Research Excellence Framework: Impact pilot exercise
Example case studies from Physics

November 2010

Introduction

1. This document provides some examples of case studies submitted to the impact pilot exercise that the Physics panel scored highly, and that indicate good practice in terms of the pilot submissions.

2. They are presented here in a revised format to that in which they were submitted. The original template required the impact arising to be described first, followed by the underpinning research and ending with evidence for both previous sections[1].

3. The expert panels recommended that the sections in the template should be reversed, starting with a clear description of the research and justification that it is of high quality, followed by an explanation of how it led to the impact and what that impact was. It was also recommended that the references to the research should be separated from references to 'user contacts' and external sources of corroboration.

4. For the purposes of publishing these examples, therefore, we invited participating institutions to revise the case studies that had been identified as suitable for publication[2]. A revised template and guidance were provided to ensure clear presentation of the evidence for publication. Further refinements to the template and guidance for the full REF will be made subsequently.

5. The examples published were selected from among the highest-scoring case studies submitted to the pilot, to show a range of types of impacts that were submitted, and to provide examples of good practice from among the pilot submissions.

6. The examples do not represent model case studies that should be replicated in REF submissions. As the range of published examples is intended to show, there are many and diverse ways in which impacts arise and can be described for assessment in the REF.

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[1] This template can be viewed in the 'Guidance on submissions for institutions participating in the pilot' available at www.ref.ac.uk under Impact pilot exercise.

[2] For this we provided further guidance, 'REF impact pilot: revised case study template and guidance' (July 2010), available at www.ref.ac.uk under Impact pilot exercise.

Teraview and teraherz imaging (University of Cambridge)

1. Short summary of the case study

Tetrahertz radiation research in the Cavendish Laboratory originated with the Department's interest in semiconductor physics, dating back to the 1970s. Tetrahertz radiation encompasses frequencies invisible to the naked eye in the electromagnetic spectrum, lying between microwave and infrared. Frequencies in this region of the spectrum offer many potential applications being intrinsically safe, non-invasive and non-destructive.

Emission and detection of Terahertz radiation using semiconductor devices was pioneered by the semiconductor physics group in the Cavendish in partnership with the Toshiba research centre based in the University. Concurrently with this key research work, a spin-out instrumentation company Teraview, was established in 2001 through Toshiba and the University of Cambridge. Subsequent joint research has produced broadband terahertz sources and detectors based on photoconductive effects which yielded high performance components. These have allowed the development of new applications of terahertz technology, particularly in healthcare with the pharmaceutical sector initially being the first beneficiary.

2.Underpinning research

The University's Semiconductor physics group has undertaken a very significant programme of research in conjunction with Teraview which has resulted in the development of broadband terahertz sources and detectors based on photoconductive effects. This terahertz technology, which was patented, creates spectroscopic information and 3D image maps with unique spectroscopic signatures not found at other wavelengths. It thus resolves many of the questions left unanswered by complementary techniques, such as optical imaging, Raman and infrared spectroscopy. Terahertz technology also produces faster and cheaper results than X-ray.

This innovative research has yielded high performance components under the leadership of Professor Sir Michael Pepper, co-founder of Teraview, and a considerable presence in the Department until his statutory retirement from his University office in December 2008. Since then, he has continued his research in the Department which is funded through his collaboration agreement with Toshiba and an EPSRC grant which ran until February 2010.

The development of the Molecular Beam Epitaxy (MBE) growth of suitable materials and fabrication of devices for broadband sources and detectors of terahertz radiation was performed in conjunction with Toshiba Cambridge Research. The time-resolved nature of these devices has enabled new and sophisticated imaging systems to be developed, starting with the highly successful *TPI imaga* systems, the first commercial terahertz imaging systems to be produced for material characterization.

The development of the MBE growth of structures for THz quantum cascade lasers led to the development of compact high power sources of THz radiation. Development work on these cascade lasers was undertaken first by the Semiconductor Physics Group in collaboration with the Universities of Pisa and Neuchatel. Their success has allowed the fabrication of high power compact sources of narrowband radiation. Ongoing research aims to develop lasers capable of operating at lower frequencies and higher temperatures while the present generation are currently being exploited for a range of applications including gas sensing, imaging as well as local oscillators.

The research developments highlighted above have allowed TeraView to develop new applications of terahertz technology, particularly in the area of healthcare. The two main applications which have been developed are:

- Detection of polymorphic changes of active ingredients in tablets
- Non-invasive imaging of the internal structure of tablets to provide a quantitative assessment of the character of the internal interfaces separating different chemical constituents. This is emerging as a technique of first choice.

Additionally, the group's investigations into the imaging of teeth and skin cancer as well as drug analysis have enabled the development of applications for terahertz imaging systems of interest to the medical profession as well as to drug companies.

Using the advantages that terahertz has over other technologies, the Semiconductor Physics Group and Teraview have been working over the last two years to develop systems for use in security and defence applications. They have demonstrated for the first time that tetrahertz light is absorbed more strongly at certain terahertz frequencies and the resulting fingerprint can be used to detect different types of plastic explosives through several layers of clothing.

3. References to the research

Terahertz pulsed spectroscopy of freshly excised human breast cancer, P. C. Ashworth, E. Pickwell-MacPherson, E. Provenzano, S. E. Pinder, A. D. Purushotham, M. Pepper and V. P. Wallace, *Optics Express*, **17**, 12444–12454 (2009).

