Institution: Queen's University Belfast

Unit of Assessment: 9

Title of case study: Nanostructure Research and Spin-out Company Causeway Sensors Ltd.

Period when the underpinning research was undertaken: 2006 – 2012

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Robert Pollard	**Senior Lecturer**	**1995 – present**
Robert Bowman	**Professor**	**1994 – present**
Antony Murphy	**Postdoctoral Researcher**	**2011 – 2015**
Breandàn Hill	**Postdoctoral Researcher**	**2013 – 2015**

Period when the claimed impact occurred: Aug 2013 – July 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

Novel methods for the fabrication and characterisation of nanostructured optical metamaterials have been developed in the School of Mathematics and Physics. This research and expertise led directly to the creation of spin-out company Causeway Sensors Limited in 2013. The company ensured adoption of the new methodologies by employing highly skilled staff from the University research team in key positions. The company has raised venture capital investment of GBP1,800,000 enabling it to establish the validity of the technology for deployment in drug development and manufacture. The company has so far employed 10 people totalling 30 years of employment (mostly at post-doctoral level) and has established a shareholder valuation of GBP4,600,000.

2. Underpinning research

Since 2005, the Centre for Nanostructured Media (previous group name: Condensed Matter & Materials Physics) at QUB has developed techniques for the controlled production and characterisation of plasmonic metamaterials. Plasmonic metamaterials are metal/dielectric composites in which collective electron oscillations can be excited at the material interfaces. These novel materials have constituent parts at the nanoscale and allow for the manipulation and control of electromagnetic radiation in ways not previously possible.

The metallic components of the composite need to be high aspect ratio rods with the long axis oriented perpendicular to the substrate plane. This is important in order to generate sufficient sensitivity for commercial application. Such perpendicularly ordered nanometre scale structures are difficult to make and produce in large area sizes. These challenges are compounded when large-scale volumes at high quality are required. The structures could not be realized using the previously established nanomanufacturing techniques of e-beam lithography and nano-imprint stamping.

Bringing techniques adapted from expertise in high vacuum surface science and magnetic recording technology, Dr Pollard's group pioneered a new class of templated metamaterials. To realise this, novel fabrication techniques compatible with modern industrial methods and extensive in-situ process monitoring were developed. These methods were able to create nanostructured optical metamaterials with very good control, both within and perpendicular to the substrate plane. The size and quality of materials enabled a deep understanding of their

behaviour to be obtained, from extensive physical characterisation and predictive computer modelling **[R1, R2]**.

The team applied the principles learned to several fields of optical physics by exploring the interaction of visible and near infrared radiation with the nanostructured metamaterials **[R3, R4]**. Particular promise was seen for refractive index sensing, wherein the optical properties of the metamaterial vary in response to changes in environmental conditions (specifically changes in the permittivity of the environment). We used this to demonstrate high sensitivity detection of biomolecules in several metamaterial structures and optical detection arrangements **[R5, R6]**.

The development of manufacturing techniques for plasmonic nanostructures together with the understanding gained of their functional properties led directly to the platform chip technology used in Causeway Sensors products.

3. References to the research

[R1] R. Atkinson, W. R. Hendren, G. A. Wurtz, W. Dickson, A. V. Zayats, P. Evans, and **R. J. Pollard,** (2006), **"**Anisotropic optical properties of arrays of gold nanorods embedded in alumina", Physical Review B, 73 (23), 235402. https://doi.org/10.1103/PhysRevB.73.235402

[R2] P. Evans, W. R. Hendren, R. Atkinson, G. A. Wurtz, W. Dickson, A. V. Zayats, and **R. J. Pollard** (2006) "Growth and properties of gold and nickel nanorods in thin film alumina." Nanotechnology, 17, 5746. http://dx.doi.org/10.1088/0957-4484/17/23/006

[R3] R. J. Pollard, **A. Murphy**, W. R. Hendren, P. R. Evans, R. Atkinson, G. A. Wurtz, A. V. Zayats, and V. A. Podolskiy **(**2009**) "**Optical Nonlocalities and Additional Waves in Epsilon-Near-Zero Metamaterials.", Physical Review Letters 102, 127405. https://doi.org/10.1103/PhysRevLett.102.127405

