Institution: Swansea University

Unit of Assessment: 8

Title of case study: Development of plasma technology processes has increased process tool sales and company growth at SPTS Technologies.

Period when the underpinning research was undertaken: 2010-2020

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:
Owen Guy	Professor	2007-present
Matt Elwin	Manager Centre for Nanohealth	2009-present
Yuifei Liu	Knowledge Transfer Partnership	2011-2014
Connie Eng	(KTP) Research Associate	2014-2016
	PDRA	

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

Advances provided by research at Swansea University's Centre for Nanohealth around novel deep-etch and deposition plasma process technology have been incorporated into novel semiconductor, packaging, microelectromechanical systems (MEMS) and healthcare products and processes by SPTS Technologies. SPTS is a global leader in wafer processing equipment for the semiconductor and related industries. Specifically, the research by Prof Owen Guy and his team has resulted in USD12,000,000 in equipment sales for SPTS since 2014, primarily in the worldwide MEMS and waveguides sectors, along with the development of a new Swansea-based SPTS R&D centre. Five employees of SPTS have also benefited from bespoke Masters' and PhD training programmes, with SPTS employing 6 Swansea graduates since 2014.

2. Underpinning research

Plasma process technologies have been used for advanced packaging, micro-electromechanical systems (MEMS), photonics, silicon semiconductor processing and power devices. The limiting challenges of the technologies have been related to high aspect ratio etch features, smooth sidewalls and low stress deposited films. Research at Swansea, started in 2010, has been developed to address some of the challenges identified.

Distinctively, the development of plasma process technology research at Swansea University began with research from Prof. Guy's group within the Centre for Nanohealth, around silicon processing of microfluidic trenches [**R1**] and a novel MEMS based drug delivery device, which enabled controlled drug release using an applied voltage [**R2**].

Following this, and in conjugation with SPTS Technologies, a semiconductor and microelectronics manufacturer (utilising a Knowledge Transfer Project [**G2**] with Y. Liu and an EPSRC Grand Challenge project [**G1**]), novel deep-etch and deposition plasma process technology for microfluidics and Bio-MEMS applications [**R3, R4, G3, G4, G5**], together with surface plasma treatments and stress-controlled plasma deposition processes were developed. Specifically, this research addressed the challenges of achieving an extremely deep etch (>1mm), high aspect ratio and vertical sidewall plasma etch, with an advanced two-step etching process being developed, assisted by using a bilayer mask [**R3**].

Plasma Etch technology has been applied to other systems including VCSELs (Vertical Cavity Surface Emitting Laser) [**G7**], SiC Power devices and dry etch wafer polishing. Using low-cost

silicon substrates and applying SPTS' Plasma Enhanced Chemical Vapor Deposition (PECVD) system, our research showed that reclaimed silicon wafers with the novel graded refractive index (RI) anti-reflection silicon nitrite coating (ARC) have significantly enhanced cell performance over non-coated cells. The research team at Swansea identified that this approach would save up to 30% wafer cost of the total solar cell modules [**R4**]. This technology was further developed to deposit low loss silicon oxynitride dielectric films for waveguide devices in communications applications [**R4**].

Following on from [**R3]**, a novel 3-step process flow was developed to produce multiple arrays of sharp-tipped, hollow microneedles, which facilitate easy insertion and controlled fluid injection into excised skin samples [**R5, G6** and patent **R6**]. The microneedles produced from this novel process allow for greater versatility over other microneedles because the central bore allows for controlled volume delivery and the bevelled tips limits pain for the patient.

3. References to the research

Quality of underpinning research: All papers have been peer reviewed (4 published in Q1 or Q2 journals, JCR 2019). The five papers have been supported by external funding from EPSRC, UK Technology Strategy Board and the Welsh Government. This research has made important contributions to the plasma and semiconductor technology internationally and contributes important knowledge to the field likely to have a lasting influence.
SPTS authors in *italics,* SU authors in **bold**

[R1]. **Eng, P.F.,** Nithiarasu, P., **Guy, O**. (2010) An experimental study on an electro-osmotic flow-based silicon heat spreader. Microfluidics and Nanofluidics 9:787-795. https//doi.org/10.1007/s10404-010-0594-3

[R2]. **Liu, Y.,** Servant, A., **Guy, O.J.,** Khuloud T., Williams, P.R., Hawkins, K. M., Kostarelos, K. (2012) An electric-field responsive microsystem for controllable miniaturised drug delivery applications. Sensors and Actuators B: Chemical 175:100-105. https://doi.org/10.1016/j.snb.2011.12.069