Terahertz Pulse Imaging of skin cancer in the time and frequency domain, R. M. Woodward, V. P. Wallace, D. D. Arnone, E. H. Linfield and M. Pepper, *J. Biol. Phys.*, **29**, 257–261 (2003) [48 cites]

Using Terahertz Pulse Spectroscopy to Study the Crystalline Structure of a Drug: A Case Study of the Polymorphs of Ranitidine Hydrochloride, P. Taday, I. V. Bradley, D. D. Arnone and M. Pepper, *J. Pharm. Sci.*, **92**, 831–838 (2003). [92 cites]

Generation and detection of ultrabroadband THz radiation using photoconductive emitters and receivers, Y. C. Shen, P. C. Upadhya, A. G. Davies, I. S. Gregory, C. Baker, W. R. Tribe, M. J. Evans, H. E. Beere and E. H. Linfield, , *Appl. Phys. Lett.*, **85**, 164–165 (2004). [43 cites]

2.9 THz quantum cascade lasers operating up to 70K in continuous wave, S. Barbieri, J. Alton, H. E. Beere, J. Fowler, E. H. Linfield and D. A. Ritchie, *Appl. Phys. Lett.*, **85**, 1674 – 1676

(2004). [93 cites]

Grants

Linfield Terahertz Imaging EPSRC 21/11/2001-09/11/2007 £1,550,255

Davies Development of a portable coherent THz spectroscopy system for medical diagnosis. EPSRC 08/01/2001- 07/01/2004 £393,635

Pepper The Physics and technology of Quantum Nanostructures 01/10/2005-28/02/2010 £4,396,812

4. The contribution, impact or benefit

The success of the Semiconductor Physics Group in developing this unique technology to emit and detect terahertz light, and to harness its remarkable diagnostic and inspection properties to provide unique 3D image and spectroscopic measurements, has facilitated solutions to a number of industries. This use of terahertz provides a non-invasive methodology for obtaining 3-dimensional and chemical information for numerous applications including defence and security, (with the identification of weapons/ explosives hidden beneath clothing), analysis of the contents of tablets and capsules in the pharmaceutical industry as well as providing analytical instrumentation for more general research and assessment needs. Other uses of the technology are in the medical imaging of cancer and industrial inspection.

Around 30 *TPI imaga,* the first commercial terahertz imaging systems have been sold at a cost of approximately £150k-£200k each. These have been supplied to laboratories in Europe, North America and the Far East. In 2007 Takeda Pharmaceutical Company Limited, Japan's largest pharmaceutical company, acquired the TPI Imaga 2000, the terahertz tablet imaging system, and this has led to an expansion of interest in both Japan and throughout Asia more generally in this technology to meet their needs in pharmaceutical research and development and in the manufacture of new and better drugs. This machine provides 3D maps of the thickness and integrity of both simple and complex coatings in both controlled and sustained release drugs, it provides the 3D distribution of ingredients, ensures that the correct amount of active ingredients used to minimise cost and to ensure that safety standards are maintained, it confirms the stability of the product and enables counterfeit detection based on terahertz images. It also detects instabilities that cannot be identified with conventional methods. Detecting and understanding these differences is fundamental to developing a higher quality, safer, cheaper and more stable drug in the next generation. Some 44 patented technologies underpin the innovation of Terahertz Pulsed Imaging, which is embedded in the systems for 3D imaging and spectroscopy.

In the area of healthcare the high quality of the generation and detection of the radiation of this technology has resulted in joint projects with medical groups as terahertz technology can distinguish healthy and cancerous tissue. Evidence is in the joint publications with the clinical community. Studies of skin cancer have shown that the growth of a tumour below the skin surface can be detected and now a joint project with Guy's Hospital has investigated the applicability of a hand held probe for assessing tumour margin during surgery for removal of breast cancer.

Recognition of the importance of this technology was evidenced in 2006 when KT Venture Group, the corporate investment arm of $2B semiconductor inspection leader KLA-Tencor, identified Teraview as the market leader in terahertz technology and made a significant investment in expectation of future research and development in the new region of the light and radio spectrum. Teraview has received some £16M investment so far, and has 25 employees.

5. References to corroborate the contribution, impact or benefit

Contact details of CEO of TeraView Ltd were given for corroboration purposes.

Kromek Ltd a spin out company manufacturing large semiconductor crystals for medical and security imaging (Durham University)

1. Short summary of the case study

Research on vapour growth of semiconductor compounds CdTe and (CdZn)Te led to a key breakthrough (now internationally patented) in growing large crystals. This has commercial implications as these form the basis for energy sensitive X-ray detectors and large area substrates for thermal imaging. The process was commercialised by a Departmental spin out company, Kromek Ltd., which now employs over 40 people in a new building opened by Prince Andrew in 2010, and has a current value of just under £50M. The company has incorporated this detector technology into medical imaging products and security systems for screening liquids and gels at airports, providing a route to reduction of current restrictions on carry-on baggage and duty free goods. This application won the $400,000 prize in the international Global Security Challenge, and the company currently has a $4M contract to provide large area thermal substrates to the US Defense Threat Reduction Agency.

2.Underpinning research

Professor Brinkman is the leader of a research group in the Durham Physics Department has worked on the growth, characterisation and exploitation of group II-VI compound semiconductors for many years. He has a longstanding interest in CdTe and CdZnTe which form the basis of energy sensitive X-ray detectors, and can also be used as substrates for thermal imaging devices. However, commercial applications of these were limited by problems in growing large crystals. Standard melt growth processes only produce wafers less than 2 inches in diameter, whereas medical imaging applications require larger area detectors. While these can be made by butting several smaller crystals together, this is uneconomic as the cost scales with the number of crystals rather than their size.

