Institution: Aston University

Unit of Assessment: UoA12 Engineering

Title of case study: Advances and commercialisation in the field of optical coherence tomography

Period when the underpinning research was undertaken: 2004-2020

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:
K Sugden	Lecturer, Reader, Professor	09/2005-present
T Drew	Research Assistant, Lecturer	2012-2015
B Coldrick	KTP Associate	2013-2016
G Swadner	Lecturer	01/2009-present
I Bennion	Professor	09/1991-09/2010
A Fratini	Senior Lecturer	07/2014-present

Period when the claimed impact occurred: 2014-2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact

Aston research into Optical Coherence Tomography (OCT) metrology resulted in new product lines:

- With Arden Photonics, Aston designed and fabricated OCT phantoms used to calibrate, test and validate the performance of OCT systems, aiding quality assurance. It remains the only commercially available OCT phantom technology in the world.
- With Optimec, Aston developed an OCT instrument that allows contact lens manufacturers to confirm that their products meet the required specification. This has enabled the adoption of new technology within the increasingly sophisticated global eye correction industry. It resulted in a second instrument with increased performance to be used in production lines.

2. Underpinning research

The research focuses on Optical Coherence Tomography (OCT), used to measure and image a three-dimensional object using laser light. The research investigated how to develop OCT systems to design and test the quality of contact and intraocular lenses, and how to calibrate those systems through the use of OCT phantoms. Ultimately, this advanced the technologies driving the increasingly sophisticated global eye correction industry with broader application in areas like medical imaging.

The impacts claimed rely on three specific areas of research:

1. The use of femtosecond (fs) inscription to create structures in transparent glasses

Aston first demonstrated femtosecond laser-inscribed fibre Bragg gratings and the direct inscription of gratings and waveguides in a range of transparent bulk materials [**R1**]. This developed the underlying understanding behind the light-material interactions and the capability to characterise the resulting refractive index changes.

Aston worked with Oxford Lasers to design and build a high specification femtosecond inscription system and further investigated the interaction mechanisms, especially those related to silica materials (both fibre and bulk glass), and established the parameters that control linewidth, depth and refractive index change. [**G1**]

2. The use of fs inscribed silica phantoms reliably to test and validate OCT system performance

Joint research with the National Physical Laboratory (NPL) demonstrated that it was possible to create 3D structures in transparent materials that could be imaged by OCT [**R2**]. This resulted in advanced phantom designs and the further development of the science behind the fabrication process, ensuring that the inscribed lines are the correct width, depth and smoothness, which is challenging in a non-linear process regime. The resulting phantom enabled users to characterise 3D OCT measurements in a repeatable way [**R2**].

The project also developed parallel processing techniques based on the use of Graphical Processing Units (GPUs) to significantly decrease the time taken to process the images. This resulted in the feature article of the month in OCT News, 01/2012.

The research has been further progressed (2017-2020) by an Arden Photonics-sponsored PhD student. The student has been investigating non-planar phantoms and the underlying science that governs the repeatability of inscription at greater material depths [**R3, R4**].

3. The development of an OCT instrument to allow contact lens manufacturers to confirm their product meets the required specification

Aston worked with AMO (a lens and contact lens manufacturer) to develop an artificial eye lens [**R5**]. Crucially, this led to a complex Finite Element Analysis (FEA) model of the lens that accurately could simulate the biomechanical behaviour that allows the eye to change from distant focus to near focus.

This provided the platform for modelling how contact lenses perform and using OCT to measure transparent structures – and led to a Knowledge Transfer Partnership (KTP) [**G2**] project during which a new generation of innovative soft contact lens measuring instruments was developed. This required the development of a bespoke OCT measurement system that was optimised for the specific requirements of the contact lens industry.

The research demonstrated how knowledge of the optical properties of curved surfaces could be used successfully to interpret OCT images of contact lenses to give accurate information on their physical dimensions [**R6**]. On completion, this project was rated outstanding by Innovate UK reviewers [**S1**]. This led to a second KTP project to explore other uses if the OCT technology in other scenarios (e.g. Intra Ocular Lenses) [**G3**].

