Institution: University of Strathclyde

Unit of Assessment: 9

Title of case study:
Creation of a cluster of innovative laser companies in Glasgow serving global markets

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

Research in solid state lasers and non-linear optics in the Department of Physics has led to the creation of innovative laser companies in Glasgow serving global scientific and industrial markets. World-leading products have opened up applications in biomedical imaging, security, defence, pollution monitoring, material processing and fundamental spectroscopy. The companies Coherent Scotland Ltd and M Squared Lasers Ltd can trace a direct link to the research in the Department of Physics and are the central theme of this case study. Since 2008, these two companies have created an estimated 600 person years of employment and £135M of sales from products underpinned by research undertaken at Strathclyde. The wider cluster of companies, researching, designing and developing laser products, including Thales Optronics and more recently the Fraunhofer Centre for Applied Photonics, which has a close working relationship with the University, has made Glasgow one of the leading European centres for innovative laser manufacture.

2. Underpinning research (indicative maximum 500 words)

Context
The underpinning research that has contributed to the creation of Coherent Scotland Ltd and M Squared Lasers Ltd, and the innovative products that they produce, can be broadly divided into two areas. The first is concerned with high resolution spectroscopy and, in particular, cooling and trapping of atoms. The second is concerned with multiphoton imaging of biomedical tissue. In both cases the products that have been developed by these manufacturers derive from research conducted at Strathclyde.

Key Findings
Atom cooling and trapping
Atom cooling and trapping has been one of the most rapidly growing areas of fundamental physics over two decades and has led to the award of several Nobel Prizes in physics (1997, 2001, 2005 and 2012). The single frequency Ti:sapphire laser has been the tool of choice for many researchers working in the area because of its high power, excellent beam quality and narrow line-width. However, for researchers undertaking research in cold atoms in the mid-1990s, commercial laser sources with suitable operating parameters for this research were not available. This led researchers in the Department of Physics to undertake basic laser research, including the novel development of the laser systems available commercially at that time, as a means to developing their own laser tools for cold atom work (Ref 1-3). This research was funded by a series of grants from various sources such as Spectra-Physics (a laser company), the National Physical Laboratory, EPSRC and the EU.
Multiphoton Imaging
The second area of underpinning research has been research into the use of solid state mode-locked lasers for multiphoton imaging of living tissue, and the development of suitable laser sources for this application. The use of multiphoton imaging has been one of the most rapidly growing areas of biomedical imaging. The practical implementation of this technique was first demonstrated using a mode-locked Ti:sapphire laser by researchers in the Department of Physics. This led to a series of papers and research projects exploring laser designs and experimental configurations to establish the most appropriate laser tool to exploit the multiphoton imaging technique (ref 4-6). This research was funded by an EPSRC LINK Award in conjunction with Bio-Rad Ltd., the premier manufacturer of confocal microscopes and now acquired by Carl Zeiss Jena.

Key Researchers:
The lead academics were Allister Ferguson (appointed as Professor of Photonics in January 1989, retired March 2012, currently holds Emeritus status) and Erling Riis (appointed as Senior Lecturer in January 1991, promoted to Reader in October 1999 and to Professor in April 2004). During the

mid-1990s when the main aspects of the underpinning research were undertaken, the team also included Alistair Sinclair and Michael Snadden (PhD students, then postdoctoral researchers), and Michael Dymott, (PhD student).

3a. References to the research (indicative maximum of six references)
References 1, 4 and 5 best represent the quality of the underpinning research.

1. "Improved trapping in a vapour-cell magneto-optic trap with multiple laser frequencies", AG Sinclair, E Riis, and MJ Snadden, J. Optical Society of America. B 11, 2333-2339 (1994); DOI: 10.1364/JOSAB.11.002333

2. "Velocity Dependence on the Force on Atoms in 3D Optical Molasses", AG Sinclair and E Riis, Optics Communications 119, 527-532 (1995); DOI: 10.1016/0030-4018(95)00379-M

3. "Two-photon spectroscopy of laser-cooled Rb using a mode-locked laser", MJ Snadden, AS Bell, E Riis and AI Ferguson, Optics Communications, 125, 70-76 (1996); DOI: 10.1016/0030-4018(95)00711-3

4. "Self-Mode-Locked Diode-Pumped Cr-LiSaF Laser Producing 34-fs Pulses at 42-mW Average Power", MJP Dymott and AI Ferguson, Optics Letters 20, 1157-1159 (1995); DOI: 10.1364/OL.20.001157

