Institution: University of Southampton

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

Title of case study: 13-01 High Power Fibre Lasers

1. Summary of the impact

High power fibre laser research undertaken at the University of Southampton has led to the creation of a new business sector in the generation of highly efficient and highly practical fibre laser technology. This has revolutionised areas of industrial material processing and enabled the development of specialist components for high-end industries (such as aviation and defence) as well as an array of new medical devices, procedures and manufacturing technologies. The research is also directly responsible for the commercial success and sustained growth of a spin-out company, SPI Lasers Ltd, which has an annual turnover of over £40 million and employs more than 250 people in the Southampton area.

2. Underpinning research

High power fibre lasers, based on rare-earth ion doped silica fibres, were effectively 'born' at Southampton University in 1985 and were in fact first demonstrated as a precursor to the optical telecoms fibre amplifier which revolutionised optical fibre communications. They have subsequently developed into a huge commercial success in their own right. Today, they are widely used in telecommunications, manufacturing, medicine and science. Their strengths lie in their stability, beam quality and the facts that they can achieve very high levels of power and are far more efficient than other lasers in their energy use. It has been the continuing development of these qualities for practical use that has been the focus of research led by Professor Alec Gambling, the founder director of the Optoelectronics Research Centre (ORC) from 1989 until his retirement in 1995, Professor Sir David Payne, who became Director of the Optoelectronics Research Centre in 1995, with Professors David Richardson (1989-present, now ORC Deputy Director), Johan Nilsson (since 1996, initially Research Fellow, now Professor) and other team members.

The research has comprised an extensive body of work on the development of optical fibres and laser concepts that have allowed scaling in the average output powers from practical fibre lasers from the ~1W regime in 1993, to the 10kW+ systems of today, as well as an extended range of operating modes extending from short-pulse to high power single-frequency operation.

ORC research between 1993 and 1997 related to the testing and identification of the critical rare earth ion dopants (ytterbium, erbium and thulium) and core glass compositions required to generate and reliably sustain ultrahigh (more than 1kW continuous power) levels at near infrared wavelengths (1.00-2.2 µm) [3.1-3.3]. The limits to pulsed energy extraction of these were examined and researchers developed large mode area core designs capable of handling high power and high pulse energies [3.4] ultimately providing access to the multi-kW class, high brightness laser regime.

Practical all-fibre techniques were also developed to couple the required pumping light derived from laser diodes into the fibre laser structure in a scalable, robust and compact fashion. This was critical to the development of the spin out company SPI Lasers Ltd and is referred to as GT-Wave technology (US Patent 6826335, 2004).

In 2004, ORC researchers conducted the world's first demonstration of a kW-class single mode fibre laser system, convincingly showing for the first time that fibre lasers could compete favourably with existing laser technology [3.5] and opening the doors to a host of new industrial and defence applications.

Further work demonstrated and refined the Master Oscillator Power Amplifier (MOPA) concept to allow high performance pulsed [3.4] and single frequency systems [3.6], greatly extending the functionality, performance and ultimate power scaling of fibre lasers.

Although the majority of the underpinning research was conducted under a series of EPSRC research grants [3.7-3.9], the funding required to demonstrate kW class operation was obtained through the US Defense Advanced Research Projects Agency (DARPA) [3.10] who recognised the ORC's pre-eminence in the field. Once the kW level was achieved, DARPA opted not to fund further work at the ORC due to the strategic significance of the result and launched large fibre laser programs in the US to bridge the UK/US technology gap.

3. References to the research (the best 3 outputs illustrating quality of work are starred)

[3.1] Minelly JD, Barnes WL, Laming RI, Morkel PR, Townsend JE, Grubb SG, Payne DN "Diode-Array pumping of Er^{3+}/Yb^{3+} Co-Doped Fiber Lasers and Amplifiers", IEEE Photonics Technology Letters, 5, pp301-303, (1993).

*[3.2] Paschotta R, Nilsson J, Tropper AC, Hanna DC.,"Ytterbium-Doped Fibre Amplifiers" IEEE Journal of Quantum Electronics, 33, pp1049-1056, (1997).

[3.3] Hayward RA, Clarkson WA, Turner PW, Nilsson J, Grudinin AB, Hanna DC "Efficient Cladding-Pumped Tm-Doped Silica Fibre Laser with High Power Single-Mode Output at 2 Microns," Electronics Letters, 36 pp711-712, (2000).

[3.4] Taverner D, Richardson, Dong L, Caplen JE, Williams K, Penty RV, "158-µJ Pulses from a Single Transverse-Mode, Large Mode Area Erbium-Doped Fiber Amplifier," Optics Letters, 22, pp378-380, (1997).

*[3.5] Jeong Y, Sahu JK, Payne DN, Nilsson J: "Ytterbium-Doped Large-Core Fiber Laser with 1.36 kW Continuous Wave Output Power," Optics Express, 12, pp6088-6092, (2004).

*[3.6] Jeong Y, Nilsson J, Sahu JK, Payne DN, Horley R, Hickey LMB, Turner PW: "Power Scaling of Single Frequency Ytterbium-Doped Fiber Master Oscillator Power Amplifier Sources up to 500W," IEEE Journal of Selected Topics in Quantum Electronics, 13, pp546-551, (2007).

Underpinning Grants

[3.7] IRC IN OPTICAL AND LASER RELATED SCIENCE & TECHNOLOGY, EPSRC grant GR/J62036/01, W.A. Gambling, 1-4-1994 to 1-10-96, £6,952,536. (Professor William Alec Gambling was founding Director of the ORC in 1989-1995, which is why the grant is in his name.)

