Institution: University of Exeter

Unit of Assessment: 9, Physics

Title of case study: How LCD research created one of the UK's fastest growing companies

1. Summary of the impact (indicative maximum 100 words)

Researchers, and the work they undertook at the University of Exeter during the 1990s, led to the formation of the Defence Evaluation and Research Agency's (now QinetiQ) first spinout company: ZBD Displays Ltd. Achieving revenue growth of 17,910% over the last five years, ZBD's unique electronic retail signage and shelf-edge labelling technology is used by major retailers all over the world. The invention used the know-how developed by ZBD's company founders whose R&D and engineering teams all include former postgraduates from the School of Physics and Astronomy, who acquired their expertise under the supervision of Professors Roy Sambles and Bill Barnes.

2. Underpinning research (indicative maximum 500 words)

Liquid Crystals Displays (LCDs) are a multi-billion-pound-a-year industry. Understanding the fundamental physics behind the operation of the liquid crystals within these devices is essential for the development of the next generation of devices. Many liquid crystals are composed of rod-shaped molecules that align roughly parallel to each other. Dictating their alignment by applying a voltage across a thin layer of the liquid crystal material allows the amount of light transmitted through them to be controlled. To advance the technology further and meet the huge market demand for lower-power LCDs, further developments in understanding the alignment of the liquid crystal layer are needed.

Since 1986, research at the University of Exeter's School of Physics and Astronomy, led by Roy Sambles, Professor of Experimental Physics (since 1991), has sought to investigate new optical techniques to characterise the alignment properties of a range of liquid crystals. This work was developed by Dr Guy Bryan-Brown, (PhD 1988-91) under Sambles' supervision, to incorporate optical gratings into the system. This was extended by Dr Emma Wood, (PhD 1989-92) again supervised by Sambles, who studied the geometry of grating coupling to optical modes in a thin, voltage-controllable liquid crystal layer [3.1] and how this might be employed in LCD technology.

In 1990, the Exeter group constructed a mini-interferometer for the fabrication of gratings and devised ways to optically characterise liquid crystal cells containing such gratings. With Sambles acting as a consultant to the LCD group at DERA (then RSRE) led by Dr Cliff Jones, (Display Group Technical Leader), further collaborative work on grating alignment in nematic liquid crystal devices ensued with Jones's team working closely with Sambles' group at Exeter.

After joining DERA, Bryan-Brown continued work on gratings and liquid crystals, establishing a capability for fabrication and assessment of the grating structures derived directly from the techniques pioneered at Exeter. He and Sambles co-authored early papers [3.2, 3.3] in this area. Between 1994 and 1996 Bryan-Brown was the industrial supervisor for Wood, a post-doctoral fellow in Sambles' research group who continued working on grating aligned liquid crystals to augment the work being done within DERA. With EPSRC and MOD funding [3.4, 3.5], Wood and others went on to explore the azimuthal anchoring energies in a range of diffraction grating structures [3.6]. Exeter also developed rigorous theoretical models used to deduce the configuration of the liquid crystal close to the grating surface [3.7]. DERA filed a number of primary

patents centred on aligning liquid crystals with gratings, the most important of which was the Zenithal Bistable Device (ZBD) [3.8]. This device broke new ground as it resulted in two optically distinct stable states at zero power, one appearing dark under crossed polarisers, and the other, light. Power is only required to switch between these states.

In 1996, Wood moved to DERA and a total of 11 patents were filed, with parallel ongoing research by Sambles at Exeter into various types of grating-aligned liquid crystals [3.9, 3.10].

3. References to the research (indicative maximum of six references)

References in bold best indicate the quality of the underpinning research.

3.1. "Grating coupling to mixed modes in a voltage controlled liquid crystal cell", E. L. Wood and J. R. Sambles, J. Mod. Opt. **40**, 493-502 (1993).

3.2. "Grating coupled liquid crystal waveguide", G. P. Bryan-Brown, J. R. Sambles and K. R. Welford, Liq. Cryst. **13**, 615-621 (1993).

