Institution: University of Strathclyde		
Unit of Assessment: B9 - Physics		
Title of case study: Photonics industry innovation and economic impact through the creation of the UK's first Fraunhofer Centre		
Period when the underpinning research was undertaken: 2000-2020		
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:**
Prof Martin Dawson	Professor	01/03/1996 – present
Dr David Burns	Senior Research Fellow	01/03/1996 – 09/11/2012
Dr Jennifer Hastie	Reader	01/10/2003 – present
Dr John-Mark Hopkins	Associate Team Leader	01/04/2001 – 30/11/2012
Prof Alan Kemp	Professor	05/08/2002 – present
Dr Nicolas Laurand	Principal Research Fellow	01/10/2006 – present
Dr Erdan Gu	Senior Research Fellow	16/07/2002 – present
Period when the claimed impact occurred: August 2013 – December 2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

Strathclyde underpinning photonics research enabled the 2012 foundation and operation of the UK's first Fraunhofer Centre, the Centre for Applied Photonics (Fh-CAP). This ground-breaking intervention in the UK innovation landscape represents a significant shift in Scottish government innovation policy. Working with Fh-CAP enables companies to accelerate technology development, develop new products, create and protect jobs and operate in international markets. Fh-CAP has exceeded its government-set targets, growing its 2020 turnover to GBP3,100,000 from contracted R&D. Since 2013, it has worked on 151 projects involving 116 companies, including 60 direct R&D contracts. Independent economic impact assessment has shown that these collaborations have resulted in additional turnover of GBP55,000,000 for Fh-CAP's customers. Fh-CAP has a current staff of 34 and has provided training for 39 doctoral students many of whom now work in the vibrant UK photonics sector.

2. Underpinning research

Context

Photonics is an enabling technology for important industrial sectors including manufacturing, communications, and healthcare. Strategic research from 2000 onwards, led by Professor Martin Dawson at Strathclyde's Institute of Photonics (part of the Department of Physics), has built up key scientific capabilities across a range of photonic source technologies and applications which underpin future industrial requirements. The success of this use-inspired research underpinned the formation of the Fraunhofer Centre for Applied Photonics (Fh-CAP).

Main research themes and key findings

The team has made a wide range of enabling contributions, particularly to laser science and the heterogeneous integration of photonic technologies and to applications research, including laser engineering and life science applications. Highlights are given below and their relevance to the establishment and ongoing activities of Fh-CAP is described in Section 4.

Semiconductor disk lasers combine semiconductor and solid-state laser technologies to deliver unique wavelength versatility and stability, and have been a major research interest of the Strathclyde group over the past two decades, with the team making several pioneering contributions in this field. In particular, they were the first to propose and demonstrate the use of intracavity diamond to remove heat directly from the chip surface [**R1**]. This enables high power operation across a much wider range of wavelengths, which the team harnessed enabling demonstrations at a number of technologically important wavelengths. Notably this work included a very successful collaboration on 2μm emitters with Fraunhofer IAF (Institute for Applied Solid State Physics) in Germany, supported through the EU FP-6 programme VERTIGO (Burns (CI), 2006-2009) [**R2**]. This collaboration was an important step on the route to the later establishment of Fh-CAP.

Another exemplar of the group's innovative approach to ***laser engineering*** was the first demonstration of direct diode-laser pumping of a Ti:sapphire laser [**R3**]. Prior to this, such an approach was widely thought to be impractical. Diode pumping reduces the size and cost of the pump by an order of magnitude, potentially greatly improving the practicality of Ti:sapphire lasers which are an enabling, if currently expensive and cumbersome tool, in many areas of science.

III-V optoelectronic devices and processing, and in particular the heterogeneous integration of dissimilar materials, is a pioneering feature of the group's research. Particularly significant research contributions have been the design and processing of GaN micro-light-emitting-diodes (μLEDs) arrays [**R4**] and their integration with CMOS control and sensor technologies (e.g. [**R5**]) to enable applications including digital lightning, instrumentation [**R5**], and communications. The group have also extended this approach to the integration of hard and soft materials for applications including visible light communication and life-science instrumentation [**R6**].