[3.8] IRC ROLLING GRANT: THE OPTOELECTRONICS RESEARCH CENTRE, EPSRC GR/L26971/01, DN Payne & DC Hanna, 1 Oct 1996- 30 Sept 2000 £6,397,585

[3.9] ADVANCED OPTICAL FIBRE AND WAVEGUIDE DEVICES AND MICROSTRUCTURED OPTICAL MATERIALS, EPSRC, GR/M81854/01, P.I. was DN Payne , 1-10-99 to 30-9-2003, £2,056,683.

[3.10] DARPA Contract MDA972-02-C-0049, DN Payne, 2002-2004, $3 million.

4. Details of the impact

The process: from research to impact

ORC research has led to the development of a new generation of a highly efficient and highly practical laser technology that has revolutionised areas of industrial material processing, the development of specialist components for high-end industries (e.g. aviation and defence) and an array of new medical devices and procedures. It is also directly responsible for the commercial success and growth of a major spin-out company SPI Lasers Ltd (SPIL) [5.1].

SPIL (originally Southampton Photonics Inc, formed in 2000) was valued at £40 million when it was floated on the Alternative Investment Market in 2005 [5.2]. In 2008 it was bought by Trumpf, one of

the world largest suppliers of industrial laser processing systems, by which time it had grown to be the second largest fibre laser company in the world [5.3].

Economic Impacts

SPIL's research and investment relationship with ORC grew under Trumpf. SPIL typically sponsors around £750k per-annum of research in fibre lasers at the ORC and researchers there have worked on a number of joint Technology Strategy Board (TSB)/EU funded projects with them. These projects resulted in the development of new products. For example, under the TSB SMARTLASER project (2009-2012) several new generations of pulsed laser product were developed for product marking applications, enabling more information to be put into smaller areas and at higher speeds. The TSB SMARTLASER products now account for 75% of SPIL's pulsed laser sales and have secured their market leading position in this important market segment. SPIL's estimated annual turnover currently stands at £40 million [5.4]. Since 2008 SPIL has expanded from 150 to in excess of 250 employees - more than 20 have been ORC PhD graduates [5.4].

While, for commercial reasons, details of specific companies supplied with SPIL fibre lasers since 2008 are not in the public domain, downstream beneficiaries include car manufacturers whose production processes now rely on laser-based cutting and welding processing to produce stronger, safer vehicles; aerospace companies such as BAE Systems who use laser machining, welding and polishing to produce planes of reduced weight and aerodynamic drag [5.4]; food and consumer goods manufacturers who mark their products with fibre lasers; and, medical component manufacturers who exploit the excellent beam quality and high powers to produce precise devices such as stents (implants used in heart surgery) thus saving lives. As a result of research carried out by the ORC, there has been a 30% increase in the number of surgical stents manufactured with fibre lasers, worldwide. [5.4]

For completeness it should be noted that a second Fibre Laser spin-out company, Fianium Ltd, was set up in 2003 by Anatoly Grudinin (ORC Professor 1993-2003), who was also initially involved in the formation of SPIL. From around 20 employees in 2008 Fianium has grown to a current workforce of 50. The activities of Fianium are the subject of a separate case study.

Impact on Practitioners and Professional Services

ORC research has been disseminated widely to academia and industry through international conferences helping to ensure rapid commercial adoption of the technology. Examples include: the Association of Laser Users (AILU) Medical Group Meeting (Edinburgh, 27/08/08) where Richardson presented findings regarding the fibre MOPA approach to an audience of 150 laser-product manufacturers, suppliers and consultancies; and The International Laser Applications Symposium (March 2013) where Payne gave a plenary talk to 200 including representatives from Rolls Royce and Micrometrics [5.5].

Impact on Society and public engagement

The ORC's stand at the 2008 Royal Society Summer Science Exhibition (1-4 July, London) generated enormous public interest and engagement in this new fibre laser technology. 12,500 members of the public (including 2,600 schoolchildren) were given the opportunity to speak directly to ORC researchers about fibre lasers and how they are being exploited in a range of applications from imaging molecules to high precision cutting metals. Visitors received personalised drinks mats created with an ORC-developed laser [5.6].

In 2013 Payne received a Knighthood for services to photonics research and applications. Other recent high profile awards for Payne include the Marconi Prize recognising advancements in communications in 2008 (past winners include Tim Berners Lee for the World Wide Web, Lawrence E Page and Sergey Brin for the development of Google) - and the AILU Award for "an outstanding contribution to the industrial use of lasers in the UK" in 2010. [5.7]

5. Sources to corroborate the impact

Formation and support of fibre laser spin out companies

[5.1] http://www.spilasers.com/Company/Corporate_overview.aspx?

[5.2] http://www.researchinformation.info/features/dec05jan06/decjan06profile.html

[5.3] http://www.machinery.co.uk/machinery-news/trumpf-moves-in-on-british-laser-firm/15348/

[5.4] CTO SPI Lasers Ltd can confirm impacts concerning SPIL, including (upon request) confidential details not included on this case study regarding applications and customers.

[5.5] http://www.ailu.org.uk/laser_technology/events/adhocpage/87/david_richardson080827.html

http://ilas2013.co.uk/presentation.html

[5.6] http://royalsociety.org/summer-science/2008/power-of-light/

[5.7] http://www.london-gazette.co.uk/issues/60367/supplements/1

http://www.marconisociety.org/events/2008marconiprize.html

http://www.ailu.org.uk/association/awards_and_prizes/ailu_awards.html