Institution: University of Liverpool

Unit of Assessment: 13 - Electrical and Electronic Engineering, Metallurgy and Materials

Title of case study: Q-Technologies Limited (University of Liverpool Spin Out company)

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

Q-Technologies Limited is an award winning company spun out from the University of Liverpool (UoL). The company mission is to bring to market the novel, patented technology developed through research undertaken by Taylor and colleagues in the Mass Spectrometry (MS) research group in the Department of Electrical Engineering and Electronics from 1995. Impact is ***economic*** resulting from formation of a profitable business, currently employing 7 people, and via IP assignment generating £1.2M in 2013. Impact is also ***environmental*** via the realisation of a novel sensor with unparalleled monitoring capabilities providing improved water quality monitoring.

2. Underpinning research (indicative maximum 500 words)

Context: Mass spectrometry (MS) is an information-rich sensing technology providing data in the mass, concentration domains in real time. MS therefore provides qualitative, quantitative and time trend data. MS can be exploited to analyse gases, liquids, and solids. MS instruments are therefore capable of answering the questions: what substance is it?, how much is there?, and how is it changing in time?.

Research: The underpinning research stems from work undertaken from the mid-1990's and onwards. Taylor recognised that a miniature quadrupole mass spectrometer (QMS) fabricated using micro-engineering (MEMS) techniques offers the advantages of greater portability at reduced cost. A miniature QMS would allow new applications for online monitoring in the security, environmental, oil, gas and medical fields. In collaboration with researchers from Imperial College of Science Technology and Medicine (ICSTM) a patent was initially filed for the invention of the world's smallest mass spectrometer at that time [3.1]. The inventive step was then developed initially under collaborative EPSRC awards GR/K54755 (from 1996-98) and GR/M 31279 from (1999-2001). This initial research demonstrated proof-of-concept by producing a prototype micro-engineered Quadrupole Mass Spectrometer (QMS) which was successful in acquiring mass spectra of common atmospheric gases [3.2]. ***This miniature QMS was the smallest of its type in the world and the first to be micro-engineered in silicon.*** The research work defined the criteria by which miniature and micro-engineered QMS devices could be designed, built and tested [3.3]. The micro-QMS was able to operate in a higher pressure regime than had been previously demonstrated. A unique computer simulation model was also developed at UoL comprising a combination of custom and commercially available software with the ability to model QMS performance to an unprecedented level of accuracy. Previous computer models were restricted by imprecise electric field calculations and the relatively small number of ions that could be modelled. The UoL software determines electric fields to a precision of 1 part in 10^{12} and is unique in the large number (typically 10^{8}) of ions simulated [3.4].

In summary, the underpinning experimental and theoretical work from 1996-2008 resulted in: the demonstration of the world's smallest QMS; 22 publications in peer-reviewed international journals, 20 conference publications; and 10 invitations to speak at meetings in UK, Europe and the USA, including the American Vacuum Symposium (AVS, Seattle, 1999), International Vacuum Congress (IVC, San Francisco, 2001), and PITTCON (2002 and 2003). A further five patents were filed from 1998 to 2006 [3.5]. The underpinning research also led to work in related areas e.g. including the development of other forms quadrupole mass filters and also of miniature ion traps for quantum computing [3.6].

Key dates: Underpinning research: 1993 onwards. First patent 1995. Q-Technologies was spun out in 2002 and patents were licensed from UoL. 2003 DTI SMART development award. First product sale 2005. Hyperbolic MS fabrication patent 2009. License to Advanced Sensors 2010.

Key researchers at **Liverpool**: Principal investigator on UoL grants Stephen Taylor (Lecturer

1988), Senior Lecturer (1996), Reader (2000), Professor (2011); Dr J.R. Gibson (Lecturer to 2007), Emeritus Professor J.H. Leck (to 2005)

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

[3.1] S.Taylor, R.R.A.Syms, T.J.Tate, H.Dorey, UK Patent 9506972, 'Improvements in and relating to quadrupole mass spectrometers' (3.4.1995)

[3.2] Syms, R.R.A, Tate, T., Ahmad, M.M. and Taylor, S. 'Design of a micromachined electrostatic quadrupole lens', IEEE Trans. on Electron. Devices, **45**, pp. 2304-2311 (1998); http://dx.doi.org/10.1109/16.726645

[3.3] S. Taylor, R. F. Tindall and R. R. A Syms, 'Silicon based quadrupole mass spectrometry using microelectromechanical systems', J. Vac. Sci. Tech. B **19,** (2), pp. 557-562 (2001); http://dx.doi.org/10.1116/1.1359172