Prof Brinkman (in collaboration with Profs Tanner and Durose, also in the Physics Department in Durham) led a BRITE-EURAM grant (1994-1997, with major academic partners including the Universities of Freibourg: Germany, Athens: Greece and Ankona : Italy) to explore and develop methods to improve the growth of CdTe. He realised that vapour growth was not subject to the same size limitations as melt growth processes, but the resulting crystals formed multiple grains rather than a single regular lattice structure. The key breakthrough in growing higher perfection crystals was made by Dr John Mullins, a postdoc working with Prof Brinkman, funded by this grant. He realised that the vapour source and deposition region could be thermally decoupled by using a bent tube rather than a straight one, so that the growing crystal was not heated directly by the source. The first high quality CdTe crystals were grown using this technique in 1997, with results published in a peer reviewed journal in 1999 [1]. A full description of the growth system was published in 2000 [2]

Research on this technique continued with a further £0.2M grant support from EPSRC (GR/N04287, 2000-2003). The potential of the process became increasingly clear, and development of this into a commercial product was supported by a £0.15M PPARC PIPPS grant

(PP/C503470/1, 2005-2006) and £1M from a DTI basic technology award for the HEXITEC consortium via EPSRC (EP/D048737/1 2006-2010). This work [3-9] culminated with the growth by Kromek of the first high perfection and good electrical property wafers of CdZnTe on GaAs in 2007. By 2009 the company had scaled this up the growth of 4 inch diameter crystals.

3. References to the research

All Journals are peer reviewed

[1] **Characterisation of cadmium telluride bulk crystals grown by a novel multi-tube vapour growth technique** *Journal of Crystal Growth 198/199 (1999) 984,* N.M. Aitken, M.DG. Potter, D.J. Buckley, J.T. Mullins, J. Carles, D.P. Halliday, K. Durose, B.K. Tanner, A.W. Brinkman

[2] **A novel multi-tube vapour growth system and its application to the growth of bulk crystals of cadmium telluride** *Journal of Crystal Growth 208 (2000) 211,* J.T. Mullins, J. Carles, N.M. Aitken, A.W. Brinkman

[3] **Photoluminescence study of a bulk vapour grown CdTe crystal** *Journal of Crystal Growth 220 (2000) 30,* D.P. Halliday, M.D.G. Potter, J.T. Mullins, A.W. Brinkman

[4] **Control of mass transport in the vapour growth of bulk crystals of CdTe and related compounds**
Journal of Crystal Growth, *Volume 275, Issues 1-2*, *15 February 2005*, *Pages e543-e547*
B.J. Cantwell, A.W. Brinkman, A. Basu

[5] **Vapor-Phase Growth of Bulk Crystals of Cadmium Telluride and Cadmium Zinc Telluride on Gallium Arsenide Seeds**
J. Electron. Materials 37 (2008) 1460 J.T. Mullins, B.J. Cantwell, A. Basu, Q. Jiang, A. Choubey, A.W. Brinkman, and B.K. Tanner

[6] **Crystal growth of large-diameter bulk CdTe on GaAs wafer seed plates**
Journal of Crystal Growth, *Volume 310, Issues 7-9*, *April 2008*, *Pages 2058-2061*
J.T. Mullins, B.J. Cantwell, A. Basu, Q. Jiang, A. Choubey, A.W. Brinkman

[7] **Close-spaced sublimation growth of homo-and hetero-epitaxial CdTe thick films**
Journal of Crystal Growth, *Volume 310, Issues 7-9*, *April 2008*, *Pages 1664-1668*
Q. Jiang, B.J. Cantwell, J.T. Mullins, A. Basu, A.W. Brinkman

[8] **Hetero-epitaxial crystal growth of CdTe on GaAs substrates**
Journal of Crystal Growth, *Volume 310, Issues 7-9*, *April 2008*, *Pages 1652-1656*
Q. Jiang, J.T. Mullins, J. Toman, T.P. Hase, B.J. Cantwell, G. Lloyd, A. Basu, A.W. Brinkman

[9] **Thick epitaxial CdTe films grown by close space sublimation on Ge substrates**
J. Phys. D: Appl. Phys. 42 No 1 (7 January 2009) 012004 (4pp) Q. Jiang, D. P. Halliday, B. K. Tanner, A. W. Brinkman, B. J. Cantwell, J. T. Mullins and A. Basu

Grants to Prof Brinkman:
EPSRC EP/DO48737/1 £931,012 July 2006 to June 2010. New Materials for High Energy Colour
EPSRC GR/N04287 £177,480 Jan 2000 to Dec 2002. Controlled Vapour Growth of CdTe
PIPPS PP/C503470/1 £152,545 Jan 2005 to Dec 2006. Evaluation of Foreign and Hybrid crystal growth

4. The contribution, impact or benefit

Profs Brinkman and Tanner took the decision to form a spin-out company in order to directly control the exploitation of their new process. They launched this as founder-directors in 2003, with venture capital from Max Robinson, a business angel who was a member of the Durham University technology transfer team, supplemented by a DTI SMART award, for the first commercial crystal

growth facility. Their first premises were in the Mountjoy Research Centre, which was then the University business incubator, with two staff, Drs Arnad Basu and Ben Cantwell, both of whom had just completed their PhDs with Prof Brinkman in the Physics Department in Durham.
The company outgrew its original offices and moved to NETPark (North East Technology Park), Sedgefield in 2005. Continued growth necessitated a move to larger premises in NETPark, opened by Prince Andrew in 2010.

