Research Assessment Exercise 2020
Impact Case Study

University: The Hong Kong Polytechnic University (PolyU)
Unit of Assessment (UoA): 08 Materials Science and Materials Technology

Title of case study: Creating and improving products for China's largest medical ultrasound producer

(1) Summary of the impact

PolyU's research collaboration with the Shantou Institute of Ultrasonic Instruments Co. Ltd (SIUI) has significantly improved medical imaging devices as well as economically benefitting the company. Professor Dai's research group has improved the performance of existing products, helped develop new products (one already on the market, a second in clinical trials, and a third in production), and delivered training to boost the company's R&D capabilities. These innovations have made the company more internationally competitive. Products improved or developed through PolyU research have had combined sales of over HK$20 M during this RAE period.

(2) Underpinning research

Ultrasounds are essential in modern medicine, providing real-time images of tissues, their movement and blood flow. Increasing the resolution of transducers and creating the ability to form real-time video images of moving parts is an invaluable aide to improving disease diagnoses.

Professor Jiyan Dai (Department of Applied Physics, PolyU, 2001-present) and his research group have focused on improving medical ultrasound transducers for the last 15 years. Ultrasound transducers (or probes) are piezoelectric devices that generate high-frequency sound waves to detect and form images of human organs and tissues. These images aid diagnoses and therapeutic treatments in hospitals.

Dai's research group has been devoted to developing many kinds of medical ultrasonic transducers from single element probe to array-type transducers. The team's single element ultrasound probes include endoscopic type transducers for digestive tract diagnosis and intravascular imaging for cardiovascular disease diagnosis. Dai's group has also developed high-frequency phase-array ultrasound transducers which can electronically focus and steer the ultrasound beam more rapidly and precisely than physically moving a single-element probe. Dai's transducers can form video images of the heart which is crucial for cardiac diseases diagnoses. With higher frequencies, the image resolution increases proportionally and therefore these can be used for small organs (such as eyes and even the hearts of embryos), neurons and skin etc. Details of the three main areas of research are outlined below.

Dai's group proposed a new acoustics matching scheme (double 1/8 wavelength of thickness instead of standard double 1/4 wavelength thick) for their transducers [1]. A medical ultrasound transducer needs an acoustic matching layer (created from different resin materials) between the piezoelectric element of the probe and the target body part being scanned, otherwise the large difference in acoustic impedances between the two prevents the sound waves from penetrating. Dai's group's innovation improves ultrasound effectiveness via improvements to this matching layer. This reduces the matching layer thickness while maintaining effective acoustic energy transmission and has been proven to increase the phase-array transducers bandwidth thereby greatly improving image quality.

A further research focus from Dai's group is the single crystal-based high-frequency (20 MHz) ultrasound phase-array transducers [2]. Research, published in 2017, developed a new acoustic matching material with high acoustic impedance and low acoustic loss as part of the high-frequency array transducer's design and fabrication process. The piezoelectric elements possess very large acoustic impedance compared to the human body (30 vs 1.5 MRayl in standard unit of acoustic impedance). A matching layer with acoustic impedance close to 8 MRayl does not exist in nature, but Dai's group synthesized a composite with such impedance value and with low attenuation, making the matching layer more effective at allowing acoustic energy transfer from transducer to human body [2].

For small probe ultrasound transducers, image quality depends on the beam focus and bandwidth. Previously the only technique available to create a focused probe transducer was to use a metal ball to press the piezo crystal into a concave shape to focus the beam. However, the crystal is broken into many small pieces. This drawback can cause significant reliability issues. Dai's key innovation was to 'dimple' the crystal; by developing a grinding technique which creates the concave shape without damaging the crystal, Dai not only improved the transducer's focus but also enlarged its bandwidth frequency. Dai's research has shown that this invention increases the generated ultrasound beam's focus, while also increasing the bandwidth by 30% compared to previous techniques [3]. Ultrasound imaging resolution increases in both lateral and axial directions. A patent, filed in 2009, [4] has subsequently been developed in the Dai team's ongoing PolyU research [5, 6].

