Institution:
Durham University

Unit of Assessment:
UoA 9: Physics

Title of case study:
Unique pressure sensitive materials for use in tactile interfaces: Peratech Holdco Ltd (**Peratech**)

Period when the underpinning research was undertaken:
Between 2003 and 2015

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:
Dr. Marek Szablewski	Associate Professor of Physics	1992 to present
Prof. Del Atkinson	Professor of Physics	2001 to present
Prof. David Bloor	Professor of Physics (from 2002: Emeritus Professor of Physics)	1989 to present

Period when the claimed impact occurred:
Between August 2013 and December 2020

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

1. Summary of the impact

Research in Durham showed that quantum tunnelling was the physical origin of the unique pressure sensitive behaviour of a new composite material, QTC® (Quantum Tunnelling Composites), developed by Peratech. This supported the commercial exploitation of QTC®, with further research since 2012 to develop these as transparent printable inks for touchscreen devices. In this REF period, Peratech's QTC® ink-based technology has been integrated into over one million devices, including products by three of the top PC notebook companies and three of the top smartphone manufacturers. This growth in sales led to Peratech doubling its workforce and opening new facilities in the USA, South Korea and Sweden. It now employs 24 staff in the UK and 49 globally.

2. Underpinning research

For background, in 1996, David Lussey, an independent technologist, approached Prof. David Bloor of Durham University Physics Department via Knowledge House, which provided an interface between academia and industry in the North East. Mr. Lussey was trying to make a conducting adhesive for an anti-theft device. He had mixed nickel powder with clear silicone polymer (bathroom sealant); it was insulating but became conductive under applied pressure. A start-up company, Peratech, was founded by Lussey to commercialise this material, but a fundamental understanding of the properties and origin of its unusual behaviour was essential to develop a viable product. Collaborative research between Peratech and Durham Physics showed that, in contrast to the behaviour of conventional percolation composites, which switch from insulator to conductor over a very small pressure range, the material changed gradually from an electrical insulator to a metal-like conductor over a large range in applied pressure. This preliminary research work characterised the properties of the material, providing the data on which the initial patent was based, and indicated potential applications.

The unique behaviour of the new material led Peratech to sponsor research in the Durham Physics Department in order to understand the origin of this phenomenon. Conventional composites consist of spherical conducting particles (either metals or carbon) embedded in a polymer, and contact between the particles is required in order to create a conduction path. Hence the material is either an insulator when the particles are not in contact, or a conductor when they are in contact. However, Scanning Electron Microscopy images revealed that the nickel

particles in the composite were spiky rather than smooth (Fig. 1). This explains the origin of the unique conduction properties as electric field enhanced quantum tunnelling, which gives the commercially protected name for these Quantum Tunnelling Composites, QTC®.

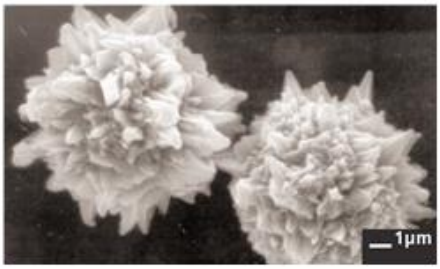

Fig.1: The Nickel particles in QTC®

With no pressure applied, the nickel particles are separated from each other by the silicone elastomer, so the material is an insulator. Under pressure, the particles get closer but do not touch, as they are completely covered (wetted) by the silicone. In 'normal' quantum tunnelling structures, the particles have to be nanometres apart for the tunnelling current to be detectable. However, the spikes on the nickel surface allow large electric fields to build up at their tips. This decreases the effective width of the potential barrier in quantum tunnelling, thus increasing the distance over which the quantum tunnelling current is significant, to 20-30nm. The current increases further as the particles are forced closer together, giving a very sensitive non-linear dependence on the applied pressure. These results were published by Bloor *et al*. in *Journal of Physics D* in 2005 [R1]. This was selected as one of the top 25 research papers in the journal for that year, and has been cited more than 150 times.

Peratech first used the original bulk QTC® coating for switches and sensors (Fig. 2), but it became apparent that an ink version of QTC® would have more potential, as ink printing is a more efficient and hence cheaper way to make structures coated with the material. Peratech empirically developed a QTC® ink, replacing the nickel with semiconductor coated titanium dioxide as the composite nanoparticles in a standard ink base. Research by the Durham group, now led by Professor Atkinson and Dr Szablewski, showed that these nanoparticles formed needle-like rods, enabling the electric field enhanced quantum tunnelling to occur between the tips of the rods, again giving a strong dependence of conductivity on applied pressure [R2, R3].

Further research in Durham, funded by a Knowledge Transfer Partnership award between 2011 and 2015, focussed on the design, formulation, and characterisation of screen-printable, pressure-sensitive transparent inks. This showed how pre-fabricating the nanoparticles to a standard size before incorporating them into the ink gave increased reliability and repeatability of response, as well as improved optical transmission [R4-R6]. This led to a complete re-design of the formulation and fabrication of the QTC® inks, and thus impacted directly on Peratech's products.