The business model was initially focused on the growth of large, high purity CdTe and CdZnTe crystals for sale to other companies which build X-ray & gamma ray detectors or infrared imaging systems. However, the company took to strategic decision to move up the product value chain by fabricating their own X-ray imaging detectors by incorporating ASIC (Application Specific Integrated Circuit) electronics onto the crystals. The potential of these attracted £1M investment in 2005 from Amphion, the UK arm of a US venture capital company interested in high tech start-up companies. Regular calls for venture capital have seen increasing investment, with the most recent round in 2009 raising £12.5M. The company was awarded the ISO2001 manufacturing quality stamp in 2008, and have recently bought Nova R&D, a California based electronics company, in order to directly supply the required ASIC technology.

The three obvious applications for X-ray imaging are medical, space and security. Kromek currently has contracts to develop pixellated detectors for medical applications with a blue-chip company, and with ESA for space based detectors. However, new requirements for security presented a clear opportunity, and with support from the UK Home Office and its investors, the company took a strategic decision to incorporate its materials into X-ray systems for liquid explosive detection. In 2008 they launched a bottle scanner which can deal with individual containers. The system, presently under trial at airports around the world, will have a direct impact on all airline passengers as it will remove, or at least reduce, the restrictions on carriage of liquids through airport security screens. The liquid scanning system, which readily distinguishes *Coca-Cola* from *Pepsi*, also has proven applications for detection of narcotics dissolved in liquids in checked luggage and has been sold to Middle-East airports for alcohol detection. The company went from winning regional awards in 2007 (Business Link North East Business award, Business Innovation Centre), to national competitions in 2008 (IET Innovation award), and European success in 2009 (Western Europe Global Security Challenge for Best Security SME). This series culminated in winning the $400,000 Global Security Challenge in 2009 for Best Security SME, while the CEO. Dr Arnab Basu won the 2009 Ernst and Young title of Young Entrepreneur of the Year.

An alternative use of the large area crystals is as substrates for thermal imaging, with applications in security, especially night vision equipment, surveillance and smart munitions. The US Defense Threat Reduction Agency has placed a $4M contract with the company to develop even larger CdZnTe crystals to increase the area of the focal plane in these devices.

Since the original company spun-out, there has been a continuing strong research collaboration between the University with the company. The two founder-directors, Profs A.W. Brinkman and B.K. Tanner, who are members of staff of the Durham Physics Department, continue to sit on the board. Prof. Tanner is the Deputy Chairman of the company. The company has directly supported 2 PhD students, as well as staff time buyout for Prof Brinkman. A former CASE student in the group, Paul Scott, is now employed by Kromek.

5. References to corroborate the contribution, impact or benefit

Global Security Challenge http://www.globalsecuritychallenge.com/page_display.php?p=6&id=55

Ernst and Young UK Young Entrepreneur of the Year 2009 http://www.ey.com/UK/en/About-us/Entrepreneur-Of-The-Year/_EOY---Alumni-videos-2009-Arnab-Basu

Company web site
http://www.kromek.com/

Newcastle airport trials
http://news.bbc.co.uk/1/hi/uk/8244150.stm

Institution of Engineering and Technology awards 2008
http://www.kromek.com/downloads/news/IETAwards_Pg6-IETAwardsNov08.pdf

Prince Andrew opening Kromek building http://www.kromek.com/news_archive.asp?Year=2010

Daily Telegraph article Sept 2010
http://www.kromek.com/downloads/news/TheTelegraph-X-rayvisionaryfindsthebottletogoglobal_2_9_2010.jpg

Nanomagnetism and anticounterfeiting (Imperial College London)

1. Short summary of the case study

A spin-out company, Ingenia Technology Ltd, was launched in 2005, to bring the technique now known as Laser Surface Authentication (LSA) to market. LSA can be used to detect and prevent forgeries by allowing a unique and uncopyable identity code to be read from material surfaces. The code is formed from naturally occurring surface roughness and does not need to be explicitly created. It is particularly useful for fighting counterfeiting and smuggling of high-value documents and products and as such makes an important contribution to industrial and consumer safety, commercial revenues and countering criminal and terrorist activity.

2.Underpinning research

LSA comes out of basic research carried out by Professor Cowburn into nanomagnetism. Professor Cowburn has developed nanometrology instrumentation to allow reflected laser light to be used as a probe of the magnetic state of nanostructures fabricated on a silicon surface [1], [2]. These initial studies were performed before Professor Cowburn joined Imperial in January 2005. In August 2005, Cowburn published a paper in Nature [3] showing how the same optical geometry could be reconfigured to allow non-magnetic information with nanometer sensitivity to be extracted and how this could be used to probe the 'natural nanostructure' present in paper and other surfaces. Fig. 1a shows the optical geometry used for LSA in which a surface is illuminated with normally incident laser light that scans across the surface. Photodetectors capture photons that have been diffusely scattered while not seeing those that are specularly scattered. It is the fluctuations in this diffusely scattered intensity as the laser probe is scanned across the surface that is related to the underlying physical structure. For example, Fig. 1b show the typical fluctuations recorded by one of the photodetectors as the laser probe is scanned across a smooth PVC surface (as used in access control and bank cards), the topography of which is shown by Atomic Force Microscopy in Fig. 1c. Ingenia Technology was born out of this finding.

