS 1209–2009

*Goldsmiths Company **Science for Society** Course*
MATERIALS SCIENCE
Cambridge, 19-24 July 2009

Introduction to the Department of Materials Science & Metallurgy

A. Lindsay Greer

Lucy Cavendish College, Cambridge, Sunday 19 July 2009

http://www.msm.cam.ac.uk

A ranking of 'Materials Technology' Departments in the UK

The Times "Good University Guide 2009"
— available on-line

Score based on quality of teaching, research and students

5	Cambridge	100
6	Oxford	93.2
7	Imperial	89.9
8	Birmingham	88.2
9	Sheffield	83.8
10	Nottingham	80.2
11	Loughborough	78.9
12	Swansea	75.9
13	Queen Mary, London	74.3
14	Manchester	72.3

Research Assessment Exercise, RAE 2008

— covering the period 2001-2007

Research is assessed as:

4* World leading
3* Internationally excellent
2* Internationally recognised
1* Nationally recognised
0 Unclassified

RAE 2008 "Metallurgy and Materials"

	GPA	%4*	staff
Cambridge	3.35	40	30
Liverpool	3.05	35	11
Kent	3.05	25	6
Oxford	3.00	25	37
Manchester	2.95	20	49
Birmingham	2.90	15	27
Sheffield	2.80	15	38
Imperial	2.70	20	27
Swansea	2.70	15	15

RAE 2008

	0	1*	2*	3*	4*	GPA
Cambridge	1	4	24	39	32	2.98
DMSM	0	0	5	55	40	3.35

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Dept. of Materials Science & Metallurgy
Objectives

- to produce high-quality graduates with a deep and wide-ranging knowledge of materials
- to perform world-class research
- to support Materials Science in the UK
- to engage in partnerships with industry and to transfer technology to industry and society

Size of the Department

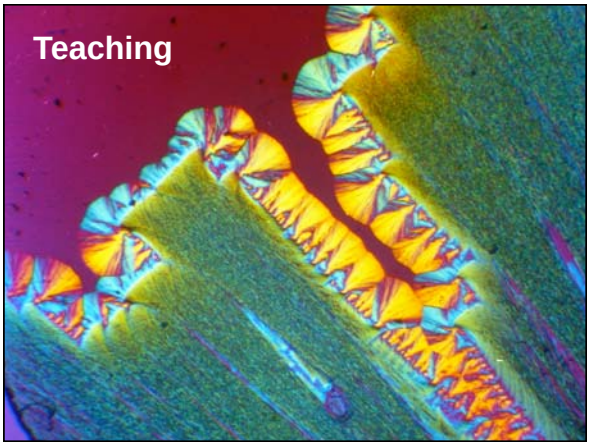
Academic staff	25
Research students	130
Post-doctoral staff	50
Support staff (technical, secretarial …)	50

Funding Sources

The spread of funding is approximately:

EPSRC:	50%
Industry:	20%
others (charities, EU):	30%

Total value of current EPSRC grants: £13M



Our teaching covers all 4 years of the Cambridge Natural Sciences Tripos —

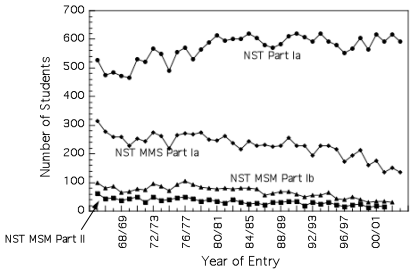
Year 1: Pt Ia Materials and Mineral Sciences
(taught jointly with the Dept. of Earth Sciences)
200 students

Year 2: Pt Ib Materials Science and Metallurgy
50 students

Year 3: Pt II Materials Science and Metallurgy
20 students

Year 4: Pt III Materials Science and Metallurgy
15 students

Trends in Student Numbers



Fraction of Pt Ia NST doing Materials 60% (in the 1960s) → 25% (now)
Fraction proceeding from Pt Ia to Pt Ib 30% → 25%
Fraction proceeding from Pt Ib to Pt II 50% → 60%

Natural Sciences Tripos Pt Ia (1st year)

In the physical sciences —

- Chemistry
  Dept. of Chemistry
- Geology
  Dept. of Earth Sciences
- Materials and Mineral Sciences
  Dept. of Materials Science and Dept. of Earth Sciences
- Physics
  Dept. of Physics

(+ Mathematics)

Range of Teaching
within the theme **processing → structure → properties**

and dealing with **metals, ceramics, polymers, composites, semiconductors, superconductors, magnetic materials**

