Institution: University of Southampton

Unit of Assessment: 09 Physics

Title of case study: 09-01 Photonic crystal LEDs

1. Summary of the impact

Implementation of photonic quasi-crystals on light emitting diodes (LEDs) can produce more light using less energy. This technology was brought to the global market via the successful commercialisation of laboratory devices derived from research in nanophotonics and the subsequent development of photonic quasi-crystals by a multi-disciplinary team from the University of Southampton. The intellectual property of the technology was acquired and adopted in 2008 by Luxtaltek Corporation, a global manufacturer of LEDs. In the period 2008-2012 Luxtaltek Corporation, made total profits of £35 million utilising the photonic quasi-crystal LED technology, employing more than 300 people in its production facilities.

2.Underpinning research

LEDs are one of the most energy-efficient lighting technologies today. They consume less energy, last longer, are smaller, more durable and offer comparable or better light quality than other incandescent energy sources. Seminal research conducted at the University of Southampton focused on the application of photonic quasi-crystals on light emitting diodes and was published in 2000 **[3.1]**. Led by Professors Jeremy Baumberg (1998 to 2007) in the School of Physics and Astronomy, and Greg Parker (1987-2010) in the School of Electronics and Computer Science (ECS), this research set out to harness the capabilities of photonic crystals – periodic optical nanostructures designed to control and manipulate light – to create technologies to improve the light efficiency of LEDs and generate white light supercontinuum. Between 1996 and 2004 this research was supported by two successive EPSRC grants **[3.5, 3.6]**. A typical semiconductor material used in the production of LEDs has a high refractive index, limiting the amount of light that can be extracted. The research into photonic quasi-crystals led to their incorporation into energy-efficient LEDs, aimed to increase light extraction and therefore increase the brightness of commercial LEDs.

Photonic crystals are composed of dielectric materials in which holes are regularly spaced in a lattice arrangement. In the same way that electrons with specific energies cannot travel through a semiconductor like silicon because of an energy band gap, photonic crystals have *photonic* band gaps that block wavelengths of light at a certain range of frequencies and prevent them from propagating. This band structure is created using man-made periodic structures rather than natural crystal structures. Physicists are therefore free to use patterns that do not occur in nature and fabricate these in well understood materials such as silicon.

Researchers at Southampton found that creating an array of microscopic holes a couple of hundred nanometres deep in dielectric layers of a silicon nitride substrate **[3.2]** disrupted the periodicity of the lattice structure, allowing them to bend light around corners at sub-millimetre scale while avoiding light escaping at the corners (which would weaken the signal) **[3.3]**. Further research demonstrated that multiple optical functions and complex systems could be implemented at high density on a single silicon chip, paving the way for low-cost, high-volume production of integrated optical devices. A US patent was applied for an invention relating to optical devices incorporating structures exhibiting a photonic band gap in April 2001 and granted in 2005 **[3.4]**.

This intellectual property formed the basis of the establishment in July 2001 of Mesophotonics Ltd. (a partnership between Baumberg, Parker and BTG, a company specialising in commercialising technologies) to further develop the photonic crystal devices and take them to market. In 2004 Professor Baumberg received the Royal Society's prestigious Mullard Award for his work in nanoscience and nanotechnology and for his contribution to the national prosperity of the UK through the spin-out company Mesophotonics Ltd. in developing optical chips. Professor

Baumberg continued to contribute to the development of nanophotonic devices until he moved to the University of Cambridge in 2007. Research, development and implementation of photonics quasi-crystals in LED epitaxy has been followed up by Dr Martin Charlton, (1999-present, Reader at ECS) one of the co-founders of Mesophotonics, who trained in the group led by Professor Baumberg. Dr Martin Charlton is currently collaborating with Prof Pavlos Lagoudakis (2006-present; Deputy Head for Research, P&A) in tuning photonic crystal geometries for optimising colour conversion in LEDs **[3.7]**.

3. References to the research

*[3.1] M.E.Zoorob, M.D.B.Charlton, G.J.Parker, J.J.Baumberg & M.C.Netti
Complete and absolute photonic bandgaps in highly symmetric photonic quasicrystals embedded in low refractive index materials. Nature, vol. 404, 13 April 2000, pp740-743

*[3.2] M.C.Netti, M.Charlton, G.J.Parker & J.J.Baumberg
Visible photonic bandgap engineering in silicon nitride waveguides. Applied Physics Letters, vol. 76, no. 8, 2000, pp991-993

*[3.3] M.D.B.Charlton, M.E.Zoorob, G.J.Parker, M.C.Netti, J.J.Baumberg, S.J.Cox & H.Kemhadjian
Experimental investigation of photonic crystal waveguide devices and line-defect waveguide bends. Materials Science & Engineering: B vol.74, (2000), pp17-24

