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

a. Context

The Dept of Materials Science & Metallurgy (**DMSM**) in the University of Cambridge (**UCAM**) has 5 *specialisms* (REF5). Research in **Structural Materials**, **Device Materials**, **Materials Chemistry** contributes to potential & actual impact, mainly in addressing grand challenges in ***Energy & Sustainability***. DMSM's research is directly relevant in: more efficient materials production & use; reduced energy consumption; cleaner energy production, storage & transmission & cleaner processing & recycling. Our work on **Medical & Pharmaceutical Materials** contributes to impact in ***Medicine & Healthcare***. Our 5th specialism **Electron Microscopy** underpins the first 4. Section (b) opens with 21 examples of actual or potential impact in the assessment period, cited in [ ] below.

Non-academic user groups & beneficiaries

In the Economy, mainly industrial companies: (i) **large multinationals** [1–4]; **SMEs** [5–7]; creation of **spin-outs** [8–21]; benefits for **investors** in these companies. In Services, **the general public** benefits from eg better reliability & performance in transport (air, rail [1,3]) & consumer devices, eg batteries [4], lighting [6,16]. In Health, **patients** benefit from increased quality of life [5,10,12]. Environment – **society** benefits from reduced CO_2 emissions [1,2,6,9,13,14,16,20], improved resources (water [6,16,18]) & cleaner processing [8,9,14,15].

Main types of impact (detailed in Section (b))

— arise from all 5 of DMSM's specialisms, and are: **Economic** [1–21], in **Public policy & service** [1,3], in **Health** [5,6,10,12,16,18], and in the **Environment** [1,8,14,16].

b. Approach to impact

Going beyond good science to pursue development reflects a pervasive culture at DMSM, where the principal route to impact is through wide engagement with industry. Main types of impact are:

Economic — performance of existing business improved through new products & processes [1–7]; Spin-out business created with significant revenue already generated [8–11,16] (& others with potential [12–15,17–21]); total of 10 spin-outs associated with DMSM since Jan 2008 [14–21]. Business sector adopted new or significantly changed technology or process [6,9,16]; Performance improved through highly skilled people taking up specialist roles that draw on their research [1,3,6].

Public policy & services — in delivering a public service, an existing technology or process has been improved [1,3]; Risks to the security of nation states reduced [3].

Health — A new medical technology developed, trialled with patients, or adopted & patient health outcomes improved [5,10,12]; Public health & quality of life has been enhanced through, eg in developing countries, improved water quality [6,16,18]; Costs of treatment have reduced [12].

Environment — improved through the introduction of new products or processes [1,8,14,16].

The cited examples of engagement with industry in the assessment period are:

[1] *Rolls-Royce*: DMSM's Univ Technology Centre (UTC) develops high-temp materials for next-generation turbines, lowering energy consumption (& cost, CO_2 emission) in air transport, other propulsion, & electricity generation. A steady stream of UTC PGRs & PDRAs take up employment in the company. The link with *RR* is long (UTC since 1994), deep, & undoubtedly has led to DMSM's **greatest overall impact** (eg on alloy development, optimization of production & component life assessment, with several key patents), yet it is so pervasive, diffuse & difficult to quantify that we have not felt able to base a case study (**CS**) on it. **[2]** *SKF*: DMSM's UTC develops improved materials for ball-bearings, of very broad relevance, with particularly pressing issues in off-shore wind turbines. **[3]** *Tata Steel*: see **CS** on Armour Steel, where the background includes an improved rail steel used in the Channel Tunnel. **[4]** Other large companies include *Pfizer*, *Morgan AM&T*, *Amazon Mining* (*Verde Potash*). **[5]** *Ranier*: R&D for manufacture of biocompatible polyurethane implants with graduated modulus, eg for spinal implants (Cadisc®). **[6]** *Plessey*: see **CS** on LED Lighting. **[7]** other SMEs include *Welding Alloys*, *Alphasense*. **[8]** *EMC*: development of solid-electrolyte sensors, particularly for gaseous emissions (eg SO_2, SO_3, H_2S). **[9]** *Metalysis*: exploits a DMSM-invented process for extraction of a wide range of metals, rare-earths & alloys at lower cost (economic & environmental) than conventional processes. **[10]** *Orthomimetics*: 1st spin-out from the Cambridge-MIT Institute, founded & led as CEO by an ex DMSM PGR (& based on his PhD), developed multilayered tissue-regeneration scaffolds to provide off-the-shelf treatments

