Section A

Institution: University of St Andrews

Unit of Assessment: UoA 09: Physics

Title of case study: Shining a light on subsea safety with side emitting optical fibre lighting systems

Period when the underpinning research was undertaken: 2000 - 2014

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by HEI:
Malcolm Dunn	Professor	01 October 1990 - 31 August 2018
Graham Miller	Research Fellow	09 January 2006 - present
Cameron Rae	Senior Lecturer	23 July 1990 - present
Tom Brown	Professor	01 April 1999 – present
Bruce Sinclair	Director of Teaching	01 October 1986 - present

Period when the claimed impact occurred: 2014 - 31 December 2020

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

Section B

1. Summary of the impact

Commercial deep-sea divers around the world face some of the most dangerous conditions of any profession. Our innovative photonics research into non-linear frequency conversion and its implementation in the design of compact, stable solid-state lasers provides safety guidance within deep water diving environments by creating a continuous line of light to indicate the route of the diver's umbilical. It also helps remotely operated vehicle (ROV) pilots minimise the risk of collision or snagging umbilicals, particularly at night or in poor visibility. This research led to the University of St Andrews forming the spin-out company, PhotoSynergy Ltd, which has developed a range of patented products based on its LIGHTPATH® side-emitting optical fibre illumination system.

Having gained recognition within the sector by winning the Subsea UK Innovation for Safety Award in 2014, our systems are influencing the operating procedures and regulations of key industry leaders such as Shell UK Ltd, who now recommend using LIGHTPATH® for dive umbilicals as an aid to diver safety. Divers themselves are requesting umbilical lighting.

LIGHTPATH® is the only dive umbilical lighting system on the market. The end user benefits in safety and efficiency are clear; since August 2013, a total of 33 LIGHTPATH® units and 101 LIGHTPATH® fibres have been installed on approximately 56% of the Dive Support Vessels (DSVs) operating in the North Sea (15% of the world's fleet), including the entire fleet of two major operators.

2. Underpinning research

The School of Physics and Astronomy at the University of St Andrews has a track record of developing laser sources that include non-linear frequency conversion within its solid-state laser group and the Photonics Innovation Centre (PIC). The green lasers developed are compact and well-matched to the human eye's peak response, giving good visibility at relatively low power [R1, R2]. Furthermore, when coupled into side-emitting plastic optical fibre, a continuous line of light is

created, which is ideal for guide path illumination.

Frequency doubled diode-pumped solid-state green lasers developed within the group were engineered to produce compact, robust sources to inject into the bundles of plastic optical fibre. This early work using laser injection (between 2000 and 2009) proved vital in demonstrating the concept of guidance lighting, providing light paths for any dark environments in the form of high quality and re-configurable safety lighting systems. Applications were identified, such as low-level escape route lighting installed in buildings or deployed by emergency services to aid evacuation.

The green light is well matched to low absorption windows within seawater, so it became evident that the system is ideally suited to subsea applications. Divers in the North Sea work in one of the most hazardous environments in the world. They operate at depths greater than 30m within a hostile marine environment, are essentially working in the dark and only have artificial light to guide them. A major issue comes with towed umbilical cables which may contain vital breathing gas, power, communications and heating to the diver. These cables are generally unlit and can easily be caught or snagged, generating major potential problems. Additionally, this cable is the diver's "breadcrumb" trail back to the safe environment of a diving bell or dive vessel.

Our research has addressed this problem by using illuminated side-emitting optical fibre that is contained within the umbilical and provides a clearly visible trail, which exactly tracks the umbilical. The light source is located remotely within the diving bell or dive vessel and so no additional (and vulnerable) electrical circuits are kept at the diver end of the system.

For this type of illumination system, a coherent light source, such as a laser, is not essential. It was the availability of reliable, second-generation LEDs which proved fundamental in transforming the concept into a viable product as LEDs are smaller, more efficient and less expensive. Research by the PIC team was essential to optimise the configuration for coupling these highly divergent LEDs efficiently into the fibre bundles. The shift to LEDs also meant that other colours were now readily available. This development proves highly beneficial when there are two divers in the water, where green and blue fibres can then be used to distinguish each diver's umbilical.

To achieve the maximum return on investment from our research and due to the commercially sensitive nature of the work, the University took the route of generating an extensive portfolio of patents between 2008 and 2011 relating to the research rather than academic publications. In addition to patents, which cover safe evacuation lighting [R3], submersible lighting systems [R4] and illuminated fibre rope for use with umbilicals [R5], the intellectual property generated also includes patented cover for dual purpose fibre illumination and data communications [R6].

This chain of development all stems from our photonics research, in which we demonstrated that by careful cavity design utilising the birefringence of intracavity elements, efficient single-frequency green generation is possible in a simple compact laser [R1]. The resulting range of products (developed from 2007 onwards) became marketed under the brand LIGHTPATH® for which the trademark was granted in 2016.

