Institution: University of Exeter

Unit of Assessment: UoA 9, Physics

a. Context

Physics and Astronomy at Exeter (herein referred to as Physics) is committed to generating impact that is as diverse as the research by which it is underpinned. The Electromagnetic and Acoustic Materials Group (EMAG) and Quantum Systems and Nanomaterials (QSN) group carry out research into materials that has benefited **manufacturing industry, the consumer, and the defence sector** through the delivery of improved materials, innovative products, and anti-counterfeiting measures. The research of the Biomedical Physics Group (BPG) benefits **patients and the National Health Service (NHS)**, with new biophysical approaches being developed for the detection and treatment of disease in tissue. The development of non-linear optical imaging tools provides unique information about organic and biological materials that is being used within the **cosmetics, pharmaceutical and agrochemical industries**. **Outreach** is vigorously pursued, with the next generation of scientists being inspired by research from natural photonics (EMAG) and the Astrophysics Group (APG). Bio-inspired designs revealed by natural photonics research have also been used to credentialise and market products in the **eye-care industry**. **National science policy** has been influenced through meetings with Parliamentarians and contributions to **EPSRC and Institute of Physics (IoP) policy** documents, while EMAG research has influenced **Ministry of Defence policy** including the UK approach to counter-terrorism.

b. Approach to impact

Developing relationships with key users, beneficiaries or audiences

The initial engagement of users, beneficiaries or audiences with new research occurs via many routes. Publication of results may lead to immediate enquiries. For example, publication of Russo's research on graphene led to enquiries from Nokia, Bausch and Lomb contacted Vukusic after seeing his natural photonics research in journals, while internet and printed articles on the structure of the tear film lipid layer led to collaboration with pharmaceutical company, SIFI S.p.A.. Publication of results for a lay audience is a deliberate tactic used by APG and Vukusic in outreach towards the general public and school children. In many cases users become engaged through interest in collaboration on underpinning research. This may occur through networking at conferences. For example, the Defence Science and Technology Laboratory (DSTL) began to sponsor acoustic metamaterials research following a conference presentation by Hibbins, while Thales and the USAF found the work on the Physics web site. Alternatively, former postdoctoral workers and PhD students working in industry make contact about specific problems, e.g. beginning a very productive collaboration between Sambles, Hibbins and QinetiQ on microwave metamaterials. Users may be referred by colleagues at other universities, as when Crown Technology contacted Hicken about inductive tagging. Otherwise academic staff may approach the end user to benefit from their complementary capability within a research project. Collaboration with Carl Zeiss GmbH began with Soeller visiting their research centre, while Hicken's collaboration with HGST grew from a 2 month research visit hosted by a former postgraduate colleague. Staff are proactive in contacting users who might be interested in their research. Most of BPG's collaborative research with clinical staff at the Royal Devon and Exeter, Derriford and Gloucestershire hospitals (GHs) began in this way. EMAG collaboration on display technology grew out of enquiries to the former RSRE at Malvern as leaders in liquid crystal technology, and then to companies such as Sharp and Hewlett Packard. Vukusic began his outreach activity by writing to about 40 schools offering to give talks, while Moger organised a workshop to promote industrial R&D applications of coherent anti-Stokes Raman scattering (CARS) microscopy that attracted more than 60 industrial delegates. Staff with established links to end users are able to direct new research towards them, and receive serious consideration due to the credibility gained from delivery of previous projects.

Nature of relationships and interactions

Impactful relationships in technology and healthcare most often develop by involving users in the underpinning research. Interaction may begin on a small scale before expanding. Consultancy provides a first step of low risk to the user. For example, Sambles made annual 1 week visits to

DERA Malvern for 10 years to exchange knowledge on liquid crystals. Alternatively the user may commission a report to scope an opportunity, as when Hicken provided advice to Crown on inductive tagging of metallic packaging. Users may favour a short-term feasibility study before committing to a substantial programme of collaborative research. This has been achieved by sponsorship of undergraduate summer projects, for example by Lorient and Crown. Short-term projects have been carried out by more experienced staff with flexible contracts. For example, an Exeter Open Innovation Fund (EOIF) award supported a postdoctoral researcher (PDR) for a first 2 years to conduct proof of concept CARS studies for 4 industrial organizations. This led to a further TSB award, while today GSK and Syngenta provide half the funding for 2 PDRs.