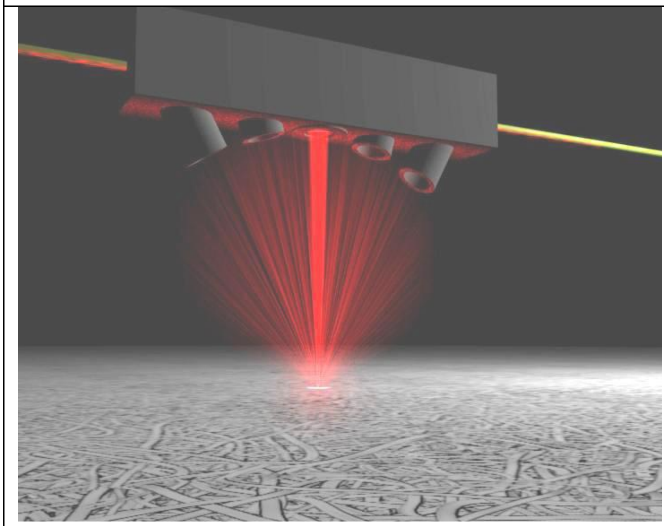
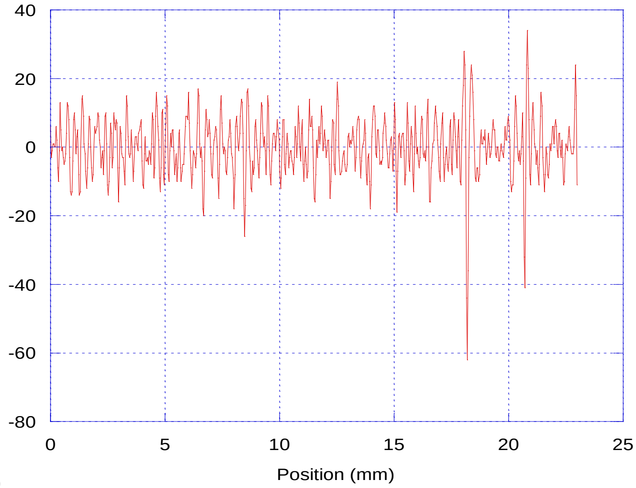


Fig. 1



(a) **Fig. 1 (b)**

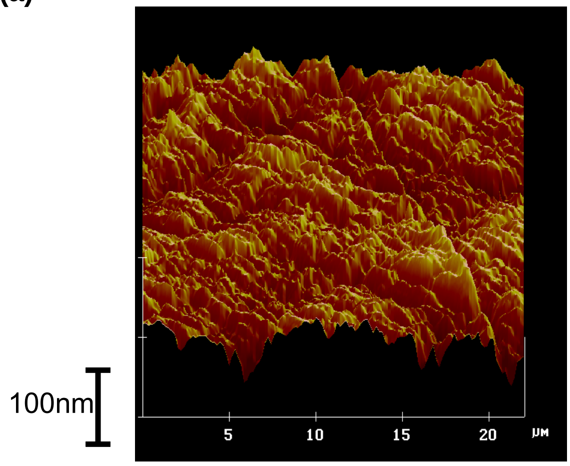


Fig. 1 (c)

Research that contributed to this initial observation that unique identification was possible was performed at Imperial. Between August 2005 and the present day, 16 researcher-years of further basic physics research has been carried out entirely at Imperial by Professor Cowburn [4], [5] to understand in detail how naturally rough surfaces scatter light and the role played by phase-coherent effects (e.g. ‘speckle’) and how the scattering geometry and data processing may be adapted to make the observed signature as robust as possible for use in real-world environments [6].

3. References to the research

1. Allwood DA, Xiong G, Cooke MD, Cowburn RP. Magneto-Optical Kerr Effect analysis of magnetic nanostructures. *J Phys D*. 2003;36:2175. *Host institution was Durham University. Peer-reviewed by publishing journal.*

2. Cowburn RP, Koltsov DK, Adeyeye AO, Welland, ME . Probing submicron nanomagnets by magneto-optics. *Appl Phys Lett.* 1998;73:3947-3949. *Host institution was Cambridge University. Peer-reviewed by publishing journal and by Royal Society at grant stage.*

3. Buchanan JDR, Cowburn RP, Jausovec AV, Petit D, Seem P, Xiong G, Atkinson D, Fenton K, Allwood DA, Bryan MT. Fingerprinting' documents and packaging. *Nature.* 2005;436:475. *Host institution was Imperial College London. Peer-reviewed by publishing journal.*

4. Seem PR, Buchanan JDR, Cowburn RP. Impact of surface roughness on laser surface authentication signatures under linear and rotational displacements. *Optics Letters*. 2009;34:3175. *Host institution was Imperial College London. Peer-reviewed by publishing journal.*

5. Seem PR. Optical scattering for security applications. 2009. *PhD Thesis, Imperial College London. Peer reviewed by PhD examiners.*

6. Patent PCT/GB2006/002689. Blockwise Analysis of Speckle Data for Article Identification. *Peer reviewed by patent examiner.*

4. The contribution, impact or benefit

The research provided both the original observation that 'natural nanostructure' could be probed with enough repeatability using a relatively simple and inexpensive laser geometry as well as the physical understanding of the scattering mechanism required to translate this laboratory observation into a proper technology that could be deployed into real-world settings.

The impact was secured by Imperial forming a partnership with the investment company Ingenia Holding Ltd which provided both the research funding required and the technology transfer know-how to launch the company, to engineer products and to form business partnerships. Imperial also allowed Professor Cowburn's teaching duties to be bought-out, thus freeing his time to serve as Chief Technology Officer to Ingenia Technology, ensuring that the research and the impact were closely aligned.

