Institution: University of Durham
Unit of Assessment: 9/Physics

Title of case study: Characterising a unique pressure sensitive material for use in mobile phones: Peratech Ltd (**Peratech**)

1. Summary of the impact

Collaborative research between Durham Physics and Industry showed that a serendipitously discovered new material had unique, pressure sensitive conduction properties which were derived from quantum tunnelling. This research, published in 2005, is cited as one of the top 25 papers in that Journal for that year. Peratech was set up to commercialise this material for applications including switches and mobile phones as the pressure sensitivity gives a new dimension to scale the response. This company now employs 25 people, has an annual turnover of £3M and won the 2012 Queens award for Enterprise in the innovation category.

2. Underpinning research

In 1996 Mr. David Lussey approached Prof. David Bloor (Durham University Physics 1989-2002) via Knowledge House, which provided an interface between academia and industry in the North East. Mr Lussey, working as an independent technologist on a security contract, was trying to make a conducting adhesive for an anti-theft device. He mixed nickel powder with clear silicone (bathroom sealant); it was insulating but became conductive under applied pressure. Pressure sensitivity opens a whole new dimension in the human-machine interface, as the resistance depends on the applied force e.g for games consoles in gauging the level of response. Mr Lussey founded a company, Peratech, to commercialise this material, but wanted a fundamental understanding of the origin of its unusual behaviour.

Collaborative research between Bloor and Lussey at Durham showed that the material changed gradually from an electrical insulator to a metal-like conductor over a large range in applied pressure. This provided the key results for the patent on the material [1], and is in strong contrast with the behaviour of conventional composites which switch from insulator to conductor over a very small range. The 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. The very different behaviour of the new material led Peratech to sponsor a CASE PhD studentship (Hands) in Durham Physics Department to better understand the structure which gave rise to this behaviour. The key research breakthrough came when a sample was taken to the Scanning Electron Microscope in Durham. These pictures revealed that the Nickel particles were spiky rather than smooth, immediately pinpointing the origin of the unique conduction properties as electric field enhanced Quantum Tunnelling. With no applied pressure, the Nickel particles were separated from each other by the silicone rubber, so the material was 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 applications, the particles have to be nanometers apart for the tunnelling current to be detectable. However, the spikes on the Nickel surface allow a large electric field to build up at their tips (Fig 1). This decreases the effective width of the potential barrier in quantum tunnelling, thus increasing the distance at which the quantum tunnelling current can be detected to 20-30nm. The current increases as the particles are forced closer together, giving a very sensitive dependence on the applied pressure. The unique properties of this Quantum Tunnelling Composite (QTC) were outlined in a paper by Bloor et al 2005 [2] in the Journal of Applied Physics, which was selected as one of the top 25 research papers in this Journal for this year

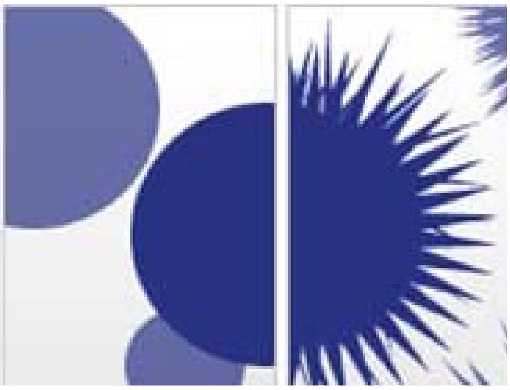

Fig 1: Comparison of shapes of conventional composite (left) and QTC (right)

More details of the material were published in [3], and its application to vapour sensing in [4-5]. This also opened up a new field of design of other composite materials whose conduction properties are controlled by quantum tunnelling [6]. These provide pressure sensitivity in touch sensitive device including screens, keyboards, controls and switches giving an extra dimension to the response compared to current touch sensitive screens which only detect position.

3. References to the research

1. Granted patent: D. Lussey, Peratech Ltd., UK Patent, PCT/GB98/00206 (WO 98/33193).
2. D. Bloor, K. Donnelly, P.J. Hands, P. Laughlin and D. Lussey, Journal of Physics D: Appl. Phys. 38, 2851 (2005).
3. D. Bloor, A. Graham, E.J. Williams, P.J. Laughlin and D. Lussey, Appl. Phys. Lett. 88, 102103 (2006)
4. P. Hands, P. Laughlin, D. Bloor, Sensors and Actuators B: Chemical 162, 400 (2012).
5. A. Graham, P. Laughlin, D. Bloor, Sensors and Actuators B: Chemical 177, 507 (2013).
6. A. Webb, M. Szablewski, D. Bloor, D. Atkinson, A. Graham, P. Laughlin, D. Lussey, Nanotechnology 24, 1655501 (2013).

The quality of the underpinning research is evidenced by the fact that [2] was selected as being one of the top 25 papers published in the Journal for that year. It has 119 citations.

