Institution:	**UNIVERSITY OF CAMBRIDGE**
Unit of Assessment:	**B13** Electrical & Electronic Engineering, **Metallurgy & Materials**

a. Overview

The Dept of Materials Science & Metallurgy (**DMSM**) lies within the School of Physical Sciences (**SPS**) of the University of Cambridge (**UCAM**). DMSM has 5 *research specialisms* (applications-oriented themes): **Structural Materials**, **Device Materials**, **Materials Chemistry**, **Medical & Pharmaceutical Materials**, & **Electron Microscopy**. DMSM has 21 established academic-staff posts including the brand-new, as yet unfilled Sir Alan Cottrell Professorship. Posts, established for one tenure only or limited by funding, bring the staff headcount to 27, & with Research Fellows & other independent researchers to 36 (FTE 33.56). In 2012-13 there were 83 PDRAs, 44.6 FTE support staff, 130 PGRs, 10 taught Masters students & 160 FTE undergraduates (UGs).

DMSM's well-cited research has high international visibility, including ~1600 papers (in *Web of Knowledge*) & 57 patent families published in the REF period. We work with ~40 companies, prioritizing transfer of technology & wealth creation through spin-outs (10 established since Jan 2008; see REF3a & Impact Case Studies). DMSM promotes Materials Science through the professional leadership of key scholars (7 staff are FRS, FREng or other National Academy; 5 hold *ERC Advanced Grants*). DMSM is proud of its role in rearing the leaders of the future: in 2013-14, we have 4 Royal Society URFs, 5 holders of other competitive fellowships, & 4 holders of *ERC Starting/Consolidator Grants*); & an excellent record of appointments to faculty positions (§c(i)).

b. Research strategy

DMSM aims to conduct research at the highest international level in the materials discipline. Our strategy is to: (i) prioritize research quality in staff appointments; (ii) maintain a broad portfolio rooted in our 5 *specialisms*, while ensuring each remains of critical mass; (iii) build on this breadth to initiate cross-disciplinary efforts in DMSM & to establish best-with-best national & international collaborations; (iv) maintain diversity of research income. DMSM's Research Committee (RC), with balanced membership (5f, 9m, from Research Fellow to Prof) overviews research strategy & launches initiatives, eg the *Cambridge Nuclear Energy Centre* (set up with DMSM's HoD as chair). RC decisions are informed by DMSM & research group strategies & government policy; the RC is advised by our *External Advisory Board* (largely industrialists), & reports to the full Staff Meeting.

Achievement of strategic aims for research during the assessment period

In RAE2008, DMSM identified 3 main aims, each realised:

(i) Augmentation of *Materials Chemistry* (through 2007 appointment of **Cheetham**) — has been evidently successful, with an *ERC Advanced Grant* to Cheetham, many high-profile publications & industrial links. As hoped for, links with UCAM Chemistry have been strengthened (with Jones, mechanosynthesis, pharmaceutical materials science; Grey, battery materials).

(ii) Three academic-staff appointments — have been made: **Ducati** (in electron microscopy, strengthening this specialism at a time of growing support since RAE2008 on new building & instruments (§d); **Oliver** (in GaN semiconductors); **Rivera** (in steels, the senior appointment in the *SKF* Univ. Technology Centre (**UTC**) established in 2009). The priorities for appointment identified in RAE2008 were: (a) *materials for sustainability* — addressed by Ducati (working inter alia on operation of photovoltaics) & Oliver (LEDs for high-efficiency lighting), both very successful & already promoted to Reader; (b) *macromolecular materials* — addressed by the appointments of Royal Society URF **Koziol** (carbon nanotubes), **Smoukov** (new *Active & Intelligent Materials* group) supported by an *ERC Consolidator Grant* (c) *device materials to interface with soft tissues* — not pursued (the key individual departed for a faculty position at EPFL).

(iii) Strategic research objectives — *international alliances* have been active since Jan 2008 (§e). DMSM's initiative on *Materials for Sustainability* has stimulated research on energy & sustainability, making DMSM a major player in UCAM's *Energy Strategic Initiative* (§e).

Current position with reference to the research position described in RAE 2008

The position of DMSM is quite transformed: (i) infrastructure – DMSM's £50M new building & major investments in equipment (§d); (ii) collaborative research funding – eg, in 2009, the £50M *Strategic Partnership* between EPSRC & Rolls-Royce, funding work at DMSM, Birmingham & Swansea to develop materials for future gas turbines; in 2010 a £6.3M grant to DMSM & to Bath, Manchester & Strathclyde for *Lighting the Future*, aiming towards efficient lighting from GaN LEDs;

(iii) engagement with industry – new *SKF* UTC on *Steels*; impact on a broad front: DMSM results exploited in production, eg steel armour, CNT composites & GaN LEDs (see Case Studies); (iv) doctoral training – inauguration of 2 EPSRC DTCs, in *Nano Science & Technology* (led by UCAM Physics; & renewed in revised form, Nov 2013), & in *Structural Metallics* (linked to the EPSRC-Rolls-Royce Strategic Partnership; & currently extended by 2 years to admit cohorts in 2014 & 15).

