| Institution: University of Bolton | | |
|---|---|---|
| **Unit of Assessment: B12-Engineering** | | |
| **Title of case study: The Commercialization of Advanced FBAR Sensors for Gas Detection and Particle Monitoring** | | |
| **Period when the underpinning research was undertaken: 2009 - 2019** | | |
| **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:** |
| Jack Luo | Professor | 2007 - 2020 |
| **Period when the claimed impact occurred: 2009 - 2020** | | |
| **Is this case study continued from a case study submitted in 2014?** N | | |

**1. Summary of the impact** (indicative maximum 100 words)

Research conducted by the University of Bolton in collaboration with University of Cambridge has significantly enhanced the capabilities within the fields of gas detection and particle monitoring. The EPSRC funded project (EP/F062966/1) led to the development and commercialization of advanced film bulk acoustic resonator (FBAR) sensors. Sorex Sensors Ltd. was formed by Cambridge Enterprise following the award of international patent, WO2013088163A1 to pursue commercialisation of this new technology. To date, Sorex Sensors Ltd. have generated a total of £2.1M in funding, employed six people and have an annual turnover of £500k per year.

**2. Underpinning research** (indicative maximum 500 words)

Research and development of the wireless sensor technology commenced in 2010 with an EPSRC funded [G1], £1.2M project, led by Prof. Luo at University of Bolton in collaboration with Universities of Cambridge and Manchester. The project led to the development of extremely high sensitivity sensors that are able to detect changes in mass as small as a few femtograms, the similar mass as a single virus. By coating the sensor surface with specific materials, the devices are able to respond to presence of particular biological and chemical targets, thus can be tailored for specific detection and monitoring applications.

The advancements documented in [3.1] highlight several advantages of the FBAR devices over pre-existing sensors: (a) they have extremely high mass sensitivity, down to a few femtograms; (b) they are very small in size, typically 100x100 to 200x200 $\mu m^2$, therefore allowing arrangement into arrays to enable measurement of multiple targets simultaneously; (c) the sensors have an incredibly low power requirement, allowing them to be operated by a coin cell battery in mobile phone or by energy harvesting from an RFID device; and (d) the sensor has dual-wave mode, thus allowing detection/sensing of two-parameters using one sensor, or one sensor with self-temperature calibration capability negating need for additional electronics for temperature calibration [3.1].

The breakthrough made within the research therefore led to the granting of an international patent (PCT/GB2012/053139) due to the identification of environmental sensor changes and temperature sensor changes with a two-layer bulk resonator. The patent was granted validating the sensors' novel capability to overcome previous challenges in regard to temperature compensation. The new sensors enable separated detection of resonances as they behave differently in response to temperature changes in contrast to stress changes.

The technical development of the sensors is documented in [3.2, 3.3, 3.6] and evidences the extent to which a shift in one or both of the piezoelectric layer resonant frequency and the combination resonant frequency is detected with the portion of the shift caused by a temperature change, and can be separated from that caused by an environmental change, realizing one sensor based detection with temperature calibration.

Following the successful development of the technology, Luo then expanded the research into smart fire protection products in collaboration with TBA Textile Ltd, funded by the KTP scheme [G2]. The research utilised the know-how gained from the previous project to develop a wireless sensor chip with integrated temperature and humidity sensors, and other electronics, capable of sensing and reporting the fire environment, the fire location and movement, towards the development of active fire protection products.

Since 2018 Luo's research has continued into integrating FBAR sensor technology within a wireless sensor system for convenient, reliable and low-cost screening and diagnosis of obstructive sleeping apnea (OSA) in mass populations. This led to a KTP project [G3] with Passion for Life Healthcare for the development of an innovative app-enabled flexible wireless sensor chip which fits on the upper lip, with the potential to detect OSA in a comfortable and reduced stress environment.

## 3. References to the research (indicative maximum of six references)

The research resulted in at least 40 papers, with 6 representatives listed below:

3.1 L. Garcia-Gancedo, J. Pedros, X.B. Zhao, G.M. Ashley, A.J. Flewitt, W.I. Milne, C.J.B. Ford, J.R. Lu, J.K. Luo, "Dual-mode thin film bulk acoustic wave resonators for parallel sensing of temperature and mass loading", Biosens. Bioelectron. 38 (2012) 369-74. https://doi.org/10.1016/j.bios.2012.06.023

3.2 L. García-Gancedo, J. Pedrós, E. Iborra, M. Clement, X.B. Zhao, J. Olivares, J. Capilla, J.K. Luo, J.R. Lu, W.I. Milne and A.J. Flewitt, "Direct comparison of the gravimetric responsitivities of ZnO-based FBARs and SMRs", Sens. Actuat. B. 183 (2013) 136-43. https://doi.org/10.1016/j.snb.2013.03.085

3.3 X.B. Zhao, G.Ashley, L.Garcia-Gancedo, H. Jin, J.K. Luo, A.J. Flewitt, J.R. Lu, "Protein functionalized ZnO Thin Film bulk acoustic resonator as an odorant biosensor", Sens. Actuat. B 163 (2012) 242-46. https://doi.org/10.1016/j.snb.2012.01.046

3.4 X.B.Zhao, F.Pan, G.Ashley, L.Garcia-Gancedo, J.K.Luo, A.Flewitt, W.I.Milne and J.R.Lu, "Label-free Detection of Human Prostate-Specific Antigen (hPSA) Using Film Bulk Acoustic Resonators (FBARs) and Spectroscopic Ellipsometry", Sens. Actuat. B 190 (2014) 946. https://doi.org/10.1016/j.snb.2013.09.064