Life science applications are a key driver for the group. Examples include innovative organic-laser based devices for refractive index sensing in the life science [**R6**], and, in collaboration strategically initiated with Edinburgh, the demonstration of an ultra-compact fluorescence lifetime measurement device based on the integration of μLED arrays (Strathclyde) with CMOS control and single photon detection (Edinburgh) [**R5**].

3. References to the research (Strathclyde affiliated authors in **bold**)

R1 **J.-M. Hopkins**, **S. A. Smith**, **C. W. Jeon**, **H. D. Sun, D. Burns**, **S. Calvez**, **M. D. Dawson**, T. Jouhti, and M. Pessa, "0.6W CW GaInNAs vertical external-cavity surface emitting laser operating at 1.32 μm," *Electronics Letters,* vol. 40, pp. 30-31, 2004 http://dx.doi.org/10.1049/el:20040049 [FWCI: 14.37]

R2 **J.-M. Hopkins**, **N. Hempler**, B. Rösener, N. Schulz, M. Rattunde, C. Manz, K. Köhler, J. Wagner, and **D. Burns**, "High-power, (AlGaIn)(AsSb) semiconductor disk laser at 2.0 μm", *Optics Letters*, Vol. 33, pp. 201-203, 2008 https://doi.org/10.1364/OL.33.000201 [FWCI: 4.09]

R3 **P. W. Roth**, **A. J. Maclean**, **D. Burns**, and **A. J. Kemp**, "Directly Diode-Laser Pumped Ti:sapphire Laser," Optics Letters, vol. 34, pp. 3334-3336, 2009 https://doi.org/10.1364/OL.34.003334 [FWCI: 2.68]

R4 **H. W. Choi**, **C. W. Jeon**, and **M. D. Dawson**, "High-resolution 128 x 96 nitride microdisplay", IEEE Electron Device Letters, vol. 25, pp. 277-279, 2004 https://doi.org/10.1109/LED.2004.826541 FWCI: 1.39]

R5 B. R. Rae, K. R. Muir, **Z. Gong**, **J. McKendry**, J. M. Girkin, **E. Gu**, D. Renshaw, **M. D. Dawson**, and R. K. Henderson, "A CMOS Time-Resolved Fluorescence Lifetime Analysis Micro-System," *Sensors,* vol. 9, pp. 9255-74, 2009 https://doi.org/10.3390/s91109255 [FWCI: 1.85]

R6 **A. M. Haughey**, **B. Guilhabert**, **A. L. Kanibolotsky**, **P. J. Skabara**, **G. A. Burley**, **M. D. Dawson**, and **N. Laurand**, "An organic semiconductor laser based on star-shaped truxene-core oligomers for refractive index sensing," *Sensors and Actuators B: Chemical,* vol. 185, pp. 132-139, 2013 https://doi.org/10.1016/j.snb.2013.04.026 [FWCI: 2.55]

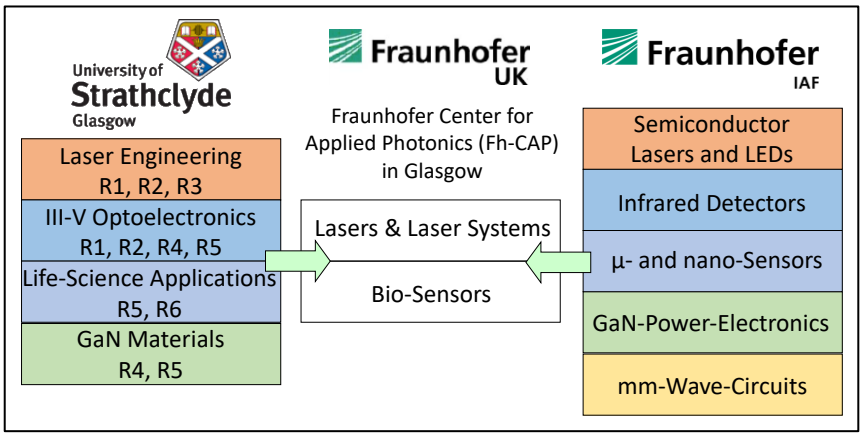
Notes on the quality of research: The field-weighted citation impact (FWCI) at 02/02/2021 for each of the above publications is noted alongside each reference. These demonstrate that the publications, representative of an extensive body of research since 2000, have had significantly higher than average influence on the academic field. The work has been supported by some GBP15,000,000 of competitively won research funding for Strathclyde-led activities in the same period, including EPSRC Platform and Programme Grants, an EPSRC Basic Technology Award, an EPSRC Challenging Engineering Fellowship (Hastie) and a Royal Academy of Engineering Chair (Kemp). Dawson was awarded the 2015 Dennis Gabor Medal and Prize from the Institute of Physics and the 2016 Aron Kressel Award from the IEEE Photonics Society.

