Institution: University of Glasgow (UofG)		
Unit of Assessment: UoA12 Engineering		
Title of case study: Optoelectronics collaboration transforms company to a global supplier/leader in semiconductor laser products		
Period when the underpinning research was undertaken: 2007–present		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): Professor Anthony Kelly	**Role(s) (e.g. job title):** Professor	**Period(s) employed by submitting HEI:** 2003–present
Period when the claimed impact occurred: 2013–present		
Is this case study continued from a case study submitted in 2014? Yes		

1. Summary of the impact

Fibre-based communication is pivotal to global communication and connectivity and requires high-quality lasers to drive the increasing demand. Collaboration between Prof Kelly and Compound Semiconductor Technologies (CST) Global transformed their business model to allow them to become a world-leading semiconductor laser supplier, with an 88% turnover increase (2016–2017). The research led to high-performance, low-cost laser devices for next-generation optical access networks and novel products for home and datacentre markets. Consequently, CST Global was acquired by Sivers IMA for ~GBP12 million (2017) and staff numbers have increased from 11 to 70. >GBP1 million of laser chips were sold each month to customers around the world, increasing internet access to households through fibre-to-the-home (FTH) connectivity.

2. Underpinning research

Professor Kelly's EPSRC project on High Power, High Frequency Mode-locked Semiconductor Lasers (EP/E065112/1) enabled him to build on a strong semiconductor lasers capability to design, fabricate and test indium phosphide-based lasers. The fundamental research [3.1, 3.2, 3.3] generated the necessary understanding of device behaviour and the capability to simulate and therefore design devices according to the intended application. For example, the development of high-power devices increased the output power of the laser from 50 to 200mW, opening up new applications such as automotive LIDAR (light detection and ranging).

A collaboration was established with CST Global in 2011, supported by a UofG First Step Award. CST Global made a strategic business decision to move from being a foundry service to manufacturing their own products. They were already familiar with Prof Kelly's expertise, and the University had the skills, tools and test equipment to design, develop and characterise devices manufactured by CST Global. This allowed them to work together to quickly develop initial data for a potential Gigabit Passive Optical Networks (GPON) laser product that was presented to customers.

Given positive market feedback, a Knowledge Transfer Partnership (KTP) was initiated to focus on the delivery of the first product, a high-performance, low-cost laser device for next generation optical access networks. The KTP associate, Dr Horacio Cantu, focused on understanding the electrical and parasitic behaviour of the device to allow performance optimisation. During this project, three semiconductor laser products were developed and introduced into the marketplace [5.4].

The research collaboration was then extended to include research into low-cost optical/radio interfaces, advanced fabrication techniques and blue laser diodes. The blue laser research (supported by EPSRC / Innovate – CoolBlue EP/R001774/1) resulted in the first practical blue semiconductor distributed feedback (DFB) laser.This was made possible by novel gratings designed by Prof Kelly and fabricated in the University's James Watt Nanofabrication Centre. Innovate UK projects and direct funding by CST Global of Prof Kelly resulted in the development of 10 Gbit/s and 25 Gbit/s laser devices and the development of etched facets.

The range of projects and the fact that they are predominately Innovate UK-funded demonstrates the commercial focus of the ongoing collaborative research. Applying the understanding developed in the research projects to device designs and improvements to key device parameters led to further application-oriented publications [3.4, 3.5, 3.6].

A recent illustrative example of commercialisation of basic research is the work on advanced etching. A new semiconductor etch tool was made available to Prof Kelly via a GBP3 million EPSRC manufacturing grant. An industrial PhD scholarship (2014–2018), co-funded by CST Global, developed advanced etching techniques on this tool and applied these techniques to the development of etched facets. This is a technology that had the potential to greatly reduce the cost of CST Global's manufacturing process and led to an Innovate UK project (LOWPASS) which successfully took this to production. The process is now used by CST Global in high-volume manufacturing and is set to become ubiquitous in their products.

3. References to the research

3.1. Green, R.P., Haji, M., Hou, L., Mezosi, G., Dylewicz, R. and Kelly, A.E. Fast saturable absorption and 10 GHz wavelength conversion in Al-quaternary multiple quantum wells. Optics Express. (2011) 19(10), pp.9737–9743; http://eprints.gla.ac.uk/53738/; doi:10.1364/OE.19.009737 *

3.2. Haji, M., Hou, L., Kelly, A.E., Akbar, J., Marsh, J.H., Arnold, J.M. and Ironside, C.N. *High frequency optoelectronic oscillators based on the optical feedback of semiconductor mode-locked laser diodes*. Optics Express. (2012) 20(3), pp.3268–3274; http://eprints.gla.ac.uk/62080/; doi:10.1364/OE.20.003268

3.3. Akbar, J., Hou, L., Haji, M., Strain, M.J., Marsh, J., Bryce, A.C. and Kelly, A. High power (130 mW) 40 GHz 155 μm mode-locked distributed Bragg reflector lasers with integrated optical amplifiers. Optics Letters. (2012) 37(3), pp.344–346; http://eprints.gla.ac.uk/61323/; doi:10.1364/OL.37.000344

3.4. Cantú, H.I., McKee, A., Eddie, I., Kelly, A.E.. Frequency Selectivity in Directly Modulated Distributed Feedback Laser Transmission Operation Using an Impedance Match Tuning Network *IEEE Journal of Quantum Electronics.* (2014) 50 (2), 106–111; http://eprints.gla.ac.uk/96463/; doi:10.1109/JQE.2013.2295548 *

3.5. Slight, T.J., Odedina, O., Meredith, W., Docherty, K.E., Kelly, A.E. InGaN/GaN distributed feedback laser diodes with deeply etched sidewall gratings IEEE Photonics Technology Letters. (2016) 28 (24), 2886–2888; http://eprints.gla.ac.uk/134084; doi:10.1109/LPT.2016.2624500

