Institution: University of the West of Scotland		
Unit of Assessment: 9: Physics		
Title of case study: Enhancing optical thin films to drive improvements in the health, industrial and agritech sectors		
Period when the underpinning research was undertaken: 2014 - 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:**
Des Gibson	Professor	2014 - 2020
Dr David Hutson	Lecturer	2007 - 2020
Dr Shigeng Song	Reader	2012 - 2020
Dr Lewis Fleming	PDRA / KTP Associate	2017 - 2020
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

Optical thin films – in the spectral region from visible to infrared – are extensively used in global industry and public sectors such as health, defence, agritech and the environment. Based on post-2014 research undertaken at University of the West of Scotland, companies including SemeFab and Pyreos Ltd have developed and sold leading-edge new sensor products, accessing new wavelength ranges, with a considerable increase in sensitivity and reduced manufacturing costs. Once transferred to industry and incorporated into products, these UWS-enhanced optical thin films have directly enabled and facilitated extensive beneficial impact through applications in medical devices, industrial safety, defence and environmental monitoring.

2. Underpinning research

Context: From 1999, the physics department's Thin Film Centre – re-constituted as the Institute of Thin Films, Sensors & Imaging (ITFSI) in 2014 – conducted fundamental research on new plasma-assisted vapour phase deposition processes. Their work identified a pathway to production of significantly improved optical thin films, while also providing understanding of the underpinning fundamental physics. Industrial companies quickly recognised the potential impact and became closely involved from an early stage. The driving motivation was achieving room temperature deposition processes compatible with temperature-sensitive substrates and use of various plasma assist regimes to improve optical thin film properties; resulting in novel patented processes. This is extremely important for applications, since it allows functionalisation of optical thin films and the resulting optimisation of required properties. The research included experimental demonstrations of room temperature deposition of new spatially variable optical thin films, broadband absorption infrared optical thin films, deposition of durable infrared optical thin films and light source/detector optopairs in the mid-infrared, complemented by theoretical analysis.

Key findings: Use of hydrogenated surface-wave microwave plasma (SWMP) assisted sputtering is a world-first for optical thin films produced using room temperature sputter based deposition processes, providing high throughput compared to currently used high temperature low throughput plasma enhanced chemical vapour deposition processes. The Institute's 2016/17 Applied Optics publications **[3.1, 3.2]**, describe a series of calculations and numerical modelling studies underpinning proof of principle laboratory research experiments. The novel process utilises SWMP assisted sputter deposition – SWMP provides large area coverage with required plasma assist energy/ reactivity to deposit dense stable optical films at room temperature. Deposition system configuration utilises a drum rotating on a horizontal axis – providing a high surface area – where precision deposition of each layer can be achieved with multiple passes across a rectangular planar pulsed DC magnetron source with subsequent exposure to the SWMP region. As described in references **[3.1, 3.2]** separation of deposition and plasma assist regions provides deposition of high purity metal or semiconductor monolayer films with subsequent microwave plasma assist providing a method to functionalise optical films.

Additional research novelty in this work is optical thin film functionalisation using hydrogenation during pulsed DC-sputtering/ SWMP assist to reduce optical thin film absorption – arising from a decrease in deep absorptive states associated with dangling bonds – to a level required for use as an optical thin film.

Resulting SWMP sputter deposition intellectual property (IP) has been protected via four patents, covering process variants and associated applications prior to publication. Relevant post-patenting, peer-reviewed publications (industrial partners indicated in brackets) describe durable infrared anti-reflection optical thin films **[3.3]**, linear variable optical filters for use in low-cost hyperspectral imaging and spectroscopy **[3.4]**, bandpass filters for non-dispersive gas sensors **[3.5, 3.6]** and broadband absorber coatings for use in enhanced detectivity thermopile detectors (patented, follow-on publication in preparation – Semefab Ltd).

3. References to the research

3.1 Song, S., Li, C., Chu, H. and **Gibson, D.,** (2017) Reactive dynamics analysis of critical Nb_2O_5 sputtering rate for drum-based metal-like deposition. *Applied Optics*, 56(4): C206 – C210. https://doi.org/10.1364/AO.56.00C206.

3.2 Li, C., **Song, S., Gibson, D.,** Child, D., Chu, H. and Waddell, E., (2016) Modeling and validation of uniform large-area optical coating deposition on a rotating drum using microwave plasma reactive sputtering. *Applied Optics*, 56(4): C65-C70. https://doi.org/10.1364/AO.56.000C65 .

3.3 Gibson, D., Song, S., Fleming, L., Ahmadzadeh, S., Chu, H., Sproules, S., Swindell, R., Zhang, X., Navabpour, P., Clark, C. and Bailey, M., (2020) Durable infrared optical coatings based on pulsed DC-sputtering of hydrogenated amorphous carbon (a-C:H). *Applied Optics*, 59(9): 2731-2738. https://doi.org/10.1364/AO.378266.