The chronology of the research and the resulting products is summarised in Figure 1.

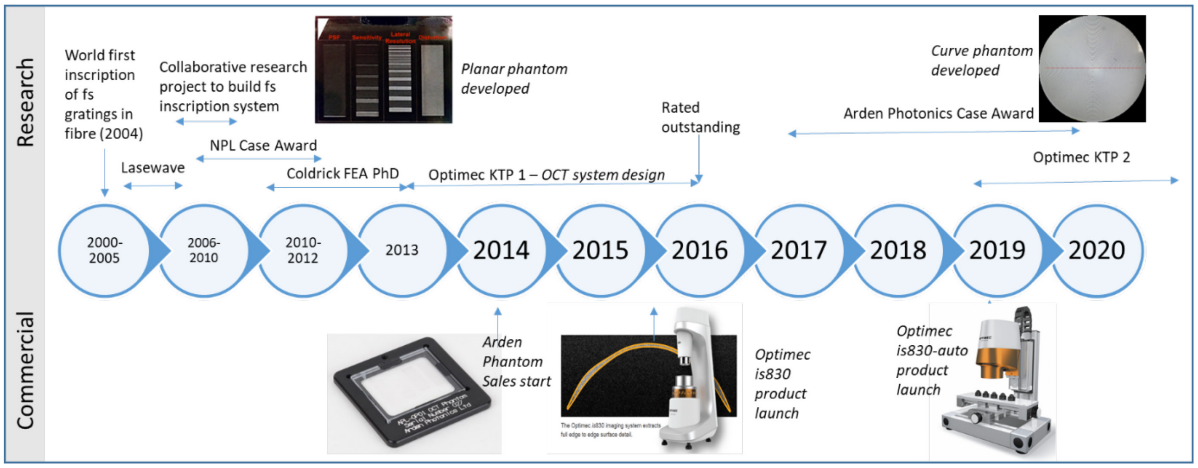

Figure 1: Impact timeline

3. References to the research

Aston staff (at time of publication) shown in bold and Aston PhD students in green

R1: **MV Dubov, I Khrushchev, I Bennion**, AG Okhrimchuk, AV Shestakov, "Waveguide inscription in YAG:Cr /sup 4+/ crystals by femtosecond laser irradiation," Conference on Lasers and Electro-Optics, 2004. (CLEO)., San Francisco, CA, 2004, pp. 2 pp. vol.1-.

R2. P H Tomlins, G N Smith, P D Woolliams, J Rasakanthan and **K Sugden**, 2011. Femtosecond laser micro-inscription of optical coherence tomography resolution test artifacts. Biomedical Optics Express, 2(5), pp.1319-1327, 10.1364/BOE.2.001319

R3. Y Lu, **N Gordon**, B Coldrick, **I Ibrahim, V Mezentsev**, D Robinson and **K Sugden**, Femtosecond laser inscribed advanced calibration phantom for optical coherence tomography (OCT), 28 Feb 2020, Advanced Fabrication Technologies for Micro/Nano Optics and Photonics XIII. von Freymann, G., Blasco, E. & Chanda, D. (eds.). SPIE, 1129205. (Proceedings of SPIE - The International Society for Optical Engineering; vol. 11292).

R4. Y Lu, **N Gordon**, D Robinson, **B Coldrick, V Mezentsev**, F Menduni, **A Fratini, K Sugden**, "Non-planar calibration phantoms for optical coherence tomography," Proc. SPIE 10544, Advanced Fabrication Technologies for Micro/Nano Optics and Photonics XI, 105441B (22 February 2018); https://doi.org/10.1117/12.2290422

R5. B J Coldrick, **J G Swadener**, and **L N Davies**, 2012. A sensitivity study of the human crystalline lens using finite element analysis. In Z. J. Yang (Ed.), Proceedings of the 20th UK national conference of the ACME (pp. 15-18). Association for Computational Mechanics in Engineering.