Longer collaborative research projects with users may be undertaken by PhD students fully or partly funded by users or through Collaborative Awards in Science and Engineering (CASE), or the university's own matched funding schemes. Microwave, RFID portal, anti-counterfeiting, THz, and acoustic work has been supported by studentships from QinetiQ, DSTL, BAe systems and Sonardyne. CASE awards with Hewlett-Packard and Sharp underpinned development of display technologies, while work on grating aligned liquid crystals led to ZBD spinning out from DERA Malvern. Research into vacancy clusters in diamond, supported by CASE awards from DeBeers, led to the development of anti-counterfeiting measures deployed in its gem stone business. Seagate have funded students to study dynamics in hard disk writers, while super-resolution microscopy products are being developed with Badrilla through CASE studentships. Alternatively, external supervision of students based at Sharp (3), QinetiQ (2), and DERA Malvern (3), has seen emphasis placed on patent generation. Materials research in Physics has been drawn together through a new EPSRC Centre for Doctoral Training (CDT) in Electromagnetic Metamaterials that will involve 10 industrial partners in hosting visits by postgraduate students and in helping to define the training that they undertake.

A deeper level of interaction may involve user funding of postdoctoral workers or participation in grant-funded projects. Within the materials area, interaction on microwave, THz and acoustic work has been supported by funding from the DSTL led Materials and Structures Technology (MAST) project. The founding of the company Arkiris through a knowledge transfer award (KTA), to exploit patents held jointly with QinetiQ, has underpinned collaboration on RFID portals and anti-counterfeiting. This work is being extended through a knowledge transfer partnership (KTP) with Graphic, a local printed circuit board manufacturer, on the embedding of RFID technology into circuit boards. Work on inductive tagging with Crown Technology received support from the EPSRC Collaboration Fund and Crown, and finally an EOIF award that led to a patent application. Collaboration with the hard disk industry (Seagate, HGST) has been supported by EPSRC grants. Commercialisation of graphene in mobile phone displays with Nokia Cambridge is being supported by an EOIF award, while manufacturing of large area graphene is supported by Picosun Finland, and fully-carbon memory devices are being pursued in collaboration with IBM Zurich. Both Picosun and IBM are partners in an EPSRC manufacturing grant. Graphene based ultra-sensitive chemical noses are being developed with Thales UK for defence purposes with Technology Strategy Board (TSB) funding. Interaction with the pharmaceutical, agrochemical and consumer goods industries on the characterization of organic and biological materials occurs through the multi-photon imaging laboratory with funding from the TSB, Syngenta, Unilever, GSK and BASF.

BPG interacts with clinicians and patients through collaborative clinical research studies at hospitals, where a number of honorary Exeter academics work closely with BPG, and where research students are regularly placed to work at the physics/clinical interface. For example, the effect of sepsis on the elasticity of red blood cells has been explored with Derriford Hospital Intensive Care, while research into the human spine and associated musculature, conducted with the Nuffield Orthopaedic Centre in Oxford, benefits patients by identifying helpful forms of exercise. Research is communicated to patients via funding agencies such as the BHF and ARC and via websites accessible to patients (Exeter co-founded the charity Back to Back). A National Institute for Health Research (NIHR) project led by Exeter, in collaboration with GHs, NHS Innovations SW and Bristol University, exploring point-of-care testing for lymphomas, has developed a patented prototype of a Raman needle probe. An EPSRC project, led by Exeter, with Rutherford Appleton Labs and GHs is utilising novel deep Raman techniques to probe breast cancers non-invasively. The technique has been patented and clinical prototypes are being developed. An industrially led

EU FP7 project is exploring novel infrared spectral imaging systems for clinical diagnosis. Exeter leads on the system integration, spectroscopy and clinical implementation. Developments in fluorescence microscopy are being commercialised with Carl Zeiss Microscopy GmbH.