The physics of the optical light scattering that underpins LSA is more complex than it first appeared. This has important consequences for the optimum way to engineer products based on LSA. Without the close relationship between the physics research within Imperial and those trying to commercialise the technology at Ingenia Technology, success would not have been possible.

Ingenia Technology now employs 11 people in London and also has an office in Zurich. Ingenia Technology has contracts with, among others, the International Atomic Energy Agency, one of the world's largest cigarette manufacturers, one of the world's largest perfume manufacturers and the German pharmaceutical giant Bayer. One of these has been using LSA as an anti-diversion technology running in live production to protect their high brand value perfumes since mid-2009.

Because this technology is used for security, strong confidentiality agreements prevent fuller disclosure of user details.

Evidence of impact

- Licensing of technology by major industrial manufacturers
- Spin-out company formed which currently employs 11 people and has attracted £6m of venture capital investment since 2005
- Research addresses major global challenges of security

- Knowledge Transfer via employment of Professor Cowburn as Chief Technology Officer to Ingenia Technology

- The technology has been internationally recognised via the award of numerous prizes:
    - EU Descartes Prize Nominee for excellence in trans-national collaborative research (2008)
    - Winner of Hermes International Technology Award - a €100,000 prize awarded at the Hanover Fair for the best new technology exhibited at the fair (2007) [13, 14]
    - Winner of Global Security Challenge – a $10,000 prize for ‘the most promising security technology start-ups in the world’ presented by Lord Drayson (2006) [15]
    - Red Herring Global 100 award (2007) – the naming of Ingenia by the investment magazine Red Herring as one of the best 100 companies in the world for investment.

5. References to corroborate the contribution, impact or benefit

1. Ingenia Technology: http://www.ingeniatechnology.com

2. Popular Science – Laser Surface Authentication System: http://bit.ly/cb378d

3. Bayer Technology Services: Laser Surface Authentication: http://bit.ly/8XtjuL

4. Laser based applications: Existing and future solutions: http://bit.ly/bH31Gc

5. Contact details provided of Chief Operating Officer, Ingenia Technology Ltd

6. Contact details provided of individual at Bayer Technology Services GmbH

7. Bayer Technology Services: Hermes Award: http://bit.ly/di6LlX

8. The Engineer: LSA scoops Hermes Award: http://bit.ly/bqumiy

9. Smiths Detection: New material fingerprinting system wins global security challenge: http://bit.ly/drGGBi

10. BBC News: Laser spots paper “fingerprints”: http://bit.ly/bGILzy

Spaceport: Combining Engagement, Research and Regeneration (Liverpool John Moores University (LJMU))

1. Short summary of the case study

Spaceport is an Astronomy and Space Visitor Centre on the banks of the Mersey. A partnership between LJMU and Mersey Ferries it grew out of the desire to extend our engagement strategy to a wider (and larger) audience and, in particular, to explore the breadth of astronomical research and knowledge with a family audience. Combining the research experience and knowledge of LJMU with the tourism credentials of Mersey Ferries has led to an attraction that regularly exceeds visitor number predictions (currently at 100,000 per year) and brings considerable income into a regeneration area. The continuing partnership between LJMU and Mersey Ferries has allowed the Centre to remain informed and influenced by the latest in research and has led to further developments including special events designed to further extend the audience (e.g., for amateur astronomers or schools from inner-city areas).

2.Underpinning research

The ARI was founded less than 20 years ago, and has already achieved international leadership in several fields. For example, ARI developed and now operates the World's largest fully robotic telescope – the Liverpool Telescope (LT) [1]. The LT is a national facility of the UK for astronomy, but also undertakes projects for many astronomers from the wider international community.

One of the primary attributes of the telescope is its ability to react very rapidly to unpredictable changes in astronomical objects. This has enabled ARI researchers to develop a world lead in the study of a number of transient astronomical phenomena. The most extreme are Gamma-Ray Bursts (GRBs) – titanic explosions associated with the death throes of giant stars in distant galaxies. Working in tandem with the NASA Swift satellite, ARI astronomers using the LT were, for the first time, able to observe the polarised signal from bursts within minutes of an alert [2,3], with significant implications for our understanding of the physics of the explosion. Such observations led to the award of the Times Higher Education Supplement "Research Project of the Year" to the ARI in 2007. The LT has also enabled the ARI to lead in research into other dramatic transient phenomena such as Novae [4] and to investigate the relationship between supernovae and high-energy transients such as GRBs and X-ray flares [5].

Linked to this work on transients is research into theoretical and observational aspects of stellar evolution. ARI research encompasses the study of the environments in which stars are formed [6] and their subsequent evolution, and the ways in which their properties contribute to the evolution of star clusters and of galaxies through time [7]. This research covers all aspects of the "life cycle" of stars.

Building upon this background the ARI provides leadership of major international projects investigating the nature and evolution of galaxies in clusters [8,9], and the formation and build-up of the population of galaxies in the field [10]. The tools for this are the most advanced international astronomical facilities, telescopes both on the ground and in space, as well as the in-house LT.

The Royal Astronomical Society's 2008 Group Award for outstanding achievement was shared by two ARI staff members working on surveys of galaxies. ARI continues to develop leads in new areas of activity, and ARI staff are working actively on the next generation of surveys and of instruments to carry them out.

This combination of a wider range of international-class research and direct access to a world-leading telescope is, obviously, ideal support for the broad appeal of an astronomy visitor centre such as Spaceport. The research feeds directly into the activities described in section 4, including talks, displays and the Merseyside Astronomy Day.

