Institution: **University of Durham**

Unit of Assessment: **9/Physics**

Title of case study: Organic solid state lighting: building a full commercial supply chain in the UK (**Polymer Lighting**)

1. Summary of the impact

Interdisciplinary research on a new class of organo-metallic light emitting polymers showed that they could produce white light very efficiently. A consortium of the University and Industry (predominantly Thorn Lighting, the largest lighting manufacturing employer in the North East) developed and patented these into a viable alternative to mercury vapour fluorescent lights with a £4.3M grant from the DTI with matched funding from industry. The companies are investing in scaling this up to a full commercial supply chain, supported by a £4M grant from the Technology Strategy Board. The success of the project helped BIS secure £20.5M to support Plastic Electronics in the UK, creating 26 jobs, and was cited as a factor in the Thorn decision not to close down its North East site, safeguarding 600 jobs.

2. Underpinning research

Research in the properties of new materials is inherently interdisciplinary, requiring multiple techniques to design, synthesise and characterise their resulting properties. In Durham there is a longstanding research collaboration to develop new organic light emitting diodes (OLEDs), split between Physics (led by Prof Monkman, member of the Department from 1988-present) and Chemistry (led by Prof Bryce, member of Chemistry from 1984-present). These devices generally emit over a narrow band in wavelength, given by the energy of the electron-hole recombination band gap in the material. Most polymers are hole transporting, so their light output is greatly enhanced by combining them with an electron-rich material. Monkman and Bryce set out in 2005 to synthesise a new electron transporting polymer to combine with the standard OLED polymers in order to increase efficiency of light production. Their new material did indeed have a higher electron mobility, but also had the unexpected property that the holes and electrons recombined into two energy levels rather than one. This dual emission results in a much broader wavelength spectrum than standard OLEDs [1-2]. Thus instead of having narrow band light from a composite of two different polymers, they had a single material which produced broadband (white) light. The patent for this process was filed in 2007 [P1].

Bryce and Monkman won an EPSRC grant (2007-10) for research to understand and improve the dual emission properties of the polymer with applications in lighting. This work led by Monkman and Bryce and resulted in an outline of the key properties of the material [3-4].

In parallel with this, Monkman and Bryce also approached the CEO of Zumtoble, the parent company of Thorn Lighting (one of the largest manufacturing employers in the NE). They saw the potential of this material, and set up a consortium comprising the University, Thorn Lighting and Cambridge Design Technology (CDT – the European research arm of Sumitomo Chemicals, who are one of the largest chemical companies in the world and the major international patent holder for polymer research). This consortium won a £4.3M grant (TOPLESS: 2007-2010) from the DTI to develop the materials and device architecture to the point where they could demonstrate a commercially viable product. This work resulted in further papers in academic, peer reviewed journals on research to improve the efficiency of the polymeric white light material, including a major research breakthrough on understanding the multiple fundamental mechanisms by which electron and hole are converted into light in the device [5]. This has opened the way to *ab initio* calculations of the efficiency of light production in new materials, so that the next generation of OLEDs can be designed to be even more efficient.

3. References to the research

[1] [White polymeric light-emitting diode based on a fluorene polymer/Ir complex blend system]() Al Attar, H. A., Monkman, A. P., Tavasli, M., Bettington, S., Bryce, M. R., *Applied Physics Letters,*

2005**, 86**, 121101.
61 citations

[2] *Recent Advances in White Organic Light-Emitting Materials and Devices (WOLEDs)*. Kamtekar, K. T., Monkman, A. P., Bryce, M. R., *Advanced Materials* 2008 **22**, 572
114 citations

[3] *Exploiting a Dual-Fluorescence Process in Fluorene-Dibenzothiophene-S,S-dioxide Co-Polymers to Give Efficient Single Polymer LEDs with Broadened Emission*. King, S. M., Perepichka, I. I., Perepichka, I. F., Dias, F. B., Bryce, M. R., Monkman, A. P., *Advanced Functional Materials* 2009, **19**, 586
30 citations

[4] *Synthesis and Spectroscopy or Poly(9,9-dioctylfluorene-2,7-diyl-co-2,8-dihexyldibenzothiophene-S,S-dio xide-3,7-diyl)s: Solution-Processable, Deep-Blue Emitters with a High Triplet Energy*. Kamtekar, K. T., Vaughan, H. L., Lyons, B. P., Monkman, A. P., Pandya, S. U., Bryce, M. R., *Macromolecules*, 2010, **43**, 4481
20 citations