3. References to the research

R1 & R2 are published in international peer-reviewed journals. R3-R6 are granted patents.

[R1] G.J. Friel, A.J. Kemp, T.K. Lake and B.D. Sinclair, "Compact and efficient Nd:YVO4 laser that generates a tunable single-frequency green output", Applied Optics, **39**, p. 4333 (2000). DOI: 10.1364/AO.39.004333

[R2] A.A. Lagatsky, E.U. Rafailov, A.R. Sarmani, C.T.A. Brown, W. Sibbett, L. Ming and P.G.R. Smith, *"Efficient femtosecond green-light source with a diode-pumped mode-locked Yb^{3+}:$KY(WO_4)_2$ laser"*, Optics Letters **30**, p.1144 (2005) DOI: 10.1364/OL.30.001144

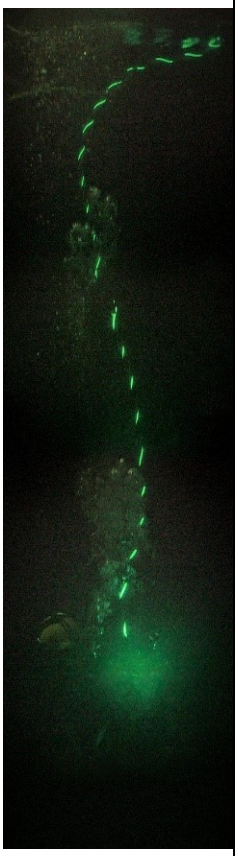
[R3] D.R.G. Walker, M.H. Dunn and C.F. Rae, "Safe evacuation lighting system", UK patent application GB2457914 filed 28/02/2008 and associated international filings. https://worldwide.espacenet.com/publicationDetails/biblio?FT=D&date=20090902&DB=EPODOC&locale=en_EP&CC=GB&NR=2457914A&KC=A&ND=4#

[R4] M.H. Dunn, G.M. Miller and D.R.G. Walker, "Integrated illuminator", European patent application EP2592455 filed 30/03/2011 and associated international filings. https://worldwide.espacenet.com/publicationDetails/biblio?DB=EPODOC&II=0&ND=3&adjacent=true&locale=en_EP&FT=D&date=20130515&CC=EP&NR=2592455A2&KC=A2#

[R5] M.H. Dunn and D.R.G. Walker, "Umbilical", US patent application US8475083 filed 31/03/2010 and associated international filings. https://worldwide.espacenet.com/publicationDetails/biblio?DB=EPODOC&II=0&ND=3&adjacent=true&locale=en_EP&FT=D&date=20111006&CC=US&NR=2011240018A1&KC=A1#

[R6] M.H. Dunn, D.R.G. Walker and D.J.M. Stothard, "Communication system", European patent application EP2474109 filed 24/08/2010 and associated international filings. https://worldwide.espacenet.com/publicationDetails/biblio?DB=EPODOC&II=0&ND=3&adjacent=true&locale=en_EP&FT=D&date=20120711&CC=EP&NR=2474109A1&KC=A1#

4. Details of impact



LIGHTPATH® is the only umbilical lighting system available for commercial offshore diving, providing a **cost-effective solution for improved safety and efficiency of subsea operations** by identifying where dive umbilicals are at any time, a feature which has proven to be particularly beneficial at night or in poor visibility. These benefits have been recognised by PhotoSynergy winning multiple awards, including the Subsea UK Innovation for Safety Award in 2014, through endorsement by industry leader Shell UK, and through widespread adoption by major DSV operators. Since its introduction to the subsea sector in 2013, there has been a steady uptake in LIGHTPATH® products, mainly by customers in the UK plus the Netherlands and Australia, with most of DSVs operating in the North Sea now utilising LIGHTPATH® equipment. **With 33 LIGHTPATH® systems and 101 associated optical fibre assemblies installed, 15% of all DSVs worldwide now benefit from this technology.**

Deep-water safety improved for oil and gas producers in the North Sea

LIGHTPATH® is a unique fibre lighting system, which offers a ground-breaking technical solution to many sectors where the safety of life is paramount. Simple yet highly effective, the versatility of LIGHTPATH® means that it can be used for a wide range of applications, from guide path lighting to delineate escape routes in buildings through to its use in challenging and hazardous areas. Its primary impact can be seen most readily within the Oil & Gas industry, where it has made a significant contribution to safety.

To date, PhotoSynergy has predominantly targeted the subsea sector, using the technology to illuminate saturation dive umbilicals, enhancing safety and productivity for all parties, including the individual diver, colleagues in the water, and the bellman (who stays in the diving bell whilst up to two divers are outside on umbilicals). In addition, it gives confidence to the underwater ROV pilot as to the location of diver umbilicals. This awareness for ROV pilots of the route of the umbilical has been an important development in minimising the risk of collision. It can significantly reduce the incidence of umbilical snagging.