3. References to the research

[1] Steele I., et al, "The Liverpool Telescope: performance and first results", 2004, Proceedings of the SPIE, 5489, p679

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4. The contribution, impact or benefit

Spaceport is an Astronomy and Space visitor centre based in a "tourist hot spot" on the banks of the Mersey. It is a joint venture between Mersey Travel and LJMU and grows from a desire within LJMU to enhance public engagement with our research, the Liverpool Telescope project, and astronomy and space in general. In this respect, we chose Mersey Travel as our partner to deliver this part of our engagement strategy as they are both a leading organisation in the region for tourism ventures and an organisation sharing the same vision.

LJMU research has had a significant impact on all areas of Spaceport from its conception. ARI astronomers were involved in all stages of the design process for the attraction, from the tender process through to final "signing off". Each specific interactive, display panel and exhibit has been tied into current astronomical knowledge and all material was checked by ARI staff. A recent "One Small Step" exhibition about the Moon is a prime example. Not only were we able to ensure accuracy and relevance of the material, but also to provide special observations and data from the Liverpool Telescope to enhance the visitor experience. However, the more important impact comes from access to the combined skills, knowledge and experience of a broad-based research-active department that feeds into the Centre to make it relevant, current and exciting.

Specific research activity is also used to broaden the audience (and hence reach) of Spaceport through special events. These include:

- The annual Merseyside Astronomy Day which combines a series of talks by professional astronomers with a day-out at Spaceport. As well as organising the event, LJMU provides the majority of the speakers. Recent subjects have included GRBs, stellar evolution, galaxy clusters and cosmology . The event has sold out every year and receives consistently excellent feedback (100% would recommend others to come).
- The Jeremiah Horrocks Day in November 2007, which involved bringing bus-loads of children from deprived areas and under-performing schools to a (very full!) day of activities based on current research.
- A series of evening lectures and Q&A sessions given by LJMU astronomers about their research.

Spaceport is now a key component of Mersey Travel's tourist portfolio which has the aim of enhancing the regeneration of the Seacombe and Birkenhead areas on the banks of the Mersey (other parts of the portfolio include the Beatles Experience). The strategic importance to Mersey Travel of the relationship with LJMU is made clear in a submission by Mersey Travel to the Science and Technology Select Committee of the House of Commons in 2006.

Opening in July 2005, the Spaceport business plan was based on original predicted visitor numbers of 90,000 in the first year, dropping gradually to 50,000 (as seen in comparable attractions). However, numbers have remained high, growing to around 100,000 per year (2009), which attests both to the quality of the centre and the appeal of the subject area. Using the standard STEAM model (Digest of Tourism Statistics, Dec. 2009 – The Mersey Partnership) for determining the economic benefits of tourism in the City Region for day visitors, this equates to a net gain of more than £2m per year. Spaceport also contributed towards the success of Mersey Ferries being ranked 1st in the City Region in 2008 – when Liverpool was European Capital of Culture - for a paid tourist attraction and an independent MORI Poll from 2006 found that 97% of visitors to Spaceport were either satisfied or very satisfied with their visit. Because of this success, the original targets for the regeneration have been met or exceeded. These included the creation of an estimated 50 new jobs, both direct and indirect, which equates to a gross value added of £1.4m pa to the City Region.

In addition to the economic benefits, Spaceport has a key role in primary and secondary education. Input from LJMU has led a good mixture of cutting-edge astronomy and curriculum-centred content, which has ensured that Spaceport is now a prime destination for school trips from across North

West England and North Wales – more than half of the visitors are school children. The visitor centre is now established as a 'public face' for LJMU's National Schools' Observatory and LJMU astronomers and NSO staff form the core of the attractions Design and Development Committee, which has a remit covering all aspects of the development of the visitor experience, from creating new exhibits to planning large temporary exhibitions.

5. References to corroborate the contribution, impact or benefit

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The Funding of Science and Discovery Centres, House of Commons Science and Technology Select Committee <http://www.publications.parliament.uk/pa/cm200607/cmselect/cmsctech/903/903i.pdf >

Contact details for an individual at Spaceport were provided for corroboration purposes.

Impact on the consumer electronics industry : The Floating Low-energy Ion Gun (FLIG) (University of Warwick)

1. Short summary of the case study

The floating low energy ion gun (FLIG)[1-4] was invented by Dowsett in 1993, in the Department of Physics at the University of Warwick. It is now a key analytical instrument in a wide range of generic semi-conductor device and other technologies such as DRAMs, quantum wells (e.g. for GaN LEDs), SiGe and high- and low- k dielectrics. Intel and its competitors have used the FLIG in the development of specific technologies such as the Pentium® and Xeon® processors. Its impact extends beyond industry to consumers worldwide because the FLIG has played a key role in the development of multicore processors in personal computers, intense low energy lighting in automotive and civil engineering, mobile telecommunications technology and many other areas of advanced electronics. Discoveries made with the FLIG, such as a universal function[5] describing the depth resolution in SIMS, are now applied in other fields such as the analysis of organic multilayer structures.

2.Underpinning research

The FLIG was invented in the Physics Department at Warwick University by Dowsett, assisted by PhD student Noel Smith, with a significant fraction of the early work being described in Smith's Thesis[4]. The underlying science behind the FLIG concept has two major drivers:

(i) In the late 1980s, the depth resolution provided by SIMS was falling short of that demanded by the Semiconductor Roadmap. In defiance of the literature of the time, and based on extrapolation of his own laboratory results at energies down to below 1 keV, Dowsett was convinced that lowering the SIMS beam energy still further, to a few hundred eV would improve the depth resolution of SIMS.