[R4] G. A. Wurtz, **R. Pollard**, W. Hendren, G. P. Wiederrecht, D. J. Gosztola, V. A. Podolskiy, and A. V. Zayats, (2011) "Designed ultrafast optical nonlinearity in a plasmonic nanorod metamaterial enhanced by nonlocality.", Nature Nanotechnology 6 (2), pp. 106-110. https://doi.org/10.1038/nnano.2010.278

[R5] A. V. Kabashin, P. Evans, S. Pastkovsky, W. Hendren, G. A. Wurtz, R. Atkinson, **R. Pollard**, V. A. Podolskiy, and A. V. Zayats, (2009), "Plasmonic nanorod metamaterials for biosensing." Nature materials, 8, pp. 867-871. https://doi.org/10.1038/nmat2546

[R6] J. McPhillips, **A. Murphy**, M. P. Jonsson, W. R. Hendren, R. Atkinson, F. Höök, A. V. Zayats, and **R. J. Pollard**, (2010), "High-performance biosensing using arrays of plasmonic nanotubes." ACS Nano 4, pp. 2210-2216. https://doi.org/10.1021/nn9015828

Citations for papers. Web of Science December 2020
R1: 118, **R2**: 112, **R3**: 195, **R4**: 330, **R5**: 1,132, **R6**: 115

Funded projects:
EP/C013204/1 "Nano-structured capacitor elements via self assembly on nano-porous alumina", EP/E011578/1 "Dynamic studies of the linear optical properties of nanostructured media",
EP/G010374/1 "Fabrication, Characterisation and Nanophotonic Applications of Plasmonic Waveguides made of Metallic Nanorod Arrays",
EP/H000917/1 "Active Plasmonics: Electronic and All-optical Control of Photonic Signals on Sub-wavelength Scales",
EP/I014004/1 "Magneto-Optic and Ellipsometric study of nanostructured media"

4. Details of the impact

Chairman of Causeway Sensors Limited noted: *"I am delighted to confirm the essential role of Physics research in the formation and growth of Causeway Sensors Limited. Causeway is building a world class technology company based on the nanostructured sensing platform first developed in the Centre for Nanostructured Media at Queen's University."* **[S1]**

This work describes impact delivered through spin-out Causeway Sensors Limited:

- Venture capital investment of GBP1,830,000 raised over three rounds in 2013 (GBP106,000), 2016 (GBP525,000) and 2018 (GBP1,200,000).
- 10 employees (7 at PhD level, 3 at Masters) with 30 person-year of employment in the REF period.

Causeway **[S2]** was founded in 2013 to commercialise the research nanostructures developed in the Centre for Nanostructured Media. The technology was found to be particularly suited to monitoring the complex interactions of biological molecules in close proximity to the nanostructures. The biological performance had been initially verified through a joint research project between the Centre for Nanostructured Media (Dr Pollard, Prof Bowman) and the School of Biological Sciences (Dr Nelson). During this project, which ran from 2010 to 2013, Dr Hill completed his PhD under the supervision of Dr Nelson. Dr Pollard, benefiting from a university sabbatical, led the foundation as CEO and two members of his research group became the first employees: Dr Murphy the current CTO and Dr Hill the head of product development. The first prototype developed was a research instrument used to validate the technology. As well as in-house company measurements, results were obtained from instruments located in the Patrick G Johnston Centre for Cancer Research.

The instrument proved capable of determining key properties (affinity, kinetics, concentration and specificity) of biological molecules at a fraction of the cost and complexity of other solutions. In 2018, Causeway Sensors Limited was awarded one of six prestigious start-up business awards from the Institute of Physics **[S3, page 20]**. The awards are given for demonstrating the impact of the successful application of physics in a diverse range of sectors. In the case of Causeway, this was "For the development of a nanotechnology based point of care solution for the detection of pathogens."

The company is currently focussed on productising its technology for widespread implementation in drug development and manufacture. The inability to measure key data directly on biological production lines means it can typically take 10 years and a billion pounds to get a drug to market. Presently, samples are extracted from the production lines and analysed on complex instrumentation in specialist laboratories.

The Causeway technology allows for the highly sensitive quantification and characterisation of biological interactions in real time, directly on the production line. This enables key decisions, on for example the best drug candidates or process conditions, to be made at the optimum time. Customer benefits include faster development times, improved yields and better drug quality. High quality wafer-based manufacturing enables Causeway products to be deployed at many places in the drug development cycle.