Physics has used its research in outreach to non-academic audiences. Both the general public and school children have been engaged with Natural Photonics research by Vukusic as the IOP lecturer, through popular science articles, national radio and television programmes, and visits and lectures at schools and societies throughout the UK, the EU, the US, and most recently Africa. Vukusic was awarded the 2013 Royal Society Kohn Award for his excellence in engaging with society in matters of science and its societal dimension. Natural photonics research has also been used to credentialise and market the bio-inspired eye-care products of Bausch and Lomb.

The annual Pre-University Physics Course (PUPC) provides 3 days of research inspired lectures and activities for typically 100 sixth-form students. Hands-on Physics experiments are also provided for the annual National Science and Engineering Week, held at Exeter, attracting about 80 school students. APG research results are made accessible to children through talks at schools, after school projects for disadvantaged children, and inclusion of images within textbooks. The general public has access to the group's work through radio interviews, popular books, planetarium displays, talks at amateur astronomical societies, TV programmes, movies such as "Journey to the Stars", on-line material, press releases, and Open Evenings in 2009 and 2010. APG provides simulation data and images for audiovisual and printed publications, assistance with its interpretation, and a large online resource on exoplanets is under development. The group has an email address for such requests. Bate advised the BBC on how to describe and portray star formation in "Wonders of the Solar System", his name appearing in the credits of the first episode.

Physics research and the esteem gained have provided opportunities to influence national science and security policy. Sambles has been a member of EPSRC council from 2008-2014 and chair of its Resource Audit Committee since 2011, has acted as advisor to the MoD on the UK approach to counter-terrorism, and became President elect of the IoP from 2013. Patience's group met with MPs to inform them about exoplanet research while Patience contributed to the IoP statement of UK exoplanet research. Plaut was selected for the Royal Society Pairing Scheme for MPs, civil servants and scientists, in 2012. She shadowed local MP Ben Bradshaw in Parliament and his constituency while he participated in hands-on experiments, including exfoliating graphene, and met postgraduate and undergraduate students.

Follow through from interaction to impact

Impact frequently results from a long-standing relationship with a user, as demonstrated by the case studies, in which the user takes responsibility for developing the impact, although Physics will participate to the point of generating patents and publicity, for example in display and microwave technologies, or in the development of novel medical tools. Physics will prioritise further support through PhD studentships and by recommending university support via EOIF awards. Physics monitors success in generating impact. A study of the impact of research student training on society, based on ~70 PhD students supervised by Sambles, has been drafted in the form of a book and will be presented to funders. Physics also monitors the impact of outreach activity. Around 5-10 of the yearly Physics UG intake mention that they attended the PUPC, while outreach activities have generated very positive feedback and follow-up emails from school children.

An agile approach to opportunities

Building upon success in generating patents with QinetiQ, Physics is actively looking to engage with new industrial collaborators e.g. expertise in planar waveguide and near field microwave measurement was rapidly used in inductive tagging for Crown Technology. Industrial (and DSTL) colleagues are deliberately kept up to date with new research developments so that they can flag opportunities. There are also dedicated email addresses on the Physics website for outreach, with requests information and use of research material being answered quickly.