Quickly realising the enormous potential of our photonics research into compact green light sources used to illuminate side-emitting optical fibres, the University formed the spinout company, PhotoSynergy Ltd, in 2001 to help commercialise the concept, aided initially by funding received from winning a SMART Scotland award in 2003. Following our research using lasers [R1, R2, R3], the first subsea prototypes were developed between 2007 and 2011 [R4, R5].

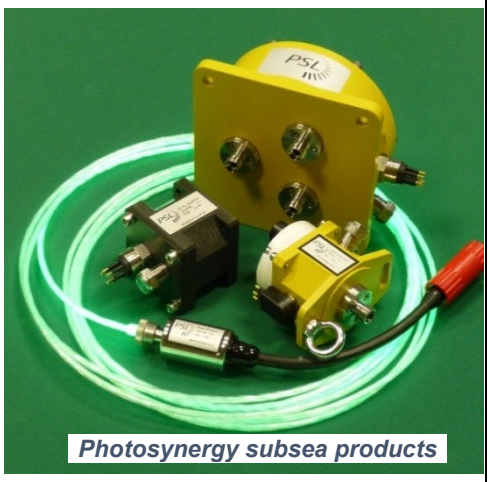
Initial testing and evaluation of the equipment took place in 2012 at The Underwater Centre in Fort William; their support during Open Days contributed significantly to raising the profile of the illuminated umbilical concept. Referring to an incident on the DSV Polar Queen, the Centre's Diving Training Manager recalled "*one of the diver's umbilicals caught in the main propulsion.* ***This could have been avoided using a system like this [LIGHTPATH®].*** *The incident happened in the middle of the night … and not being able to see the umbilical was one of the main factors*". [S1]

Several companies then supported our concept in development, carrying out trials in the North Sea using both Saturation and wet bell systems, before adopting the system as standard. The General Manager of The Underwater Centre stated in 2014: "*It's a very important piece of new technology, which we can see has* ***significant benefits to commercial divers and ROV pilot***

technicians when working offshore or in poor light.*"* [S2, p. 3]

Bibby Offshore led the North Sea deployment. In 2014, their Diving and Dive Systems Operations Manager said that on their DSVs *"different colours were used for each diver to avoid confusion when they were working close together in poor light conditions.* ***The main benefit is that the divers can readily identify where their umbilicals are at any time, preventing potential problems with unseen snagging hazards****. The ROV can also quickly check the divers' umbilicals are completely clear before landing large items on the seabed.* ***The divers themselves started requesting umbilical lighting*** *quickly following the early offshore trials. This, in itself, speaks volumes."* [S2]. In 2016 their Diving Manager added, "***Bibby Offshore regard the LIGHTPATH as a significant safety enhancement and use it as standard on all our DSVs****"* [S3, p. 95].

In 2014, North Sea Operator **Shell UK Ltd included our LIGHTPATH® technology for the first time in its diving operations and management guidance document** which aims to ensure compliance with latest legislation and industry best practice, stating "*A Lightpath fibre should be incorporated in surface supplied and saturation diver's umbilicals to provide a continuous line of light indicating the route of the umbilical for the divers and ROV(s)*" [S4, p. 71].



Photosynergy subsea products

LIGHTPATH®'s importance to safety within the Oil & Gas industry has been recognised by it being short-listed for Innovation and Safety Awards on four separate occasions between 2014 and 2017, ultimately **winning the Subsea UK Innovation for Safety award in 2014** [S5]. This proved to be a key milestone in the uptake of LIGHTPATH®, coming from such a prestigious organisation as Subsea UK who have over 290 member companies from within the subsea industry, a GBP7,800,000,000 sector with over 45,000 employees and approximately 650 companies.

<u>Improved efficiency for DSV operators in the North Sea</u>

To operate at depths in excess of 50m for extended periods, divers live and work in a pressurised saturation system onboard a DSV, breathing a mixture of helium and oxygen to reduce the risk of decompression sickness. Saturation divers live in this sealed off world, often at 10 times atmospheric pressure, for weeks at a time. Commercial North Sea deep-water saturation diving is contracted out by the major oil & gas producers to a few specialist companies each with a small number of DSVs in their fleet. These vessels carry out subsea construction, decommissioning and inspection, repair & maintenance (IRM) of offshore platforms and associated installations. Typically, a DSV may have 70 to 150 personnel onboard whose sole purpose is to keep the team of 12 to 24 divers safe and well and provide an environment in which to work efficiently.