(3) References to the research

[1] S. T. Lau, H. Li, K. S. Wong, Q. F. Zhou, D. Zhou, Y. C. Li, H. S. Luo, K. K. Shung, and J. Y. Dai, Multiple matching scheme for broadband 0.72Pb (Mg1/3Nb2/3) O3−0.28PbTiO30.72Pb (Mg1/3Nb2/3) O3 − 0.28PbTiO3 single crystal phased-array transducer, *J. Appl. Phys.* 105, 094908 (2009).
[2] Chi-Man Wong, Yan Chen, Haosu Luo, Jiyan Dai, Kwok-Ho Lam, Helen Lai-wa Chan, Development of a 20-MHz wide-bandwidth PMN-PT single crystal phased-array ultrasound transducer, *Ultrasonics* 73 (2017) 181–186.
[3] Y. Chen, K.H. Lam, D. Zhou, W.F. Cheng, J.Y. Dai, H.S. Luo, H.L.W. Chan, High frequency PMN-PT single crystal focusing transducer fabricated by a mechanical dimpling technique, *Ultrasonics*, 53, 345-349, Feb (2013).
[4] K.H. Lam, Y. Chen, J.Y. Dai, H.L.H. Chan, Rotational Ultrasound Imaging System (旋转超声成像系统), *Chinese Patent*: ZL201010 542689.2. Licensed to SIUI Ltd.
[5] Dan Zhou, Kwok Fung Cheung, Yan Chen, Sien Ting Lau, Qifa Zhou, K. Kirk Shung, H.S. Luo, J.Y. Dai and H.L.W. Chan, Fabrication and Performance of Endoscopic Ultrasound Radial Arrays Based on PMN-PT Single Crystal/Epoxy 1-3 Composite, *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, vol. 58, 477 (2011).
[6] J. Chen, J.Y. Dai, C. Zhang, Z.T. Zhang, and G.P. Feng, Bandwidth improvement of LiNbO3 ultrasonic transducers by half-concaved inversion layer approach, *REVIEW OF SCIENTIFIC INSTRUMENTS* 83, 114903 Nov (2012).

Professor Dai's research has received funding of RMB 5.3M by the National Basic Research Program of China and a total of HK$6.5M from three competitive ITF grants.

(4) Details of the impact

Shantou Institute of Ultrasonic Instruments Company (SIUI) is one of China's leading medical ultrasound systems manufacturers. They have been the Chinese government's preferred choice for

medical equipment since 2014 [A]. Dai's group have been collaborating with SIUI since 2005. The company has benefited from the research when developing single crystal transducers and producing different transducer types, in particular high-frequency (10 MHz above) arrays. Director & Deputy General Manager, SIUI:

> *"Prof. Dai's research into ultrasound transducers is forward-looking and responsive to the development of the industry. The ideas and methods of his group's research are advanced and innovative, and have provided us with advantages for the development of new products, advice on solutions to our production problems, and helped us train our staff to improve our own R&D. The collaborations with Professor Dai have helped our technology and our products improve, increasing our company's competitiveness*" [B]

SIUI is China's biggest manufacturing base of ultrasound instruments, with multiple advanced production lines and a global sale/service network. Currently SIUI's annual production capability is up to 20,000 transducers for medical ultrasound [A]. They also produce industrial ultrasonic detectors, and medical imaging systems, employ around 600 staff and generate a total annual production value of RMB 500 M (HK$556 M) [B]. The collaboration between PolyU and SIUI has had the following impacts:

Economic impact through development of new transducers
Dai's research has helped SIUI develop ***three new transducers***, with one already on the market.

The new acoustic matching materials and technical fabrication skills for high-frequency transducers helped SIUI to develop a new transducer: a super high-frequency linear array transducer with frequency higher than 10 MHz [2]. This increased bandwidth improves resolution. The transducer (model L10LC) has been used in products on the market since 2016 (e.g. in the *Apogee 5T*, and the newly launched *Apogee 6500* ultrasound product [C]). To date, more than 100 units have been sold to more than 10 countries and 80 hospitals from East Asia to Europe with sales of about RMB 18 M (HK$20M) [B].