Research highlights over the assessment period & strategy, area-by-area

Structural Materials — Steels: world-firsts: a) prediction & verification of non-cubic bainitic ferrite; b) design of bearing steel that renders H innocuous (radically different from conventional aim to reduce H content); c) thermodynamics-based computation estimating the mechanical properties without fitting parameters. Rolls-Royce UTC: d) first in-situ imaging of dendrite growth & of fatigue crack propagation in superalloys; e) development, now leading to commercialization, of 1 superalloy for turbine blades, 4 for discs; 1 for combuster liners; & an Mo alloy for forging dies; f) development of novel abrasive systems for turbine-blade tips; g) world-wide implementation of a new environmental lifing for high-temperature components & through-process assessment of Y & La additions for oxidation resistance; h) underpinning fundamental research eg of dislocation structures controlling deformation. Carbon nanotubes (CNTs): breakthroughs/world-firsts: i) achieving control of CNT-type selection in bulk production; j) soldering technology for CNTs; k) comprehensive development of C-based conducting wires; l) CNT-wound electric motor & transformer; m) new electrothermal heaters. Other highlights: n) development of nanoindentation tests over an unrivalled temperature range (100–1000 K); o) advanced fundamental understanding of plasticity at fine scales, exploited to study hard coatings & complex crystal structures. **Vision:** a) development of lightweight steels (10% reduction in density); b) establishing firm theoretical bases for understanding hydrogen in steels; c) developing ultraconductive CNT/Cu wires; d) further development of novel ultra-high temperature testing facilities, aimed at development of innovative high-temperature materials, abrasive systems & thermal-barrier coatings.

Device Materials — World-firsts include: a) discovery & control of triplet superconductivity in ferromagnets, b) prediction & discovery of new ordered self-assembled nanocomposite films, c) growth of electroactive tunnel barriers leading to *Nature*/*Science* papers showing applications; d) growth of non-polar quantum dots (QDs) (InGaN) by MOVPE; e) measurement of photo-luminescence lifetime from a single non-polar QD (10× decrease compared to *c*-plane polar QDs); f) GaN growth on 6" Si substrates has revolutionised manufacturing of low-cost high-efficiency GaN LEDs (REF3a & Case Study). DMSM's new building has enabled optimization of our thin-film deposition systems, incl new atomic-layer deposition, through interaction with Cambridge Science Park, TSB funding & equipment donation. Two new physical property measurement systems support a wide range of research. UCAM funding has been secured for a helium liquefier to secure low-temp measurement capabilities. **Vision:** EPSRC/UCAM funding secured for advanced pulsed-laser deposition/XPS analysis system will support research more focused on the interfaces between materials. The new-building location will foster collaboration with Physics & with Electrical Engineering on topics such as LED lighting for data communication. We aim to transfer growth expertise from GaN LEDs to power electronic devices on 6" Si, & for a new MOCVD growth reactor to grow GaN devices on larger wafers for further cost reduction.

Materials Chemistry — Work on dense inorganic-organic frameworks has shown a plethora of interesting properties: a) discoveries of multiferroic behaviour, negative linear compressibility, facile amorphization, a ring-opening phase transition; b) first detailed studies of mechanical & magnetic properties; c) creation of hybrid nanosheets by exfoliation of layered structures by ultrasonication. Other highlights: d) FFC Cambridge process leads to commercial sales of tantalum by *Metalysis*; e) DMSM-designed cell sees successful clinical trials of oxygen therapy (see Case Study); f) technology for Sn-filled carbon nanotubes successfully transferred to *Morgan AM&T*; g) method for making black silicon discovered, exploited by *Tavarua*; h) clean, low-energy process (licensed to *Johnson Controls Inc*) for recovering electroactive paste material from automotive batteries as precursors for making new batteries; i) S-infiltrated carbon scaffolds (now licensed) for new Li-S batteries with energy densities 2× those of the best Li-ion batteries, with improved life (approaching 1000 cycles); j) *Chinuka* process, combining reduction of metal oxides with electrorefining for metals, attracts worldwide interest; k) metal-oxide photocatalyst (subject of a spin-out) absorbing UV & visible light shows reaction rates up to 100× faster for disinfecting water & destroying pollutants in air. **Vision:** DMSM will further develop work on needs arising from low-C energy:

increased capacity of batteries; recycling the ever-growing piles of battery & electronic waste.

Medical & Pharmaceutical Materials — Work on biomimetic porous scaffolds led to international patents, spin-out *Orthomimetics* shortlisted for the MacRobert Prize (2009) & sold for €16M (2010), successful clinical trials, & award of the CE mark to the product. This model has been applied to more complex therapeutic applications, with advances made in breast-cancer research, blood-product generation, dental treatments & heart repair (with support from the British Heart Foundation high-profile "Mending Broken Hearts" initiative). Resorbable nanocomposites for bone grafting, & artificial ligaments have succeeded in animal trials. Clinical trials of spinal-disc prostheses, developed with *Ranier Technology*, show a 5× increase in quality-adjusted life years after 1 yr, compared to spinal fusion, & a 2× increase over competing treatments. Our guides with flexible electronics for peripheral nerve regeneration were featured in the EPSRC's "IMPACT!" exhibition in London in 2009. **Vision:** prioritizing healthcare areas such as the ageing population & sensor technologies. Novel computational approaches will draw together existing large bodies of poorly coordinated literature within overarching theoretical frameworks & computationally assisted medical materials design. Target clinical application areas for the next 5 years will be cardiovascular surgery, haematology, oncology, urology & orthopaedics.