- structure and bonding, crystallography
- microstructure and phase diagrams
- physical, mechanical and chemical properties of materials
- device materials
- biomaterials & biomedical materials
- design, and materials selection

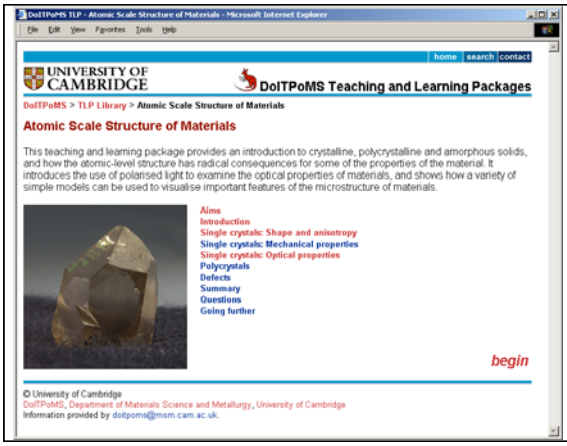
Teaching on the Web — DoITPoMS
Dissemination of IT for the Promotion of Materials Science

(www.doitpoms.ac.uk)

— a flagship project for IT

AIMS

- to enhance teaching and learning of Materials Science
- to establish a library of electronic teaching resources
- to promote wider general awareness of Materials Science



Outreach Activities (to Primary Schools)

SeeK http://www.seekscience.org

- started in 1997 — local school visits
- teacher support and liaison
- has reached 4500 primary school kids, 75 schools

"Thank you for coming to do science with us, you made it really fun!"
Collette (year 5)

Funding: COPUS (Committee on the Public Understanding of Science), EPSRC (Partnerships for Public Understanding award), Ann Foundation, Cambridge City Council Children & Youth Services, Active Community Fund University of Cambridge, Aspiration Funding University of Cambridge

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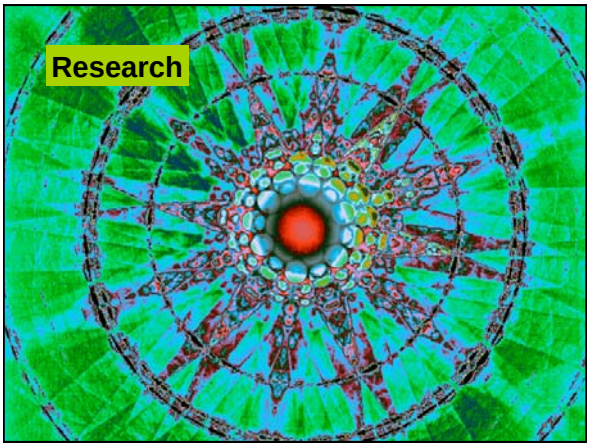
M.Phil. Course

Micro- and Nanotechnology Enterprise

— course Director is Dr R. V. Kumar



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Five areas of core competence —

- Structural Materials
- Device Materials
- Materials Chemistry
- Medical & Pharmaceutical Materials
- Electron Microscopy

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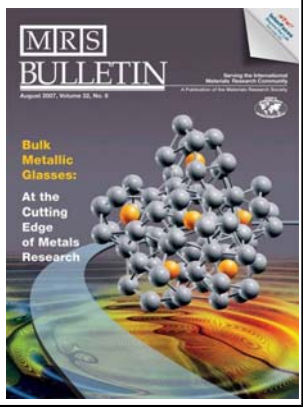
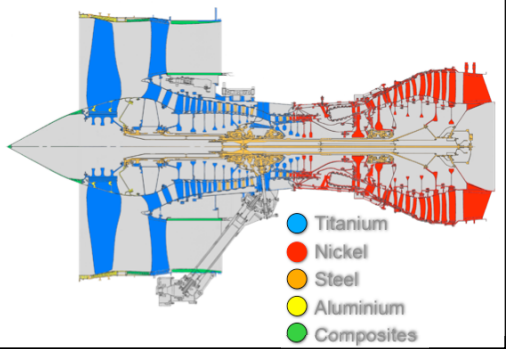
Structural Materials

- **physical metallurgy** (Bhadeshia, Greer) — nanostructured steels in tonnage quantities, metallic glasses
- **Rolls-Royce University Technology Partnership** (Humphreys)



Materials used in a gas-turbine aeroengine



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- **Carbon nanotubes** (Windle)
- **Gordon Laboratory** (Clyne)
  work on advanced coatings and composites
  Cambridge Micromechanical Testing Centre (CAMTEC)

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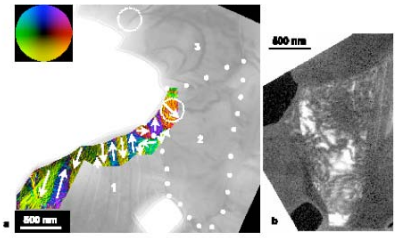
Device Materials

