Institution: Queen's University Belfast

Unit of Assessment: 9

Title of case study: Queen's University Belfast-Seagate partnership to support inward investment and growing R&D in the wider data storage technology sector

Period when the underpinning research was undertaken: 2005-2015

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:
Robert Bowman	Professor	**1994-present**
Marty Gregg	Professor	**1995-present**
Bob Pollard	Senior lecturer	**1995-present**

Period when the claimed impact occurred: 2014-2020

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

1. Summary of the impact

Materials physics research in QUB has underpinned the emergence of a research-driven, tech-based ecosystem in Northern Ireland (NI). In 2010, a nascent collaboration with Seagate Technology saw the establishment of a strategic research facility in QUB that contributed to Seagate channelling GBP81,000,000 in foreign direct investment (FDI) into NI. This has rapidly expanded UK R&D capabilities in world-leading technology and created 60 R&D positions. This research-driven FDI has led to an accelerating portfolio of impact; industrial collaboration that underpins 2 Centres for Doctoral Training in QUB, industry-sponsored doctorates to close skills gaps in NI, the funding of a research chair, driving a further GBP21,500,000 of private investment in a seed-corn UKRI Strength in Places bid, and an additional GBP8,000,000 *via* the Belfast Regional City Deal.

2. Underpinning research

Whilst hard disk drives (HDD) are a mature, magnetics based, technology, they are still subject to continuous improvements and refinements and occasional technological step changes. Heat Assisted Magnetic Recording (HAMR) is capable of delivering the recording density growth in this decade to make HDD capacities move from 18 towards 50TB. HAMR represents a major challenge in integrated photonics, using a plasmonic transducer radiating in the near field regime in the read/write head-to-heat disk media, to aid writing to smaller grain sizes. This will enable greater data densities, all the while supporting and leveraging future capability of the magnetic read/write functions. As noted by Seagate in BBC article (link in **[S1]**) *"in the very near future, conceivably all books ever written in history could be stored on as few as 20 HAMR drives".*

The Centre for Nanostructured Media (CNM) focuses on plasmonics and the physics and processing of nanoscale ferroic materials relevant to advanced data storage technology. The research is exploited in a collaborative & co-produced environment to provide research insight into deposition capability, nanoscale fabrication and modelling using common tools and software. These activities are allied to the training of highly skilled PhD graduates, who frequently transition into the developing regional ecosystem that is supported by this research. The three academics (Bowman, Gregg and Pollard) are all centrally involved in the research below. Prof. Bowman is the lead collaborator with Seagate and all three work with industry-linked PhDs in CNM.

Controlled deposition for novel magnetic systems [R1]:

CNM has explored the coupling between ferromagnetic and rare earth materials in the nanometre regime **[R1]**. The aim is to establish if magnetic moments can be realised that would enable greater writing fields, in a magnetic write pole of the read/write head in next generation recording heads. The lead author, a PhD student, was employed by Seagate Technology. Co-produced research, funded by Seagate Technology, was granted a US Patent **[R1]**.

Focused ion beam (FIB) mesoscale patterning [R2, R3]:

Meso and nanoscale behaviours are often masked by extrinsic effects. The extraction of micro and nanoscale samples from millimetre crystals or devices by FIB allows creation of ideal test systems. Since 2004 the group at QUB have developed extensive experience in creating a wide variety of structures using this technique **[R2]**. Leveraging this expertise and combining it with finite element modelling for realistic devices, has revealed the nanoscale magnetic field distribution of the 'write pole' in the read/write head of a hard disk drive **[R3]**. The work was co-produced with Seagate Technology.

Anodic alumina templating of nanowires [R4, R5, R6]:

This process allows low cost, lithography-free formation of large-area arrays of sub-100 nm nanoscale structures, where materials can be tailored and aspect ratios controlled. These are relevant, as they allow the study of the science that underpins structures of the same size and geometry to those of the near field transducer used in HAMR, and similar magnetic storage devices.

These templates have been manufactured in gold for nanoscale plasmonics **[R4],** ferromagnetic structures, and have even been integrated in more sophisticated core/shell devices to explore magneto-plasmonic interactions **[R5].** The output lead author, a PhD student, was later employed by Seagate Technology. Furthermore, the Au structures can be used in metamaterials-based biosensing e.g. surface enhanced Raman Scattering **[R6]**.