[5] Triplet Harvesting with 100% Efficiency by Way of Thermally Activated Delayed Fluorescence in Charge Transfer OLED Emitters, Dias, F.B., Bourdakos, K.N., Jankus, V., Moss, K.C., Kamtekar, K.T., Bhalla, V., Santos, J., Bryce, M.R., Monkman, A.P., Advanced Materials, 2013, **25**, 3707

Grant support
EPSRC (EP/E040810) (2007-2010) 'Exploiting dual emission from single polymers to achieve highly-efficient colour-tunable and white organic light-emitting devices' PI Bryce, Co-I Monkman, for a total £0.68M, of which £0.24M came to Physics.

Patent filed
P1 Novel Light emitting polymeric compositions and uses thereof. Applicant University of Durham. Inventors A Monkman, I.F. Perepichka, I.I. Perepichka,, M.R. Bryce, WO/2007/132236

4. Details of the impact

The aim of the TOPLESS (2007-2010) project was to develop the materials and device architectures to the point where they were demonstrably commercialisable [C1]. Durham's research contribution to this was to greatly increase the efficiency of polymer white light production [1-5], and two of these key breakthroughs are the subjects of patents filed by Thorn [P2-P3]. By 2009 the consortium could build the most efficient polymer solid state lighting panels ever made, with performance approaching that of current industry standard, mercury vapour based, fluorescent lighting units. However, the OLEDs are safer, easier to recycle and more environmentally sustainable, because they contain no mercury. This was recognised by the TOPLESS project winning the Environmental category of the Technology & Innovation Awards of *The Engineer* [C2]. In an interview with Prof Geoff Williams, the TOPLESS project manager who gained his PhD from Durham University, then working in Thorn Lighting said "*The University of Durham …have the ability, within their photo-physics group to understand precise charge transfer within the polymers, this is a valuable to feedback tool for the development of the next generation of materials*." [C3].
These successes demonstrated that the devices would be commercially competitive if a fabrication process could be developed which was economic yet gave high quality, reproducible results. Initial work from TOPLESS demonstrated that slot dye coating, a form of meniscus printing onto a glass substrate, could be used to produce the ultrathin, uniform polymer films over the large areas required. However, this prototype production method needed to be scaled up to in order to form the basis of an industrial manufacturing process. To do this, the original TOPLESS consortium was expanded, with new industrial partners including Pilkington Glass (for the substrate), Cambridge Inkjet Technology (to print bus bars on the anodes of the OLEDs) and Tridonic (a sister company of Thorn, again based in the NE, to make all the electronic controls for the lighting). These industrial partners form the basis of a complete supply chain to incorporate the material into

commercial units. The development of a full manufacturing process from this was supported by a £4M grant (TOPDRAWER: 2010-2013) from the Technology Strategy Board (sponsored by BIS) [C4]. The first commercially available units are expected in 2015, but 'concept' design units are included in an OLED lighting installation in the entrance of the Thorne Spennymoor plant (Fig 1: C5).

While the TOPDRAWER grant covers the research and development costs, the full scale industrial process also requires specialist infrastructure. The TOPLESS consortium designed a pre-production line for manufacture of solid state lighting, costed at £4.5M. This was funded by BIS and ERDF as part of a much wider £20.5M package of support for plastic electronics in the UK. The equipment was installed at the national Centre for Plastic Electronics (PETEC), based at NETPark (the Universities technology incubator start up site) in Sedgefield in early 2011, greatly expanding the regional infrastructure for plastic electronics, providing 26 new jobs at PETEC with the aim of stimulating 250 jobs regionally and 1500 nationally [C6].

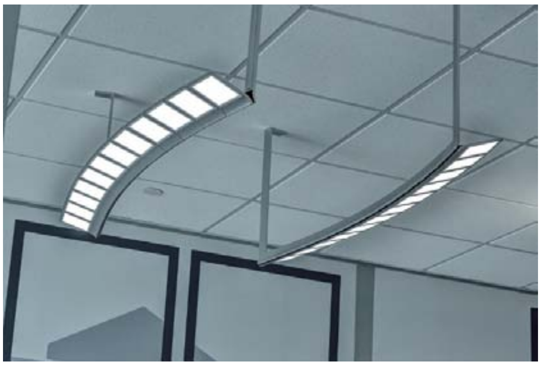

Fig 1. Concept design for OLED lighting on display at Thorn Spennymoor entrance [C5].