Electron Microscopy (EM) — World-firsts include: a) compressed sensing for hi-fi reconstruction from few images; b) charge-flipping algorithm for electron crystallography; c) diffuse electron scattering to quantify vibrations of molecular semiconductors; d) 3D visualization of localized surface-plasmon resonances; e) imaging of superconducting fluxons in a commercial TEM & of fluxons in MgB_2; f) recording reflections in electron diffraction arising from anti-ferromagnetic domains; g) demonstration that the structural transition in pnictide superconductors is first-order. The focus is on correlating nanoscale structure with underlying physical & chemical behaviour, developing methods for characterization of energy-related nanomaterials, including photovoltaic, catalytic, photocatalytic & polymeric devices, allied to industrial collaboration & support. **Vision:** DMSM's new building provides one of the world's best platforms for EM. Two new (UCAM-funded) instruments complement the broad array of TEMs & SEMs, including a monochromated, aberration-corrected *Titan*. Existing strengths will be developed: eg 3D plasmon imaging, 3D crystallographic imaging (orientation tomography) & electron diffraction, implementing new concepts (eg compressed sensing) across microscopy disciplines. Broadened studies in spectroscopy will include photo-induced processes in hybrid solar cells & plasmonic materials.

Strategic plans at Department level — as well as the research plans area-by-area, DMSM aims: (i) to appoint an internationally leading scholar to the Cottrell Chair, (ii) to develop industrial collaboration in the context of the Maxwell Centre (§d), (iii) to continue academic staff renewal by appointments at international level. With the *Lennard-Jones Centre* (§e), and the newly funded EPSRC CDT on *Computational Methods for Materials Science* (jointly with UCAM Engineering, Chemistry & Physics) we expect Materials Modelling to develop into a full *research specialism*.

c. People, including:

i. Staffing strategy & staff development

Staffing Strategy, Research Strategy & Physical Infrastructure — DMSM plans for constant academic-staff numbers, but will see natural turnover. The age distribution is fairly uniform: with retirement at 67 (UCAM's EJRA), there will be 9 staff posts for refilling up to 2023. The staffing strategy is to focus on **quality**, actively seeking out & recruiting the most able & creative researchers. We advertise **internationally**, & aim for a **diverse field** of candidates (eg by contacting female holders of Research Fellowships). In RAE2008, DMSM had 1 established named professorship; we now (partly through philanthropic support) have 3; these posts play a strategic role in attracting **leaders at the highest international level**. Such special cases are balanced by the majority of appointments, which are (initially) to lectureships. At all levels, appointment committees have cross-departmental representation, vital in a subject like MSM.

DMSM, SPS & UCAM deliver substantial **start-up packages** in order to attract the very best internationally at all appointment levels. Such support is vital to propel the **careers of junior staff.** We note that DMSM appointees rapidly establish sustainable groups, eg through ERC *Starting/Consolidator Grants* (& 1 *Proof-of-Concept Grant*) totalling £5.4M to Ducati, Koziol, Oliver, Smoukov. DMSM recognises the strategic importance of attracting **Research Fellows** to nurture the best new talent & to explore new areas; our career development work to achieve this, & our

record of success, are covered below. In attracting staff at all levels, **world-class physical infrastructure** is vital; recent investments in equipment, & above all DMSM's new building (§d), have put us at the leading edge of materials-science departments worldwide.

Career Development Support — DMSM has a strong culture of mentoring & peer support encouraging development at all stages of an academic career. PDRAs are aided to submit strong applications for competitive research fellowships. Since Jan 2008, some 22 successful applications include: Royal Society URFs (4); other Royal Society (Dorothy Hodgkin, Newton International) (3); overseas (Catalan Gov't, NSERC Canada) (2); Leverhulme Early Career; UCAM Fellowships (Herchel Smith, Oppenheimer) (2); Daphne Jackson; Cambridge College Junior Res Fellows (9). DMSM has a long record of its members winning permanent/tenure-track academic posts. Since Jan 2008, current members have been appointed to 6 Full Prof & 25 Asst Prof/Lectureships incl at: Barcelona, Cambridge (2), Erlangen-Nürnberg, Hong Kong, Imperial College (4), Lille, Madrid, Münster, Open Univ (2), Oxford, Paris (2), Rice, RWTH Aachen, Southampton, Strasbourg.

Efforts are made to mentor & support academic staff for internal promotion. Since Jan 2008, DMSM has achieved 6 promotions to Reader (4f, 2m) & 7 to Prof (3f, 4m) — 80% of individuals applying have been promoted, representing 62% of permanently established staff. The annual exercise applies transparent criteria in a highly structured competition, with final decisions made by a VC-chaired committee. Promotion requires evidence of a significant international research reputation, with strong support from external referees. Academic staff are entitled to fully paid sabbatical leave to refresh their research; this is a key stimulant of long-term career success.

UCAM promotes the career development & progression of staff eg through its **Emerging Leaders Programme**. The opportunity for biennial appraisal review is available both to academics and to PDRAs. Staff are strongly encouraged to identify training needs to be met by **Personal & Professional Development** courses, including a **Researcher Development** programme designed specifically to meet the needs of research staff and PGRs. ECRs can access training for research staff & the **Academic Practice** programme for new lecturers.

Appointments of academic & research staff, at levels below Readership, are subject to satisfactory completion of **probation**: **UCAM Pathways in Higher Education Practice** offers induction, personalised orientation & professional development during this period. DMSM assigns a **Mentor**, tasked to advise & inform on everyday aspects of the new role & to share skills, knowledge & experience. More experienced staff can draw on peer-mentoring.

UCAM's **Careers Service** offers advice to academic & research staff at all levels; staff in the SPS can access a bespoke programme. UCAM runs an **Employer Forum** focused on postgraduate researchers & research staff that incorporates training & development initiatives.