4. Details of the impact

From research to impact – foundations and ongoing

Strathclyde and Fraunhofer IAF's successful research collaboration on semiconductor disk lasers emitting at 2μm [**R2**] laid the foundation for a wide-ranging and strategic partnership between Strathclyde and Fraunhofer IAF's parent organisation Fraunhofer Gesellschaft (FhG), resulting in 2012 in the incorporation of the UK's first Fraunhofer Centre, the Fraunhofer Centre for Applied Photonics (Fh-CAP). From FhG'S perspective, a vital precondition for the foundation of Fh-CAP

was the strong alignment of research, technology and application interests and capabilities of the two organisations, notably across the spectrum of research areas described in Section 2.



This is highlighted in the figure (left), based on one in initial planning documents for the partnership, which shows the complementary competencies of the partner organisations. References to the outputs cited in Section 3 have been added. Fh-CAP's Executive Director confirms [S1] that while Strathclyde's collaboration with Fraunhofer IAF on 2µm semiconductor lasers was an important initial focus, the establishment of Fh-CAP was predicated '*on the wider Strathclyde research base in, for example, lasers, optoelectronics and life science applications. This Strathclyde expertise not only seeded the foundation of Fh-CAP through both knowledge and personnel transfer from Strathclyde, it continues to form a core part of the R&D competency that underpins the impact we generate with partner companies.*' [S1]

A number of features of Fh-CAP's operating model continue to support and encourage ongoing research collaboration with Strathclyde. Fh-CAP facilities have, since its establishment, been located on-campus, and are currently co-located with the University's Institute of Photonics. Staff transfer between the organisations is encouraged. Initially, the 6 founding Fh-CAP employees transferred from Strathclyde and today 16.5FTE Fh-CAP staff, of a total 34FTE, are former Strathclyde staff or research students [S1]. Further, Prof Dawson holds a joint appointment, serving 0.5FTE as Head of Centre at Fh-CAP.

Since 2014, Fh-CAP has committed some GBP664,000 in part support for 5 research fellowship positions at Strathclyde as part of a key programme to underpin their internal R&D activities, and ongoing impact creation, via continuing links back into the underpinning Strathclyde research base. Highlights include prestigious, externally validated, awards of a Royal Academy of Engineering Research Chair in laser engineering and Senior Research Fellowship in chip-scale photonics, an EPSRC Innovation Fellowship in digitally modulated light and single photon detection and a UKRI Turing AI Acceleration Fellowship in neuromorphic photonics.