[3.4] Patent US6888994 (also published as CA2404743A1, CA2404743C, CN1268953C, CN1427960A, EP1269229A1,US20040091224, WO2001077726A1), Granted in 2005. Inventors: Jeremy J. Baumberg, Martin D. B. Charlton, Maria C. Netti, Gregory J. Parker, Majd E. Zoorob

[3.5] GR/L24236/01 PI: Prof Greg Parker, TWO AND THREE-DIMENSIONAL PHOTONIC BAND GAP STRUCTURES IN SI AND SI/GE, EPSRC, 01/12/1996-29/02/2000, £182153

[3.6] GR/N37261/01 PI: Prof G. Parker, PHOTONIC CRYSTAL CIRCUITS & DEVICES, EPSRC, 01/11/2000-30/04/2004, £490752

[3.7] Patent application WO2010092362A3 (also published as CN102396065A, EP2396818A2, US20120112165, WO2010092362A2). Inventors: Martin David Brian Charlton, Pavlos Lagoudakis, Soontorn Chanyawadee. Applicant, University Of Southampton.

4. Details of the impact

The overall beneficiary of Southampton's underpinning research on photonic quasi-crystals and their applications has been Luxtaltek Corporation [5.1], a leading global manufacturer of photonic crystal LED devices.

The process of Research leading to Impact

As a direct result of the Southampton research, spinout company Mesophotonics Ltd. successfully developed a range of products that incorporated photonic crystals into LEDs. These products offered an increased brightness of ~15% on other LEDs, which gave them a significant competitive advantage. In April 2008, this arm of Mesophotonics' business and the company's photonic crystal intellectual property (IP) were acquired by Luxtaltek Corporation, a Taiwanese LED manufacturer [5.2]**.**

Economic Impact

Following its acquisition of the Mesophotonics IP, Luxtaltek announced it would shift its focus to manufacturing high-brightness LEDs using the photonic crystal IP to increase the production and brightness of its LED chips. This is a clear indication of economic impact where *a business has adopted a new technology through acquisition of IP* that came from research on photonic crystals

for improving the efficiency of optical devices.

Luxtaltek expanded the manufacturing capacity of its Chuan Factory with new chip fabrication facilities [5.3] indicating the *improvement of the performance of the business through introduction of new,* photonic crystal LEDs*, products.*

To acquire and support this new activity Luxtaltek invested approximately £10m. Consultancy to lead Luxtaltek's research, development and implementation of photonics-crystals in LED epitaxy is provided by Dr Martin Charlton. The involvement of Dr Martin Charlton *indicates that a new technology was adopted through provision of consultancy that drew on his research.*

Evidence of economic impact

LuxtalTek now manufactures and supplies LED chips and crystalline grains, used in digital displays, traffic signs, household electrical appliance and automobile products all over the world [5.4]. In 2009 UniLite reported Luxtaltek's monthly production capacity of 550m blue LED chips and 1.5 billion LED chips for outdoor-display use. In the period 2008-2012, Luxtaltek made total profits of £35 million on LEDs with photonic quasi-crystals [5.5]. Luxtaltek is currently employing more than 300 people in its photonic crystal LEDs production facilities [5.6].

Impact on the environment

By influencing the business strategy of one of the world's LED manufacturers, the research has also contributed to an international move towards more energy efficient lighting. LEDs hold multiple advantages over incandescent energy sources, notably lower energy consumption, smaller size and longer lifetimes, and are widely used in high-efficiency lighting applications. The US Department of Energy advocates the use of LEDs. It says on its website: "Widespread use of LED lighting has the greatest potential impact on energy savings in the United States. By 2027, widespread use of LEDs could save 348TWh … of electricity: this is the equivalent of the annual electrical output of 44 large electric power plants (1000 megawatts each) and a total savings of more than US$30 billion at today's electricity prices." [5.7]

5. Sources to corroborate the impact

5.1 http://www.luxtaltek.com/en/company.php

5.2 http://www.withersrogers.com/case_studies/luxtaltek

5.3 http://www.luxtaltek.com/en/company02.php

5.4 http://www.docstoc.com/docs/51255757/Unilite--Company-Profile---Aug-06-2011

5.5 Statement by the Director of Luxtaltek Corporation Dr Sean Lin.

5.6 http://www.securities.com/Public/company-profile/TW/Luxtaltek_Corporation__%E6%B4%B2%E7%A3%8A%E7%A7%91%E6%8A%80__en_2315693.html

5.7 http://energy.gov/energysaver/articles/led-lighting