Implementation of the Concordat — PDRAs in DMSM can access targeted training events, networking opportunities, & advice on commercialization of research. DMSM's annual *Armourers & Brasiers' Company Postdoc Fellowship* (£2,500) rewards outstanding performance. Excellent PDRA work is also recognised through the discretionary award of additional salary increments. UCAM's commitment to continued improvement is formalized in its **Code of Practice for Research Development**, **Code of Practice for the Employment of Contract Research Staff** & **The Concordat**. Inductions help new research staff integrate & identify the support & training available; an accommodation service & UCAM-owned accommodation prioritize new arrivals.

Growth in PDRA numbers in DMSM is paralleled across UCAM, where in 2012 PDRAs became the largest staff group (nearly 40%). In response, the first £300M phase of UCAM's North West Cambridge development, opening 2015–16, includes high-quality, sustainable housing for >600 PDRAs & their families, with retail & social facilities, & homes for PGRs. UCAM's new **Director of Postdoctoral Affairs** will coordinate & develop strategy for the entire PDRA community, fund-raise for further NW Cambridge facilities, & act as an advocate for PDRAs in UCAM's governance.

Staff with Personal Research Fellowships — DMSM benefits greatly from attracting an international cohort of Research Fellows (part of our staffing strategy) & building their careers to take up academic posts with us or elsewhere. We list the 21 (9f,12m) based in DMSM in the assessment period [Abbrev: CC, College Cambridge; F, Fellowship; JRF, Junior Research F (typically 3 years); L, Lectureship; URF, Royal Society University Research F], their nationality, start year (& place of immediately previous employment if not DMSM), & appointments. For any individual, only the latest fellowship held is specified. Those still in DMSM are underlined:

Durrell, UK, EPSRC Adv Res F. (2005), to UCAM Engg (Sen Res Assoc, 2010); **Sandeman**,

UK, URF (2005), to Imperial (L, 2009); **Eder**, Austria, APART Adv Res F (2006), to U Münster (Prof, 2010); **Oliver**, UK, URF (2006), to DMSM (L, 2009); **Bithell**, UK, Daphne Jackson F (2007, from schools), to Inst for Cont Educ UCAM (Teaching Officer, 2011); **Ducati**, Italy, URF (2007), to DMSM (L, 2009); **Herrero Albillos**, Spain, Ramón Areces F (2007, from U Zaragoza), to BESSY II Berlin (2009); **Israel**, USA, JRF Wolfson CC (2007, from U Texas Austin), to industry (Solar Academy & Solland Solar, Aachen, 2009); **Loudon**, UK, URF (2007, from Cornell); **Tan**, Malaysia, JRF Wolfson CC (2008), to Oxford (L, 2012); **Koziol**, Poland, RS URF (2008); **Egilmez**, Canada, NSERC (2009, from Alberta), to Amer Univ Sharjah (Asst Prof 2013); **Harrington**, UK, JRF Downing CC (2009), to industry (Johnson Matthey, 2011); **Wimbush**, UK, Leverhulme Early Career F (2009), to Industrial Research Ltd, NZ (Sen Scientist, 2011); **Moram**, Ireland, URF (2010), to Imperial Coll (L, 2011); **Musselman**, Canada, JRF Girton CC (2010), to Physics UCAM (PDRA, 2012); **Cheung**, HK, RS Newton Internat F (2011, from Univ of HK), to CityU HK (2013); **Kar-Narayan**, India, RS Dorothy Hodgkin (2011); **Robinson**, UK, URF (2011); **Husmann**, Germany, Daphne Jackson F (2012, from Open Univ); **Ringe**, Canada, RS Newton Internat F (2012, from Northwestern U); **Banerjee**, India, JRF Wolfson CC (2013), **Bennett**, UK, JRF Trinity Hall C (2013, from schools); **Moya**, Spain, URF (2013, from U Barcelona). In addition we have had 2 Royal Society Industry Fellows: **Rae** from DMSM into industry, **Curran** from industry into DMSM.

International Appointments, Recruitment & Visiting Scholars — DMSM benefits from a broad international community. PDRAs are typically 34% UK, 36% other EU, & 30% overseas. DMSM members appointed to academic positions elsewhere include France, Germany (2), India (2), Ireland & New Zealand. We benefit greatly from visiting overseas academics. DMSM hosts the annual *Kelly Lectureship* (internationally, a leading Materials-Sci visiting lectureship): **Olson**, Northwestern, USA (2008); **Rao**, JNCASR, Bangalore (2009); **Lu**, IMR, Shenyang, China (2010); **Fert** (Nobel laureate), Univ. Paris-Sud (2011); **Taub**, General Motors, USA (2012); **Humphreys**, DMSM (2013). In addition, in the assessment period, >30 overseas **academic visitors** have made sabbatical or research visits of a month or more, adding to the vitality of our research.

Equalities & Diversity — DMSM achieved its **Athena SWAN Bronze Award** in April 2013 & aims for Silver in 2015. The 4-yr average (2009-12) shows women in DMSM's key cohorts to be: UGs 30%, PGRs 30%, PDRAs 27%, research fellows 37%, & established academic staff (2012-13) 32% (of which, senior lecturers & below 0% women; readers & above, 37%). DMSM profs are 23% women, far ahead of the UCAM average in STEM subjects (12.5%) & the SPS average (6%). While the proportion of women UGs is not under DMSM's control in the UCAM admissions system, we have made efforts at higher levels; the feedback on the Athena SWAN application noted "the data appears to show that there is support for women at key transition points & for development."