for sports injuries, trauma & early osteoarthritis; sold (2010) to *Tigenix* for €16M. **[11]** *Q-Flo*: see **CS** on CNTs & Carbon Nanofibres. **[12]** *InotecAMD*: see **CS** on Oxygen Therapy. **[13]** *Camfridge*: energy-efficient & gas-free magnetic cooling technology. **[14]** *Chinuka Ltd* (2008) & *La Serena Technologies Ltd* (2011): reduction & refining processes for Ta, Ti & U, & licensing to other parties. **[15]** *Green PB* (2008): environmentally friendly recycling of lead in lead-acid batteries. Pilot plant planned for Hyderabad, India, & process development with *Johnson Controls Inc* (world's largest Pb battery company). **[16]** *CamGaN* (2010) *& Intellec* (2011): see **CS** on LED Lighting. **[17]** *Cambridge Nanosystems Ltd* (2012): produces equipment for the synthesis of a wide range of carbon nanomaterials incl carbon nanotubes (CNTs). **[18]** *CAMSES* (2012): photocatalyst-modified TiO_2 accelerates water decontamination 30x under ambient light. Further exploitation in air pollution mitigation & hydrogen synthesis. **[19]** *Energy Fluids Ltd* (2012): CNT dispersions as nano-fluids for cooling technologies, lubricants & energy storage. **[20]** *Tavarua International Inc* (2012): technology for making black (antireflective) silicon. **[21]** *Epoch Wires* (2013): superconducting wires, benefiting from DMSM work on MgB_2, for energy transmission, MRI & magnetic levitation.

These examples are evidence of a strong, active **impact-focused culture at DMSM**: our Case Studies are but the tip of the iceberg of our impact-probable research. In the REF period, **17** DMSM academics have published a total of **57 patent families**.

To promote engagement, a *Research & Business Development Manager* (RBDM) (60% of full time until March 2013, now 40%), supported by DMSM funds & HEIF5, deals with approaches from industry & pro-actively cultivates links, focusing on attracting industrial research funding. The RBDM organises DMSM's annual *Armourers & Brasiers' Cambridge Forum*, a half-day event (5 talks, the presentation of the *A&B Materials Science Venture Prize*, & the Kelly Lecture) with reception & dinner, showcasing Materials Science. In 2012 & 2013 the 250 attending included ~100 representing ~50 industrial companies, raising many funding opportunities. The RBDM edits our biannual newsletter *Material Eyes*, the mailing list of >2950 being mainly alumni & industrial contacts. *M Eyes* highlights DMSM research, often focusing on potential for applications. DMSM's work has featured in UCAM's magazine *Research Horizons* (in 10 of the 17 issues since Jan 2008), in a UCAM full-day *Horizon* conference on Materials (Dec 2008), & in EPSRC's *Pioneer* magazine (in 4 of the 10 issues since Jan 2008). DMSM has been a participant/leader in UCAM workshops/presentations with many companies, incl: [text removed for publication]

, exploring possible research of mutual interest. Staff are urged to promote their work in other fora, eg demonstration of a CNT-fibre-wired electric motor at the Royal Society Summer Exhibition 2013, attracting great interest, especially from industry.

Industrial beneficiaries are remarkably varied in scale. With **large multinationals** research is in collaboration with the company & new IP is filed by the company or by UCAM & licensed; with **SMEs** DMSM helps bring new products to their portfolio, expand their business, often through a *KTN studentship* or *Knowledge Transfer Associate* working in the company; **Spin-outs** are created with the help of *Cambridge Enterprise* (*CE*), UCAM's vehicle for technology transfer.

UCAM's IP policy requires disclosure of, & asserts Univ ownership of, registrable IP (patents), to ensure that inventorship is fairly established, obligations to sponsors are honoured, & an equitable return is made to inventors & UCAM. With *CE*, the inventor's share of licensing revenue is generous (90% below £100k, falling to 34% above £200k), with similar arrangements for equity in spin-outs. Inventors may exploit their invention independently of *CE*; then only 15% of income above £200k is retained by UCAM once direct costs are recovered. *CE*, wholly UCAM-owned, is not constrained by 'shareholder' interests in taking inventions forward. *CE*'s *Seed Fund* provides up to £125k to UCAM start-ups as a convertible loan or in return for equity. UCAM & other investors have established *Cambridge Investment Capital* (£50M funds) to provide follow-on investments in new ventures, complementing existing active 'angel' & seed funding.