Through the establishment of, and ongoing research collaboration with, Fh-CAP, Strathclyde underpinning research has contributed to impact in three areas:

- Influence on Government innovation policy and increased UK innovation infrastructure
- Economic impact of Fh-CAP as a commercial business – income generation and creation of high-quality, high-tech jobs
- Increased R&D capability of, and new product development by, Fh-CAP partners and customers across several industry sectors

Impact 1: Government innovation policy and innovation infrastructure

Fh-CAP was established as a joint venture between FhG and Strathclyde, with additional public sector investment from the Scottish Government, Scottish Enterprise (SE) and the Scottish Funding Council (SFC). A total investment of GBP8,700,000 from these bodies, including [Text removed for publication] foreign direct investment from FhG, provided a 5-year core funding package for Fh-CAP during its start-up period (2012-2017). Scottish public sector institutional investment in the establishment of Fh-CAP represents a significant policy statement in terms of support for innovation in Scotland's vibrant photonics and quantum technology sector. By choosing to provide support for an intermediary organisation with the mission and expertise to bridge the gap between UK academic excellence in photonics and this dynamic industry sector, government demonstrated a commitment to the ambitions of the influential Hauser and Dyson reviews of 2010, both of which called for enhanced infrastructural mechanisms to accelerate the transfer of technology to industry.

Fh-CAP quickly demonstrated its effectiveness in the technology intermediary role, with a 2019 independent review on behalf of the Scottish Government noting that the organisation had met, or was on target to meet, its government set development targets to 2020, including exceeding its target for industry funding to 2019, as a result of its '*high-quality work, its continued success in engaging with companies, and the high level of repeat business it achieves.*' [**S2**]

The success of the Fh-CAP approach is further confirmed by the Chief Executive of industry organisation Technology Scotland, which represents around 120 organisations across the enabling technologies sector including photonics and quantum technology, who commented that *'Fh-CAP has partnered with a significant number of our member organisations on applied R&D projects here in Scotland, in addition to their projects across the UK and beyond. ….. Fh-CAP is now an integral part of the Scottish innovation landscape, helping to enhance the output of the photonics sector and accelerating the pull through of technology by our member companies.*'[**S3**]

Fh-CAP has also taken on a significant role in the training of highly skilled doctoral students who go on to provide a key staffing pool for the Scotland photonics and quantum technology cluster in particular, and UK high-tech manufacturing more generally. Fh-CAP has invested GBP1,460,000 in training 39 doctoral students since August 2013, the majority (29) based in Fh-CAP, and the balance based in collaborating university research teams across 4 universities [**S1**]. As of December 2020, 14 students have graduated with 9 going on to work in the UK photonics industry (including 3 now staff members at Fh-CAP) and 2 in the EU photonics industry. The remaining 3 are working in UK and EU academia and research facilities. The University Liaison & Emerging Technology Manager at technology and aerospace company Leonardo acknowledges the vital contribution to the training of the future workforce at PhD and EngD levels and notes: '*the Fraunhofer CAP students we have recruited have an excellent and wide skill set, not just technical, and are making an important contribution to our business.'* [**S4**]

Impact 2: Economic impact of Fraunhofer CAP as a commercial business

Trading as part of Fraunhofer Research UK Ltd, a company limited by guarantee also established in Glasgow in 2012 to act as the UK headquarters for Fraunhofer activities, Fh-CAP has directly created economic impact throughout the REF impact assessment period through income generation from technology development activities funded by a range of commercial and public partners and the creation of high quality, high-tech jobs.

Fh-CAP occupies a 700sqm facility within Strathclyde's Technology and Innovation Centre, 50% of which is high-quality optics, laser and electronics lab facilities. Employment has grown from 9 staff in August 2013 to 34 staff in December 2020, 25 of whom are trained to a doctoral level [**S1**].

As a business, Fh-CAP's turnover has grown year on year since August 2013, with 2020 turnover from contracted R&D for industrial benefit reaching GBP3,000,000. [Text removed for publication] In the same period, Fh-CAP has worked on 151 projects involving 116 companies, including 60 direct R&D contracts with companies and 40 Innovate UK programmes. The total value of these projects is GBP87,000,000, GBP19,200,000 of which came to Fh-CAP [**S1**].

Impact 3: Impact created by Fraunhofer CAP's partners and customers

In addition to its direct economic impact as a commercial organisation, Fh-CAP activities contribute to the creation of significant impact for a wide range of partners and customers across several industry sectors including quantum technologies, renewable energy and healthcare. One key impact has been to bring R&D capability that companies are unable to support in-house, enabling greater innovation in the SME-dominated photonics sector [**S3**]. Further, impacts span many areas, including business benefits such as impact on company strategy, product development, employment and sales, as well as downstream impacts on the environment and contributions to health and well-being.