3.3. "Grating coupled liquid crystal waveguides using nematics and smectics", G. P. Bryan-Brown, J. R. Sambles and K. R. Welford, J. Appl. Phys. 73, 3603-3607 (1993).

3.4. Grants to JR Sambles (PI): 1993, £29,599, MOD Grant with W L Barnes, to support research on Liquid Crystal Devices; 1995, £24,111, MOD grant to work on optics of Liquid Crystals; 1996, £24,000, MOD grant to work on optics of Ferroelectric Liquid Crystals

3.5. Grants to J R Sambles (PI): 1993-1996, £137,000, SERC Grant with G W Bradberry on grating alignment of liquid crystals; 1997-2000, £173,435 EPSRC Grant with G W Bradberry on optical probing of surface anchoring of liquid crystals.

3.6. "Determination of azimuthal anchoring energy in grating-aligned twisted nematic liquid crystal layers", E. L. Wood, G. W. Bradberry, P. S. Cann and J. R. Sambles, J. Appl. Phys. 82, 2483-2487 (1997).

3.7. "Characterisation of a grating coupled liquid crystal cell using a rigorous theoretical model", J. B. Harris, E. L. Wood, T. W. Priest and J. R. Sambles, J. Mod. Opt. **7**, 1379-1388 (1996).

3.8. "Bistable Nematic Liquid Crystal Device", G. P. Bryan-Brown, C. V. Brown and J. C. Jones, US Patent 06249332 (1995).

3.9. "Diffraction gratings, liquid crystals and guided modes", J. R. Sambles and E. L. Wood, Mol. Cryst. Liq. Cryst. **321**, 349–358 (1998).

3.10. "Groove depth dependence of the anchoring strength of a zero-order grating aligned liquid crystal", B. T. Hallam and J. R. Sambles, Liq. Cryst. 27, 1207-1211 (2000).

4. Details of the impact (indicative maximum 750 words)

Researchers trained at Exeter and supervised by Sambles in the fundamental physics of liquid crystal devices developed with others the novel technology and knowledge transfer essential to the creation of a spinout company. This company has gone on to establish a dominant share of what is set to become a multi-billion-pound global market in electronic labelling for retailers. In the words of ZBD Founder and Director of Technology [5.1] "On so many levels from: specific knowledge of grating alignment of liquid crystals, general liquid crystal fabrication techniques; access to theoretical modelling; to learning how to solve problems as a team; I've benefitted from my time at Exeter and DERA and ZBD have benefitted from my training."

Jones, Bryan-Brown and Wood raised £1.5m in Venture Capital funding to create DERA's first ever

spinout company ZBD Displays Ltd in 2000. The company has since grown to employ nearly 60 people, based mainly in the UK, but also in offices in the United States, France, Germany and Hong Kong. Twenty of the 60-strong staff are scientists and engineers, seven of whom are at PhD level. It is an indication of the influence of Exeter's research expertise that four of those seven PhD students completed their degrees under the supervision of Sambles and Barnes at Exeter, in addition to the fact that Bryan-Brown and Wood began their liquid crystal grating studies at Exeter.

ZBD was founded to exploit the invention by Bryan-Brown, Brown and Jones of the Zenithal Bistable Device, which is based on the alignment of liquid crystals on gratings. The technology enabled the creation of a new type of low-power LCD. The image it generates remains on the display even when the power is switched off, meaning it operates at a fraction of the cost of traditional (TFT) LCD displays and is more environmentally friendly. Supermarkets use it for displaying pricing and product information instead of printed labels, as it can be updated instantly, and it is applicable to anything that has a display and is battery-powered, such as an mp3 player or e-tablet. The technology enables organisations to update hundreds of e-paper displays from a central source, ensuring that pricing and other information is accurate and consistent, while saving on consumables and the time and effort required to replace paper labels.

