Institution: University of Durham

Unit of Assessment: 9/Physics

Title of case study: Optical waveguides as a basis for a sensitive detector system (**Farfield**)

1. Summary of the impact

Research in Durham Physics Department on optical waveguides was used to build a novel interferometer which can measure real time changes in dimension and density of a thin film adsorbed on a sensor chip. This has multiple applications in surface science and biophysics, e.g. in measuring conformal and other structural changes in proteins as they interact with drug candidate molecules. The device was developed as a commercial product by a spin-out company, Farfield Sensors, which sold the interferometers to research institutes and industry. The Farfield Group was bought in 2010 by Biolin Scientific for £2.5M.

2. Underpinning research

Dr Graham Cross has longstanding research interests in optical waveguide photonic devices. In the late 1990's he was experimenting with waveguides made from new polymeric materials which had just become available as these have lower dielectric permittivity and so can carry higher bandwidth signals. He was approached by Mr Neville Freeman from GEC-Marconi, who was also using polymers but for a rather different application in vapour sensing. He was using the change in polymer conductivity to measure the amount of gas absorbed, but found that this was neither sensitive nor robust. Instead, he wanted to try to use the change in refractive index of the polymer to trace the gas absorption. Interferometry is the most sensitive way to measure the change in any optical property and Dr Cross's waveguide work immediately suggested a practical experimental technique. Dr Cross designed a system where each waveguide was a water absorbing polymer, separated by an insulating layer of water impervious polyolefin, all mounted on a layer of glass. Each waveguide disperses the light at the end, so they act as a Young's slit experiment. As the upper layer is exposed to water vapour, its refractive index changes and the phase of the light in the upper waveguide changes relative to that in the lower reference beam. This offset in the interference fringes in the far field (hence the company name) gives a very sensitive and robust way to measure the amount of water vapour absorbed onto the top polymer, to the extent that it could be followed in real time [1].

The initial device was specific to water as the polymer would not necessarily absorb other substances of interest. However, Dr Cross realised that the idea could be extended to any material as the light field is not wholly confined within the waveguide but decays exponentially away from the boundary. This part of the optical field, known as the evanescent (vanishing) field, will interact with any ultra-thin film of material placed on top of the upper waveguide via exciting bound or partially bound optical modes. The interaction alters the speed of propagation ("phase velocity") in the sensing waveguide relative to the lower reference waveguide, again giving an offset to the interference fringes. This meant that the polymer materials were not required at all for the waveguides, and more robust structures could be built from silicon oxy-nitride. (Fig 1, [2]).

However, Dr Cross also realised that the optical modes excited by the evanescent wave interaction are different for different polarization modes, and this difference can be used to derive the absolute thickness of the ultra-thin layer (Fig 2). The final design then includes a ferroelectric

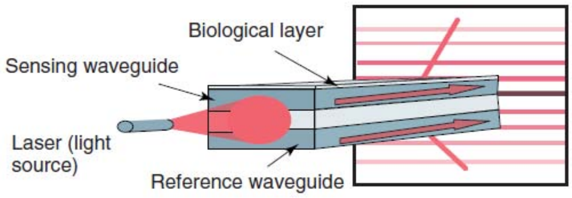

Fig 1 Schematic design for the instrument with silicon oxynitride layer waveguides

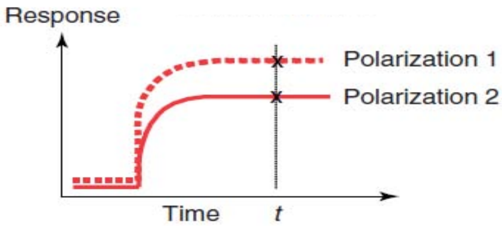

Fig 2: Change in response with polarization state

liquid crystal rotator between the illuminating laser and waveguide stack to act as a switchable half wave plate. The two polarization measures are taken at a typical rate of 50Hz, tracking thickness of the layer on timescales of 20ms [2]. Fast tracking of changing shape is especially important for biomolecules, as the shape of proteins is as important as their chemical composition in determining their characteristics. This paper demonstrated the technique by measuring the thickness of an adsorbed layer of the rigid protein streptavidin as it developed in real time [2].