A 2020 independent review of Fh-CAP included a detailed economic impact assessment utilising established Scottish Enterprise Impact Appraisal and Evaluation Guidance. Starting with a detailed survey of Fh-CAP's customers in Scotland, the conclusions are as follows [**S5**]:

- Approximately 70% of companies reported that collaboration with Fh-CAP had enabled them to secure public sector funding to support their R&D.
- On average, projects undertaken in collaboration with Fh-CAP moved from technology readiness level (TRL) 2 to TRL 6.

- Within the period 2013-2020, collaborations with Fh-CAP have resulted in additional turnover of GBP27,100,000 for Scottish companies, equating to a total net Gross Value Add (GVA) to the economy of GBP2,660,000; noting that some 50% of Fh-CAP's partners are Scottish-based [**S1**], this allows an estimate of total additional turnover for all Fh-CAP partners of GBP55,000,000 and a total net GVA of GBP5,300,000.
- Further the majority of this additional turnover, estimated at 78%, is from sales outside the UK: engagement with Fh-CAP is enabling its customers to operate effectively in global markets.

The following examples give a flavour of the range and depth of impact realised to date by Fh-CAP's customers and partners.

Development of a compact Rb stabilised semiconductor laser product with Optocap/Alter
A series of projects with Scottish company Optocap Ltd (now part of European company Alter Technology) brought together Fh-CAP's laser design expertise and Alter's manufacturing capability to enable new products, in particular a new class of semiconductor lasers for quantum technology applications, the FLAME and REMOTE series, launched in 2019. This represents a significant change in the company's strategy from service provider to also being a product manufacturer, which would not have happened without the partnership with Fh-CAP. The market for the lasers is as a critical OEM component in optical clocks, accelerometers, and quantum computers. Now selling units internationally, the partnership has enabled Alter to secure a minimum of 5 high value jobs along with Innovate UK funding totalling GBP27,900,000 (to all partners), allowing them to further improve performance and expand wavelength coverage [**S6**].

Development of LIDAR systems for renewables sector [Text removed for publication]
[Text removed for publication] [**S7**].

Development of hydrogen detection system for National Nuclear Lab (NNL) / Sellafield
The detection of hydrogen is of crucial importance in the nuclear industry, one requirement being as a mechanism for remote condition monitoring in long-term (~100 years) nuclear materials storage, where conditions preclude the use of man-portable sniffing detectors. The ability to do this has significant health and safety, environmental protection and cost benefits, including reducing costs to the tax payer. Developed under the nuclear industry's Game Changers Innovation Programme [**S8**], a collaboration with Sellafield Ltd resulted in the proof-of-concept demonstration in 2019 of a Raman spectroscopy based system providing remote 3-dimensional mapping of hydrogen concentrations down to 0.05% at distances of up to 100m. These trials informed system design and the refinement of internal procedures. The system was actively deployed into a nuclear material store at Sellafield in February 2020 [**S9**]. This is the first active deployment of technology resulting from the Game Changer programme.

5. Sources to corroborate the impact

S1 Corroborating statement from Executive Director, Fraunhofer CAP (08/03/2021)
S2 Executive Summary, independent mid-term evaluation of Fraunhofer CAP (2019)
S3 Corroborating statement from Chief Executive, Technology Scotland (03/03/2021)
S4 Corroborating statement from University Liaison & Emerging Technology Manager, Leonardo
S5 Independent economic impact assessment of Fraunhofer CAP (2020) pages 9-15
S6 Corroborating statement from CEO, Alter Technology TUV NORD UK LTD (05/03/2021)
S7 [Text removed for publication]
S8 Sellafield Ltd 2019/20 Annual Research and Development review (p.10-11, 21) https://bit.ly/3bFDUxv
S9 Corroborating statement from Head of Research & Development, Sellafield Ltd (03/02/2021)