We promote the **Dignity at Work** policy to new staff, supported by workshops. We direct students & staff to UCAM's **Occupational Health Service**, promoting the physical & mental well-being, & providing free counselling. Staff & students informing us of a disability are assessed by UCAM's **Disability Resource Centre**, who then liaise with us about measures needed to accommodate special needs. With the new building, we have **wheelchair access** to all labs, teaching rooms & offices (a dramatic improvement compared with the old buildings).

UCAM's **Women in Science, Engineering & Technology Initiative** for women from UG to prof includes: a CV-mentoring scheme; an annual lecture from women scientists working in policy, industry & academia; career-development seminars for early career, postdoctoral & PhD-level women scientists; a Senior Gender Equality Network; maternity/paternity/adoption leave provisions broader than required by law; & a Returning Carer Scheme. UCAM offers **equality & diversity training** to all staff. UCAM has two workplace nurseries & provides a holiday playscheme.

ii. Research students

Recruitment — Through its reputation, DMSM is able to attract top-quality applicants. Each year, 30–40 PGRs are admitted, mostly to a *PhD* (3–4 years depending on programme/funding) & a few to a 1-year *MPhil by Research*. All applicants are interviewed (by *Skype* if necessary). Most applicants have Master's degrees in relevant subjects. The quality of our UK-educated intake is illustrated by the admission of several *IOM3 Royal Charter Prize* (highest award for a UK Materials graduate), & *AT Green Award* (best graduate specializing in ceramics) winners — the 2008, 2010 & 2011 winners of both awards have chosen DMSM for their research. Our PGRs are typically 42% UK, 18.5% other EU, 11% China, 7.5% India, 4% N American, & 17% other overseas. Financial support is provided by highly competitive awards from the EPSRC, EU, Cambridge

Trusts & other UCAM, industry or home-country awards. The exceptional quality of DMSM PGRs, & the value added by UCAM, is shown by the many awards they receive (see below).

Training & support — DMSM follows UCAM's Code of Practice: each PGR is assigned a **supervisor** to advise on the planning & execution of their research & to provide feedback. Support is offered by an **advisor** (member of staff in a cognate research area), in the PGR's College (by Tutor etc.), & by the Graduate Union. PGRs can apply for financial help from UCAM & College funds; the Board of Graduate Studies provides a **database of funding opportunities**. The **International Student Team** provides specialist advice. Overseas PGRs must meet UCAM's stringent language requirements on admission. For those needing help, the Language Centre offers workshops & self-study courses. In DMSM, training & support are coordinated by the *Graduate Education Committee*, with input from the *Staff-Graduate Student Consultative Committee*. DMSM participates in two 4-year programmes: **DTC in Structural Metallics** (training integrated across Cambridge, Birmingham & Swansea Univs); & the **DTC in Nano Science & Technology** (with specialist nanoscience & technology courses, & courses in *science communication*, *business & research* & *management of technology & innovation*).

PGRs can access libraries, workshops, experimental facilities & computing, & the wide range of opportunities for developing technical skills: year-1 induction includes a range of *techniques* lectures (~20 hrs) & two compulsory assessed courses from a choice of 9 (each 4-8 hrs). PGRs sponsored by industry may receive on-site training. Benefits flow from being in the competitive, stimulating, supportive environment of high-achieving PGRs & other researchers in DMSM.

PGRs are encouraged to attend **research colloquia** in DMSM & elsewhere to widen their perspectives. **Teaching of UGs** can be a vital part of PGR education. PGRs are encouraged to develop their skills by demonstrating in laboratory classes, supervising research projects & teaching small-groups ('supervisions', for which specialist training is given). DMSM prioritizes PGRs attending, especially, **international meetings**, with support from DMSM, College etc. DMSM gives training in oral & poster presentations. Since Jan 2008 DMSM PGRs have won **21 prizes** (& our PDRAs/RFs a further **8 prizes**): eg best poster/oral presentation at int'l conf, young scientist award, young engineer award, best paper, literature review prize, best PhD thesis, etc.

DMSM fosters entrepreneurship through UCAM's **Centre for Entrepreneurial Learning (CfEL)** which offers training & direct support for PGRs developing spin-off companies. **Cambridge Univ Technology & Enterprise Club**, a student organisation, hosts talks, workshops, mentoring & networking sessions to develop business insights. DMSM PGRs: **David Zhu** led the team that won the *Armourers & Brasiers' Materials Science Venture Prize* (2008), **Giorgio Divitini** & **Najeeb Ullah** won 2nd prize in the *Cambridge/Dow Sustainability Innovation Student Challenge* (2011-12) & **Lewis Liu**: Final team, *2011 Rice Business Plan Competition*; 1st place, Western Europe, *Intel Challenge 2010*; Grand Prize, *UCAM Entrepreneur's Business Creation Competition*; Runner-up, *International Business Plan Competition, Licensing Executives Society*.

As part of the **Researcher Development Programme** in the SPS, DMSM expects PGRs to spend 10 days per year developing transferable skills & to compile a training record to show this. Such opportunities, including on-line courses, (eg from the Computing Service, Staff Development Office, Careers Service & Language Centre) are publicized to all PGRs. **One-to-one skills analysis sessions** focus on the individual. The Cambridge local **GRADschool** is freely available for 2nd & 3rd year PGRs, who are strongly encouraged to enrol as this residential course offers additional opportunities for personal reflection & development.

