Institution: University of the West of Scotland		
Unit of Assessment: 12: Engineering		
Title of case study: Disruptive piezoelectric thin film technology for low cost mass producible ultrasonic transducers		
Period when the underpinning research was undertaken: 2014 - 2018		
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:**
Dr Dave Hughes	Post-Doctoral Research Assistant	2016 - 2018
Dr David Hutson	Lecturer	2008 - 2020
Prof Des Gibson	Professor	2014 - 2020
Prof Katherine Kirk	Professor	2000 - 2018
Dr Richard Fu	Lecturer	2011 - 2015
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

Ultrasonic transducers are extensively used in USD3,400,000,000 global industry and public sectors, including medical imaging and non-destructive structural integrity evaluation of materials. A new generation of piezoelectric transducers based on thin film research at the University of the West of Scotland (UWS) Institute of Thin Films, Sensors & Imaging (ITFSI), has been patented and commercialised via a multiple-award winning UWS ITFSI high-growth spin-out Novosound Ltd. The pioneering technology was transferred to Novosound Ltd, where transducers have been constructed and sold into global markets. This has led to considerable investments and rapid job creation, as these transducers have extensive beneficial impact in materials processing, wearable healthcare and aerospace.

2. Underpinning research

Context: Novosound's patented technology was developed from 2007 by UWS Institute of Thin Films, Sensors & Imaging (ITFSI), conducting fundamental research on new piezoelectric thin film materials such as zinc oxide as an alternative approach to fabrication of ultrasonic transducers. Their work identified a pathway to production of significantly reduced cost, improved performance and mass producible ultrasonic transducers based on semiconductor manufacturing techniques **[3.A- 3.B]**. The work also provided an understanding of the underpinning fundamental engineering and material science. The research included experimental demonstrations of thin film piezoelectric materials, deposition onto various substrate materials including flexible foil providing three dimensional ultrasonic imaging capability, complemented by full theoretical analysis **[3.C]**. Novosound has utilised the latest Thin Film Deposition Technologies to solve all these problems with a unique printed ultrasound sensor that is truly flexible, high resolution and continues to operate in high temperature/extreme environments.

Novel research developments: A key insight was that novel piezoelectric highly orientated thin film structures deposited using DC magnetron reactive sputtering from an aluminium to form aluminium nitride **[3.1, 3.2]** and zinc to form zinc oxide **[3.3, 3.4],** providing necessary piezoelectric performance for use as ultrasonic transducers. The reactively sputtered thin films result in required crystalline orientation with the necessary piezo-electric behaviour. Currently used ultrasonic transducers are machined from bulk piezoelectric ceramics such as lead zirconate titanate (PZT). Piezoelectric thin film have significant benefits compared with PZT including self-polling, have excellent Curie temperatures (consequent high temperature performance) **[3.5]**, are chemically robust and lead-free.

Work described in **[3.6]** demonstrated piezoelectric thin film performance on 20um thick flexible foil, a world first providing a method for three dimensional ultrasonic imaging. The thickness of the substrate has an effect on the resonant frequency of the transducer with the following transducer improvements - the foil, being outwards facing, provides environmental protection of the piezoelectric thin film located within the body of the transducer and the foil becomes one of the transducer electrodes - providing reduced cost and provides a process offering mass production.

The deposition of piezoelectric thin films is an advanced process. The films require an oriented crystal structure with equally exacting mechanical characteristics. To facilitate this process, Novosound uses equipment developed by the semi-conductor industry rather than with precision machining equipment used to fashion complex structures from ceramic blocks. The functional film is an additive process more akin to nanotechnology. The future of ultrasonic transducer manufacturing is likely to follow the path currently championed by Novosound. Wafer scale manufacturing of this type will lead to high volumes of useful thin films driving down costs and opening up new areas of exploitation.

The enabling technology used by the UWS ITFSI spin-out company Novosound Ltd, is the piezoelectric zinc oxide deposited on a flexible aluminium foil. This thin film material is core to the business, deposited under vacuum conditions in which the crystal structure and hence the polarisation of the functional thin-film is controlled using well-established techniques with intellectual property protected via two patents **[3.D, 3.E]**. The foil can be lightly pressed into shapes permitting the focus of the ultrasonic probe into a small volume and is ideal for medical, dental and NDE applications. Other applications using lithography permits the manufacture of transducer arrays for three dimensional imaging.