<u>Spin-out Investment Development</u>

The initial equity of GBP106,000 used to found the Company came from the University investment arm QUBIS **[S4]** and local Angel entrepreneur Dr Hugh Cormican (founder of Andor Technology and Cirdan Imaging). Dr Cormican, a Queen's Physics graduate, became aware of Dr Pollard's research during a UKRI funded knowledge transfer partnership between Cirdan Imaging and the Centre for Nanostructured Media (2010 to 2012).

At this stage, the University assigned the company a patent and exclusive licence to the work carried out on the series of EPSRC grants awarded from 2006 to 2013. From this initial

position, the company has substantially developed its intellectual property, including further patents **[S5]** developed from this earlier university research.

The company used this initial equity investment to leverage support from Invest NI, under the European Union's Investment for Growth and Jobs Programme. The project from October 2015 to March 2017 undertook research and development activities to prove the potential of the business, principally through the development of surface coatings for the detection of biochemical species. Sufficient progress was made to attract venture capital firm Kernel Capital to invest GBP500,000 in October 2016. A partner at Kernel Capital, said at the time: ***"Causeway Sensors is a prime example of the success that can be achieved from bringing a concept through the research to commercialisation process. This investment will help Causeway to develop the potential of its nanotechnology and to grow and scale both nationally and internationally while also stimulating the local economy and creating new employment opportunities."*** **[S6]**

Following this investment, the company has continued its close relationship with Queen's and in particular the School of Mathematics and Physics. The company has negotiated a teaching and administration replacement, enabling Dr Pollard to remain as CEO. As a QUBIS backed spin-out company, Causeway has been able to negotiate access to vital equipment and laboratory space in the Centre for Nanostructured Media. **[S1]**, **[S4]**

The company's improved understanding of the underlying technology and market opportunities enabled a follow-on investment round in January 2018. Kernel Capital through The Bank of Ireland Kernel Capital Growth Fund (NI), led a GBP1,200,000 project in syndication with QUBIS and private investors. A further GBP300,000 grant funding was secured from the European Regional Development Fund (Invest NI) and Innovate UK. **[S7]**

Client discovery and feedback has identified a market opportunity in the drug discovery and bio-production industry. Causeway has established a current shareholding value of GBP4,600,000 since foundation and is actively engaging with further investment partners for a series A round in 2021 **[S1]**.

The company recognises that the ecosystem in which it operates is a vital part of the recipe for success in a high-tech start-up company. Queen's University and the Centre for Nanostructured Media are proud of their contributions to this ecosystem. In 2010, the Centre established an industrial prototyping laboratory (ANSIN). Backed by both Invest NI and Seagate Technology, ANSIN enabled Causeway to translate high quality research to industrial relevance.

"Being able to hire PhD level employees trained at Queen's University has been a major reason for Causeway Sensors progress to date. We currently sponsor two EngD students at the Centre for Doctoral Training (CDT) in Photonic Integration and Advanced Data Storage housed between Queen's and Glasgow Universities. This affects positive technical change by providing access to excellent facilities and staff at the Universities together with great training for our employees. Building contacts with the University and other non-competing technology companies is also of significant benefit. Indeed, the company in partnership with Queen's University and Seagate Technology has recently been awarded seedcorn funding to develop a full UKRI Strength in Places Fund proposal." **[S1]**, **[S8]**

5. Sources to corroborate the impact

[S1] Letter of Corroboration, Chairman, Causeway Sensors Limited
[S2] http://www.causewaysensors.com/
[S3] IOP Business Awards 2018 Brochure
[S4] https://www.qubis.co.uk/portfolio/21/causeway-sensors-ltd
[S5] Analysing apparatus and method GB2545157A:US15/766,147: EP16775725.1A
Biomarker detection apparatus GB2570909A:US16/270,843: EP19156535.7

Analysing system for multi-well sample carriers GB1911553.4A
[S6] https://www.belfasttelegraph.co.uk/business/news/500k-boost-for-causeway-sensors-35128470.html
[S7] https://www.rte.ie/news/business/2018/0320/948730-causeway-sensors-investment/
https://www.irishtimes.com/business/health-pharma/belfast-based-causeway-sensors-gains-1-5m-investment-1.3432921
[S8] https://www.smartnanoni.com/