3.4 Song, S., Gibson, D., Ahmadzadeh, S., Chu, H., Warden, B., Overend, R., Macfarlane, F., Murray, P., Marshall, S., Aitkenhead, M., Bienkowski, D. and Allison, R., (2020) Low-cost hyper-spectral imaging system using a linear variable bandpass filter for agritech applications. *Applied Optics*, 59(5): A167-A175. https://doi.org/10.1364/AO.378269

3.5 Wang P, Fu X., **Gibson D., Fleming L.**, Ahmadzadeh, S., Li, C., Muhiyudin, M., **Song S., Hutson, D.,** Moodie, D., MacGregor, C., Steer, M., (2018) Optimised Performance of Non-Dispersive Infrared Gas Sensors Using Multilayer Thin Film Bandpass Filters. *Coatings*. 8(12): 472. https://doi.org/10.3390/coatings8120472.

3.6 Muhiyudin, M., **Hutson, D., Gibson, D.,** Waddell, E., **Song, S.**, Ahmadzadeh, S., (2020) Miniaturised Infrared Spectrophotometer for Low Power Consumption Multi-Gas Sensing. *Sensors*. 20(14): 3843. https://doi.org/10.3390/s20143843 .

<u>**Grants**</u>

3.A Gibson, D., Shigeng, S., *Knowledge Transfer Partnership*, Innovate UK: KTP with Alphasense Ltd, November 2018 to November 2020, GBP115,590.

3.B Gibson, D., Shigeng, S., *Improved and low-cost infrared linear variable filters for spectrometry*, Censis Innovation Centre Award, September 2019 to March 2020, GBP49,757.00

3.C Gibson, D., Hutson, D., Shigeng,S., *Chemical Sensor based on a Miniaturised Infrared Spectrophotometer*, EraNet Horizon 20/20, May 2018 to October 2020, GBP381,649.

3.D Hutson, D., Gibson, D., *Enhanced Performance Low Cost MEMS based Thermopile & Hotplate Detector/ Light Source*, Censis Innovation Centre Award 10 month programme, 2016, GBP46,152.

3.E Shigeng.S., Gibson, D., *Feasibility of a Hyper Spectral Crop Camera (HCC) for agriculture optimisation*, Innovate UK, June 2016 to November 2017, GBP55,159.

3.F Gibson, D., Shigeng, S., *Alphasense Start-Up Project, Novel broadband durable infrared optical thin films as an enabling technology for micro-spectrophotometers applied to sensing & imaging and protective coating applications*, Scottish Enterprise, 2015, Phase 1 GBP164,700 , Phase 2: August 2016 to January 2018, GBP362,815

3.G Gibson, D., *High-performance autonomous gas and environment sensor platform for building automation and horticulture*, Innovate UK, 2015, GBP58,640

Patents

3.H Gibson, D., Hutson, D. and Song, S., 2020. *An absorber, a detector comprising the absorber and a method of fabricating the absorber*. GB2016210.3. https://www.ipo.gov.uk/p-ipsum/Case/ApplicationNumber/GB2016210.3

3.I Gibson, D. and Song, S., 2018. *Apparatus and methods for depositing durable optical coating*. GB2561865A. https://worldwide.espacenet.com/patent/search?q=pn%3DGB2561865A

3.L Gibson, D., Song, S. and Hutson, D., 2018. *Apparatus and Methods for Depositing Variable Interference Filters*. EP3583242A2. https://worldwide.espacenet.com/patent/search?q=pn%3DEP3583242A2

3.M Gibson, D. and Waddell, E., 2018. *Infrared Spectrophotometer*. GB2559957. https://worldwide.espacenet.com/patent/search?q=pn%3DGB2559957A

4. Details of the impact

Process from research to impact: Fundamental research into new optical thin films was conducted by ITFSI, publishing regularly in leading journals and protecting generated intellectual property through four patents. The ITFSI researchers led the initial and follow-on work, all conducted at the University of the West of Scotland, funded since 2014 by a series of Knowledge Transfer awards (approximately GBP700,000) alongside research council grants (approximately GBP2,500,00), Scottish government high growth start-up funding (approximately GBP600,000) and a company (Gasclip Technologies Inc.) funded research contract (approximately GBP500,000). Companies such as Semefab Ltd, Pyreos Ltd and Alphasense Ltd were involved at an early stage, building prototypes incorporating optical thin films and using them to conduct trials which have changed their thinking and business plans. Semefab Ltd co-founder and CEO confirms **[5.1, 3.D, 3.E]**: *"The innovative collaborative projects with UWS ITFSI have provided Semefab with core optical thin film technology which combined with our high volume production capabilities brings a range of exciting new products to market."*

Description of impact: During the period 2014 to present, the optical thin films in question have positively impacted across a wide range of sectors. Evidence of impact can be found in the following examples:

- Linear variable filters **[3.L],** covering various spectral regions and applications.
- Testimonies from CEO at Wideblue (spectral range visible, application hyperspectral imaging) **[5.2, 3.4, 3.F]**; and Experior Microtech **[5.3 - spectral range visible, application miniaturised visible spectrometers for various applications]**
- Testimonies from CTO of Alphasense (spectral range near infrared, application ppm level detection of volatile organic compounds) **[5.4, 3.B]** and Pyreos (spectral range mid infrared, application proprietary) **[5.5, 3.C].**

Sources **[5.1-5.4]** have confirmed UWS ITFSI patented LVF technology meets their strict requirements. Additional impacted sectors include broadband absorber coatings, providing enhanced sensitivity performance infrared detectors for use in non-contact thermometry and gas sensing **[5.1, 3.D, 3.H, 3.I].** Also, novel mid infrared light source and detector optopair technology is based on low-cost, mass-producible IV-VI based optical thin films **[5.5, 5.6]** for use in autonomous gas sensors **[3.C]**. Sources **[5.1-5.6]** verify cited optical thin films are production-ready for applications such as agritech, point-of-care medical devices, environmental monitoring and industrial safety. The impact, therefore, is bringing global societal as well as economic benefits.

Reach and significance: The SWMP sputter deposition method provides novel patented optical thin film processes, providing cited industrial partners with UK-based, production-ready capability and enhanced product performance and competitiveness. UWS have progressed the formation of a spinout company, Albasense Ltd (companies house registration number SC 598193), supported through the award of a Scottish Enterprise High Growth Spin-Out project **[3.F]**. Albasense Ltd was also a Converge Challenge finalist 2020 and the company is the primary commercial interface with cited commercial partners **[5.1-5.6].** The chief technical officer of Alphasense Ltd, the UK's largest gas sensor manufacturer, confirms **[5.4, 3.B]:**

"The UWS ITFSI patented LVF manufacturing method, commercialised through the UWS university spinout Albasense Ltd, provides Alphasense with a UK based unique high throughput supply at a cost level circa 20% of other European and US supplier costs."

Alphasense Ltd **[5.4]** also confirms joint UWS/ Alphasense patent in preparation covering new LVF based spectrometer) indicate forecast production requirements of 5,000 miniaturised spectrometers per year, adding GBP2,000,000 sales per annum and an additional five staff.

Semefab Ltd **[5.1]** to date have produced more than 12 million infrared detectors with an annual sales value of GBP1,800,000, with an additional 8 personnel. A primary market driving the need for such detectors is non-contact thermometry for use in diagnosis/ management of Covid-19.

Pyreos Ltd **[5.5]** confirm UWS ITFSI mid infrared LVFs are production-proven, with forecasted resulting additional sales of GBP300,000 per annum.

The recent emergence of battery-powered, wireless detectors is enabling new implementations; however, widespread uptake in safety-critical applications is currently being limited by availability of ultra-low power non-dispersive infrared (NDIR) gas sensors that fail-to-safe and have a long sensor lifetime. The driving motivation is combination of ultra-low power consumption, miniaturisation, low cost and mass producibility. This is extremely important for applications, since it addresses a need for autonomous wireless compatible gas sensor solutions, allowing "fit and forget" deployment. The UWS optical thin film based mid infrared light source and detector optopair technology addresses this need.

The CEO and founder of Helia Photonics Ltd confirms **[5.6, 3.D]**: "*The ERANET Horizon 2020 project with UWS ITFSI resulted in proven novel optical thin film based low cost, mass producible mid-infrared light source and detector optopairs – an enabling technology for ultralow power consumption and autonomous non-dispersive infrared gas sensors. This is currently being commercialised in conjunction with UWS ITFSI spinout Albasense Ltd."*

UWS ITFSI has secured a company sponsored research contract – Gasclip Technologies Inc (GTI) – for production prototyping **[5.7]** and a GTI/ Albasense heads of terms for follow-on production **[5.8]** of a wearable ultralow power consumption methane sensor **[5.8: production quantities 5000 per month, unit price USD70, annual sales USD4,200,000]**. Achieving the ultralow power performance is enabled by UWS ITFSI optical thin film based light source/ detector optopairs – providing GTI with extended sensor operational time.

5. Sources to corroborate the impact

5.1: Statement from Semefab Ltd. corroborates the claim that the research at UWS is contributing directly to successful products and job creation.

5.2: Statement from Wideblue Ltd confirming production status of UWS patented LVF technology for use in low-cost volume manufacturable hyperspectral imaging camera.

5.3: Statement from Experior Micro Technologies Ltd confirming production status of UWS patented LVF technology for use in visible spectra miniaturised spectrometers.

5.4: Statement from Alphasense Ltd confirming production status of UWS patented LVF technology for use in near infrared spectrometers - volatile organic compound detection.

5.5: Statement from Pyreos Ltd confirming production status of UWS patented LVF technology for use in mid-infrared pyroelectric detector arrays for various applications.

5.6: Statement from Helia Photonics confirming commercialisation of optical thin film based mid-infrared light source/ detector optopairs - in ultralow power consumption sensors.

5.7: Gasclip research project contract.

5.8: Gasclip/ Albasense heads of terms.