3. References to the research

3.1 Hou, R., **Hutson, D. and Kirk, K J.,** (2013) Development of sputtered AlN thin-film ultrasonic transducers for durable high-temperature applications. *Insight - Non-destructive Testing and Condition Monitoring*. 55(6): 302-307. https://doi.org/10.1784/insi.2012.55.6.302

3.2 Hou, R., **Hutson, D., Kirk, K J. and Fu, Y. Q.,** (2012) AlN thin film transducers for high temperature non-destructive testing applications. *Journal of Applied Physics*. 111(7): 074510. https://doi.org/10.1063/1.3700345

3.3 Hou, R., **Fu, Y. Q.,** Hutson, D., Zhao, C., Gimenez, E. and Kirk, K. J., (2016) Use of sputtered zinc oxide film on aluminium foil substrate to produce a flexible and low profile ultrasonic transducer. *Ultrasonics*. 68: 54-60. https://doi.org/10.1016/j.ultras.2016.02.008

3.4 Zhou, X. S., Zhang, J., Hou, R., Zhao, C., **Kirk, K J., Hutson, D.,** Hu, P. A., Peng, S. M., Zu, X. T. and **Fu, Y. Q.,** (2014) Electrode loading effect and high temperature performance of ZnO thin film ultrasonic transducers. *Applied Surface Science*. 315: 307-313. https://doi.org/10.1016/j.apsusc.2014.07.114

3.5 Hou, R., **Hutson, D. & Kirk, K J.,** (2012) Investigation of thin-film ultrasonic transducers for high-temperature application. *Insight - Non-destructive Testing and Condition Monitoring*. 54(2): 68-71. https://doi.org/10.1784/insi.2012.54.2.68

3.6 Zhou, X. S., Zhao, C., Hou, R., Zhang, J., **Kirk, K J., Hutson, D.,** Guo, Y. J., Hu, P. A., Peng, S. M., Zu, X. T. and **Fu, Y. Q.,** (2014) Sputtered ZnO film on aluminium foils for flexible ultrasonic transducers. *Ultrasonics*. 54(7): 1991-1998. https://doi.org/10.1016/j.ultras.2014.05.006

Grants

3.A Gibson, D., Hughes, D., *Ultrasound Imaging High Growth Spin Out programme*, Scottish Enterprise, May 2016 to September 2017, GBP192,658

3.B Gibson, D., Hughes, D., *Ultrasound Imaging High Growth Spin Out programme*, Scottish Enterprise, May 2017 to August 2018, GBP356,445

3.C Kirk, K J., *High Temperature Transducer*, TUV Rheinland Sonovation B.V, Dec 2016 to January 2017, GBP8,500

PATENTS

3.D Hughes, D. and Hutson, D., (2018) *Ultrasound Transducer*, Patent No. GB1619108.2, Available at:
https://worldwide.espacenet.com/patent/search/family/060331661/publication/GB2555835B?q=pn%3DGB2555835B

3.E Hughes, D. and Gibson, D., (2019) *Formation of piezoelectric devices*, Patent number EP19716472A. Available at:
https://worldwide.espacenet.com/patent/search/family/061903159/publication/EP3759745A2?q=pn%3DEP3759745A2

4. Details of the impact

Process from research to impact: The development of patented low cost mass producible ultrasonic transducers started with research on sputtering zinc oxide film technique that has been widely disseminated by the key researchers Hutson, Hoa, Kirk and Fu. The core intellectual property, relating to the manufacturing process, has been protected by Hughes, Hutson and Gibson **[3.D and 3.E].** To realise the commercial benefits, a University spin-out company has been formed with pre-incorporation funding from the Scottish Enterprise High Growth Spin-out Programme (HGSP), and the senior technical team recruited to expedite the disruptive technology **[5.1].**

New spinout company: Novosound and its novel technology attracted GBP1,500,000 Private Equity investment led by Par Equity and Kelvin Capital immediately after starting trading in 2018 and following the successful conclusion of the HGSP grant. The core intellectual property was transferred with assigned rights to exploit the technology. The uptake of interest from investors and potential end-users has been significant. The company won the Converge Challenge competition, which had around 130 competitive applications **[5.2]**. The company also received the Institute of Physics Business Award in 2019 **[5.6]**. In December 2019, the company completed a Series A investment round where Foresight Williams Technology EIS Fund invested GBP1,500,000 alongside GBP500,000 from the Foresight Scottish Growth Fund to the company **[5.3 and 5.4 b]** which is based at the BioCity Glasgow incubator **[5.3].** Kerry Sharp, Director of Scottish Investment Bank, said: "*Novosound is a young, innovative and exciting company whose work has the potential to completely transform the way ultrasound sensors are applied by addressing the limitations currently associated with the technology. The company identified a problem, has developed a solution and has done remarkably well to raise the capital required to develop its product and scale up its activities in a short space of time*" **[5.1].**

Novosound has recruited an international, high-profile chairman to lead the company in its plans to rapidly scale up. Dr Derek Mathieson, ex-Baker Hughes Senior Executive, joined Novosound in August 2020 **[5.7].** In September 2020, Dr Dave Hughes, Novosound's Founder & CTO, was awarded 'Director of the Year, Start-Up' by the Institute of Directors – selected from 200 entries and 54 final contenders **[5.8].**

Nature of impact: Ultrasonic transducers for non-destructive testing (NDT) and for diagnostic and therapeutic applications in medicine such as ultrasound have traditionally been machined from ceramics which typically contain a significant amount of lead (PZT). Limited in the frequency over which they can operate, the disruptive material exploited by Novosound is prepared by an entirely different process. The piezoelectric thin films are grown to the required thickness by physical vapour deposition using equipment developed by the semi-conductor industry. The films contain mostly zinc and challenge the use of the restricted material lead (cf RoSH Directives) in transducers. The films are also self-activating and the films are deposited on flexible substrates enabling a new range of products requiring shaped transducers.