Support and recognition of impact activity

Outreach activity has been supported by Physics through travel funds and time release to Vukusic as IOP lecturer, and to Hatchell when also engaged by the IOP, while computers and laboratory facilities are provided gratis. Part of a grant from the Exeter Science Strategy Exoplanet Theme

was dedicated to outreach. The university provides services required for interaction with non-academic partners, such as use of laboratories at reduced cost, press and conference offices, and the assistance of RKT in preparing quotations for projects, writing collaboration agreements, non-disclosure agreements, and patent applications. The university used Higher Education Innovation Funding (HEIF) to establish the EOIF for the development of impact. Since 2011 Physics received 11 EOIF awards, with total value of £950k including in kind contributions from business partners. Projects include the development of a graphene based formaldehyde sensor with Dart Sensors, exploitation of Graphexeter for transparent electronics with Nokia, and spin out of RFID technology with QinetiQ through Arkiris. Impact activity is recognized through the staff workload model, while the university introduced the Exeter Impact Awards in 2011 to reward staff who have generated impact. Russo and Vukusic have both been shortlisted for the 2013 awards.

c. Strategy and plans

Physics promotes impact through its Research Strategy Group (RSG), in which the Academic Leads, Director of Research, and Head of Discipline meet to consider all aspects of Research Strategy. Every staff member undertakes an annual Performance and Development Review (PDR) in which impact activity is one of 7 standing items for discussion. RSG encourages the dissemination of results to a wider audience and applications to university-led schemes for the necessary resources, examples being given in section (b). RSG also makes recommendations to the College for Engineering, Mathematics and Physical Sciences (CEMPS) for allocation of funds for visits to non-academic users, time allocation within the workload model, use of facilities, or matching funds for user sponsored projects. RSG receives updates from Academic Leads on the progress of grant applications being generated by each research group. Each staff member outlines their intended grant proposals for the coming year during their PDR, and these are brought to a RSG meeting that a member of RKT is invited to attend. The potential impact is discussed, and feedback and suggestions for maximising impact are provided. RKT also provides RSG with up to date information about mechanisms that it has put in place to promote impact.

Physics also benefits from the university's wider strategy for impact generation. For example RKT maintains a directory of research activity on its website (http://www.exeter.ac.uk/research/rkt/) that allows non-academic users to identify research activity relevant to its needs. RKT strategy encourages positive engagement and knowledge transfer with users and aims to obtain 40 per cent of research income from knowledge transfer sources by 2015. The strategy also aims to establish more than 10 strategic alliances with non-academic organizations within the same time frame. Physics is expected to lead with partners such as DSTL, GSK and QinetiQ. Collaboration with selected foreign universities is being pursued to promote impact on a global scale, with pump-priming funds being allocated through the international office, for example providing a PhD scholarship for collaboration on spintronics with Brown University. RKT strategy also recognizes the importance of an inter and multi-disciplinary approach to the generation of impact, and to this end the Exeter Science Exchange (ESE) was founded with support from EPSRC's Bridging the Gaps (BtG) programme. BtG also encouraged Plaut to pair with local MP Ben Bradshaw and facilitated a continuing relationship. The university's LINK and Open Innovation Funds were put in place partly to promote a multi-disciplinary approach to user problems.

d. Relationship to case studies

Experience gained from the case studies helped to develop the strategy in part (c). In three of the case studies, much of the impact was the result of continuous close collaboration with an industrial partner (***DeBeers***, ***QinetiQ*** and ***ZBD-DERA***), demonstrating that for timely, significant and well-evidenced impact to occur, contact with users should be established before the enabling research is even undertaken. The potential for impact must therefore be considered during the writing of the grant application, with RSG brokering an introduction or recommending allocation of resources for early contact with a potential user. The case study based upon interaction with ***Bausch & Lomb*** has demonstrated that excellent research can command a non-academic audience, and attract new users, if sufficient care is taken to present results in an accessible manner. RSG now actively encourages dissemination of this kind. Indeed the ***Inspiring the Next Generation of Physicists*** case study provides an example of best practice, and RSG acted to strengthen this case study by recommending that impact funds be allocated for travel to Ethiopia and Malawi.