Progress monitoring — After 9 months, PhD students must: submit a thesis (15k word limit), successfully complete approved taught graduate courses, & present to the student cohort in order to be formally registered for a PhD. The oral examination is by 2 staff members other than the PGR's supervisor, & covers the thesis itself, its general field, & the content of the courses attended. Supervisors report each term on progress using an on-line system. Reports, available to the PGR, are monitored by DMSM, Degree Committee, College, & Board of Graduate Studies, who recommend action in case of concern.

d. Income, infrastructure & facilities

Investment — for the first time in its history, DMSM is in a **new building designed for purpose** at a cost of ~£50M. The project, approved in Mar 2009, was completed with the move over July to Sept 2013. The gross internal floor area of 10,600 m^2 gives 31% extra lab space (now 3,704 m^2 net) to accommodate DMSM's research to a higher standard. The **Wolfson electron microscopy**

suite is on a separate 2m-deep concrete slab, providing rooms with low-vibration ratings (NIST grade A); acoustic & electromagnetic interference are also at state-of-the-art low levels.

Additionally, with £42M non-government (industrial research & philanthropic) funds held by partner Depts (incl DMSM), £21M was won (in 2013) from HEFCE's *UK Research Partnership Investment Fund (2012-15)* for the **Maxwell Centre**. UCAM is contributing £4.5M to the project cost. The Centre will be a 5-min walk from the new DMSM building & will promote close & growing interaction with industry, provide interaction space, & laboratories for industrial collaborative programmes, & house CDTs & visiting industrial scientists. Approximately 30 DMSM researchers will be there (~15% of the Centre total). DMSM will (2014) also benefit from UCAM's £20M investment in the West Cambridge Data Centre housing the *High Performance Computing Service* & intensive research computer clusters. Ongoing UCAM investment in buildings & site infrastructure on the **West Cambridge Science & Technology Campus** provides a vibrant location for the newly arrived DMSM, close to Electrical Engineering, the Hauser Forum (housing *Cambridge Enterprise* & the *Entrepreneurship Centre*), Institute for Manufacturing, Nanoscience & Physics; with Chemical Engg & Biotechnology and the Maxwell Centre due for completion in 2015.

Laboratory refurbishment — spend of **£645k** (UCAM funds) to house new MOCVD system (see below) temporarily, pending completion of DMSM's new building.

Equipment expenditure (on items >£10k) — actual spend by DMSM in the assessment period totals **£4,617k** (UCAM £2,617k; EPSRC £1,393k; EC £265k; Overseas gov't/industry £213k; UK industry £108k; TSB £22k). UCAM funds, directed through & coordinated by the School of Physical Sciences, were for cross-departmental facilities for: (i) X-ray diffraction (£141k for diffractometer installed in & maintained by DMSM, from total School spend of £490k); (ii) electron microscopy (£1,406k for DMSM out of School £2,237k total). Other major items: MOCVD system (£1,066k, EPSRC); floating-zone furnace (£248k, UCAM); cryogenic measurement system (£129k, EC).

Specialist infrastructure & facilities — DMSM supports diverse specialist research facilities, notably a comprehensive range of precision thin-film-growth systems (8 UHV sputter, 5 pulsed-laser deposition & 2 GaN MOCVD), processing systems for nanomaterials & nanotubes, & extensive capabilities for structural & property characterization. X-ray diffraction (XRD) & electron microscopy (EM), operated as staffed user facilities, serve all of DMSM's specialisms, & because of their quality & range (boosted by recent purchases of state-of-the-art instruments in each class, see above), they attract other UCAM & external users. 'XRD' has 12 instruments, from standard powder diffractometers to high-resolution & small-angle systems; it has ~100 users each year, 15% from outside DMSM. 'EM' has 5 scanning-electron/focused-ion-beam microscopes & 7 transmission electron microscopes. Each year, the EM Facility trains >100 (15% from outside DMSM) & has ~300 users (DMSM, 12 other UCAM depts & external). DMSM researchers have access to a wide range of equipment (eg SQUIDs, & specialized XRD) in other UCAM depts. The UCAM library provides access to more than 90,000 electronic journals & ~400 databases.

Research Funding Portfolio — External research income (net) rose from £8.43M (2008-09) to £10.07M (2012-13, provisional figure), up 19.5% over 4 years. The **156 grants** activated over the assessment period total **£57.6M** (excl EPSRC studentships, but incl industrial student support). For these, the sources are: **EC** (**37%** of total value); **EPSRC** (**32%**); **industry** (**21%**, from 37 companies, largest £2.04M for SKF UTC); **charities** (Royal Society, Leverhulme Trust, etc) (**5%**); **UK Gov't** (**2%**); **overseas** (**2%**). The most dramatic change over the assessment period is the increase in EC funding, from the 9% noted in RAE2008. The EC total incl £13.98M from our 9 ERC grants. Charity support in the same period includes £0.35M from the Isaac Newton Trust, a source unique to Cambridge. DMSM Trust Funds, yielding £69k pa, provide further research support.

Since Jan 2008 philanthropic support has accelerated: from *Tata Steel* (£2M endowment for professorship), the *Wolfson Foundation* & 4 other donors (£2.8M for DMSM's new building), mainly alumni (£0.3M to assist in establishing the Cottrell Professorship).

Future plans — focus on the Maxwell Centre (above) to grow collaboration with industry. DMSM has appointed a *Knowledge Transfer Facilitator* to work with our existing *Research & Business Development Manager* to enhance our links with industry. We expect a rebalancing from EC & towards EPSRC funding. We aim to build on the current momentum in philanthropic fundraising.