4. Details of the impact

The research by Prof Bloor was key to the initial patenting and has continued to provide the company with academic support for its claims, thereby strengthening its' position to negotiate start-up finance and attract potential customers. Mr Lussey, in an web interview, says '*That University connection started Peratech*' [C1].

Peratech first used the QTC coating for textile switches and sensors, but it became apparent that an ink version of QTC would have great potential as ink printing is a much more efficient and hence cheaper way to make structures coated with the material. Mr Lussey was able to make a pressure sensitive ink from a standard ink base but with semiconductor coated Titanium dioxide particles rather than Nickel as the QTC particles. However, he could not develop this further without a basic understanding of its properties. Dr Del Atkinson at Durham worked on the micro-morphology of the ink, again using the scanning electron microscopy facilities in Durham to show the structural properties of the new material. Here the key aspect was that the nanoparticles were needle-like rods, so the electric field enhanced quantum tunnelling occurred between the tips of the rods, again giving the strong dependence of conductivity on applied pressure [6]. This opaque QTC ink coating is now the subject of licence agreements with major international companies e.g. Nissha printing, one of the worlds' largest manufacturer of touch screen technology. Nissha signed a $1.4M licence agreement with Peratech to use QTC technology to create the next generation of touch screens with 3D input (x,y position and pressure) for mobile phones and portable electronic devices. The licensing agreement gives Nissha exclusive worldwide rights to use the technology for screens smaller than 3.5 inches by 5.5 inches for an initial period of one year [C2]. This success attracted £1.1M funding from YFM, a company which invests in SMEs across the UK [C3].

The opacity of the standard QTC ink means it has to be printed underneath the screen, with backplane electronics behind this to detect position and pressure. Peratech initially used commercial solutions for these electronics, but now has its own design office in Korea which produces electrode and backplane designs as well as firmware and software especially for QTC. Peratech has used these facilities to develop its own customised touch processing unit [C4].

However, the focus of recent development work has been instead to design a transparent QTC ink which can be printed on the front of a screen. This is much simpler to incorporate in the manufacturing process, as it means that the printing is directly onto the flat screen substrate [C5]. New readout electronics designs for transparent multi-touch sensors are being developed that span the entire screen, giving full pressure sensing at all positions simultaneously. Peratech is now working with the Centre for Process Innovation (CPI) Plastic Electronics Technology Center on NETPark to explore printing QTC screens, sensors and switches using standard printing machines. This gives a major reduction in production costs compared to the previous approach where

Peratech used a screen-printing process. The project will also allow the integration of QTC devices with other forms of printable electronics. This joint project is supported by government funding from the Technology Strategy Board [C6].

While the market for pressure sensitive inks is very large, there are also smaller niche markets for more general pressure sensitive materials. The properties of the QTC™ material means that it can detect multiple gestures and functions, responding instantly to contact in a similar way to human skin. This has applications in robotics, with Peratech commissioned by NASA to build the hand/glove sensor for Robonaut, a humanoid robot to work in space alongside astronauts [C7]. Later versions flew to the ISS on STS-133 in 2011 (Fig 2), and the work resulted in Peratech being given one of NASAs Tech Brief awards in 2012 [C8]. Peratech also had a joint project with MIT (commissioned in 2010) to develop technology by which people can interact tactilely with a robot in much the same way as they would with another human (see Fig 3, C9).

Fig 2: Robonaut 2 – the first dexterous humanoid robot in space – is pictured on ISS. Credit NASA

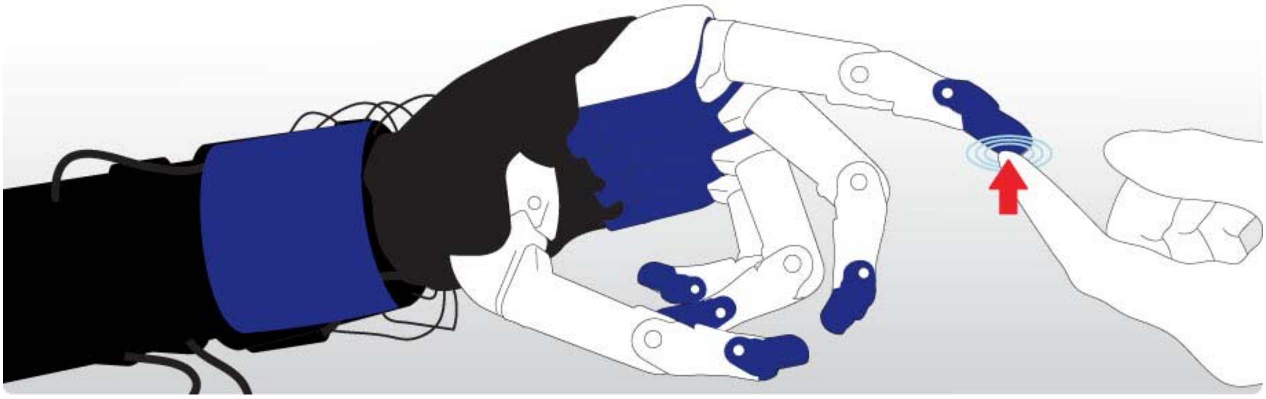

Fig 3:Tactile human-machine interface with QTC skin developed for robotics with NASA and MIT