- led by Blamire, focusing on magnetic, ferroelectric, semiconducting and superconducting thin films
- unique capabilities for deposition
- close collaborations with the Dept.of Physics and with the Nanoscience Centre
- world-leading research on multiferroic, ferroelectric and magnetic oxide materials
  — GaN light-emitting diodes



Charge order and **ferromagnetism** were thought to be mutually exclusive, but it appears that they can co-exist after all —

- grain 1 is ferromagnetic
- grain 3 is charge-ordered
- grain 2 shows co-existence

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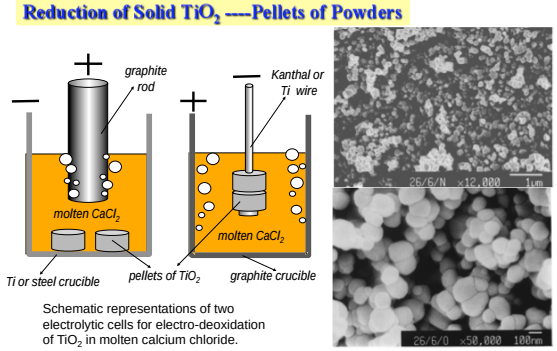
Materials Chemistry

led by Fray and Cheetham

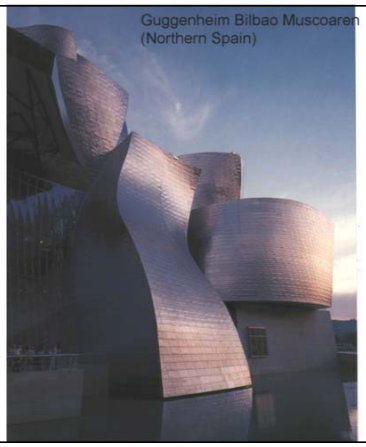
- hybrid materials
- sensors
- novel methods of reducing metal oxides
- recycling
- catalysts
- hydrogen storage
- solid-state lighting
- fuel cells
- corrosion

Reduction of Solid TiO_2 ----Pellets of Powders



Schematic representations of two electrolytic cells for electro-deoxidation of TiO_2 in molten calcium chloride.

ref. GZ Chen et al, ***Nature***, 407 (2000) 361



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Medical and Pharmaceutical Materials

- led by Best and Cameron
- **Cambridge Centre for Medical Materials**
  - — orthopaedic applications
  - — nerve-tissue regeneration
  - — surgical glues
  - — wound dressings
  - — 3D imaging
- close collaboration with Addenbrooke's Hospital (Orthopaedic Research Unit)
- **Pfizer Centre for Pharmaceutical Materials Science**
  - — production and characterisation of tablets
  - — development of experimental and computational models for drug inhalation devices
  - — tomographic imaging of pharmaceutical tablets

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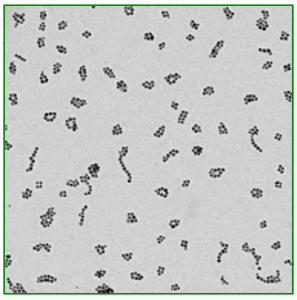
Electron Microscopy

- led by Midgley
- development and application of state-of-the art
- electron microscopy techniques
- characterizing the physical, chemical and structural nature of materials at the sub-nanometre level
- energy-filter TEM
- electron holography
- electron tomography
- nanoscale characterization

Co nanoparticle bracelets

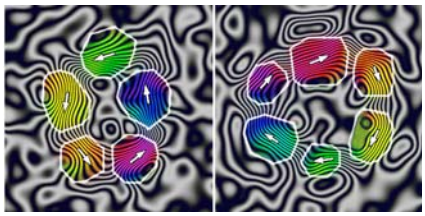
Each Co particle is:

20 nm in size and expected to contain a single magnetic domain



Sample from Alex Wei and Steve Tripp (Purdue University)

Co nanoparticle bracelets



128 times phase amplified magnetic contribution to measured phase

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Spin-Out Companies & Licensing Agreements

University of Cambridge spin-out companies:

British Titanium plc and **Metalysis Ltd** — built on the electro-deoxidation process, developed by Fray and co-workers. Metalysis has raised about £20M and has a jointly owned company with Rolls Royce plc, Metalysis Malaysia Sdn Bhd, producing tantalum in Malaysia.

Camfridge Ltd is exploring a new range of magnetocaloric compounds for use in a novel solid-state refrigerator.