While the research above has indirect impact with Seagate Technology, it has also been the basis for both additional indirect and non-linear impacts regionally. This has led to a broadening and deepening linkage, through plasmonics devices, to adjacent sectors such as healthcare. This has brought a wider network of company partners to the table **[S7, S8, S9, S10]**.

3. References to the research

[R1] C. Ward, G. Scheunert, W.R. Hendren, R. Hardeman, M.A. Gubbins & R.M. Bowman, (2013), "Realizing a high magnetic moment in Gd/Cr/FeCo: The role of the rare earth", Applied Physics Letters, 102, 092403. https://doi.org/10.1063/1.4794820 **Subsequently patented as** 'Storage device head using high magnetic moment material including a rare earth material and a transition metal' M.A. Gubbins et al, US-9773512-B2 (2017). https://app.dimensions.ai/details/patent/US-9773512-B2 **26** citations on Scopus (as of 30th December 2020).

[R2] M. Saad, P. Baxter, R. Bowman, M. Gregg, F.D. Morrison, & J.F. Scott, (2004), "Intrinsic dielectric response in ferroelectric nano-capacitors" Journal of Physics: Condensed Matter, 6, L451-456. https://doi.org/10.1088/0953-8984/16/41/L04 **134** Citations on Scopus (as of 30th December 2020)

[R3] J.F. Einsle, C. Gatel, A. Masseboeuf, R. Cours, M.A. Bashir, M. Gubbins, R.M.Bowman & E.Snoeck, (2014), "In situ electron holography of the dynamic magnetic field emanating from a hard-disk drive writer", Nano Research, 8, 1241-49 (2014). https://doi.org/10.1007/s12274-014-0610-0 **9** Citations on Scopus (as of 30th December 2020)

[R4] P. Evans, P. W. Hendren, R. Atkinson, G. Wurtz, W. Dickson, A. Zayats, & R. Pollard, (2006), "Growth and properties of gold and nickel nanorods in thin film alumina" Nanotechnology, 17, pp. 5746-5753, https://doi.org/10.1088/0957-4484/17/23/006 **115** Citations on Scopus (as of 30th December 2020)

[R5] B. Toal, M. McMillen, A. Murphy, W. Hendren, M. Arredondo & R. Pollard, (2014), "Optical and magneto-optical properties of gold core cobalt shell magnetoplasmonic nanowire

arrays.", Nanoscale, 6, 12905–12911. https://doi.org/10.1039/C4NR03792H **17** Citations on Scopus (as of 30th December 2020)

[R6] M. D. Doherty, A. Murphy, R. J. Pollard and P. Dawson, (2013), "Surface-Enhanced Raman Scattering from Metallic Nanostructures: Bridging the Gap between the Near-Field and Far-Field Responses.", Physical Review X, 3, 011001. https://doi.org/10.1103/PhysRevX.3.011001 **46** Citations on Scopus (as of 30th December 2020)