3. References to the research

[R1] D. Bloor, K. Donnelly, P.J. Hands, P. Laughlin and D. Lussey (2005). *A metal-polymer composite with unusual properties* ***Journal of Physics D: Appl. Phys****.* 38, 2851-2860. DOI:10.1088/0022-3727/38/16/018

[R2] A. J. Webb, M. Szablewski, D. Bloor, D.Atkinson, A. Graham, P. Laughlin and D. Lussey (2013). *A multi-component nanocomposite screen-printed ink with non-linear touch sensitive electrical conductivity*. (2013) ***Nanotechnology*** 24, 165501-165509. DOI:10.1088/0957-4484/24/16/165501

[R3] A.J. Webb, D. Bloor, M. Szablewski and D. Atkinson (2014) *Temperature Dependence of Electrical Transport in a Pressure-Sensitive Nanocomposite* ***ACS Appl. Mater. Interfaces*** 6, 15, 12573-12580. DOI:10.1021/am502515u

[R4] S. Dempsey, M. Szablewski, D. Bloor, and D. Atkinson, (2015). *Printable, transparent force sensing resistive materials for touchscreen applications,* ***Key Engineering Materials*** 644, 120-124. DOI:10.4028/KEM.644.120

[R5] S. J. Dempsey, M. Szablewski, and D. Atkinson (2015). *Tactile sensing in human computer interfaces the inclusion of pressure sensitivity as a third dimension of user input*. ***Sensors and Actuators A: Physical***, 232, 229-250. DOI:10.1016/j.sna.2015.05.025

[R6] A. J. Webb, S. J. Dempsey, D. Bloor, A. Graham, P. Laughlin, D. Lussey, M. Szablewski and D. Atkinson (2013). *A Novel Screen-Printed Multi-Component Nanocomposite Ink with A Pressure Sensitive Electrical Resistance Functionality* ***IEEE Nanotechnology (IEEE-NANO)***, 671-674. DOI:10.1109/NANO.2013.6720832

The underpinning applied materials research undertaken at Durham was published in the most relevant peer reviewed international journals. The founding research [R1] has over 250 citations and the key papers describing the research on the inks have over 50 citations.

4. Details of the impact

Jonathan Stark, CEO of Peratech, said in 2019: *"Peratech's collaboration with Durham University has provided us with a raft of theoretical insights, a host of nanoscale analytical tools, and a community with the scientific discipline to characterise structures and their links to the functional behaviour of our sensing solutions. …….. and we could not have accomplished nearly the number of things we have done without our partners in furthering the art and application of the Physical Sciences."* [E6].

The underpinning knowledge base from the research undertaken in Physics at Durham enabled Peratech to go from a start-up to a Small to Medium Size (SME) enterprise with a turnover of approximately GBP3million and employing 25 people by 2013. Based in Brompton on Swale, North Yorkshire, an area of low employment, Peratech first used the original bulk QTC® composite in textile switches and sensors, for example on ski jackets to connect to an iPod, using touch technology (Fig. 2). Critically, despite commercial and innovation successes it became apparent around this time that an industrially compatible printable version of QTC® would have greater applications potential, as the printable ink is much more efficient, and hence cheaper, and could be integrated into production processes for a wider range of electrical and electronic applications. Peratech empirically developed QTC® ink formulations and research at Durham produced a physical understanding of the printed microstructures and the physical basis of the stress sensitive functional performance. It is these research insights [R2-R6] into the structure and performance of QTC® inks that underpin the latest impact.

Fig. 2: QTC® textile control buttons

Despite significant progress in ink developments, the company ran into financial difficulties in 2013/2014. A significant fraction of company assets resided in the intellectual property portfolio (patents and insights underpinned by Durham research), then valued at just under GBP1million. This provided confidence for new financial backers to undertake a rescue. The assets were absorbed into a new company, Peratech Holdco Ltd., in February 2014, with which Durham has on-going collaborations. The original Peratech Ltd. company was liquidated in 2016.

Durham's research continued to impact upon the development of the ink with Peratech Holdco Ltd. (henceforth Peratech), developing a reliable process to manufacture the pressure sensitive ink. Sensor surfaces were developed using printed films of the QTC® ink that can be configured to sense the X-Y touch location and detect the force response in the Z-axis. The response to pressure is predictable, repeatable and consistent over time.

Fig.3: Gaming mouse with QTC®

This has obvious application in touchscreen devices. Apple previously utilised a 3D touch response (which recognised 3 levels of force press) on their iPhone but subsequently abandoned this technology in favour of their Haptic touch system (which responds to tap duration rather than force), leaving the Peratech materials as the only commercial 3D force-sensing technology currently available. Peratech has collaborated with several leading notebook manufacturers to incorporate its 3D force-sensing technology into products through the use of the pressure sensitive inks. The details are not publicly available for commercial reasons [E1], but these applications include innovations relating to the user interaction experience of the products. Peratech already has 1 million devices around the world incorporating QTC® materials technology [E2]. One example which is in the public domain is the integration of QTC® sensors into the Swiftpoint Z Gaming Mouse in 2017, making the first mouse with force-sensing analogue buttons and with pivot, tilt and roll [E3]. Swiftpoint, a technology development company with offices in New Zealand and the US, specialises in advanced Human Computer Interface software and devices (Fig. 3).

