Institution:
University of Glasgow

Unit of Assessment:
B15: General Engineering

Title of case study:
Novel laser products open up new markets for spin-out company Intense

1. Summary of the impact

High-power lasers developed at the University of Glasgow now lie at the heart of state-of-the-art technologies in the commercial printing, medical and defence markets. University of Glasgow spin-out company Intense has introduced more than 10 new diode laser products with superior brightness, longer lifetimes and increased reliability to these markets since 2008. [Text removed for publication.] In 2011 Intense was bought by ORIX USA Corporate Finance Group for an undisclosed sum.

2. Underpinning research

Between 1995 and 2002, Professor John Marsh (Lecturer 1986-96, Professor 1996-present) and colleagues at the University of Glasgow, developed a significant body of published work and patents that led to the formation of Intense Ltd in 2000.

The demand for improved optical communications systems, optical sensing applications and optical data processing drove a requirement for increased functionality from optoelectronic devices and research to improve manufacturing processes for optical integrated systems. These devices and systems integrated multiple photonic functions, analogous to electronic integrated circuits, typically operating in the visible spectrum or near infrared.

Marsh secured a series of EPSRC-funded rolling grants from 1995 to 2002 (GR/K45968/01, GR/L75467/01) entitled 'Multi-Giga-Hertz Integrated Optoelectronics Systems'. These grants led to major developments in Quantum Well Intermixing (QWI) technology resulting in improvements both in device and system performance and manufacturing processes.

The QWI process [1] is a powerful tool used to integrate multiple semiconductor components into complex, monolithic photonic systems. QWI allows the local bandgap of regions of a wafer to be modified after growth; multiple bandgaps are also possible [2]. The process enables the manufacture of arrays of diode lasers with very high yield, superior brightness, longer lifetimes and increased reliability. The resulting small form-factor, cost effective and extremely versatile optical systems are superior to the worldwide competing products. QWI enables the integration of passive regions at the facets of laser diode emitters, arrays and bars, giving excellent performance, enhanced reliability and leading to superior manufacturing yield.

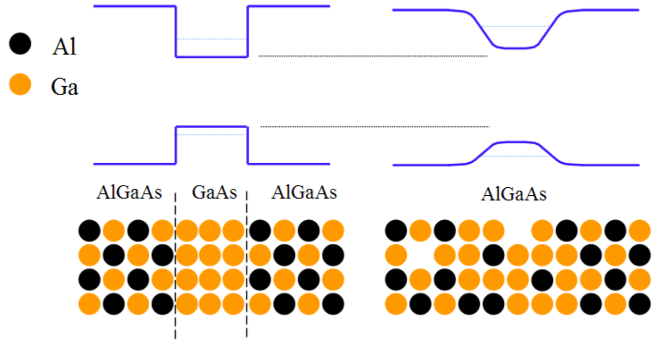

Figure: Illustration of band-structure and layer structure of a non-processed (left) vs. a QWI processed quantum well (right)

The research by Marsh was in collaboration with colleagues from the School of Engineering: J. M. Arnold (Lecturer 1985-94, Professor 1994-2012), J. S. Aitchison (Lecturer 1990-99, Professor 1999-2001), A. C. Bryce (Research Assistant

1985-1993, Research Technologist 1993-97, Senior Research Fellow 1997-2007, Professor 2007-11) Professor, 1985–2011), R. M. De La Rue (Professor, 1986-present), C. N. Ironside, (Lecturer 1984-92, Senior Lecturer 1992-94, Reader 1994-99, Professor 1999-present), P. J. R. Laybourn (Professor 1985-2007), Prof C. R. Stanley (Professor, 1972-present), Prof C. D. W. Wilkinson (Professor, 1992-2005) and Dr Craig Hamilton (Research Assistant, 1995-2000). This was undertaken in two main phases funded by £3 million in EPSRC grants (GR/K45968 and GR/L75467).

During phase 1 (1995 to 1997) QWI was a key technology in demonstrating new devices for controlling guided wave optical systems over the frequency range from DC up to the frequency of the optical carrier itself. QWI enabled fully-integrated optoelectronic sub-systems on a single wafer including Q-switched lasers, mode-locked lasers [3] and grating-based devices.

In parallel to phase 1, Marsh secured additional funding from EPSRC for ‘Compact High Power Visible Laser Diode Arrays’, which focused on red lasers (1995 to 1997, GR/K61098/01). The research utilised novel multi-mode interference (MMI) coupling schemes to fabricate lasers with high power and good beam quality. Integrated couplers were designed so that multiple input laser beams could be imaged into a single output. A laser array of multiple elements was fabricated and monolithically integrated with the MMI coupler region. To minimise losses and catastrophic optical damage, the coupler section was bandgap widened using QWI. A robust QWI process for red lasers was developed [4] representing a significant breakthrough and the MMI technologies were patented, licensed to the University spin-out Intense Ltd and used in the development of Intense products.

Phase 2 (1997 to 2002) developed QWI technologies for fabrication of gratings, with specific focus on developing the technology for the manufacture of diode lasers. Seven patents (including patents P1, P2) were filed during 2000-2001 as a direct result of the significant developments achieved during this programme of research. The inventions within the patents mitigated a number of problems inherent in QWI manufacturing methods including: losses caused by residual diffusion or implantation dopants [5]; catastrophic optical mirror damage due to heat build up; poor beam quality; low brightness; and limited power. The patents were also licensed to Intense Ltd.