4. Details of the impact

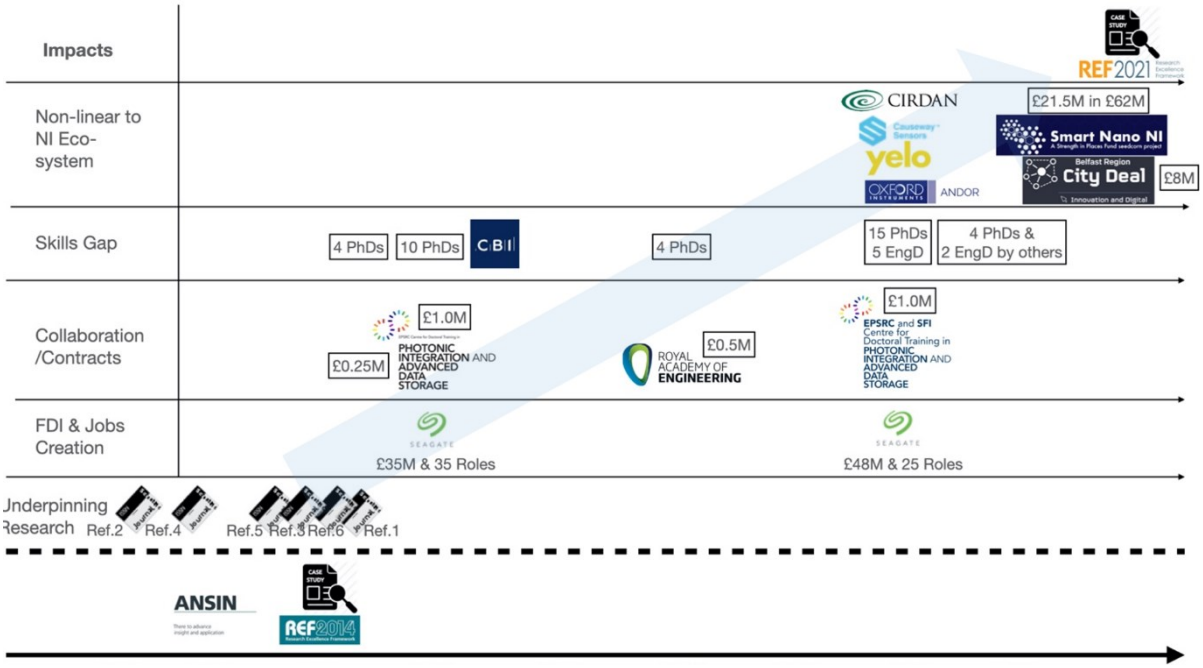

Figure 1. Schematic outlining the expansion of the QUB-led technology based ecosystem

In 2010, Seagate Technology established ANSIN – an open innovation advanced materials hub at Queen's with three objectives:
1. undertake low TRL collaborative research with them
2. act as a vehicle to seed and establish new collaborative programmes with third parties growing regional and national ecosystems in support of data storage and non-competing technology
3. establish an environment to train doctoral level students that would support the aspirations for growth in the R&D mandate of their Springtown site in the UK.
The indirect impact that led to that establishment was a REF 2014 case study.

Figure 1 shows growing indirect and non-linear impacts with Seagate, and others, since 2014. These impacts encompass:

- Research and collaboration underpinning corporate investment of GBP81,000,000 in NI
- major collaborations with industry through direct funding
- anchoring and widening the engagement of successive Centres for Doctoral Training
- a Royal Academy of Engineering (RAEng) research chair
- closure of identified skills gaps
- supporting & sustaining 60 high value R&D jobs
- developing major regional/national initiatives in UKRI Strength in Places consortia and the Belfast Regional City Deal.

Highlights include:

2014 - GBP35,000,000 investment creating 35 new R&D roles indirectly impacted by the research environment. The President and VP of Operations & Technology at that time, and now CEO, stated "*This R&D project will see the Springtown R&D team, supported by Ansin at Queen's University Belfast, apply its expertise to the task of developing HAMR technology and help the company achieve competitive advantage*." **[S1].**

In **[S7]** the Executive Director of Invest NI outlines how "*In our economic appraisals the success in seeing this growth of UK based R&D is directly and indirectly attributable to their use of the underpinning research base and activity at Queen's*." This appraisal saw Invest NI support these activities with GBP7,800,000 in 2014.

2014 - EPSRC Centre for Doctoral Training (CDT) in 'Photonic Integration & Advanced Data Storage' was established with Seagate Technology as anchor-tenant providing GBP1,000,000 of support to the CDT and 10 PhD studentships (20% of the full cohort). This exemplifies how corporate sector investment driven by QUB-led research can feed back into the university sector. This represents the genesis of the 'feedback loop' for the QUB-led ecosystem in NI **[S2]**.

2015 - QUB-Seagate impact is featured as a Case Study in the CBI's Best of Both Worlds – Guide to Business-University Collaborations – as noted by the Senior R&D Director "*An additional benefit for Seagate and the wider society is support for the university as a source of highly educated, relevant and employable PhDs in science and technology*." **[S3].**

2017 - Seagate Technology / RAEng Research Chair with GBP500,000 contribution to continue a mission/direction described by the CTO at the time "*This project is recognition of the long partnership Seagate has developed with Queen's. ….. This partnership is a great opportunity to increase awareness for our technical needs to the photonics community in UK, and beyond, and will support our recruitment of skilled photonic R&D and engineering staff.*" **[S4]** and amplified by Stephen Luczo (ex CEO and Executive Chairman) "*Queen's significantly contributes to the global technology industry and the economy in terms of producing skilled, work-ready graduates...*" **[S5].**

2019 – Building on the success of the initial CDT and strengthening research support from Ansin in QUB (as was anticipated in 2014), Seagate invested GBP48,000,000 into the Springtown Facility in Derry **[S6]**. This was further supported by an additional GBP9,950,000 from Invest NI to deliver an overall package valued at almost GPB58,000,000 for the region and creating a further 25 roles in R&D in the Derry area.