R6. **B J Coldrick**, C Richards, **K Sugden, J S Wolffsohn and T E Drew**, 2016. Developments in contact lens measurement: A comparative study of industry standard geometric inspection and optical coherence tomography. Contact Lens and Anterior Eye, 39(4), pp.270-276. 10.1016/j.clae.2016.01.002

GRANT FUNDING

G1: Department of Trade and Industry (LINK), Bennion & Sugden, Advanced femtosecond laser machining and inscription system, £144,893, 02/2006-08/11

G2: Innovate UK, KTP009278, Sugden, Drew & Zhou, To develop a new generation of innovative soft contact lens measuring instruments, utilising novel techniques to reflect improved accuracy of lens manufacturing processes, £155,997, 07/2013-03/2016

G3: Innovate UK, KTP011456, Fratini, Klados & Geoghagan, To develop the capability for precision metrology using Optical Coherence Tomography, by exploiting novel calibration and image processing techniques to deliver an innovative range of devices for use in ophthalmic and non-ophthalmic manufacturing sectors, £232,523, 04/2019-09/2021

4. Details of the impact

Worldwide, tens of millions of people benefit from contact or intraocular lenses to correct their eyesight. In the last five years, lens design has become increasingly complex – e.g. allowing contact lenses to have multiple focal points. This requires more accurate metrology for quality control purposes.

OCT can be used for this metrology and a wide range of other applications, but their calibration and accuracy must also be validated through the use of calibration phantoms.

[**R1-4**] enabled the development of high value (~US$1550) calibration phantoms that qualitatively and quantitatively characterise the spatial resolution, sensitivity, distortion and scan linearity of OCT systems.

Arden Photonics introduced the OCT phantom at a 2013 trade show and commercial sales began in 2014. They have since sold to customers in 14 countries with the highest sales in the US, Germany, China and South Korea [**S2**].

The Arden OCT phantom remains the only commercially available OCT phantom. It enables users to check that the system's performance hasn't changed due to misalignment. Manufacturers use the phantoms to ensure their system meets specifications, e.g. a manufacturer of OCT imaging catheters for heart surgery, uses the phantom in the final stage of their quality assurance process [**S2**].

Aston continues fabricate the devices and supports Arden with technical queries. Recent work led to the development of: (1) phantoms that extend much deeper into the glass, and (2) phantoms written into a lens for the calibration of systems such as the is830 (see below) where it can be used to correct distorted images, such as those of curved objects like contact lenses. Both were presented in a joint paper with Arden Photonics at Photonics West in 2020 [**R4**] which generated further interest in the phantom range [**S2**]. Over the REF period Arden also benefited from: access to test and measurement equipment that would be too expensive for an SME to invest in; access to networking and expert advice on rapidly changing photonics technology; access to fabrication equipment to be able to launch an advanced product without large capital outlay; ability to engage experts in product development [**S2**].

Aston research [**R2,5,6**] also led to impact through a second company. Optimec provides measurement and inspection technology for the world's leading contact and intraocular lens manufacturers. As lens design increases in complexity, new metrology challenges have arisen, particularly around identifying and measuring key geometric features. Existing technologies were incapable of providing the required level of measurement precision.

Optimec and Aston began collaborating through a KTP in 2013. The collaboration enabled Optimec to develop their skills in OCT to develop next generation lens metrology equipment, resulting in the is830 instrument, figure 2. The is830 is a high value product that represents a step-change in performance and gives Optimec a commercial advantage [**S3**]. It provides comprehensive lens measurements, combining sagittal depth, curvature, thickness, diameter and orientation in a single system (Fig.2 right). The is830 [text removed for publication] and also offers improvements in usability which made it suitable for wider deployment [**S3**].

Since its global launch in 2016, the instrument has been sold [text removed for publication], the world's largest contact lens manufacturers [**S4**]. A 2016 YouTube video demonstrating the new system was released showing the effect of dehydration on lenses and gained >1,300 views [**S3**].