The Managing Director of County Durham Development Company, the organisation which runs NETPark, credits the collaboration with Durham University with rescuing 600 jobs at the Thorn Spennymoor site after the company proposed to move its operation to Romania. "*When Thorn Lighting's operation in the County faced the threat of relocation to Eastern Europe we helped convince the company's leaders to stay and invest £24 million in a new facility. The new plant at Spennymoor safeguarded 600 jobs and created new R&D posts*." [C7]. The Director of Innovation Development at CDDC said "*It would have ripped the heart out of Spennymoor had they gone, so we told them they really shouldn't do that because they would lose their market leadership in the UK. We told them, if you are into lighting then you will be interested in the solid state lighting which is being done at Durham University and commercialised here at PETEC. Thorn decided after six months of persuasion and negotiation that not only would they stay, but they would build a new factory with £24M of their own money*." [C8]

While the University research was key in discovering and developing the new material, the commercialization of the OLEDs to a full lighting product was only possible with major multibillion pound industrial partners [C9]. The University-Industry consortium funded by TOPLESS led to especially strong links between the Physics Department and Thorn Lighting, the largest lighting manufacturing employer in the North East. Research staff from Thorn were seconded to Durham as part of the TOPLESS project (Kamtekar, Goudin). They joined the University postdocs already working on the material (Lyons, Dias, Vaughan, Jankus, Perepichka, now a Lecturer at UCLan, Tavasli: now a lecturer at Uludag, University, Turkey, Siddle, now working for a NE chemical company). Thorn and CDT also now co-sponsors an EPSRC grant, while CDT have co-sponsored Dias on a 5 year Fellowship in the Physics Department. All these links mean that the Knowledge Transfer from the project is on-going. CDT-Sumitomo now routinely use the new material characterisation techniques developed in the TOPLESS project, buying the equipment to replicate the process on their own site in Cambridge [C10]. CDT Chief Technology Officer says "*they continue to value the contribution from Durham and because of that have entered into OLAE+ [Organic and Large Area Electronics] EU funded project with Durham and other institutions*" [C10].

5. Sources to corroborate the impact

C1 TOPLESS project (2007-10)
http://www.oled-info.com/project-topless-thin-organic-polymeric-light-emitting-semi-conductor-surfaces

C2 TOPLESS award
http://www.theengineer.co.uk/awards/technology-and-innovation-award-winners-

revealed/1006316.article

C3 Interview with Dr Geoff Williams
http://www.oled-info.com/cdt/interview_with_dr_goeff_williams_project_topless_manager

C4 TOP DRAWER project (2010-13)
http://news.bis.gov.uk/content/Detail.aspx?ReleaseID=414184&NewsAreaID=2

C5 Thorn OLED concept lighting at Spennymoor
http://www.oled-info.com/thorn-lighting-installs-two-new-oled-lighting-fixtures-lg-chem-panels

C6 PETEC investment (p51-52)
http://www.official-documents.gov.uk/document/hc1011/hc01/0125/0125.pdf

C7 Thorn lighting to stay in Spennymoor, Stewart Wilkins CDDC
http://www.nebusiness.co.uk/business-news/archive/2009/11/12/shaping-the-economic-future-of-co-durham-51140-25146776/

C8 Thorn lighting to stay in Spennymoor, Catherine Jones CDDC
http://www.bq-magazine.co.uk/interview/ne/netpark

C9 Geoff Williams Article on Polymer Lighting
https://connect.innovateuk.org/documents/2895721/3711867/Organic+Solid+State+Lighting+-+Article+by+Geoff+Williams.pdf/d204b71f-3236-4532-a433-ec0d873a4847

C10 Jeremy Burroughes CDT Chief Technology Officer
Email filed with evidence

Patents Filed
P2 Multi-layer organic device, applicant: Thorn Lighting, inventors A Monkman and H Al Attar WO/2011/042443

P3 Electroluminescent materials and devices: applicant: Thorn Lighting, inventors G Williams and A Monkman WO/2011/033078