Peratech has continued to grow based on the QTC® materials ink-based technology. In order to scale up operations, in October 2017, Peratech successfully raised GBP9.2million in venture capital investment from Merck Ventures, Arie Capital and existing investors. Merck Ventures are the corporate venture capital arm of Merck, with a mandate to invest in innovative technologies and products with the potential to significantly impact on Merck's core business areas. Sven Harmsen, Investment Director with Merck Ventures said, "*Leading Peratech's round of financing underlines Merck Ventures' ambition to invest in game-changing materials innovations. We are excited to see Peratech develop and commercialise a technology that has the potential to disrupt the way we use touch sensing in the mobile, automotive, industrial, and medical device markets. The timing is right as leading OEMs [original equipment manufacturers] in these markets are starting to deploy innovative HMIs [human-machine interfaces] utilising force and 3D touch. Peratech's technology is ready for commercial use and it can further scale its product engineering and manufacturing.*" [E4]

During the same month, Peratech was awarded the 2017 *New Product of the Year (Electronic)* award, for the 3D Multi-Touch Matrix sensor, at the British Engineering Excellence Awards (BEEAs) [E5].

Despite the 2014 restructure, Peratech has doubled its workforce since 2013 [E6], currently employing 24 staff in the UK (many of whom are Durham graduates) and 49 globally [E6]. It has facilities and offices in the United Kingdom (UK), United States of America (USA), Korea and Sweden.

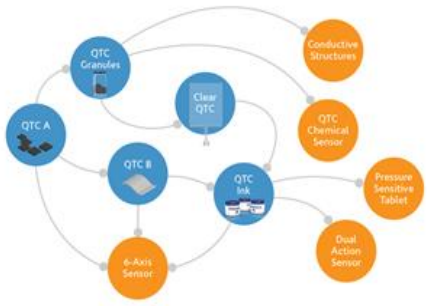

Fig. 4: Peratech patent portfolio highlighting the central role of the QTC® inks.

The company holds many worldwide patents, one third of which name Durham Physics academics as inventors. The patent portfolio highlights the key role of the QTC® ink, as it includes patents on the formulation and preparation of a QTC® ink, a clear transparent QTC® ink and a QTC® material containing acicular conductive filler particles (Fig 4). A patent filed as a result of the 2011 to 2015 Knowledge Transfer Partnership research programme in Durham Physics [E7] underpins Peratech's brave, and successful, complete redesign of its ink. This enabled the product to perform better, with higher repeatability, and at 20% of the previous cost of production [E6].

Recent developments in QTC® materials have allowed an expanded range of application uses, especially in volume markets such as automotive controls sensing. Peratech's latest human machine interface concept [E8, E9] uniquely exploits the edges of a device (for example, a smartphone) to provide a better user experience. Thin sensors with Peratech's QTC® technology are mechanically integrated into key areas of a smartphone to capture a user's natural single-handed grip, ergonomic finger movements, intuitive presses and squeezes to control key functions. These can be used to simplify mute, sleep, volume, zoom, scroll, and emergency call functions while improving one-handed usability. While subject to strict confidentiality agreements, these developments have led to innovations by the three top global smartphone manufacturers. Most recently, Peratech and the Chinese company Visionox have signed a Memorandum of Understanding to jointly develop integrated display and force-touch modules [E10]. Founded in 2001 and holding over 6,500 patents, Visionox Technology Inc. is a high-tech enterprise, listed on the Shenzhen Stock Exchange, focusing on OLED (organic light emitting diode) technology development, production, and sales, particularly of display screens.

5. Sources to corroborate the impact

[E1] Peratech Press Release (27 October 2016).
[E2] Peratech Webpage 'About Peratech' (https://www.peratech.com/about.html).
[E3] Peratech Webpage 'Swiftpoint Z Gaming Mouse' (https://www.peratech.com/swiftpoint-z-gaming-mouse.html); the pressure sensitive gaming mouse retails at GBP195.90 from Amazon, manufactured by Swiftpoint Ventures https://www.swiftpoint.com/products/
[E4] Article on www.prnewswire.com: 'Peratech Raises USD12.4 Million (GBP9.2 Million) in Financing From Merck Ventures, Arie Capital and Existing Investors to Scale Up Technology Solutions' (23 October 2017).
[E5] Peratech Press Release (9 October 2017).
[E6] Testimonial from the Peratech CEO (15 November 2019).
[E7] Durham University Doctoral thesis: DEMPSEY, SARAH,JESSICA (2016) *Structure and Functionality of Novel Nanocomposite Granules for a Pressure-Sensitive Ink with Applications in Touchscreen Technologies.* (http://etheses.dur.ac.uk/11509/).
[E8] https://www.facebook.com/CNNCreate/videos/mike-garrett-head-of-software-peratech/2111707318845723/ Video showing Peratech's Force Sensitive Sensor.
[E9] Quality Magazine article 'Peratech QTC-Based EDGE Force Sensing Solution' (1 April 2019).
[E10] Peratech Press Release (7 October 2019).