An acknowledgement of the impact of this work is that Peratech won the 2012 Queen's Award for Enterprise in the Innovation Category for QTC. The citation says that "the new materials have spawned an extensive range of highly-reliable solid state sensors and switches. The innovation has facilitated the development of light-weight, low-power, portable devices with three-dimensional input features." This is the UK's most prestigious award for business performance and recognises and rewards outstanding achievement by British companies [C10]. This joins several other awards such as 2011 British Engineering excellence award, 2011 Growing Business award, 2011 Printed Electonics award. Mr Lussey recently won 'AV technologist of the year 2013', an award which recognises outstanding achievement by an individual in advancing AV technology [C11].

The company holds 100+ worldwide patents [C12], employs 25 people, and has increased turnover dramatically over the REF period, reaching ~£3M per annum in 2012 (see Fig 4).

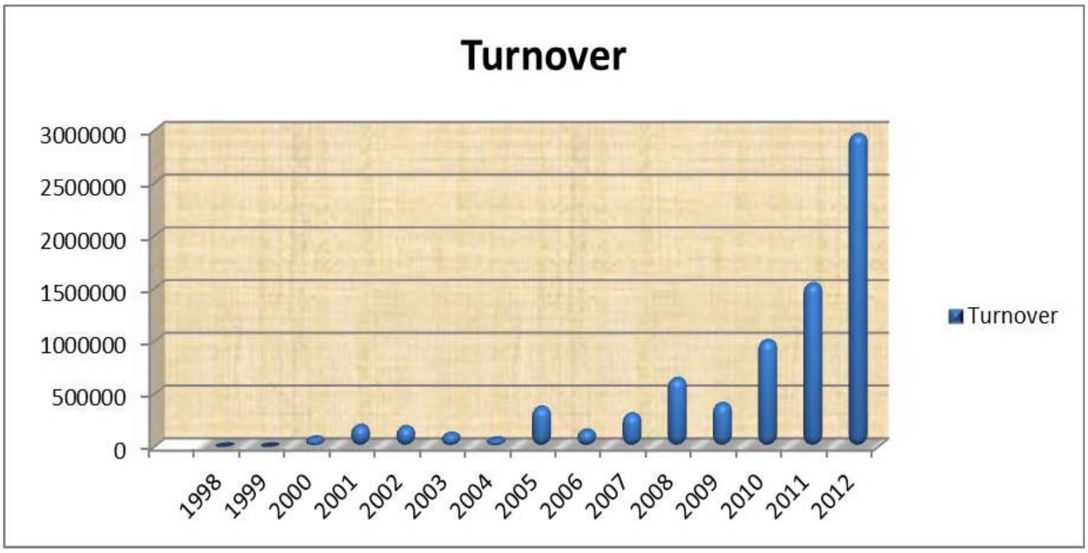

Fig 4. Annual turnover of Peratech from 1998 to 2012, showing how the company has expanded since 2008 (courtesy D Lussey [C13])

5. Sources to corroborate the impact

C1 David Lussey Interview for Innomatnet Project (video filed with supporting evidence)
http://vimeo.com/56006577
C2 Nissha licence
http://peratech.com/nissha.html
C3 YFM funding
http://peratech.com/yfm-group.html
C4 touch processing unit
http://www.peratech.com/qtc-touch-processing-unit.html
C5 QTC clear (transparent ink)
http://www.peratech.com/qtc-clear-screenprint-ink.html
C6 Peratech – PETeC joint project for printing QTC clear and electronics together
http://www.uk-cpi.com/news/peratech-working-on-new-ink-formulations-with-cpi/
C7 QTC for touch sensitivity on NASA Robonaut hand, T.B. Martin et al, NASA Tech. Briefs **28**, No. 10, 29 (2004) also published in 2004 IEEE International conference on automation and robotics
http://www-robotics.cs.umass.edu/Papers/icra04_martin.pdf
C8 Peratech NASA tech brief award
http://www.peratech.com/nasa-robonaut.html
C9 Peratech MIT robotics contract
http://www.peratech.com/mit.html
C10 Queens award 2012
http://www.peratech.com/queens-award.html
C11 Mr Lussey wins AV News Technologist of the year
http://www.peratech.com/av-news-awards-2013.html
C12 Patent list
http://www.peratech.com/patents-and-science-papers.html
C13 Peratech company turnover
Filed with evidence