[R3]. **Liu, Y., Eng, P.F., Guy, O.J.,** *Roberts, K., Ashraf, H., Knight, N.* (2013) Advanced deep reactive-ion etching technology for hollow microneedles for transdermal blood sampling and drug delivery. IET Nanobiotechnology 7:59-62. https://doi.org/10.1049/iet-nbt.2012.0018

[R4]. **Liu, Y., Guy, O.J.,** *Patel, J., Ashraf, H., Knight, N.* (2013) Refractive index graded anti-reflection coating for solar cells based on low cost reclaimed silicon. Microelectronic Engineering 110: 418-42. https://doi.org/10.1016/j.mee.2013.03.003

[R5]. *Bolton, C.J.W.,* Howells, O., Blayney, G. J., **Eng, P.F.,** Birchall, J.C., Gualeni, B., *Roberts, K., Ashraf, H.,* **Guy, O.J.** (2020) Hollow Silicon Microneedle Fabrication using Advanced Plasma Etch Technologies for Applications in Transdermal Drug Delivery. Lab on Chip 20: 2788-2795. https://doi.org/10.1039/D0LC00567C

[R6]. **Liu, Y., Guy, O.J.** (2015) Manufacture of microneedles. US20160264408 A1, EP3060290A1, WO2015059437A1, https://bit.ly/37L1Het (patent)

Grants

[G1]. Williams, R., (PI), Wright, C., Claypole, T., Wilks, S., Maffeis, T., Evans, P., Thimbleby, H., Summers, H., Guy, O., Hawkins, K., Barrow, M., Penny, M. (CoIs) (05.2009-04-2012). Point of care nanotechnology for early blood clot detection and characterisation in disease screening, theranostic and self-monitoring applications. EPSRC, [EP/G061882/1], GBP906,522.

[G2]. Guy, O. (PI) (06.2010-12.2013). To develop Atomic Layer Deposition and nano structure growth process capability on a plasma enhanced deposition system utilising Liquid Delivery system. KTP with Welsh Government/SPTS Technologies Ltd, [KTP007901], GBP172,932. **Awarded "Grade A (Outstanding)" by the Technology Strategy Board.**

[G3]. Guy, O., (PI), Summers, H., (CoI), Birchall, J., (CoI), Coulson, S (CoI). (05.2014-11.2016). Manufacture of silicon microneedles for drug & vaccine delivery. EPSRC, [EP/L020734/1] GBP564,437.
[G4]. Guy, O., (Swansea PI), Birchell J.P. (Project PI). (09.2013-05.2016). Precise cell therapy using minimally invasive microneedle devices. InnovateUK [TS/L001640-1], GBP250,000 (GBP75,000 Swansea University).
[G5]. Extraject Technologies Ltd (PI), Guy, O. (CoI). (11.2013-04.2016). Novel therapies for skin pigmentation disorders. InnovateUK [101498], GBP328,505.
[G6]. Guy, O. (PI). (08.2019 – 11.2022). To develop process capability on a new Molecular Deposition System tool platform at a new joint demo facility. KTP with Welsh Government/SPTS Technologies Ltd [011971], GBP230,250.
[G7]. Guy, O. (PI). (03.2017 – 05.2018). HEMAN V: High Efficiency MANufacturing of VCSELs, InnovateUK [102890], GBP285,213.

4. Details of the impact

Company development and economic impact

Our collaboration with SPTS Technologies was initiated through a KTP, for which we were awarded a "Grade A (Outstanding)" by the Technology Strategy Board (now Innovate UK). SPTS has been able to develop new processes using Swansea/CNH research such as "*enhanced adhesion processes for MEMS applications, combined wet and dry etch processes and PECVD ammonia free nitride and silicon oxynitride for LED and waveguide applications*" [**C1**]. In addition, Swansea University's research on plasma etch, deposition and surface treatment process, has directly contributed to a patent [**C2**] by SPTS on a method of depositing an amorphous silicon film (Y. Liu named as an inventor).

The application of these new processes has enabled the company to develop novel products in semiconductor, packaging, MEMS and healthcare sectors for new markets (China/Malaysia) with *"the impact from Swansea research related to circa USD10,000,000 in tool sales"* [Senior Director, SPTS**, C1**] and *"in the past three years (2016 - 2019) in particular, sales of tools related to waveguide process development were USD2,000,000, which involved critical input from Swansea University research"* [Senior Director, SPTS**, C1**].