3.6. Cantú, H.I., McKee, A., Childs, D., Watson, S. and Kelly, A.E. Dynamic performance of detuned ridge waveguide AlInGaAs distributed feedback laser diodes. Microwave and Optical Technology Letters. (2017) 59(6), pp.1468–1470; http://eprints.gla.ac.uk/140554; doi:10.1002/mop.30561

4. Details of the impact

Over the past decade, the world has become increasingly connected, as high-speed fibre optic digital communication brings Internet access to households around the globe with fibre-to-the-home (FTH) connectivity. The roll-out of this technology depends on fast, powerful, low-cost lasers to facilitate the data transfer over these connections. The collaboration between UofG's Prof Kelly, and CST Global has enabled them to become a world-leading supplier of semiconductor lasers [5.1, 5.2]. Whilst the impact of this research is primarily economic, secondary impacts exist through CST Global being able to meet the societal demand for access to fibre optic broadband and cable TV.

CST Global acknowledge that Prof Kelly's expertise is what drew them to collaborate with UofG: The Former CEO of CST Global: *"[Kelly] is a world-authority on gallium nitride and indium phosphide optical devices, with both academic and commercial experience in these areas. He has successfully commercialized a range of technologies, critical to next-generation, high-speed applications, where CST Global is currently producing and developing new products"* [5.3].

Prior to its collaboration with UofG, CST Global was a foundry business, providing custom fabrication services [5.1 paragraph 4]. Expansion of CST Global was dependent on a business model change to selling products instead of services. The skills and capability available at UofG in high-speed communications systems testing, device modelling and advanced characterisation (built up via Scottish Research Pool investment and Research Council project funding) allowed CST Global to develop products through funded collaborations [5.1 paragraph 4, 5.4].

The close working relationship with UofG has been maintained since 2011 through research collaborations, secondments and KTPs. One of the first collaborations was a Knowledge Transfer Partnership: *'The main achievement for the project was the successful development of the 10Gbit/s product to a maturity where it was shipping to customers as samples and towards the end of the project as product. The significance of this has not to be underestimated. [This] has allowed CSTG to move up the value chain in terms of product complexity and therefore margin'* [5.4]. The former-KTP Associate is now an employee of CST Global and continues to liaise with UofG and transfer knowledge to CST Global's engineers [5.1 paragraph 5].

The ongoing partnership has resulted in three new semiconductor laser product lines being introduced, with more in development through Prof Kelly's secondments to the company. These products generated >GBP10 million in orders during 2016 alone [5.1 paragraph 5], which enabled CST Global's expansion into the Asian market and up the value chain to higher profit margin products, moving from USD0.2 per unit to USD2 per unit, with the potential to increase to USD20 per unit once the 25 Gbit/s product line has been qualified [5.1 paragraph 5]. CST Global are now among the top suppliers in the world, with most of their market in China and India [5.1 paragraph 6, 5.2]. Due to its strong performance and potential for growth, CST Global was acquired by Sivers IMA in April 2017 for ~GBP12 million [5.1 paragraph 6, 5.2]. CST Global's success from collaborating with UofG was the key driver of this acquisition, which has since led to further expansion of CST Global and also improved funding access [5.1 paragraph 6].

As a consequence of the critical UofG collaboration, CST Global has become Europe's highest volume laser supplier, shipping GBP1 million laser chips/month. CST Global currently employs 70 chip fabrication staff at a facility near Glasgow [5.2]. Its annual sales turnover for 2015/16 was ~GBP3.5 million; as a consequence of the acquisition, turnover was 88% higher in 2017 (GBP6.7 million) [5.1, 5.5, 5.6].

CST Global links with UK supply chain companies, thus providing a vibrant industry sector. CST Global has been a partner in Horizon 2020 project iBrow, enabling enhanced wireless broadband data transfer, with industry partners including IQE, Alcatel-Lucent and InescTec, and is leading two Innovate UK-funded projects, CoolBlue and LowPass, working with UofG. CST Global's strong connection with UofG has kept the company '*at the forefront of the III-V compound semiconductor market*' [5.7].

In 2017, through an EPSRC Impact Accelerator Account grant, Prof. Kelly was seconded to CST Global to develop capability in the 25 Gbit/s laser market supplying the datacentre market, a high-growth area. In 2018, the company announced alpha testing of 25 Gbit/s lasers that will command far higher prices than existing products while maintaining the same chip manufacturing footprint, delivering a higher profit margin for the same manufacturing yield [5.8].

Demand for such products is rapidly growing in China [5.9] where the number of cable TV subscribers is expected to rise to 353 million by 2022 [5.10, page 1]. CST Global's ability to meet China's increased demand for internet-enabled TV is enabled by collaboration with Prof Kelly at UofG.

5. Sources to corroborate the impact

5.1. Testimonial from former CEO of CST Global
5.2. Testimonial from current CEO of CST Global
5.3. CST Global press release: Dr Tony Kelly to consult with CST Global on next-generation, high-speed, opto-electronic technology
5.4. Knowledge Transfer Partnership University of Glasgow/CST Global, final report.
5.5. CST Global press release: confirmed its audited turnover had increased by 88%, to GBP6.7 million in 2017.
5.6. Press release: Sivers IMA Positive Growth
5.7. Powerful partnership Interface shortlisting – Shortlist for Scottish Knowledge Exchange Award 2019 for academic-business collaboration
5.8. CST Global proves the feasibility of its uncooled, ridge waveguide, 25Gbps, CWDM, DFB lasers press release
5.9. CST Global targets Chinese market with new comms laser technology – Optical Connections News
5.10. Online Video Industry in China Report (2018)