5. "All-solid-state Ultrafast Lasers Facilitate Multiphoton Excitation Fluorescence Imaging", DL Wokosin, V Centonze, JG White, D Armstrong, G Robertson and AI Ferguson, IEEE Journal of Selected Topics in Quantum Electronics 2, 1051-1065 (1996); DOI: 10.1109/2944.577337

6. "Multiple-photon excitation imaging with an all-solid-state laser", DL Wokosin, VF Centonze, JG White, SN Hird, S Sepsenwol, GPA Malcolm, GT Maker and AI Ferguson, Proc. SPIE 2678, Optical Diagnostics of Living Cells and Biofluids, 38 (May 10, 1996); DOI:10.1117/12.239552

3b. Evidence for quality of research (grants, patents etc.).
The research was supported by £1.3M of research funding during the period 1993-2001 from a range of sources including EPSRC, EU and the National Physical Laboratory.

4. Details of the impact (indicative maximum 750 words)
Process of impact generation from research
The success of Strathclyde's cold atom research using the in-house developed single frequency Ti:sapphire laser led to demand from other researchers for access to the laser technology. This was met by the setting up of a spin-out company, Microlase Optical Systems Ltd, in 1992 by Professor Ferguson and two former graduate students. A single frequency Ti:sapphire laser system, together with an external cavity frequency doubler, formed the core of the Microlase business. Throughout the 1990s Microlase was able to build on the technology being developed in the Department of Physics and by the late 1990s the company had grown to about 20 people with annual sales of about £3M principally through sales of the single frequency Ti:sapphire and frequency doubler (MBR and MBD). Work during this period included building the laser source for the first all-solid-state multiphoton system to be developed (Source 1).

Microlase was sold to Coherent Inc in late 1999 becoming Coherent Scotland Ltd but still under the management of the original founders of Microlase. This opened many industrial markets and Coherent made significant investment in plant and factory facilities. The Coherent facility in Glasgow is one of the most advanced in the Coherent group of companies. The original Microlase MBR and MBD products still contribute to the Coherent Scotland Ltd product portfolio.

The laser system of choice for multiphoton imaging is now the mode-locked Ti:sapphire laser. Further Strathclyde research on these lasers in the late 1990s and 2000s (eg Ref 4-6) contributed to the development of mulitphoton imaging as a tool for biological imaging, including the exploration of suitable laser sources and imaging configurations. To address this new market opportunity, Coherent Scotland Ltd, developed a new product, the Chameleon mode-locked Ti-sapphire source, which was launched in 2003. This laser system is an integral part of multiphoton imaging systems now very widely used as an imaging tool in the leading life sciences laboratories across the world.
In 2006, the original founders of Microlase left Coherent Scotland and established a new laser

company, M Squared Lasers Ltd, to develop laser systems based on research at Strathclyde and elsewhere. M Squared Lasers produces a compact and automated version of the single frequency Ti-Sapphire laser. This is supplemented by several other diode pumped solid state laser and non-linear optical systems much of which was originally researched at Strathclyde. A further spin-out, Solus Technologies Ltd, a subsidiary of M Squared Lasers Ltd, is developing semiconductor disk laser products, an area also initially researched at Strathclyde.

Description of impact

The key components of the impact in the REF assessment period underpinned by the Strathclyde research are as follows:

- The economic impact associated with Coherent Scotland and M Squared Lasers, in terms of turnover, employment, profit etc.
- The impact created by the sale of these companies' products into a range of application market sectors; this includes economic impact for companies in the manufacturing, healthcare and other sectors, as well as related environmental and health impacts

But for the underpinning research described in Section 2, this impact would not have been created. Further there is related impact generated via the extensive cluster of laser development and manufacturing in the West of Scotland, which is due at least in part to the underpinning research carried out at the University of Strathclyde since 1993.

The performance of Coherent Scotland during the REF assessment period is summarised below (Source 2):

Year		
2008		
2009		
2010		
2011		
2012		

[Text and data in table removed for publication.]

In terms of product portfolio, the original Microlase Ti:sapphire laser (MBR) continues to be a commercial success and remains part of the Coherent Scotland Ltd product portfolio. An updated and automated version of the MBR laser has been developed by M Squared Lasers. It is estimated that between these companies well over 1000 of these systems have been sold, largely for research applications, both in universities and other research laboratory settings, including for high resolution spectroscopy and cold atom physics.