3. References to the research

[1] J. H. Marsh, ’Quantum well intermixing’, *Semiconductor Science and Technology*, 8, 1136-1155, 1993 doi: 10.1088/0268-1242/8/6/022 *

[2] X. F. Liu, B. C. Qiu, M. L. Ke, A. C. Bryce, J. H. Marsh, ‘Control of multiple bandgap shifts in InGaAs-AlInGaAs multiple-quantum-well material using different thicknesses of PECVD SiO_2 protection layers’, *IEEE Photonics Technology Letters*, 12: (9), pp1141-1143, Sep 2000. doi: 10.1109/68.874215

[3] A. C. Bryce, F. Camacho, P. Cusumano and J. H. Marsh, ’CW and mode locked integrated extended cavity lasers fabricated using impurity free vacancy disordering’, *IEEE Journal of Selected Topics in Quantum Electronics*, 3, 885 892, 1997. doi: 10.1109/2944.640642 *

[4] C. J. Hamilton, O. P. Kowalski, K. McIlvaney, A. C. Bryce, J. H. Marsh and C. C. Button, ’Bandgap tuning of visible laser material’, *Electronics Letters*, 34, 665-666, 1998. doi: 10.1049/el:19980434

[5] S. D. McDougall, O. P. Kowalski, C. J. Hamilton, F. Camacho, B. C. Qiu, M. L. Ke, R. M. De La Rue, A. C. Bryce, J. H. Marsh, ’Monolithic integration via a universal damage enhanced quantum well intermixing technique’, *IEEE Journal of Selected Topics in Quantum Electronics*, 4, 636-646, 1998 doi: 10.1109/2944.720474 *

Key Patents:

[P1] J. H. Marsh and C. J. Hamilton, ‘Semiconductor Lasers’, US Patent 6,717,971 (priority GB 0101641 Filed 23/1/2001 by University of Glasgow)

[P2] J. H. Marsh and C. J. Hamilton, ‘Optical Devices’, US Patent 6,671,300 (priority GB 0101640 Filed 23/1/2001 by University of Glasgow)

[P3] J. H. Marsh, C. J. Hamilton, O. P. Kowalski, S. D. McDougall, X. Liu, B. Qiu, ‘Method of manufacturing optical devices and related improvements’, US Patent 6,719,884 (priority GB 0122182 Filed 13/9/2001 by both University of Glasgow and Intense Photonics Ltd)

* best indicators of research

4. Details of the impact

Professor John Marsh’s research on Quantum Well Intermixing (QWI) has underpinned more than 10 new diode laser products and upgrades developed by the spin-out company Intense since 2008. The world-leading, individually addressable laser arrays have in turn enabled new product developments in high-speed colour printing of the highest commercial quality with significant increases in cost effectiveness and productivity. QWI has also been used in devices for the medical, industrial and defence markets.

Developing new and improved diode laser products

Intense Ltd was formed in 2000 by Professor John Marsh and Research Assistant Dr Craig Hamilton based on the University’s patented portfolio of QWI and related technologies. Marsh was seconded as Chief Technical Officer on a 0.9 FTE basis to Intense from 2001 until 2009. Several EPSRC-supported Research Assistants and research students joined the company at or shortly after its foundation, including Dr Olek Kowalski, Dr Stewart McDougall, Dr Bocang Qiu, Dr Xuefeng Li, Dr Valentin Loyo and Dr Dan Yanson. In 2011 Intense Ltd was sold to ORIX USA Corporate Finance Group for an undisclosed sum and continues to develop, manufacture and sell its products based on University of Glasgow QWI IP under the Intense name.

The Intense CEO has verified that

> *“Since 2008, the impact of research at the University of Glasgow, particularly research on Quantum Well Intermixing, on products manufactured by Intense Inc can be demonstrated by the following:*
>
> - *Intense has released 10-12 new products*
> - *Intense has a further 4-6 products in development*
> - *These products have been sold to 10-12 new customers and 10-12 existing customers*
> - *We have been able to launch 8-10 unique products into the printing/defence/medical market sectors*
> - *QWI has enabled us to develop higher performance products in terms of the combination of output power and wavelength than our competitors*
> - *We have grown our sales in the Defence, Print and Medical markets by 10-25%*
> - *The value of sales from QWI enabled products since 2008 is $12-15M*
> - *Market opportunities have opened up in China, Europe and North America*
>
> *Intense is a living example of how the research and technology development being conducted at the University of Glasgow can be used to help tech start ups develop cutting edge, state of the art products which provide those start ups the solid foundation and industry traction upon which to build a successful and sustainable business model with solid growth prospects.”*

Underpinning advances in the printing industry

The QWI process enabled array technology developed by Intense has had a particularly profound influence on the printing industry as the processes have played a major role in enabling wide arrays of lasers to be manufactured. The Intense INSlam individually addressable arrays have been responsible for major developments in next generation colour laser printers [Text removed for publication.] INSlam multi-beam systems allow up to 64 multiple lines to be scanned in parallel from a single semiconductor chip. The INSlam technology reduced the cost of modules and increased print productivity by increasing scanning speed; this in turn enabled further significant improvements in cost effectiveness and productivity for high-speed, high-quality colour printing.

[Text removed for publication.]

5. Sources to corroborate the impact

Corroborating impact on Intense products and markets

- Chief Executive Officer, Intense (contact details provided)
- Intense Ltd. Announces High Power, High Brightness 808 nm Single Mode Diodes for Solid State Laser Pumping (May 2008, based on QWI)
- Electronic Specifier News Release (January 2012, example of Intense new products)
- Intense website (January 2012, news of product release based on QWI)

Corroborating contributing to print industry products

- [Text removed for publication.]
- [Text removed for publication.]
- [Text removed for publication.]
- [Text removed for publication.]