Institution: Heriot-Watt University

Unit of Assessment: 9 Physics

a. Context

Physics at Heriot-Watt University has a track record of research and innovation that covers the full spectrum, from fundamental studies through to research of immediate relevance to industry and commerce, which builds on our extensive network of business and industry contacts. Our current research is engaged with both economic and societal issues, from new technologies predominantly applied to manufacturing industries, health care and well-being, shaping environmental policy, through to public engagement and involvement in social and philosophical perspectives that define our place in the Universe. Exemplars are our strategic alliances with UK industry such as Renishaw, AWE and Selex ES, recent spin-out companies like Optoscribe, Chromacity, Power Textiles and Alba Photonics, our multi-focal-plane imaging add-ons for commercial microscopes and our outreach with the Quantum Circus and internationally supported TED ('Ideas worth Spreading') events. Our strategy supports the generation of impact across all sectors with targeted actions as evidenced by our £800k of directly-funded industrial research.

Physics research at Heriot-Watt was historically focussed in the Department of Physics (creating for example long lasting and successful spin-out companies such as Edinburgh Instruments founded 1971 and Helia Photonics founded 2002), latterly in the School of Engineering & Physical Sciences and most recently across two new research institutes, the Institutes of Photonics & Quantum Sciences (IPaQS) and of Biological Chemistry, Biophysics & Bioengineering (IB3). These structural changes reflect the evolving nature of research challenges and position physics centrally in the School's multidisplinary approach to addressing our extensive engagement with industry. Heriot-Watt University has embedded impact and knowledge exchange at the heart of our academic staff development programmes.

b. Approach to impact

The basis of our impact strategy is partnership with industrial and other users of research that address economic, environmental, cultural and sociological challenges of the modern world, coupled with encouraging innovation and enterprise through imaginative staff and research student development programmes.

Key sectors: Our research excellence across photonics technologies allows us to generate impact in a wide range of sectors. From ultrafast laser development to polymer holograms in bank notes to novel 3D in-vivo imaging, our work impacts multiple sectors with both reach and significance. Our photonics research benefits not only from the related pool of theoretical research in the IPaQS, but also from a close working relationship with the applied physicists submitted to UoA15 General Engineering and life scientists submitted under UoA8 Chemistry.

Photonics: We have spun out four companies during the current REF period, for example, Optoscribe, a high tech start-up commercialising novel 3D laser inscription for micro-manufacturing based on the research of Kar. Optoscribe provide unique spatial multiplexer devices for increased communication bandwidth. These robust monolithic optical components have been delivered to blue-chip customers such as NASA and Bell-Alcatel. We have continued to work closely with our Strategic Alliance partners AWE, Renishaw & Selex ES throughout the REF period attracting ~£300k for projects in the areas of diffractive optics and instrumentation. Reid's ultrafast laser research, seeded by industrial and EPSRC funding, has produced Physics' latest spin-out company, Chromacity, which markets tunable femto/picosecond lasers into life-science and spectroscopy markets, and has also contributed to staff development in impact via Leburn's award of a RSE Enterprise Fellowship.

Imaging: In 2008 we signed a strategic alliance with Selex ES, part of the Finmeccanica group. The diffractive optics group of Taghizadeh have worked closely under contract with them on a number of projects including the development of diffractive optical elements used in mid- to long-range target recognition. Similarly close collaboration with BAE Systems led to their deployment of Heriot-Watt holographic elements for the in-helmet display's for the Euro-fighter jet simulator, and, with the European Central Bank, to durable holographic elements for polymer bank note security. Taghizadeh formed a spin-out, Alba Photonics Ltd, in 2010 to further exploit diffractive optical

technologies. Developments in exploiting our research expertise in two-photon microscopy (Reid) for integrated circuit fault diagnosis is detailed in a Case Study. Buller's single photon depth imaging and range-finding work has also stimulated further in-house development and application of this technology at Selex ES and DSTL.

***Societal impact**:* We seek to inform and excite a wider audience about our research using a variety of engagement channels. For example, Maniscalco organized the International Science Day and Quantum Circus (www.quantumcircus.com) with a total audience around 8000 and was chosen to present her research on the quantum Zeno effect to a large non-expert audience at TED Global 2009 and co-produced the award-winning 40-minute documentary, "Inside the Light: The Mystery of Light in Quantum Physics", explaining the interaction of light and matter at the quantum level, featuring Nobel Laureate Serge Haroche (seen by ~3000 so far). Faccio has coordinated a unique "behind the scenes" event for 35 delegates of TED Global 2013 – coordinating- a four-hour hands-on experience within our University experimental facilities. He has also contributed to interviews featuring his research, aired on the BBC and featured in mass-media from New Scientist to The Economist as well as French and Italian journals (Science & Vie, La Recherche, Newton etc.). Based around our research we promote STEM subjects to a younger audience via, for example, our Schools lectures programme, which in period has delivered >100 lectures to >2700 pupils, and our in-house schools practical lab (partly IOP sponsored) has benefitted >1200 pupils.

Supporting Impact: We undertake a number of activities both within Physics and across the University to support the generation and reach of impact from our research.

***Physics initiatives**:* Now renewed until 2018, Heriot-Watt Physics has led an EPSRC Industrial Doctorate Centre since 2001 partnering with other Scottish Universities. In addition to relevant business skills training, EngD students have a four year company-based research project and since 2009, the EngD programme (www.idcphotonics.hw.ac.uk) has trained over 50 EngD "Research Engineers" across 35 companies. Company testimonials indicate the profound impact the students R&D has made on companies' product development and strategic direction. We have committed ~£1M to the bid in the form of student scholarships to leverage EPSRC funding.