Coherent Scotland Ltd continues to expand its Glasgow operation. The Glasgow facility is now Coherent Inc's centre for the development of its highly successful ultra-short pulse laser systems based on the mode-locked Ti:sapphire system and marketed as the Chameleon. Launched in 2003, the landmark of 1000 systems shipped was passed in 2010 (source 4), and total sales are now approaching 2000 systems. The use of multiphoton imaging as a practical research tool by biological scientists and clinicians has been transformed by the Chameleon laser. The Chameleon is now a workhorse for multiphoton imaging applications in biology, optogenetics and neuroscience, enabling clinical research into diseases of societal importance such as Alzheimers.

More recent products developed by Coherent Scotland have enabled step-change applications in semiconductor wafer inspection and in materials processing. The Azure, a deep-UV (266nm) laser, is a compact, low-noise, CW source specifically designed for easy integration into an industrial environment. This short wavelength is essential for the inspection of sub-20nm nodes in next generation semiconductor wafer manufacture. Customers for this product are major capital equipment manufacturers who in turn sell to major semiconductor chip manufacturers. The Talisker is a family of industrial picosecond lasers for micromachining applications. Customers for this product include manufacturers of high brightness LEDs, solar panels, touch panel displays for phones and tablets, and medical devices. These are largely mass market products which offer improved operating efficiencies and performance (eg more accurate touch screens) compared with

predecessors as well as reduced damage to the environment.

M-Squared Lasers is one of the fastest growing technology companies in the UK serving a global marketplace (Source 5). [Text removed for publication.] The company has grown from 5 to 40 staff and two of its five directors are Strathclyde Physics PhD graduates. M-Squared Lasers' products are sold into markets including research, biophotonics, defence and security, remote sensing and metrology.

The performance of Microlase, Coherent Scotland and M-Squared Lasers has been recognised by the following:

- The Microlase/Coherent Scotland/M Squared Lasers/University of Strathclyde story was one of four finalists in Praxis Unico's Impact Awards 2013 in the category "Business Impact Achieved".
- Coherent Scotland was awarded one of five Institute of Physics Innovation Awards in 2013 "For the development and commercialisation of a range of table-top tuneable lasers for use in research and industry".
- In 2012, M-Squared Lasers was listed 8th in the Deloitte UK Fast 50 (a ranking of the 50 fastest growing technology companies in the UK according to revenue growth over the previous 5 years) and was in the Top 100 (73rd) of the Deloitte EMEA Fast 500 (a ranking of the fastest growing technology companies in Europe, Middle East and Africa).

The impact of implementation of Strathclyde's laser research is wider than that discussed above. The aforementioned cluster of companies and the consequent availability of specialist skills have made it attractive for Thales Optronics to locate all its laser manufacturing in Glasgow, amounting to a product annual turnover of £25M, 50 laser manufacturing staff and 20 laser development staff (Source 7). The combination of Coherent, M Squared Lasers and Thales, together with the research capabilities of the University's Institute of Photonics, were critical in the decision of the Fraunhofer Society to choose to set up its first UK research centre in Glasgow in the area of applied photonics (Fraunhofer-CAP) in 2012. Of special note was Fraunhofer-CAP's involvement with M Squared Lasers which resulted in a number of high value research contracts in 2013, contributing to Fraunhofer-CAP's current £1.6M contract portfolio (Source 8). These developments would not have occurred without the primary Physics research at Strathclyde.

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

1. http://loci.wisc.edu/research/multiphoton-imaging-system corroborates that Microlase Ltd and the University of Strathclyde contributed to the development of the first all-solid-state multiphoton imaging system.
2. General Manager of Coherent Scotland Ltd will corroborate the statements about Coherent Scotland Ltd
3. Coherent annual accounts 2012, http://www.coherent.com/downloads/Coherent2012AR.pdf , page 40 corroborates for Coherent Inc sales for 2012 as $769M (£480M)
4. "Coherent ships 1000 Chameleon lasers for MPE Imaging" – press release 17 September 2010 http://www.coherent.com/investors/index.cfm?fuseaction=Popups.ViewRelease&ID=874
5. Chief Executive Officer of M Squared Lasers Ltd will corroborate statements about M Squared Lasers Ltd and Solus Technologies Ltd.
6. http://www.businessgrowthfund.co.uk/m-squared-lasers/ corroborates Business Growth Fund investment in M Squared Lasers
7. Statement from the Technical Director of Thales Optronics corroborates statement about Thales decision to locate laser manufacturing in Glasgow
8. Statement from the Executive Director of Fraunhofer UK corroborates statements about Fraunhofer UK and Fraunhofer-CAP.