ZBD is now the world's leading provider of fully graphic e-paper display systems for retailers. As a result of underpinning research into grating alignment of liquid crystals, the company possesses what it describes as "an extensive intellectual property portfolio and unparalleled expertise in LCD design and manufacture". Growth has been rapid. ZBD has raised over £50m of venture funding and, since launching shelf-edge label products in 2008, has sold several million displays across Europe [5.2, 5.3, 5.4]. In 2012, it reported for the previous financial year [5.2]:

- Revenue growth to $19.6m (£12.6m) from $6.4m (£4.1m), maintaining an annual growth rate of 200% since commercialisation began in 2008;
- A presence in 15 retail sectors in 24 countries and at least 50% of the world's leading retailers engaged with, or in discussions with, ZBD;
- Growth in retail clients from 52 to 130 with e-paper for retail the primary revenue driver;
- Growth in non-retail customer numbers from seven to 40 across eight sectors.

In 2012, ZBD reached the number one spot in the Deloitte Technology Fast 50 [5.3], a ranking of the 50 fastest-growing technology companies in the UK. Rankings are based on percentage revenue growth over five years. ZBD's revenues grew 17,910% during this period. In the same year, ZBD ranked **fifth** in the Sunday Times' Tech Track 100 league table [5.4, 5.5]. Also in 2012, ZBD won an Innovation Award from the Institute of Physics [5.6] for its unique e-paper display technology. ZBD's Chief Technical Officer Cliff Jones said that the award was "testament to ZBD's focus on applying new physics to our unique bistable e-paper technology" [5.7].

The company continues to develop novel displays based upon liquid crystal grating structures, and maintains a world-leading expertise in liquid crystal alignment that derives directly from its roots in the Exeter group. Its CEO believes its investment in R&D (around 50% of its funding) is a principal reason behind the company's success in 2009 when it invested over £3m. The impact of Exeter's research training can be traced, through ZBD's success, to the benefits experienced by ZBD's key customers. Coop Denmark, a Danish retail giant with revenues of $9.2bn, has introduced ZBD's electronic shelf labelling to more than 100 of its stores because it "can use it to make our operations more efficient, launch promotions more effectively and differentiate our stores from our competitors" [5.8]. UK baby specialist Kiddicare has committed to using the labelling in ten new

superstores scheduled to open in 2013. Norwegian discount retail chain Bunnpris is using ZBD's technology in its 200 stores [5.9], as are Italian supermarket giant SISA [5.9], T-Mobile Austria, Estonia's leading telecoms provider EMT, U.S. electronics retailer Vann's and Dutch electrical retailer Plasmadiscounter [5.9]. In September 2012, ZBD opened a new HQ in Paris [5.10].

To fully deploy e-paper displays across all products in all retailers amounts to a global market size of $100B. While this is large investment it is still much smaller than the annual efficiency savings that can be made by retailers by avoiding waste, avoiding lost sales as well as fully utilising their active pricing systems. While paper signage has acted as a bottleneck to fully implementing retail IT, electronic signage now finally unlocks a fully integrated system.

5. Sources to corroborate the impact (indicative maximum of 10 references)

5.1. Letter of corroboration, Founder, Director of Technology, and former PhD Student, ZBD Solutions.
5.2. http://www.zbdsolutions.com/news/news-19062012.html
5.3. Deloitte Fast 50 Winners 2012. http://www.deloitte.co.uk/fast50/winners/2012-case-studies/zbd.cfm
5.4. http://www.zbdsolutions.com/news/news-17092012.html
5.5. SundayTimes' Tech Track 100 league table http://www.fasttrack.co.uk/fasttrack/leagues/tech100leaguetable.asp?siteID=3&searchName=&yr=2012&sort=num&area1=99
5.6. http://www.youtube.com/watch?v=DdhYPL87LZQ
5.7. http://www.zbdsolutions.com/news/news-13092012.html
5.8. http://www.zbdsolutions.com/resources/downloads/Coop_Denmark_CaseStudy_LTR_UK_v1b_WEB.pdf
5.9. http://www.zbdsolutions.com/resources/downloads/BUNNPRIS_CaseStudy_v1f.pdf http://www.zbdsolutions.com/resources/downloads/ZBD_SISA_CaseStudy_A4_v1l_WEB.pdf http://www.zbdsolutions.com/resources/downloads/Plasma_CaseStudy_A4_WEB_v1c.pdf
5.10. http://www.zbdsolutions.com/news/news-25092012.html