Professional Services — [text removed for publication]

e. Collaboration & contribution to the discipline or research base

Research collaborations — Substantive collaborations are manifest verifiably, eg in co-authored papers. An arbitrary sample of DMSM papers in the REF period (the 100 most recent in *WoK* on 10 Aug 2013) finds **76** papers each showing 1 or more collaborations outside DMSM: **15** with another UCAM dept; **14** with another UK univ (Bristol, Durham, Imperial, Liverpool, Manchester, Open, Oxford, Southampton, Strathclyde, UCL); **52** with overseas univ: Australia(2), Belgium(2), China(8), Colombia, Czech Rep, France(3), Germany(7), Greece(2), India(3), Ireland, Iran(3), Japan(3), S Korea(3), Netherlands, Poland(3), Qatar, Spain(2), Slovenia, Switzerland, Taiwan, Turkey, USA(11); **30** with a National Lab or Research Inst: France(3), Germany(4), Greece, Hungary, Japan, Poland(3), Portugal, S Korea, Singapore, Spain(2), Slovakia, Switzerland, UK(2), USA(2); **11** with an industry co-author: Czech Rep, Germany, Greece(2), Italy, Sweden, UK(3).

DMSM has a culture of collaboration outside UCAM, & overseas; UCAM's sabbatical policy facilitates outside links; the reputation of UCAM & DMSM attracts visitors; Colleges facilitate visits through accommodation & Visiting & Overseas Fellowships. In the assessment period, coordinated & facilitated by UCAM's *International Strategy Office*, DMSM has signed MoUs/agreements with institutions in Japan (2), Kazakhstan, Malaysia, Oman, Russia. DMSM has been a participant or leader in UCAM workshops/presentations with many visiting national/regional delegations, including: [text removed for publication]

. There are many collaborations at UCAM level eg: the *Centre for Carbon Reduction in Chemical Technology* set up by UCAM in Singapore with partners NTU & NUS as part of the CREATE programme; the *Low Carbon Energy University Alliance* linking UCAM, MIT & Tsinghua. International collaborations are often supported by specific funding, eg DMSM new funding since Jan 2008 includes 7 British Council awards, at least 12 collaborative EC FP7 grants, & ~20 grants from overseas/multinational companies.

Interdisciplinary research — our breadth (5 specialisms) favours interdisciplinarity, even within DMSM, & promotes outside links (eg our extensive medical-materials collaboration with the Orthopaedics Research Unit at Addenbrooke's Hospital). DMSM also favours participation in UCAM research centres bridging across departments/disciplines: **Melville Laboratory for Polymer Synthesis**, based in *Chemistry*, is joint with *Engg*, *DMSM* & *Physics*; **BP Institute for Multi-Phase Flow** (**BPI**), based in *Earth Sci*, includes *Applied Maths*, *Chemistry*, *Chemical Engg*, *DMSM* & *Physics*; **Lennard-Jones Centre for Computational Materials** links research across *DMSM*, *Chemical Engg*, *Chemistry*, *Engg* & *Physics*. UCAM stimulates innovative interdisciplinarity through **Strategic Research Initiatives & Networks** (SRIs & SRNs), supported by 3 research analysts. DMSM is particularly involved with the **SRIs** on: **Energy** (tackling grand challenges in energy which require integration of science, technology & policy research) & **Cardiovascular Research** (DMSM's Cameron is on the Steering Committee); and the **SRNs**: **NanoForum** (for interdisciplinary research in nanotechnology across UCAM) & **Sensors** (exploiting technologies developed across UCAM to encourage innovation through interdisciplinary collaborations).

Collaborations informing research activities & strategy — DMSM's oldest (1994) ongoing link with industry, its *Rolls-Royce UTC*, focuses on developing next-generation materials for cleaner, more efficient gas turbines. Very successful in its research & in training of world-class materials scientists & metallurgical engineers, the UTC has attracted 10 DMSM academics (& 2 in other UCAM depts) to work in relevant areas, & it in turn benefits from their input. The *SKF* UTC (2009) was inspired by the *R-R* UTC, & DMSM continues to explore possibilities with other companies. BP's *International Centre for Advanced Materials* (ICAM, 2012) aims to advance fundamental understanding & the use of advanced materials across the oil & gas industry. Led by Manchester, ICAM has spokes in UCAM, Imperial Coll & Univ of Illinois at Urbana-Champaign. The 10-yr grant is expected to support 25 new academic posts, along with 100 post-grad researchers & 80 PDRAs. Based on UCAM's excellent experience with the **BPI** (above), we expect that ICAM will draw academics to areas of relevance. ICAM already funds DMSM's **Bhadeshia** to design steels resistant to hydrogen embrittlement. The UCAM/MIT/Tsinghua *Low-Carbon Alliance* is another case where collaboration takes DMSM research in new directions, with broadened relevance.

Leadership —

National or international advisory board membership — Staff have chaired or been members of Advisory Boards/Review Committees for academic institutions across the world: for AMMRF

Australia; Chalmers Univ (Mater Sci) Sweden; Chin Acad Sci Chengdu; Diamond Light Source; EPFL Lausanne; Erlangen Univ; HZB Berlin; ICMS Bangalore; IFW Dresden; IMDEA Madrid; Imperial Coll (Mater Dept); Inst Power Engg Warsaw; Karlsruhe Inst Technol; KAUST Pres Adv Council, Saudi Arabia; LBNL Berkeley Molecular Foundry; Manchester (Photon Sci Inst); NIMS Japan; NORTEM Norway; Oxford (Mater Dept); POSTECH S Korea; Sandia Nat Lab (SSLS-EFRC); Science Foundation Ireland; SuperSTEM Lab; WPI-AIMR, Tohoku Univ Japan; Zagreb Inst Metallurgy. Others have served as UK members on Int'l Committees: QMN for *Life Extension of Nuclear Reactors* (USA); PMDM for *Proactive Management of Nuclear Reactors* (Japan); Int'l Organization for Standardisation (ISO) Technical Committee TC 201 on *Surface Chemical Analysis*; Int'l Union for Vacuum Science, Techniques & Applications (Surface Engg Division).