The above-mentioned tools (equipment) include enhanced/reduced wafer adhesion processes, molecular vapour deposition processes, silicon etch technology for microfluidic devices, novel processes for solar cells and LEDs (light emitting diodes), a gallium arsenide etch process for lasers (VCSELS) and wafer dicing.

In part recognition of its fruitful collaboration with Swansea/CNH, SPTS gifted the University (through its department of research and innovation) GBP600,000 of shares in BluGlass Limited in May 2014 - the largest gift ever donated to the University [**C3**].

"SPTS has strong ties with Swansea University, and has benefited from the knowledge exchange projects through the University's Department of Research and Innovation (DRI)" SPTS then CEO stated. *"The DRI, which acts as the bridge between industry and academia, has enabled us to extend the scope of our research beyond our existing markets and gain access to funding, which has proven invaluable to our R&D teams. This gift of shares in BluGlass is our way to pay back by 'paying it forward' to the University in not just the current value of the shares but the potential future value of BluGlass and the opportunities for potential collaboration between Swansea University, BluGlass and Sydney's Macquarie University"* [**C3**].

SPTS' collaborative research with CNH/Swansea University has led to several awards, including the *Insider* Business 'Partnership Award' 2014 [**C4**], which recognized the most impressive partnership between industry and academia, taking into account the extent of co-operation and mutually beneficial outcomes. SPTS/Swansea University were also finalists for the ESTNET (now Technology Connected) partnership award in 2015 [**C5**].

Company development (staffing & upskilling)

In addition, by working with Swansea University, SPTS has been able to employ 6 Swansea graduates [HR manager, SPTS, **C6**] and upskill its employees, with five members of staff already having completed or enrolled for PhDs at Swansea [**C7**]. CNH runs seminars for SPTS employees (in 2020 alone 142 SPTS employees attended online Swansea led webinars [**C8**]) on various aspects of semiconductor technology.

"The programme helps to give SPTS employees, who have studied a range of science and engineering subjects, a better understanding of up-to-date power electronics and the reasons why wide bandgap materials are now becoming so important in our industry" [Marketing Communications Manager, SPTS, **C8**].

CNH researchers are involved in outreach and dissemination activities, with SPTS and Swansea jointly presenting at conferences and events. Indeed, the "SEMI Talent Forum 2020", a global student talent event, was brought to Swansea by SPTS and SEMI (the organization representing the global semiconductor industry). This resulted in 20 applications from Swansea University graduates for SPTS job vacancies in 2020 [HR Manager, SPTS, **C6**].

The Senior Director of SPTS notes:

'SPTS has also been able to grow its workforce by 20% since 2014, including employing Swansea University graduates, as a direct result of our links with the Swansea University research team. You have also been instrumental in generating opportunities for SPTS to up-skill and gain academic qualifications (PhDs) as well as gaining experience in new market sectors. SPTS has sponsored/is sponsoring several MSc and PhD students, who are a crucial component in further expansion of our business' [**C1**].

Company integration into Compound Semiconductor Cluster in Wales

Arising from the very first KTP between Prof Guy and SPTS, the company has become part of the nascent but rapidly developing semiconductor ecosystem in South Wales. Owing to its research in semiconductor technologies with CNH, it is now an industrial partner in the ASSET (Application Specific Semiconductor Etching Technology) project, where new technologies for applications in automotive sensing, 5G, photonics and healthcare are being developed. It is also a founding industrial member the GBP90,000,000 Centre for Integrative Semiconductor Materials (CISM) [**C9, C10**].

5. Sources to corroborate the impact

[C1] Letter from Senior Director, SPTS Technologies
[C2] Patent - Method of Depositing an Amorphous Silicon Film https://bit.ly/2O8XTwJ
[C3] SPTS gifts £600,000 worth of BluGlass shares to Swansea University https://bit.ly/3q5kes9
[C4] SPTS Technologies and Swansea University receive Insider's business and education partnership award https://bit.ly/2NP0Y5d
[C5] ESTNET 2015 awards https://bit.ly/2My5qgL
[C6] Email testimonial from SPTS European HR Manager (available on request)
[C7] Email testimonial from SPTS Process Manager, R&D Accounts (available on request)
[C8] Email testimonial from SPTS Marketing Communication Manager (available on request)
[C9] ASSET project gains £1.3m in Welsh Government funding https://bit.ly/3q2JJu0
[C10] UKRPIF making £30m investment in new Centre for Integrative Semiconductor Materials at Swansea University https://bit.ly/3bKYs7X