Institution: University of Oxford

Unit of Assessment: 9 – Physics

Title of case study: [6] Oxford Photovoltaics

1. Summary of the impact

Solid-state dye sensitized solar cell technology has been developed and exploited through the licensing of 11 patents to spin-out company Oxford Photovoltaics Ltd. (Oxford PV). Based on Oxford research, Oxford PV was spun out of the University of Oxford in 2010 and has developed solar cells that are manufactured from cheap and abundant materials and printed directly onto glass. To date, Oxford PV has attracted over £3.3M of investment and has grown to employ 11 people. *[text removed for publication]*

2. Underpinning research

Solid-state dye-sensitized solar cells (SDSCs)

Conventional silicon solar cells require the charge carriers (electrons or holes) to travel long (micron) distances without recombining. Dye-sensitized solar cells (DSC) avoid this by using a nanostructured material which splits up the electrons and holes as soon as they are created in a dye and uses interpenetrating layers to carry them to the cell electrodes. The first generation of these cells used an organic dye, titanium dioxide (TiO_2) to conduct the electrons, and a liquid electrolyte for the holes, which, although very cheap to produce, proved to be unstable and difficult to seal. Replacing the liquid with a solid to transport the holes makes the cells more reliable and potentially more efficient. Research by Dr Henry Snaith's group on SDSCs has led to both improved efficiency and better stability through optimisation and replacement of the different cell components.

In October 2007, Dr Henry Snaith was appointed as an RCUK Fellow in the Department of Physics at the University of Oxford and he became a University Lecturer in 2012.

Efficiency of SDSCs

Snaith and his team showed that cell performance could be substantially improved by replacing the TiO_2 with tin oxide particles coated with thin layers of TiO_2 and magnesium oxide. Careful processing and design gave an incident photon-to-electron conversion efficiency of up to 85% – a first for SDSCs [1]. Snaith was able to enhance the photocurrent generation further by including metallic nanoparticles to act as plasmonic light-harvesting antennae [2].

Stability of SDSCs

A further issue for SDSCs was that although in principle they should be much more stable than electrolyte based DSCs, it had been found that they required the presence of oxygen to prevent a short-circuiting path developing in the device. Snaith identified the degradation of the oxide insulators as the cause and showed that adding a mesoporous layer of aluminium oxide solved this problem, enabling solid-state dye-sensitized solar cells to be produced [3].

Mesoporous single crystals

In 2013 Snaith's team developed a method for growing mesoporous single crystals without the need for high temperature sintering, thus opening up a route for reducing the production costs and the possibility of using flexible substrates. Using these structures with a conventional dye gave efficiencies of 3%, and replacing the dye with a perovskite gave efficiencies over 7% [4]. Further improvements to the charge collection in the cells have now given rise to cells with efficiencies of up to 15%, which is approaching that of conventional silicon cells.

In 2012, Snaith won the Institute of Physics Paterson medal and prize "for his important contributions to the field of excitonic solar cells."

3. References to the research (Oxford authors, * denotes best indicators of quality)

*[1] Snaith HJ and Ducati C, (2010), SnO2-Based Dye-Sensitized Hybrid Solar Cells Exhibiting Near Unity Absorbed Photon-to-Electron Conversion Efficiency, *Nano Letters*, 10, 1259-1265. doi:10.1021/nl903809r, citations: 91 (Scopus). *This paper demonstrated how adding TiO_2 and MgO layers to the SnO_2 could be used to give SDSCs with efficiencies of up to 2.8%*.

*[2] Brown MD, Suteewong T, Kumar RSS, D'Innocenzo V, Petrozza A, Lee MM, Wiesner U,

Snaith HJ, (2011), Plasmonic dye-sensitized solar cells using core-shell metal-insulator nanoparticles, *Nano Letters*, 11 , 438-445, doi: 10.1021/nl1031106, citations: 108 (Scopus). This paper *describes how adding Au-SiO_2 nanoparticles gives enhanced absorption and raises efficiency up to 4%.*

[3] Docampo P and Snaith HJ, (2011), Obviating the requirement for oxygen in SnO2-based solid-state dye-sensitized solar cells, *Nanotechnology*, 22, doi: 10.1088/0957-4484/22/22/225403, citations: 3 (Scopus). *This paper describes how the introduction of a layer of aluminium oxide solves the long term stability problem for SDSCs.*

*[4] Crossland EJW, Noel N, Sivaram V, Leijtens T, Alexander-Webber JA, Snaith HJ, (2013), Mesoporous TiO2 single crystals delivering enhanced mobility and optoelectronic device performance, *Nature*, 495, 215-219, doi:10.1038/nature11936, citations: 10 (Scopus). *This reports the development of the mesoporous growth process leading to reduced fabrication costs and an efficiency up to 7.3%. Subsequent developments by Snaith have led to efficiencies over 15%.*