In total (between 2014 and 2019) these activities have delivered GBP81,000,000 corporate investment into the UK. This has rapidly expanded production at the Derry Facility *"…with it now contributing ~40% of the overall HAMR transducer development effort.*" up from 5% in 2014 **[S2]**. Invest NI note *"…the success in seeing this growth on UK based R&D is directly and indirectly attributable to the underpinning research base and activity at Queen's*". **[S7]** While roles were initially filled by staff from across the world, including PhD students responsible for the underpinning outputs *e.g.* Ward **[R1]** and Toal **[R5]**, it was critical that a local pipeline in NI to sustain these posts was established. In response to this need, the EPSRC CDT at QUB has provided sustained support for doctoral training activity. This resulted in 20% of the first cohort of students taking roles in Springtown R&D in 2018/19. *"We recognised the CDT as a critical asset ensuring a skilled pipeline for the years into the future (as proven with our early hires from its first cohort)"* **[S2].**

On the back of this second tranche of FDI by Seagate, Invest NI provided an additional GBP10,000,000 in funding that "*As a benchmark, recent Seagate project evaluations evidenced net quantitative economic benefits of c£6.50 for every £1 of grant invested.*" **[S2]**. This is a return on investment of > 600% and is direct evidence of how QUB research is underpinning growth and expansion of the tech sector in NI.

2019 - EPSRC – SFI CDT in "Photonic Integrated Advanced Data Storage" with Seagate Technology continuing as anchor tenant (investing over GBP1,000,000) towards 15 PhDs and 5 EngDs. Significantly, recognising cognate research and skills gaps, other NI photonics-based companies (Causeway Sensors Ltd, Cirdan Imaging Ltd, Andor Technology Ltd, and Yelo Ltd) also participated in the CDT, providing sponsorship to 26 of the 35 industry-aligned positions **[S2].**

2020 – Seagate leads a NI consortium along with Queen's into the seed-corn stage of Wave II of the UKRI Strength in Places Fund with a GBP62,000,000 proposition to establish a Smart Nano-manufacturing corridor. The bid includes GBP21,500,000 of private R&D investment that could lead to 700 roles and GBP300,000,000 of activity over ten years **[S2, S7, S8]**. The indirect impact is also recognised in the Belfast Regional City Deal, where an GBP8,000,000 investment within the Advanced Manufacturing Innovation Centre is included in its Business Plan **[S9]**. The non-linear impact of the research is exemplified by Yelo Ltd joining the CDT to sponsor trained PhDs and participate in SNMC "*the underpinning research activities in plasmonic metamaterials and nanophotonics at Queen's in partnership with Seagate have potential to open up new markets for us where we'll need new skills.*" **[S10].** Such investment of local materials and photonics-based companies is direct evidence of a) how QUB-led research is closing the skills gap and b) ever-strengthening feedback loop with the wider technology sector in Northern Ireland.

5. Sources to corroborate the impact

[S1] BBC News 23 October 2014, Seagate creates 35 jobs in multi-million Derry investment, available at https://www.bbc.co.uk/news/uk-northern-ireland-foyle-west-29736119

[S2] Letter from Chief Technology Officer, Seagate Technology

[S3] Best of both worlds: guide to business-university collaboration, Confederation of British Industry, 1 January 2015, Page 25 - available at https://www.ncub.co.uk/index.php?option=com_docman&view=download&alias=489-best-of-both-worlds-cbi&category_slug=reports&Itemid=2728

[S4] Royal Academy of Engineering , 5 April 2017, Hard drives of the future: Research Chair to develop new materials enabling advanced data storage, available at https://www.raeng.org.uk/news/news-releases/2017/april/hard-drives-of-the-future-research-chair-to-develo

[S5] Seagate Technology, 15 December 2017, Queen's University Belfast Honors Seagate's Stephen Luczo, available at https://www.seagate.com/gb/en/news/news-archive/queens-university-belfast-honors-seagates-stephen-luczo-pr-master/

[S6] Seagate Technology 26 April 2019, £57.4 Million Investment Announced By Seagate Technology, available at https://www.seagate.com/gb/en/news/news-archive/£57.4-million-investment-announced-by-seagate-technology-pr/

[S7] Letter from Executive Director, Invest Northern Ireland

[S8] UKRI Strength in Places Seedcorn Consortium Smart Nanomanufacturing Corridor (SNMC) Economic Appraisal Report available at https://www.smartnanoni.com

[S9] Letter from Belfast Digital Innovation Commissioner, Belfast City Council

[S10] Letter from Managing Director, Yelo Ltd.