3.5 K.J. Xie, S.M. Zhang, S.R. Dong, S.J. Li, C.N. Yu, K.D. Xu, W.K. Chen, W.Guo, J.K. Luo, Z.H. Wu, "Portable wireless electrocorticography system with a flexible microelectrodes array for epilepsy treatment", Sci. Rep. 7 (2017) 7808. https://doi.org/10.1038/s41598-017-07823-3

3.6 A. Flewitt, W. Milne, L.Garcia-Gancedo, J. Luo, 'Identification of environmental sensor changes and temperature sensor changes with a two layer bulk acoustic wave resonator', International patent WO2013088163A1. https://patents.google.com/patent/WO2013088163A1/en

*Grants*

G1. J. Luo, '**Film Bulk Acoustic Resonator-based Ultra-Sensitive Biosensor Array Using Low Cost Piezoelectric Polymer as the Active Material'** (2008 – 2012). EPSRC (EP/F06294X/1), £282K.

G2. J.Luo, 'Smart fire protection products' (2016 – 2017) .KTP010325 - Knowledge Transfer Partnership between The University of Bolton and TBA Textiles Limited, Funded by Technology Strategy Board. £58K

G3. J. Luo, 'Wireless sensors for detecting obstructive sleep apnoea' (2018 – 2021) KTP011210 – Knowledge Transfer Partnership between The University of Bolton and Passion for Life Healthcare (UK) Limited, Funded by Innovate UK, £114K

**4. Details of the impact** (indicative maximum 750 words)

The research led by Bolton has delivered the underpinning science and technology for developing new FBAR devices that have significantly enhanced the accessible functionality and capability of next generation chemical and physical sensors. The high performance and lower cost proposition of the FBAR based technology gained support from Cambridge Enterprises, which then led to the creation of Sorex Sensors Ltd. The arising intellectual property has since been protected through the granted patent: WO2013088163A1 and commercialisation of the technology is being led by Sorex Sensors Ltd., of which Andrew Flewitt, Prof. Luo's co-investigator during the EPSRC funded project (EP/F062966/1) is on the board of Directors.

To date, Sorex Sensors Ltd have generated a total of £2.1M in seed funding, employs six people and has an annual turnover of just over £500k per year. The company operates in a well-established global market for sensors estimated to be £133 billion in 2019 growing to £249 billion by 2024 (a CAGR of 13.3%) [5.1]. In 2018, The University of Bolton also received £1120 in fees associated to the patent recognition of the instrumental role Prof. Luo played in the development of the new technology [5.2, 5.3].

In October 2019, Sorex Sensors Ltd. launched its first product of which Andrew Flewitt cited the FBAR sensor as a central component in his supporting statement. The product which would not have been possible without the development of the FBAR technology utilises the sensors' versatility by creating a platform to enable developers to incorporate the FBAR sensor within a broad range of lab-on-chip applications such as the monitoring of indoor air quality. The product consists of marketing the FBAR sensor alongside a development kit to enable end users to visualize the data collated by the sensor. Currently, the sensor and the development kit are designed to be utilised within semiconductor manufacturing equipment, such as atomic layer deposition systems, where it can monitor amounts and deposition rates of ultrathin films.

Since its initial development, this FBAR sensor technology has been identified as having a broad range of applications, particularly within the fields of gas detection and particle monitoring. Sorex stated that they are continuing to utilise the lab-on-chip FBAR sensor technology developed by Prof. Luo to target applications in monitoring of the indoor air quality [5.2]. In Andrew Flewitt' s wording:

*There is also emerging evidence that poor indoor air quality is an indicator of a high risk of COVID being spread in the environment. As such, we believe that this technology has the potential to have a highly beneficial impact on everyone's health and wellbeing in the medium term.*

The development of FBAR sensors has also led to an increased capacity within the field of wireless sensor and their capabilities. As a result of the new thin film acoustic wave devices researchers around the world now have the capability to explore and develop integrated, disposable, and flexible lab-on-chip devices into various sensing and actuating applications, particularly in biochemical sensors, physical sensors, wireless sensor networks for Internet of Things, smart manufacturing, smart city etc.

The FBAR sensor consists of a metal-thin film piezoelectric material-metal sandwich resonating structure of the size of 100x100$\mu m^2$, and can be fabricated by CMOS-compatible process, which ensures the low cost and mass production. This is a result of the sensor design which changes the resonant frequency of the device, providing an extremely accurate measurement of the amount of mass on the sensor. Furthermore, the sensor uses microwatts for power and can detect changes in mass down to femtograms the same order of magnitude of mass of a single virus. Combining all these factors and increased capacity means the new FBAR sensor is not only the most accurate sensor available but also the most cost effective and readily manufactured using established industrial processes, therefore has both a significant economic and environmental impact.

**5. Sources to corroborate the impact** (indicative maximum of 10 references)

5.1 https://www.bccresearch.com/market-research/instrumentation-and-sensors/sensors-technologies-markets-report.html Report on Sensors: Technologies and global markets

5.2 Director, Sorex Sensors LTD. *Confirms the use and impact of the research at Sorex Sensors LTD.*

*5.3* Post-Deal Coordinator, Cambridge Enterprise Ltd. *Confirms invention agreement between University of Bolton and Cambridge Enterprise Ltd and payments made for the use of the research by Sorex Sensors Ltd.*