(ii) In order to do this in a way which gave rise to a routine analytical technique it was necessary greatly to improve space charge transport in focussed ion beam columns, and reduce the chromatic and spherical aberrations to maximize the usefulness of the transported current. At that time a few pA on target into a spot size of 50 µm was typical for a beam of energy 1 keV.

No real progress on (i) was possible without (ii), which was funded by the Royal Society's Paul Instrument fund[6]. The success of the prototype was dependent on the superb electronics and mechanical engineering support in the Warwick Department of Physics and this is reflected by the fact that technical staff are co-authors on the early papers[1]. The Paul Instrument Fund application was peer reviewed and overseen by a mentor. Note that the maximum impact was achieved initially through presentations at a venue (SIMS X) where instrument manufacturers and users were present simultaneously[1-4]. Subsequently, precise details of the instrumentation could no longer be published as they became commercially confidential. Research output can be divided into (a) a set of original conference papers, related patents[7] and PhD theses[4], which derive directly from the original research; (b) key papers which establish our contribution to the applications research[8], for example the development of the concept of the SIMS response function[9], and (c) many contributions to the development of ultra –low energy SIMS as a quantitative technique (e.g. reference 10), and papers and advances in materials processing and device technology made by other owners of the instrumentation.

Early results were reported at SIMS X in Munster in October 1995, and within a few minutes of the presentation describing the device, the three principal SIMS manufacturers of the time all tried to close deals to use the technology. Atomika were the successful bidders, and made an exclusive OEM deal with Ionoptika, a UK SME based near Southampton to whom Warwick had licensed the FLIG. The FLIG was the founding product of the company which now builds state of the art ToF-SIMS amongst other instrumentation, and still supplies the FLIG. The Atomika 4500, 4550 and 4600 instruments were the outcome of the initial IP licensing agreement.

3. References to the research

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4. The contribution, impact or benefit

Since its initial development in 1993, its commercialization for OEM application by Ionoptika Ltd.[1], and the first sale to Intel of a FLIG-based instrument in 1996 by Atomika Instruments GmbH[2], the FLIG has been in constant use in the R&D laboratories of the World's major semiconductor and technology companies, as an integral part of the Atomika (now Cameca) range of Secondary Ion Mass Spectrometry (SIMS) instrumentation[3]. Companies and institutes with FLIG-based tools include Intel[4], AMD, Motorola, TSMC[4], Nichia, Toshiba, Osram, IMEC (BE), NUS (Singapore), Imperial College, University of Warwick, MA-tek, Fibics and around 20 more internationally. The impact of FLIG-based tools has been continuous since 1993. They are still in routine use today as R&D tools for research on new semiconductors such as diamond and established electronic materials, as well as in more routine process control. The FLIG has so far earned Ionoptika almost £4M in revenue, and substantial royalties have been paid to Warwick, the inventor, and the Paul Fund (who recovered their investment).

All modern semiconductor devices depend on highly reproducible, nanometre scale multilayer engineering for dielectrics, semiconductor doping and heterostructures. Research and process development at this level requires analytical tools with sufficient sensitivity and spatial resolution to measure prototype and production wafer compositions accurately, and ultra low energy secondary ion mass spectrometry (uleSIMS) is a key method in this area. Dowsett's prototype FLIG–based SIMS instrument (EVA 3000) was the first SIMS instrument in the world capable of routine SIMS analysis at energies down to 200 eV. Subsequently, the IP for the FLIG was licensed to Ionoptika Ltd (UK) and the Atomika Instruments GmbH 4500 SIMS depth profiler was specifically developed as a vehicle for the FLIG. This was the World's first commercial instrument with an ultra low energy SIMS capability.
To date, there are over 1000 Google hits on FLIG associated items, and Dowsett's acronym, although trademarked by Ionoptika, has become generically synonymous with this type of technology. There are at least 50 peer reviewed papers from a wide range of international bodies acknowledging the use of the FLIG or Atomika/Cameca 4500, 4550 and 4600 instruments. There have been hundreds of presentations at semiconductor workshops, which are the principal means of dissemination in the industry and use of the FLIG has spread well beyond its original technological drivers, silicon and silicon germanium and gallium arsenide as examples from Dowsett's own group demonstrate[5-7].

The commercial version of the FLIG[3] is significantly different from the prototype, with re-engineered optics and its own custom high brightness duoplasmatron (both designed by Dowsett). The Duoplasmatron is descended from an earlier design by Drummond and Long. The success of the commercial FLIG, which can deliver around 500 nA of usable beam at 500 eV, depended on the development of this very high brightness, cold cathode duoplasmatron with a low energy spread, which delivers both oxygen and other gas species such as inert gases and nitrogen (which normally require a hot cathode source). Further elements of the innovative design include a matched column that transports the beam at high energy to the vicinity of the sample, and a multi-element, low aberration retarding lens to cut the impact energy by between a factor of 10 and 30. Dowsett also designed the secondary ion optical and detector systems of the Atomika 4550 and the 4600, and continues to provide support and expertise to both manufacturers and users of the technology as a consultant. Warwick has recently signed a further licence agreement with Ionoptika, covering new FLIG-related ion source technology[8] developed by Dowsett and his son.

Dowsett's SIMS response function gave rise to a current ISO standard (ISO 20341:2003)[9]. The function is thus also an outcome of significant impact deriving from the original FLIG development. . It is becoming known as Dowsett's function in the field and has now become important to both the semiconductor depth profiling community and in the new science arising from the depth profiling of organic materials (see e.g. recent papers by Tomita et al., the SIMS XVII proceedings, Shard et al., and Winograd et al.).

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