Institution: University of Surrey

Unit of Assessment: UOA 13 Electrical and Electronic Engineering, Metallurgy and Materials

Title of case study: The National Ion Beam Facility at the Service of UK Industry

1. Summary of the impact (indicative maximum 100 words)

The Surrey Ion Beam Centre (based at the University of Surrey) pioneered the field of ion beam applications and is regarded as world leading, having initiated a significant number of high profile research activities for which it received recognition through the Queen's Anniversary prize in 2002. It works actively with industry, developing bespoke processes and services, particularly for the photonics industry, ultimately generating millions of pounds for the UK economy. It also serves as a European Centre for doctoral training.

2. Underpinning research (indicative maximum 500 words)

Surrey's Ion Beam Centre (IBC) is one of the world leaders in the field of ion beam research and is seen by industry and academia as a pioneer in this field. It initiated the use of rapid thermal annealing, now universally used by the semiconductor industry. It also developed "radiation-hard" silicon-on-insulator substrates for space and military applications, which are in use world-wide.

In 1997 the IBC developed DataFurnace, a computer algorithm to enable quantified analysis using ion beam techniques. It is able to solve the inverse problem ("given the spectrum, what is the profile") *automatically*, without user intervention using Bayesian inference and Markov chain methods [1]. Recently the IBC has used DataFurnace to initiate work with Forensic Laboratories, Police and Home Office in the UK and in Europe [2].

In the mid 1990's, the IBC began work on silicon photonics, initiating research on $\beta FeSi_2$ [3] demonstrating light emission at 1.5 μm and later combining this with defect engineering to produce efficient room temperature emission [4]. Devices are currently under test for optically excited laser structures and 2 patents on 1.3 μm emitters - G centres and rare earth sensitised long IR wavelength detectors and emitters have been filed. Surrey has long been at the forefront of development of integrated optics with recent work in silicon photonics concentrating on the development of dense wavelength division multiplexing waveguides and high speed optical modulator and detector technologies. This work is in collaboration Intel, Kotura and Bookham Technologies (now Oclaro).

From 2004 to 2008, an EPSRC sponsored network led by the IBC was instrumental in bringing together a community of clinicians, scientists and engineers and making the case to government for a new type of radiotherapy using proton beams [5]. In January 2012 the government announced two new clinical centres using this technology (at a cost of £80M each).

With colleagues in Japan, the IBC has pioneered the development of a new analytical technique, MeV SIMS [6], for high molecular mass concentration maps in ambient pressure conditions with high spatial resolution. This is not currently possible using any other technique. The IBC has also pioneered the concept of "Total IBA", in which the full suite of Ion Beam Analysis (IBA) techniques (back-scattering, forward-scattering, X-ray and gamma-ray spectroscopies etc.) is used simultaneously to provide a single self-consistent view of a sample. The DataFurnace was created specifically to aid this process. The IBC also leads the world in high precision backscattering analysis, demonstrating a traceable precision of better than 1% in its work. This underpinning research on the analysis techniques has enabled the IBC to attract a large number of projects from around the world.

3. References to the research (indicative maximum of six references)

1. N. P. Barradas, C. Jeynes, and R. P. Webb Simulated annealing analysis of Rutherford backscattering data Appl. Phys. Lett. 1997, 71, 291 (1997)
2. Bright NJ, Webb RP, Bleay S, Hinder S, Ward N, Watts JF, Kirkby KJ, Bailey MJ. (2012) 'Determination of the deposition order of overlapping latent fingerprints and inks using Secondary Ion Mass Spectrometry (SIMS).'. Analytical Chemistry, 84, pp. 4083-4087. doi 10.1021/ac300185j
3. D Leong, M Harry, KJ Reeson, KP Homewood A Silicon/Iron-Disilicide Light-Emitting Diode Operating at a Wavelength Of 1.5 µm Nature, 1997, Vol.387, No.6634, Pp.686-688
4. Wai Lek Ng, M. A. Lourenco, R. M. Gwilliam, S. Ledain, G. Shao & K. P. Homewood An efficient room-temperature silicon-based light-emitting diode, Nature, 2001, Vol 410, 192-194
5. N G Burnet. K J Kirkby, N F Kirkby Biomedical Applications of High Energy Ion Beams Clinical Oncology 16, 384-385, (2004).
6. Wakamatsu Y, Yamada H, Ninomiya S, Jones BN, Seki T, Aoki T, Webb R, Matsuo J. (2010) 'Biomolecular emission by swift heavy ion bombardment'. AIP Conference Proceedings: 18th International Conference on Ion Implantation Technology, Kyoto, Japan: IIT 2010: 18th International Conference on Ion Implantation Technology 1321, pp. 233-236. doi: 10.1063/1.3548357

4. Details of the impact (indicative maximum 750 words)

Over many years the IBC has developed its portfolio of industrial users, with bespoke processes developed to meet the needs of the industrial customer. Users for the IBC facilities now come from the UK and Europe, USA, Japan and Australia. Work initiated at Surrey generates millions of pounds for the EU economy and contributes to cultural and societal issues throughout the world. In 2002 the University of Surrey was awarded the Queen's Anniversary award for Ion Implantation and Optoelectronics. The citation reads;

"For over thirty years the University has been recognised as a pre-eminent institution in the field of ion implantation and optoelectronics. Its innovative research into these key technologies has had an outstanding impact on the development of the modern electronics industry worldwide."