The techniques are equally important in surface science applications. The team used a thin film of tetraethylene glycol monododecyl ether ($C_{12}E_{14}$), a well characterized non-ionic surfactant which is commonly used in industrial formulations, and showed that the adsorbed layer thickness increases as the surfactant concentration increases. This suggests that the surfactant molecules adopt a prone attitude at low concentrations, resulting in thin, relatively dense layer coverage, changing to a more upright stance at higher concentrations. This is in good agreement with previous neutron reflection results [3]. The sensitivity is such that it can also be used to follow the surface changes during formation of a layer of liquid crystal [4].

3. References to the research

[1] *Young's fringes from vertically integrated slab waveguides: Applications to humidity sensing* Cross, G.H., Ren .T and Freeman N.J., *Journal of Applied Physics*, 86, 6483 (1999)
42 citations from web of science

[2] *A new quantitative optical biosensor for protein characterisation* Cross G.H., Reeves A.A., Brand S., Popplewell J.F., Peel, L.L., Swann M.J., Freeman N.J., *Biosensors and Bioelectronics*, 19, 383 (2003)
113 citations in web of science

[3] *The metrics of surface adsorbed small molecules on the Young's fringe dual-slab waveguide interferometer* Cross, G.H., Reeves, A., Brand, S., Swann, M.J., Peel, L.L., Freeman, N.J. and Lu, J.R. *J. Phys. D (Appl. Phys.)*, 37, 74 (2004)
61 citations in web of science

[4] *Surface anchoring structure of a liquid crystal monolayer studied via dual polarization interferometry* Cross, G.H. and Tan O., *Phys. Rev. E* 79, 021703 (2009)

The quality of the research is also evidenced by over 100 publications in the refereed literature which use Farfield Dual Polarization Instruments
http://www.farfield-group.com/pdfs/Farfield_Publications.pdf

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

Cross and Freeman had very early realised that there were multiple commercial uses within the surface science and biophysics communities of this new, very sensitive measurement device. They co-founded Farfield Sensors in 1997, and filed patents for the original design ideas [P1-P2]. By 2002 they had developed this into a commercial product, the *Ana*Light Bio200, a Dual Polarization Interferometer (DPI) for the measurement of real-time structural change in molecular systems [C1]. This won the National Physical Laboratory National Measurement Award 2003 for Innovation in Measurement, recognising Farfield's technical innovation and impact on current industrial metrology, as well as a suite of other awards [C2]. The company moved to purpose built premises in Crewe [C1], and in 2008 they launched a second generation instrument design, the AnaLight 4D which could quantify the degree of order and disruption in lipid bilayers as well as measure molecular dimensions and density on surfaces. This new tool generated substantial interest and the company doubled its turnover in 2008, having its best year ever [C3]. It extended its customer base to 17 countries, recruiting a new Far East agent and a new member of the core scientific staff [C1].

Two of the machines were bought by P&G, a US company with $80Billlion turnover in consumer products. An example project was to test different dishwasher detergents for their rinse time. A faster rinse reduces the water usage, leading to environmental gains, but the detergent needs to be completely removed in order to leave glasses 'squeaky clean', a criteria which is especially important in Japan. P&G used the DPI to characterise the maximum surface layer of detergent required for it to be classed as 'squeaky clean' (the first reliable automated predictive test for this), and so were able to develop faster rinse formulations. The Analytical GCO, P&G Newcastle, identified the impact to the company '*As a result, 2 head counts in Product Design were freed up to do other work. More importantly, the insights gained via understanding the phase behaviour at interfaces explains why some formulations rinse off more slowly than others…faster rinsing formulations for Japan Joy have been identified and launched in the market and keep our business in Japan growing.*' [C4]