Industry, Research Councils, learned societies, etc. — Some 8 staff are directors of companies (17 in total). Since Jan 2008, DMSM has generated 10 spin-outs (REF3a). Staff serve as chairs or members of committees for BIS, British Standards Inst, British Vacuum Council, CCP5, EPSRC, European Council on Superconductivity, Federation of European Materials Societies, IOM3, IOP, Leverhulme Trust, Materials Research Soc, RAEng, Royal Comm 1851 Exhibition, Royal Society, Royal Soc of Chem, World Energy Council. Highlights are: Treasurer & Vice-President of the Royal Soc; Co-Chair of Royal Soc URF Panel A; Pres FEMS; Pres European Microscopy Soc; Chair Science & Engineering Cttee Royal Comm 1851 Exhibition. Staff are active in the EPSRC peer-review college; on many EPSRC & EC/ERC committees; & as chair/member of panels acting for funding agencies in Belgium, Finland, Germany, Ireland, Israel, Norway, Poland, & USDOE & NSF.

Conferences & invited lectures — in the assessment period, DMSM staff have given some 176 invited plenary/keynote lectures at major int'l conferences & prestigious named lectures (eg at Univ W Indies; Arizona State; UTP Malaysia; IOM3 London; DRDO Delhi; Florida State; Oxford; IIT Mumbai; Chinese Acad Sci); Univ Wales Aberystwyth; ETH Zurich; Case West Res; Univ Guelph & Toronto; Groningen). For international conferences, staff have served as chair (in 15 cases), co-organiser (39 cases), symposium/session organiser (25 cases), on Advisory Committees (22).

Membership or fellowship of learned societies — within the assessment period **Fray** & **Humphreys** were elected FRS, **Best** & **Clyne** as FREng, **Burstein** as Hon Fell RS New Zealand, **Cheetham** as Foreign Member of German Academy of Sciences Leopoldina & Mongolian Academy of Sciences, & Mem of Academia Europaea, **Windle** as Foreign Fellow National Academy of Sciences, India. Other elections include: Fellow American Physical Soc (2), FBSE, FIMMM (2), FInstP, Academician World Acad of Ceramics, Fellow City & Guilds of London Institute, Fellow Building Research Establishment, Hon Mem Indian Institute of Metals. Hon Member Materials Research Society of India, Hon Member Iron & Steel Institute of Japan.

Journal editorships — some **19** DMSM staff are/were involved, incl **10** as Editor/Editor-in-Chief & a further **3** as Assoc/Deputy Editor of: *APL Mater*, *Corros Sci*, *J Ceram Proc Res*, *J Mater Sci Materials in Medicine*, *Min Proc Extrac Metall*, *Philos Mag*, *Philos Mag Lett*, *Sci Technol Adv Mater*, *Sci Technol Welding Joining*, *Scripta Mater*, *Ultramicroscopy*. They serve(d) on the Editorial Boards of **24** journals (incl *Appl Phys Lett*, *Adv Funct Ma*ter, *Biomacromolecules*, *Curr Nanoscience*, *J Energy Sci*, *J Magn Magn Mater*, *J Phys Chem Solids*, *J Roy Soc Interface*, *Phil Trans Roy Soc Lond A*), & have been Guest Editors for **12** special issues.

Awards, etc — 2010 was special: **David Duke** (our Principal Technician) MBE in New-Year Honours; **Colin Humphreys** knighted in Queen's Birthday Honours, both for 'services to science'. Two unusual distinctions: **Fray** had a whole international conference (450 people) in his honour (Cancun, 2011), & the *Colin **Humphreys** Education Award & Medal* established by IOM3 in his honour (2008). In the REF period, 11 staff won major prizes from learned societies & professional bodies: incl from the *Chinese Academy of Sciences*, the *Electrochemical Society* (Max Bredig Award — 1st time this prestigious US award went to the UK), *Federation of European Materials Societies* (Innovation Award), *Indian Acad of Sci* (Raman Chair), *IOM3* medals (Chapman, Griffith, Kroll, Platinum (2), Rosenhain), *IoP* (Supercond Grp Prize)*****, *Royal Society* (Leverhulme Medal), *Royal Soc of Chem* (Nyholm Prize), *TMS* (Bruce Chalmers Award), *TWAS* (Medal Lecturer). Hon Doctorates awarded at St Andrews, Tumkur Univ India & Univ of Malaysia*****). Other recognitions: *Belweder Prof* (Poland), Hon Fellow JNCASR Bangalore, *Presidential Fellowship* Northwestern Univ*****, *Nationally Recognised Researcher* (SNI II) National Council of Sci & Technol Mexico*****, JSPS *Long-Term Invitation Fellowship* (Tokyo)*****, *Distinguished Visiting Fellow CNRS*, (LPS, Paris)*****. Junior staff (below Reader rank) are well represented among these awardees (indicated by *****).