This generous return & flexibility in approach has proved important to DMSM in encouraging & rewarding entrepreneurial activity & in attracting staff with entrepreneurial ambition from other institutions. DMSM academics are further encouraged to pursue impact by recognition of their achievements in the annual promotions exercise & by elections to FREng, etc. People at all levels are encouraged to compete for prizes, & many have been won by our PGRs. In

the assessment period, prizes include: *Armourers & Brasiers' Materials Science Venture Prize* 2008 [15]; Final team, *2011 Rice Business Plan Competition* (world's largest such) [16]; 1st place, Western Europe, *Intel Challenge 2010*; Grand Prize*, UCAM Entrepreneur's Business Creation Competition*; Runner-up*, International Business Plan Competition, Licensing Executives Society*; 2nd in the *Cambridge/Dow Sustainability Innovation Student Challenge* (2011-12) [18].

c. Strategy & plans

The examples in Section (b) flow from our focused strategy for impact. In August 2013 DMSM appointed a **Knowledge Transfer Facilitator** (KTF) (50% time), supported by the EPSRC Impact Acceleration a/c, enabling us to put still more emphasis on promoting exploitation of our research. Working within a network of KTFs in other UCAM depts & in cooperation with *CE* (only a 4-min walk from DMSM's new building at West Cambridge), our KTF will enable a step-change in impact & enterprise activities for DMSM. The newly approved **Maxwell Centre**, centrepiece for industrial partnership with UCAM physical sciences incl DMSM, will be housed in a bespoke building (£25.6M, completion due 2015) a 5-min walk from DMSM's new building. The Centre is anticipated as being transformative: it will consolidate & significantly expand univ-industry interaction space, & feature a state-of-the-art central lab space for joint collaborative projects between internal & external users. By dedicating space where industrial partners can spend significant time, it will facilitate dialogue & serendipity to drive new areas of research & innovation. DMSM's longstanding & ongoing strategies for impact are broad: **(i)** Develop in-depth relationships with high-tech materials-based companies, often aiming to form a UTC. **(ii)** Encourage collaborations with other companies, through sponsored research. **(iii)** Cultivate new industrial contacts, showcasing DMSM work through events & visits. **(iv)** Teach PGRs & staff about enterprise & the importance of IP, often through courses taught by our own staff active in generating impact (eg **Fray**, who features in our CS on Oxygen Therapy). **(v)** Encourage PGRs to participate in enterprise-related activities across UCAM, such as *Enterprise Tuesday* (networking & seminars at UCAM's Centre for Entrepreneurial Learning, CfEL), *Cambridge University Entrepreneurs* events & competitions, *i-teams* projects, in which an interdisciplinary team examines the commercial prospects for new technology. **(vi)** Pursue funding from UK & EC research councils to permit speculative research so that IP can be generated that is then capable of commercialization through licensing or a spin-out. **(vii)** Exploit our network of role-models (see next paragraph) to maintain our impact-focused culture, & to provide expert advice from their local experience.

These strategies can be seen in action in the background to the CS on LEDs for lighting: DMSM agreed in 2000 to house a GaN reactor for local company *Aixtron*. This unique facility enabled **Humphreys** to attract significant EPSRC funding, ultimately leading to new IP. PGR Lewis Liu attended an *EPSRC Ignite Programme* in UCAM's CfEL, sparking his interest in commercialization: within 6 days he had written his first business plan. Work funded by a RS Brian Mercer Award (2011-12) allowed Liu & Humphreys, with PDRA Dandan Zhu, to set up *CamGaN*. Former DMSM PGR, & founder of *Orthomimetics*, Andrew Lynn, assisted & became *CamGaN*'s CEO. Soon after, *CamGaN* (& *Intellec*) were bought (£10M) by *Plessey*, with *CE* giving key support, including on patenting. **Features that emerge are the stimulus for entrepreneurship at UCAM, DMSM's competitive spirit & its network of companies, key contacts &, crucially, role models.**

d. Relationship to Case Studies (CSs)

The **CS**s show key input from each of our 5 specialisms, & exemplify DMSM's strategy of hiring at the highest possible level: each **CS**, led by a world-class scholar (FRS & other recognition), is based on prolonged fundamental research. The LEDs for Lighting CS was built on the expertise of **Humphreys**. In the Steel Armour CS, **Bhadeshia**'s response to a specific MOD call had a clear path to impact in collaboration with *DSTL* & *Corus* (now *Tata Steel*), facilitated by long-term links, notably DMSM PGRs taking up specialist roles in *Tata*. Tata's recognition of Bhadeshia's expertise lay behind their endowment of his Chair, when the MD of *Tata* noted "In this partnership we are fortunate to have found a combination of passion, inspiration & dedication towards the further development of steel." The CNTs & Carbon Nanofibres CS arose from the polymer expertise of **Windle**. For the new CNT materials, impact has been realised by (i) licensing to an SME, (ii) a spin-out to promote technology transfer internationally. The Oxygen Therapy CS grew out of **Fray**'s long-standing eminence in electrochemistry. The spin-out rested on UCAM VC funds & local 'angel' investment. Together, these studies demonstrate the flexibility & agility of DMSM & UCAM to choose the development route best suited to each particular case.