Orthomimetics develops implants for cartilage and ligament, and raised £5M in venture capital funding in December 2006. It grew from research within the CMI-funded interdisciplinary research cluster in Biomaterials and Tissue Engineering.

Q-Flo has been formed as a technical transfer vehicle for the fibre process and other associated application areas of carbon nanotubes.

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Licensing:

Inotec AMD Ltd (UK) — exploiting technology for oxygen supply via a patented bandage, to accelerate wound healing. Human and equine trials will take place later this year.

Fibretech (UK) — licensing of fibrous core structures of all-metal sandwich panels, forming the basis of a new product (Fibrecore)www.fibretech.com/products_fibrecore.htm).

Thomas Swan Ltd (UK) — carbon nanotube synthesis (Elicarb™).

EMC Ltd (UK) — marketing a hydrogen sensor for molten aluminium.

Electrovaya (Canada) — licensing technology for encapsulating Sn, Al and Si in C nanotubes as anodes for Li-ion batteries.

Filtronic (UK) — planned manufacture of GaN-based LEDs

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Materials Research Priorities for Sustainability

- rising CO_2 emissions can lead to global warming and other environmental degradation, e.g., acidification
- over-dependence on oil is politically unwise
- **sustainability of large-scale energy consumption** may rest on reduced CO_2 emission
- **sustainability of large-scale materials consumption** may depend on increasing use of materials with low energy cost

How can the Department best contribute to the UK efforts in these areas?

UK Law on Climate-Change

- will promote research and investment in low-carbon technologies
- establishment of the £600M Energy Technologies Institute next year – "to enable the UK to take a lead role in sustainable energy research"
- sets targets for reductions in CO_2 emissions:
  - — 26-32% by 2020
  - — 60% by 2050

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Energy Savings from White GaN-based LEDs

(Humphreys / Cheetham)

Global CO_2 Emissions from Lighting

- Lighting is one of the biggest causes of greenhouse gas emissions
- 1,900 Megatonnes of CO_2 emissions per year (from power stations for lighting)
- 70% of the global CO_2 emissions of all cars
- 3 times more than emissions from aviation
  - – (International Energy Agency Report, 2006)

The Need: Ultra-Efficient Lighting

- 20% of all electricity consumption in the UK is for lighting
- in Thailand, over 40% is for lighting
- can we use white LEDs for home and office lighting?

Efficiency of White LEDs

Light bulb efficiency = 5% (15 lm/W)

Fluorescent lamp = 15-25% (50-80 lm/W)

White LEDs (best) = 30% (100 lm/W at 350 mA)

White LEDs (lab) = 50% (150 lm/W at 20 mA)

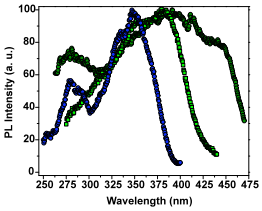
White LEDs (target) = 50-80% (150-250 lm/W at 350 mA)

Sodium lamp = 130 lm/W

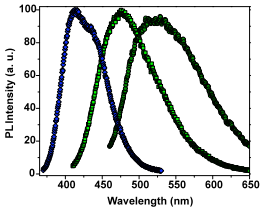
Major opportunity for white LEDs -- sale of filament light bulbs banned throughout Europe from 2009 (decision at EU summit in 2008)

Tunable Phosphors in the System Sr-Ba-Si-O-N

Excitation spectra



Emission spectra



Le Toquin & Cheetham (2007)

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Potential Relevance of Materials Research

- **fuel cells, membranes**
- **materials for hydrogen storage**
- **solid-state lighting (GaN, etc.)**
- **catalysts for processing at ambient temperatures, including hydrogen production**
- **structural materials for fission reactors**
- **structural materials for fusion reactors (the first wall)**
- **materials for more efficient gas turbines (higher temperature)**
- **materials for more efficient solar cells**
- **sequestration of carbon**
- **direct conversion of sunlight into hydrogen (and oxygen)**

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Impact — will our lives be changed?

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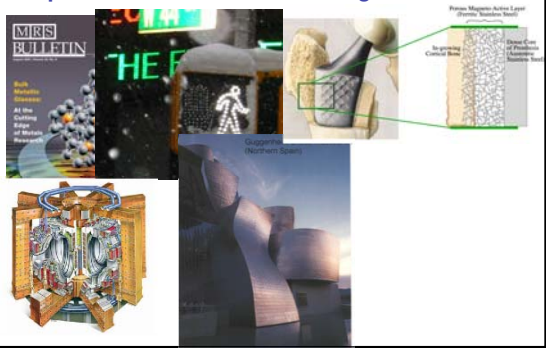

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