[3.4] T. J. Hogan and S. Taylor, 'Performance simulation of a quadrupole mass filter operating in the first and third stability zones, IEEE Trans. Instrum. Meas. **57,** (3) pp. 498-508 (2008); http://dx.doi.org/10.1109/TIM.2007.911632

[3.5] (i) European Patent 96908282.5, 'Improvements in and relating to quadrupole mass spectrometers' (1998), (ii) US Serial Patent: 6,025, 591, 'Quadrupole Mass Spectrometers' (15.3.2000) (iii) D. M. Burns, S. Taylor, J. R. Gibson, UK Patent GB2390222, 'Quadrupole Mass Filters' (19.5.2004); (iv) US Serial Patent 6,940,068 'Quadrupole Mass Filters' (9.6.2005); (v) European Patent EP1649488 'Quadrupole Mass Filters' (2006)

[3.6] B.Brkic, S.Taylor, J.F.Ralph and N.France, 'High Fidelity simulations of ion trajectories in miniature ion traps using the boundary element method', Phys Rev A, **73** (1), 012326 (2006) and selected for publication in Virtual Journal of Quantum Information, **6** (2), (Feb 2006). http://dx.doi.org/10.1103/PhysRevA.73.012326

Key research grants and awards which underpin the IMPACT

[3.7] S. Taylor, J.H. Leck, K.I. Nuttall; "Micromachined Quadrupole Mass Spectrometer" EPSRC (GR/K54755), Period: 1/2/96 -31/1/98; £79,438; Supplement: £11,557 to 31/4/98

[3.8] S. Taylor and J.H. Leck; "Silicon microengineered platforms for arrayed quadrupole mass spectrometers" EPSRC (GR/M31279), Period: 1/2/99 – 31/1/01; Amount: £115,759

[3.9] S. Taylor, "Traceable Mass Spectrometry: the development of fast, accurate, multi component MS" EPSRC CASE (02303152); Period:1.10.02 - 30.9.05; Amount: £52,229

[3.10] Q-Technologies Ltd DTI (SMART award), "Technical and Commercial feasibility of the micromachined mass spectrometer" Ref: GOVNW6120TEC Period 11.11.02–31.8.04; Amount: £60,000

[3.11] S. Taylor, I. Young and A. Dugdale, "Monitoring Respiratory Gases using a miniature mass spectrometer" MRC (G0401462) Period 1.9.05-31.8.06; Amount £58,252

[3.12] S. Taylor, C.J. Sutcliffe and P.R. Chalker, "Microengineering of QMS using RP techniques" EPSRC (EP/F008848/1) 1.1.07-31.03.09. Amount £142,349

[3.13] S. Taylor, "Production enhancement through a miniature mass spectrometric oil in water monitoring system", Industry Technology Facilitator ITF/PP43207, Period 1.11.08–30.09.10, Amount £212,954

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

Q-Technologies Ltd is an award-winning company spun out from the University of Liverpool (UoL). The underpinning research described in section 2 led directly to the company formation. The company mission is to bring to market the novel, patented technology developed through research in the Department undertaken by Taylor and colleagues. The company holds exclusive licences from the UoL for the original patented technology [3.1] and other technology [3.5]. Starting up, the company was awarded a DTI SMART award to formulate a business plan to take forward its initial R&D [3.10]. This led to the commercialisation of the underpinning research and to the development of miniature quadrupole mass spectrometer (QMS) instrumentation. Other patents in the area of portable MS followed ([3.5] above) with licenses and /or assignments to other companies [e.g 5,2(iii)]. In each case, Q-Technologies has retained a back licence for its own use in developing further products and applications.