***University initiatives**:* HWU has a long tradition of working with industry. In 2009 it revolutionised its model for knowledge exchange, expanding on the traditional existing research-funding and technology-transfer unit, Research and Enterprise Services (RES). The overall package, reinforced with additional support and resources from research-pooling initiatives, including SUPA, provided £6.2M of investment over 4 years. Expert support in the delivery of impact is now provided by the dedicated business-engagement staff who are embedded in the School. They work alongside industry professionals who provide expert licensing and new-company support. This has created a simple and desirable single pipeline to enable the flow of knowledge and expertise between researchers and users. An innovative aspect has been the leadership by HWU of a pan-Scotland 'Converge Challenge' programme to create market-facing entrepreneurs. The annual programme has provided training to 90 staff from all the Scottish universities, with webinars attended by >1,400 researchers.

***Training**:* The Research Futures program is delivered by the University's award winning Centre for Academic Leadership and Development (Times Higher Education awards for 'Outstanding Support for Early Career Researchers', 2010 and 'Leadership & Management' 2013; EU recognition for HR Excellence in Research, 2010, 2012). This programme goes well beyond the often bland transferrable skills offerings, building on 5 years' experience of designing and delivering successful Scottish Crucible, Heriot-Watt Crucible and European Crucible programmes. The Crucible is a highly successful, professional and personal-leadership and networking development programme initiated by NESTA and led across Scotland by Heriot-Watt University. Outstanding external facilitators such as Quentin Cooper and Vivienne Parry deliver 'KE-Training' events and the national "KE Scotland Conference" for Scottish PhD students and early career researchers. Our physicists have been successful in the aforementioned pan-Scotland, Converge Challenge business plan competition, conceived and run since 2010 by Heriot-Watt University.

***Outcomes**:* From this supportive environment there have been four new physics spin-out companies in the REF period, and two successful applications for prestigious Royal Society of Edinburgh Enterprise Fellowships (Psaila, Leburn). Following such a fellowship, Optoscribe,

headed up by Dr Psaila, was winner of the Alba Innovation national business competition in 2011 winning a support package worth up to £50,000. We have also supported two members of staff in winning three Scottish Enterprise Proof-of-Concept and SMART feasibility awards totalling (£390k) to enable the step from the Laboratory to the development phase. These underpinned the development of Power Textiles Ltd (Wilson, integrating silicon solar cells into flexible textiles), and Alba Photonics (Taghizadeh, microstructured optical elements).

c. Strategy and plans

Much of our research is directly relevant to industrial users and therefore it is natural to develop long-term partnerships with collaborators. In new areas where the market is less obvious to established companies we support the formation of new companies that carry our research into the marketplace.

We have consciously assembled the critical mass of expertise across optics and photonics which allows us to be agile in response to new opportunities and emerging industrial users needs. We quickly build teams with the requisite expertise to tackle specific user challenges. e.g. combining nonlinear pattern dynamics expertise with advanced imaging for bio-medical target tracking applications. With strong and tested networks in place, we will continue to lead on future optics and photonics research challenges of relevance to companies.

Our strength in areas which have developed over the past five years provide new opportunities for our research to make an impact:

***Quantum sciences**:* We have substantially augmented our existing strengths in Quantum Sciences, as we seek to translate our theoretical and experimental excellence into the emerging quantum technologies sector (see REF5 for details). Specifically the recent appointment of two experimental staff working in this area, Ferrera (integrated optics) and Chen (meta-materials) will act as a further enabling conduit between fundamental developments and real-world applications. Our >£1M investment in local nanofabrication facilities further supports this strategy.

***Life-science imaging**:* Funded collaborations show the relevance of our biomedical imaging research, e.g. a >£9M EPSRC-funded Interdisciplinary Research Centre with Edinburgh Royal Infirmary Intensive Care Unit (and the Universities of Edinburgh & Bath), and a >£2M MRC-funded Next Generation Microscopy award with the Institute of Genetics & Molecular Medicine (the Edinburgh Super-Resolution Imaging Consortium). Our imaging methods support two other Next Generation Microscopy awards (MRC with Harwell and Oxford with Davis), and are exploited by the Howard Hughes Medical Institute (USA). Work with Beatson Cancer Research Institute, and links with optical instrument manufacturers Leica Microsystems, Olympus, Nikon, Hamamatsu, etc, promote the breadth and impact of our bio-medical imaging work.

As evidenced by the submission of IPaQS staff into General Engineering and Chemistry UoA's Heriot-Watt will continue to recruit staff in cognate disciplines to foster and enable the interdisciplinary research that is of most relevance to industrial sectors. We will continue to support our established Strategic Research Alliances with AWE, Renishaw and Selex ES. Such alliances are invaluable in sustaining a long-term relationship with significant players in Industry. We actively seek out new Alliance partnering opportunities, where the fit and perspective is real enough to foster a lasting, mutually beneficial relationship.

d. Relationship to case studies

Submitted case studies reflect a cross section of impact from our research. The Securency (banknote security) and AWE studies emerged from long-standing relationships; such extensive interactions develop a deep mutual understanding of the needs of both the research user and the research team which enables significant impact to be fostered. The 'Optically-based Fault localization..' case emerged from on-going microscopy research and exemplifies how expertise in nonlinear optics, became, with some imagination, a new tool for the silicon IC industry in partnership with a forward looking company DCG Systems. Both Securency and DCG Systems approached us for help based on their recognition of our proven research expertise.