Applications in biophysics include drug discovery and development as the instrument is sensitive enough to track the response of a protein to a potential drug in real time and without any additional tagging of the molecules which could disrupt the response. Farfield was a partner in the 3 year European FP7 program ASMENA (2008-11) to develop new platforms for drug screening and analytical profiling based on in vitro measurements of the functional and conformal change in membrane proteins [C5]. Similar pan-European projects include the SABIO collaboration to develop a diagnostic test for Hepititis A, B and C [C6], and the INTOPSENS project, funded under the FP7 HealthCompetence programme, to demonstrate a compact polymer and silicon-based CMOS-compatible photonics sensor system for a rapid diagnostic test for sepsis at `point of care' [C7]. They are also part of the NEURASYNC network to study Parkinson's disease (PD). This is the second most common neurodegenerative disorder, characterized pathologically by the accumulation of aggregated conformations of the presynaptic protein alpha-synuclein. Farfield's role was to use the AnaLight DPI for state of the art in vitro assays with biomarkers and experimental therapeutics targeting alpha-synuclein [C8].

In 2009, the company took its sensor fabrication to Inex, at Newcastle-upon-Tyne in order to move from a 4" to a 6" process and it extended its range of chip surfaces. It was accepted into the North West England High Growth business support programme. There was expansion of bioscience-based sales activity in the form of a co-marketing agreement with IdentiGen in Germany and the customer base extending to 19 countries with first-time installations in Korea and the Kingdom of Saudi Arabia [C1]. The company took on a new postdoc in 2010 and launched the Farfield **AnaLight 4D Workstation,** allowing combined studies of affinity, kinetics, conformation and thermodynamics of biomolecules (Fig 4 [C9]).

Fig 3: AnaLight 4D workstation

However, the worsening economic climate brought difficulties for the company and it was bought out in April 2010 by the publically quoted Swedish scientific instrument supplier Biolin Scientific, who acquired all existing shares in the Farfield Group for £2.5M [C10]. Farfield continued to market and sell under the Farfield brand worldwide, remaining a separate product company within the Biolin organisation. All Farfield staff were retained after the acquisition [C10] and, indeed, three new core staff, a Product development Manager, a Business development Manager and an application specialist, were subsequently recruited [C11]. Iberlaser SA took on representation of Farfield in Spain, and Farfield relocated to new premises at Manchester Airport with improved laboratory and training facilities. Automation was enhanced during the year with the Dual Plate Autosampler, the customer base expanded to 20 countries, and Biolin Inc, the US division of Biolin, took on a new post-doctoral scientist to support the Dual Polarisation Interferometry. However, Biolin took the strategic decision to discontinue the manufacture and sales of the Dual Polarisation Interferometer on December 30th 2011, though the company has made the commitment to support existing customers up till the end of December 2016 [C12].

Despite its demise, the instrument nevertheless has made a significant contribution to biosensing and the surface science sectors, and there remain scores of instruments in use around the world.

5. Sources to corroborate the impact

[C1] Farfield-Group history
http://www.farfield-group.com/company_history.asp

[C2] Farfield awards
http://www.farfield-group.com/company_history_awards.asp

[C3] Financial reports from companies house
Filed with evidence

[C4] Quote from Dr Eric Robles (Analytical GCO, P&G Newcastle Innovation Centre)
Filed with evidence

[C5] ASMENA collaboration 2008-2011
http://www.farfield-group.com/readstory.asp?sid=106&ln=5.0.1

[C6] SABIO Hepititis test: 2006-2009
http://www.farfield-group.com/readstory.asp?sid=90&ln=5.0.3

[C7] INTOPSENS collaboration
http://www.farfield-group.com/readstory.asp?sid=101&ln=5.0.1

[C8] Neurasync network for Parkinson's disease 2009-2013
http://www.farfield-group.com/readstory.asp?sid=105&ln=5.0.1

[C9] AnaLight 4D workstation brochure
http://www.farfield-group.com/pdfs/AnaLight_4D_workstation.pdf

[C10] biolin takeover
http://www.farfield-group.com/readstory.asp?sid=110&ln=5.0.0

[C11] new staff
http://www.farfield-group.com/readstory.asp?sid=112&ln=5.0.0

[C12] Biolin discontinue DPI
http://www.farfield-group.com/readstory.asp?sid=118&ln=5.0

[P1] Published patent: A chemical sensor. Freeman N.J. and Cross G.H., 1998 WO/1998/022807

[P2] Published patent: Sensor Assembly. Cross, G.H., Freeman, N.J. and Swann, M.J. 2001 WO-A-01/36946