Economic impact: Significant impact has occurred from 2008 to date. Q-Technologies is now an established spin out employing 7 people. The know-how gained and technology transferred from the research at the University, has enabled Q-Technologies to provide three further MS products and solutions in the application areas of process control and monitoring. These include: (i) a portable QMS for online fission gas monitoring; (ii) a membrane inlet MS (MIMS) for real time oil in water monitoring; and (iii) the novel MS software simulation tool developed in the Department [3.4] has also been marketed and sold through Q-Technologies.
In 2009 the company patented a unique method of hyperbolic electrode fabrication for miniature MS based on research undertaken in the Department and described above [5.1]. In 2010 the company assigned this IP (retaining a back licence) and know how to Advanced Sensors Ltd, who are a leading technology based provider of sensors to the oil and gas sector. Miniature MS technology developed in Liverpool: ***"…has now been incorporated alongside Advanced Sensors' successful ultra violet (UV) based Oil-in-Water (OiW) analyser to create a combined MS-OiW analyser with unparalleled monitoring capabilities. The product TM-1000 is currently marketed on the website…Success of the initial deployments will generate revenue for the company of £1.2m in 2013 growing to £2.5m in 2015"*** [5.2(ii) and 5.4]. In 2012 Advanced Sensors won the HSBC National Business Thinking Award for its products and innovation. In April 2013 the Q-Technologies won a Merseyside Innovation Award (MIA) [5.5].
Environmental impact: "Produced water" is a term used in the oil industry to describe water that is produced along with the oil and gas. This type of water is recycled, but regulatory environmental statutes currently limit the levels of oil to less than 30ppm. The combined instrument developed by Q-Technologies and Advanced Sensors (TM-1000) represents a stepwise change in OiW analysis, since it is the first sensor of its kind to offer *in situ* MS for field deployment as well as ultra violet fluoresence sensing in the same instrument. ***"The unique combination of two orthogonal sensing technologies… offers produced water measurement capabilities to sub-ppm levels as well as being able to distinguish between oil from different fields and other environmental hazards (e.g, H_2S) via the MS measurement. This latter feature is likely to be significant in future environmental legislation with respect to shale gas extraction"*** [5.2(ii)]

Beneficiaries:
During the period from 2008 to date (i) Advanced Sensors Ltd has benefitted commercially by bringing a novel sensor to market (ii) Q-Technologies and UoL have benefitted via licence income that has accrued to the company [5.2(i) and (ii)]. (iii) Oil companies deploying the novel sensor have benefitted by being able to meet stricter environmental regulatory standards.

Impact summary:
Economic: Q-Technologies is a successful and profitable SME, founded as a spin out company from UoL to commercialise research in MS. The company currently employs 7 people. The income stream secured from its currently assigned IP has guaranteed minimum royalties (from the license agreement with Advanced Sensors) for Q-Technologies going forward from 2010 which exceed £800k. [5.2 (i), 5.3]. Advanced Sensors Ltd has generated revenues of £1.2M in 2013 from initial deployment of a novel oil in water analyser incorporating the QMS.

Environmental: The TM-1000 product sold through Advanced Sensors, monitors oil in water produced through oil and gas drilling operations to ppb sensitivity [5.2 (ii)]. This unique sensor not only allows levels of oil to be determined, but also the oil fractions and other environmental contaminants. The product is a UK world-first with unparalleled performance. It allows enhanced carbon abatement via superior water quality monitoring and thereby provides reduced environmental contamination [5.4]

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

[5.1] J.E.Duffin and S.Taylor, UK Patent GB2009/051115, 'Wire cut method' (3.9.2009) confirms initial impact through technology development that provided future IPR income and economic impacts.

[5.2] Individual users/beneficiaries to corroborate claims:

(i) The Company Secretary at Q-Technologies Ltd, has provided a letter to corroborate successful technology transfer (IP and know how) from Prof S. Taylor and Mass Spectrometry group at the University of Liverpool to Q-Technologies Ltd
(ii) The CEO of Advanced Sensors Ltd, has provided a letter corroborate successful technology transfer (IP and know how) from Prof S.Taylor, Q-Technologies and University of Liverpool to Advanced Sensors Ltd for their TM-1000 OiW product.
(iii) Chief Engineer, Reliance Precision Ltd can corroborate claims of successful technology transfer to Reliance with respect to a novel method of electronic control of the quadrupole mass filter.

[5.3] Q-Technologies Ltd company website, showing current company position, licence and revenue details: http://www.q-technologies.co.uk

[5.4] For the TM-1000 product see Advanced Sensors Ltd website: http://www.advancedsensors.co.uk/products/side-stream-slip-stream/tm-1000

[5.5] Details of the Merseyside Innovation award recognition: http://q-technologies.co.uk/latest-news-2/

[5.6] http://www.advancedsensors.co.uk/uploads/tech-papers/oct2011/ipec-advanced-sensors-mass-spectrometer.pdf provides evidence of the impact of the MIMMS technology

[5.7] http://www.advancedsensors.co.uk/uploads/tech-papers/oct2011/ipec-advanced-sensors-mass-spectrometer.pdf provides evidence of the impact of the MIMMS technology