The thin films mounted on flexible substrates also have applications in established industries using conventional inspection equipment. Ultrasonic probes are widely used to inspect the quality of welds and joints in metals and composite materials. Aerospace and the Oil & Gas industries have long made use of ultrasonic probes with limited scope to inspect complicated geometries and with the required resolution. The disruptive technology can be shaped easily and the thin film materials, if driven at higher frequencies, promise improved resolution. The main impact here is the availability of low cost bespoke solutions to hitherto complex inspections **[5.9]**. The disruptive thin film material is low profile and, by its nature, can also be permanently installed on a machine component, e.g., a bearing assembly or within a composite material. This leads to important impact in condition health monitoring of safety critical structures.

The company plans on moving in to healthcare with the primary impact for end users in the use of the films on flexible substrates for dentistry. The routine use of ionising radiation in dental examinations is of concern not only for the dental practitioners but also their patients. The reduction and possibly the total elimination of X-rays in the examination of tooth development is of particular interest in treatment in children. A scan using the disruptive technology is novel and revolutionary in this field of health care.

Economic benefits: Employing 30 staff in executive, technical, marketing, sales and administration roles (September 2020), Novosound is firmly aligned with the strategic goal for the Scottish Government to provide High Tech employment in Central Scotland **[5.4 b].** The company sells its technical products to **North America**, **UK** and the **EU** and have reduced cost of ownership and improved measurement accuracy and also improve efficiencies elsewhere in the end-user businesses. Offering solutions using this novel technology in preventative maintenance projects has reduced downtime and costs, and is of particular benefit to industries sensitive to operational losses such as the Energy Production Sector.

The deposition of piezoelectric thin films is an advanced process. The films require an oriented crystal structure with equally exacting mechanical characteristics. To facilitate this process Novosound uses equipment developed by the semi-conductor industry rather than with precision machining equipment used to fashion complex structures from ceramic blocks. The functional film is an additive process more akin to nanotechnology. The future of ultrasonic transducer manufacturing is likely to follow the path currently championed by Novosound. Wafer scale manufacturing of this type will lead to high volumes of useful thin films, driving down costs and opening up new areas of exploitation

5. Sources to corroborate the impact

5.1 Novosound secured GBP3.300,000 Series A investment which was covered by Scottish Enterprise https://www.scottish-enterprise-mediacentre.com/news/innovative-scottish-ultrasound-company-secures-gbp-3-3m-investment

5.2 Details of Converge Challenge 2017 competition:https://portal.convergechallenge.com/alumni/case-studies/novosound

5.3 Biocity, one of Scotland's leading Business Incubator Services announces Novosound as a tenant. https://biocity.co.uk/company/novosound/

5.4 Publicity of Series-A investment:

a. https://www.businessleader.co.uk/foresight-invests-2m-into-ultrasound-technology-company-novosound/78073
b. https://www.thetimes.co.uk/article/holyrood-growth-fund-backs-groundbreaking-ultrasound-start-up-dzp5ldw83

5.5 As a result of Novosound's sector leadership the Scottish Government announces extra financial support for high growth spin out businesses https://www.gov.scot/news/investing-in-scotlands-entrepreneurs-and-innovators/

5.6 Details of the Institute of Physics Award 2019 https://digit.fyi/novosound-institute-of-physics-awards/

5.7 Publicity of the appointment of Dr Derek Mathieson, August 2020. https://www.scotsman.com/business/expanding-scots-tech-innovator-novosound-names-former-baker-hughes-exec-chairman-2950998

5.8 Publicity of Dr Dave Hughes' IoD Award, September 2020. https://www.scotsman.com/business/top-scottish-company-directors-recognised-iod-awards-2965451

5.9 The Aerospace industry announces the arrival of Novosound technology which will revolutionise aerospace engineering: https://www.aerospacetestinginternational.com/news/ndt/thin-film-ultrasonic-sensor-for-aerospace-ndt-to-launch-in-june.html

5.10 The British Institute of Non Destructive Testing announces the arrival of Novosound technology https://www.bindt.org/News/April-2020/overcoming-the-limitations-of-conventional-ultrasound-sensors-in-ndt-with-proprietary-and-novel-thin-film-technology/