Since August 2013, **a total of 33 LIGHTPATH® units and 101 LIGHTPATH® fibres have been sold** [S6] for **installation on approximately 56% of North Sea DSVs (15% of the worldwide fleet)**, bringing improved safety to divers and **improving operational efficiency for the DSV operators.**

The Group Diving Manager of Harkand, another company operating DSVs, said in 2016: *"LIGHTPATH further enhances the diver's ability to manage their umbilical,* ***improving their safety and simultaneously delivering more efficient operations****".* Adding "***LIGHTPATH helps reduce recovery time*** *as the diver can track and identify their route back to the bell, as well as identify any snags and entanglement of the umbilical due to the variations in colour offered by the equipment. It also ensures divers and ROV pilots can constantly monitor that the umbilical is clear during equipment deployment and recovery, which are generally high-risk activities".* [S3, p. 95]

At least 9 of the 16 DSVs currently operational in the North Sea have been equipped with LIGHTPATH® including the entire fleet of the leading IRM companies, Bibby Offshore (now Rever Offshore) and TechnipFMC. To install LIGHTPATH® on a DSV with twin diving bells, such

TechnipFMC's Deep Discover DSV

as the TechnipFMC Deep Discoverer (pictured), would typically require 6 optical fibre assemblies and between 3 and 6 lighting units at a one-off installation cost of approximately GBP20,000 – this is a fraction of the vessel's daily charter rate. Despite not being mandatory, LIGHTPATH® is a successful and affordable solution for improved safety and efficiency for DSV operators as evidenced by its widespread adoption in the North Sea.

Economic benefits to PhotoSynergy Ltd and product diversification

In addition to the end user benefits in safety and efficiency, there are economic benefits to PhotoSynergy itself as it strives to grow the business, to its suppliers and to those who support LIGHTPATH® in the field. Sales to date from its LIGHTPATH® subsea product range have generated a revenue for PhotoSynergy of GBP186,000 [S6]. Whilst this has largely been sales directly to UK operators in the North Sea some have come via third-party subsea service companies and some directly through sales in the Netherlands and Australia. Many sales have been repeated orders from customers installing LIGHTPATH® across their DSV fleet.

Although primarily in use in the North Sea, LIGHTPATH® is marketed worldwide through trade exhibitions and via distributors with devices operational as far afield as Australia and Singapore. Working closely with leading industry bodies such as Oil & Gas UK and Subsea UK has enabled LIGHTPATH® to be extensively showcased in both the UK press and trade magazines [S7], leading to product diversification to address adjacent markets.

In a joint venture with JCE Group (UK) Ltd, a world leader in Safe Area Control Systems, PhotoSynergy has developed 'LIGHTPATH® Ex' variants for hazardous areas and explosive environments, e.g., offshore platforms or petrochemical facilities. The new products achieved the stringent ATEX certification in 2016, which ensures equipment is compliant with European Directives regarding the health and safety protection of workers potentially at risk from explosive atmospheres [S8].

In collaboration with WFS Technologies Ltd (now CSignum Ltd), an on-demand wireless version was launched in 2016. The system, Seatooth Lightrope, combines two advanced technologies: WFS's Seatooth®, a subsea wireless communication system that can download and log information gathered on subsea installations remotely, and LIGHTPATH®. The WFS Chairman said: "*This is a further example of the 'Subsea Internet of Things', where intelligent devices automatically communicate with one another wirelessly, improving efficiency and safety*." [S9, p. 71].

5. Sources to corroborate the impact

[S1] Photosynergy Lightrope at The Underwater Centre video https://www.youtube.com/watch?v=XVe2FEa4ahc, at 1':00"

[S2] https://www.energyvoice.com/other-news/healthandsafety/51514/pioneering-system-scots-firm-lights-way-dive-safety/ Jan 2014, p. 2

[S3] www.SubCableNews.com Edition 164, Feb 2016, pp. 94-95 https://ecitydoc.com/queue/project-updates_pdf?queue_id=-1

[S4] Shell UK Ltd "Underwater Operations - Diving Operations & Management Guidance" document number 0184-001 Rev 5.0 June 2014 (restricted circulation), §15.10, p.2

[S5] Compilation of webpages showing industry awards for which LIGHTPATH® has been shortlisted or won, pp. 2-3, 11, 14 & 18

[S6] Photosynergy Ltd. sales data & Companies House accounts excerpts, Sept. 2020

[S7] Wireline magazine Issue 30 Winter 2014-2015, p3 & pp. 29-32 https://oilandgasuk.co.uk/wp-content/uploads/2015/05/CO035.pdf

[S8] LIGHTPATH® EX flyer and ATEX certificate, Nov. 2016

[S9] PES Wind magazine Issue 1 2017, pp. 70-72 http://cdn.pes.eu.com/v/20160826/wp-content/uploads/2017/04/PES-Wind-1-17-PhotoSynergy-Ltd-PES-ESSENTIAL-1.pdf