Work on silicon photonics led to the formation of a Surrey spinout company SiLight Technologies and a prestigious ERC grant, augmented recently by an EU commercialisation award. In 2008 Surrey took the lead role in £5M EPSRC UK Silicon-Photonics-Consortium to work on advanced Si integrated optics. Surrey's work has included joint patents with Intel on ion-implanted erasable Bragg-gratings, a technology that allows a route to full wafer device testing methodologies at the production level, which is now being implemented by Intel.

The IBC works with industry world-wide developing bespoke processes. Much of this work is carried out via non-disclosure agreements. Below are examples of the work undertaken by the IBC between 2008-13 for industry and the public sector, which reflect the impact the IBC has made.

Twin Creeks Technologies (USA) manufacture a new material for solar-cell applications using a technology devised by IBC (2008-2011). This method can produce solar cells for about 40 cents per watt, half that of even the most cheaply produced cells coming out of China. *Twin Creeks*

Technologies believe that at 40 cents a watt, solar could quickly become as profitable as conventional fossil fuels. *Element6* collaborate with the IBC in the fabrication of photonic structures (2004-13) to produce commercial devices for quantum information processing. *Coherent* also use the IBC for processing key enabling components for laser products. They say;

"They draw a direct competitive advantage from having the full control over the processing of these components, which they believe is only available at the IBC. The ability to control and tailor the implantation process to specific requirements enables Coherent to offer products with superior performance and reliability". They also say that "around a third of their staff hinge on the products enabled by ion implantation at Surrey". They plan to double their business over the next 3 years. "Having access to the IBC in the UK has proven to be an immense advantage during the product development phase."

For the past 10 years (2003-13) the IBC has been providing *RFMD* and its predecessor *Filtronic* (a manufacturer of RF integrated circuits) with ion implantation for their optical modulators for high frequency communications (up to 100GHz). The IBC is also working with *Raytheon UK* (2009-13) to provide ion implantation processing for CMOS on silicon carbide high temperature devices. They are in the process of providing commercial devices operating at 400°C for use in the oil, gas and geothermal down hole electronics and aerospace markets. In addition, over the past 5 years (2008-13) the IBC has provided ion beam facilities for 42 other Companies, as well as 15 National Centres and other publicly funded bodies.

DataFurnace is one of only 2 algorithms recognised by the International Atomic Energy Agency (IAEA) and is licensed to 23 laboratories world-wide. The IBC uses its analysis techniques and DataFurnace to work on a variety of problems which impinge on the economy and society. These include working with NASA, ESA and the Natural History Museum (NHM) (2010-2013) to determine the origin of craters on material retrieved from the Hubble space telescope. Interestingly, most (>80%) are found to be extra-terrestrial in origin; this has impact on the planning of space clean-up projects and long-term space missions. The NHM said;

"With the help of the expertise and equipment at the IBC we have been able to provenance the origin of a much greater number of impacts on samples returned from low Earth orbit than would have been possible with more conventional techniques. The extra sensitivity that has been obtained has helped us to identify which … were created by collision with natural asteroid or comet dust particles, and which by orbital debris, the result of human activity in space."

The IBC has also worked with conservators at the Rosslyn Chapel in Scotland (2010-13) to help them re-create the original colours of the stained glass in the Chapel. The Scottish Glass Centre says;

"Without the help of the IBC we would have only been able to use traditional and at times conjectural techniques to establish missing detail but their painstaking analysis has helped us accurately re-create the windows and to return them to their former glory".

The IBC has also analysed Jane Austen's hair (2010) and, although it contains more arsenic than would be expected in the current day, it seems unlikely that she was deliberately poisoned! In the field of biomedical applications a Network led by the IBC played a vital part in making the case for proton beam therapy (PBT) in the UK (2004-13). This involved bringing the clinical community together and making a case for its adoption to government. The Chair of the National Cancer

Research Institute's CTRad Working Group, says;

"The work of the IBC was instrumental in bringing the community together, …. The foundation provided by the Network facilitated the early work of developing the case for PBT, and through the Network the IBC can legitimately take some of the credit for the government announcement in January 2012, that two PBT centres would be developed in England."

5. Sources to corroborate the impact (indicative maximum of 10 references)

a) US 7274041 B2 K P Homewood, R M Gwilliam, G Shao Method for locally modifying electronic and optoelectronic properties of crystalline materials an devices made from such materials (2001)
WO 2012069397 A2 K P Homewood, R M Gwilliam Optoelectronic Devices (2012)
http://www.google.co.uk/patents/US8380027;

b) http://gizmodo.com/twin-creeks-technologies/

c) Coherent. Provided statement

d) Electron Probe Microanalyst at Natural History Museum . Provided statement

e) Head of Conservation Scottish Glass. Provided statement

f) Chair of the National Cancer Research Institute. Provided Statement.

g) International Atomic Energy Agency (IAEA) dataFurnace. Contact details provided.

h) Beaming in on a deadly disease The Guardian August 10th 2006
http://www.guardian.co.uk/science/2006/aug/10/cancer.health

i) New heights for proton therapy cancer treatment Thursday 21 August 2008
http://www.guardian.co.uk/technology/2008/aug/21/research.medicine