Due to the increased mechanical engineering brought to the company by the KTP associate, Optimec invested [text removed for publication] in a Computer Numerical Control (CNC) machine and brought the manufacture of metal parts into the company. This has reduced parts costs by [text removed for publication] and improved lead times for parts from 16 to 6 weeks [**S3**].

Optimec CEO, said: "*The Optimec is830 is the result of a highly successful and award-winning KTP with Aston University. The Project Associate…, now Head of Technical Development at Optimec, developed the instrument over the course of his two-and-a-half-year placement… The is830 is a game-changing instrument in the contact lens metrology sector.*" [**S5**]

Optimec has since built on the new technology platform to launch the is830 Auto (Fig.2, centre). The is830 Auto is designed to be integrated into a production line for in-line quality control and has also resulted in a completely new market for Optimec in interocular lens metrology. The is830 Auto allows manufacturers, for the first time, to measure complex lenses on the production line rather than offline in a lab. The system can measure approximately 300 to 400 lenses per hour. Since its April 2018 launch at EFCLIN (European Federation of the Contact Lens and IOL Industries), the instrument has been evaluated by many of the world's largest contact lens manufacturers [**S3**].

In July 2020, recognising the growth potential, Optimec created a new company, Optimec Systems, to continue the development of the OCT-based is830 range of instruments for both

bench top and fully automated applications[**S3**]. This collaboration has in resulted a significant revenue of [text removed for publication] million for Optimec and Optimec Systems combined. [Text removed for publication] systems have been sold to date in under 4 years to global contact lens and interocular lens manufacturers around the world [text removed for publication] [**S6**], with increasing demand currently being seen in automation. Demonstrable collaborations between industry and academic can be seen in the form of two Knowledge Transfer Partnerships spanning the REF period with a combined value of £343,000 [**S1,S3**].

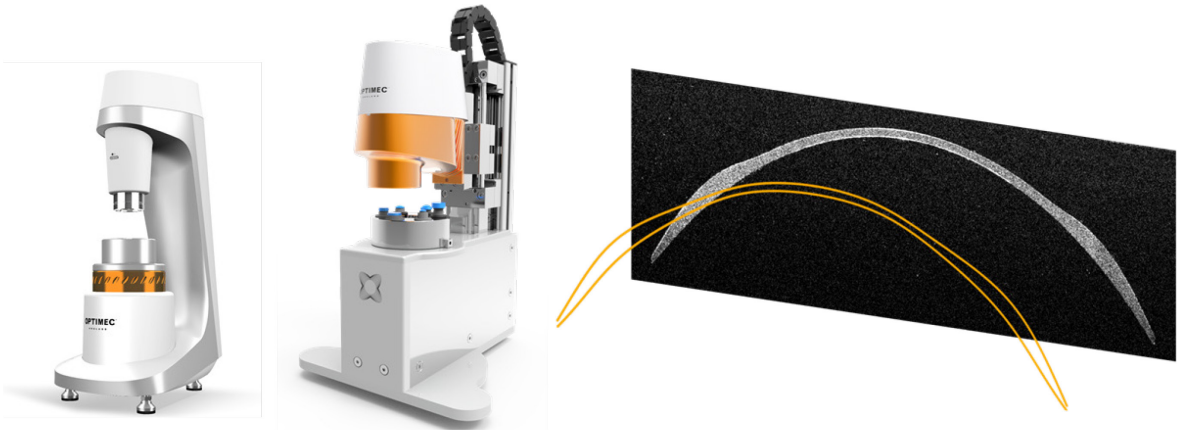

Figure 2: (left) the is830, (centre) is830-Auto, (right) OCT image and extracted geometry

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

S1 Report from Innovate UK on outstanding project, June 2017

S2 Letter from Managing Director of Arden Photonics Ltd, November 2020

S3 Letter from Managing Director of Optimec Ltd, September 2020

S4 Video – Optimec contact lens hydration measurement: https://www.youtube.com/watch?app=desktop&v=t0y_-QhtWrM

S5 Malvern based Optimec win prestigious design and innovation award, Worcestershire LEP news site, May 2019

S6 Email from Director of Optimec Systems Ltd, January 2021