4. Details of the impact

Creation of a new company

Oxford PV was spun out of the University of Oxford in December 2010 as a direct result of Snaith's research. The company was set up with an exclusive licence to commercialise technology protected by 5 patents based on [1], [2] and [3]. Snaith's research is the core driver for the company: Oxford PV say *"Oxford PV is a single product company and at this point that product is entirely dependent on Dr. Snaith's research and technology."* Snaith is Chief Scientific Officer for Oxford PV and a further 6 patents from his research have been exclusively licensed to the company since its establishment. Oxford PV is based at Begbroke Science Park, Oxford, and employs 11 staff [A].

Semiconductor solar cells dominate commercial photovoltaic markets, with crystalline silicon (1st generation) and thin-film solar cell technology (2nd generation). Affordable global uptake of solar energy requires a significant reduction in materials and manufacturing costs and must therefore be based on abundant materials. The high material cost of crystalline silicon cells has resulted in the search for alternative low cost solutions such as thin film solar cell technology. However thin film solar cells that are currently available use scarce elements in their construction, for example indium and tellurium. Conventional liquid electrolytes are also volatile, corrosive and difficult to seal and hence severely limit the overall performance and feasibility.

Oxford PV has developed 3rd generation technology using Snaith's research to make solar cells from cheap and abundant materials that are fabricated using simple screen-printing techniques. Replacing liquid electrolytes with solid-state hole conductors improves the performance. The efficiency of lab-based cells is over 15% (world-leading for its class) and the manufacturing costs are estimated at 30% of the current lowest cost of thin film technologies.

Oxford PV targets the Building Integrated Photovoltaic (BIPV) sector and its business model is to have their solar cells printed onto windows that are integrated into office buildings. US energy analyst Nanomarkets forecasts revenues for BIPVs to rise to $16bn by 2017.

Investment and funding

In the difficult current investor climate, Oxford PV has received high levels of investment and funding totalling over £3.3m in 2.5 years, demonstrating the viability of the company. To our knowledge, other UK solar spin-outs in the REF period have failed to raise substantial external funds.

Investment into Oxford PV includes £700k secured in June 2011 in their first fundraising round. Investors include MTI, Parkwalk, World Gold Council and business angels. £30k was also invested by the University of Oxford's University Challenge Seed Fund (UCSF). David Ward, Managing Partner and Head of Cleantech investing at MTI said: *"We've been analysing the Photovoltaics section for some considerable time. OPV is unusual in that it pairs world class science with a founder team that is very focused on execution and growing the business in a pragmatic way that gives the best chance of commercial success."*

£2.03m was raised in their second fundraising round in 2013. Again this was led by cleantech investment specialists MTI, who said: *"We are delighted with the technical and commercial progress of the business since MTI supported OPV's spin out in 2011. The company is addressing a huge potential market opportunity and the building of the product development facility is an important step on the road to full commercialisation."*

In addition to these investments, Oxford PV was awarded a £250k Technology Strategy Board (TSB) R&D grant in 2012 and a £211k grant from the EU FP7 in 2013.

Recognition and prizes

In 2010, Oxford PV won the Disruptive Solutions for Energy, Digital Healthcare and Sustainability Problems award from the TSB, beating 550 UK companies. In 2012, Oxford PV were winners of the TSB's competition-led trade mission to San Francisco 'Clean and Cool Mission' for twenty of the UK's best, high-growth potential cleantech companies ready to do business in the US and overseas. Oxford PV was the winner of the 2013 Renewable Energy Association's British Renewable Energy Award for innovation 2013 for "*a technology with the potential to turn iconic glass buildings into powerhouses, with no compromise to building performance."* In 2013, Oxford PV won the Best Early Stage Investment in a Disruptive Technology Business Award at the UK Business Angels Association Awards, sponsored by the TSB. In 2013, Snaith won the TSB Solar Award for Research *"for his outstanding scientific work pushing up the efficiency of new solid state solar cells and also his practical focus contributing to the formation and funding of Oxford Photovoltaics Ltd."*

Adoption of Oxford PV glass in building specifications

Oxford PV glass has been included in the specifications for new buildings. Decisions have been made by construction companies to use Oxford PV technology and by architects to include Oxford PV technology in their bids for contracts for new development projects.

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5. Sources to corroborate the impact

[A] Letter from Chief Executive Officer of Oxford Photovoltaics (held on file) confirms Oxford PV's product reliance on Snaith's research and company details including total investment received and number of staff.
[B] *[text removed for publication]*