According to a hospital that purchased an L10LC product, the transducer leads to "***better diagnostic effects***" compared to conventional linear array transducers on a wide range of tissues, including superficial tissues such as thyroid and mammary glands, as well as musculoskeletal, peripheral nerve and peripheral blood vessels, etc. Their tests found better spatial resolution and grey-scale contrast, and more sensitive colour Doppler [D].

Figure 1 shows an L10LC thyroid scan (right hand side) versus a lower frequency transducer.

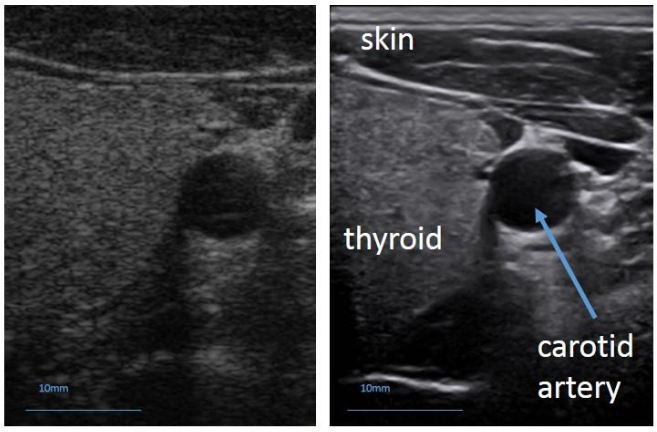

Figure 1. Left = 7MHz, Right = 14MHz L10LC

SIUI's website notes, "*At the trade show this year, SIUI's brand new ultrasound imaging solutions - Apogee 6500 - attracted a lot of attention with their intelligent processing technology, excellent image quality, high working efficiency and ergonomic design.*

Moreover, equipped with a high frequency probe whose center frequency is over 10MHz, Apogee 6500 is able to produce outstanding performance in peripheral nerve and musculoskeletal ultrasound. It has won great admiration from all the professionals by showing images with high resolution even on difficult patients." [E].

In 2018, SIUI licensed our patented technique for creating a concave crystal surface [3, 4], and based on this have developed a new transducer that rivals global brand leaders, such as Philips and Siemens, in terms of reliability and resolution. The transducer (S10R) is currently being validated through a clinical trial started in August 2019 and due to finish in September 2020.

SIUI has also developed a new single-crystal phase-array transducer (P3I20) based on the advanced acoustic materials research [1]. This is entering production and is expected to be on the market by 2020. SIUI note that "*The development of these new transducers has boosted our company's technical capabilities as well as enhanced our market competitiveness*" [B].

Improving commercial competitiveness through product improvement
Applying PolyU research, ***three product types have been improved*** [B], further boosting SIUI's competitiveness.

By adopting our acoustic matching scheme [1], SIUI's array transducers have shown superior bandwidth performance improving the quality of the scans for users. In this RAE period, the relevant probe products enjoyed sales of RMB 2.5M (HK$2.78 M) [B]**.**

The design methods of matching layers and backing layer [1] are also partially used in producing high-frequency transducers with super-wide bandwidth. In this RAE period, these transducers enjoyed sales of RMB 2.5M (HK$ 2.78M).

The new acoustic matching materials [2] for high-frequency transducers helped SIUI improve the fabrication technologies for a sub-category of SIUI ultrasound products with larger than 10 MHz frequency. The sales value of this family of products is about RMB 13M (HK$14.4 M) in this RAE period.

Increasing innovation and knowledge
SIUI have also benefited from their long-term relationship with Professor Dai through ongoing access to the group's latest research and knowhow. SIUI sent two engineers for three months in 2018 to receive training from Dai's group in making single crystal ultrasound transducers. From this training, knowledge about piezoelectric single crystals and processing skills in making phase-array transducers have been transferred to the company, ***improving their R&D strength***. Engineers have also been sent to Dai's group for shorter visits in 2019 to learn the design and fabrication technologies of self-focus type transducers, high-frequency phase-array transducers and 2D array transducers.

Director of SIUI: "*The training from Prof. Dai enhanced the research skills and research methods of our technical staff and equipped them with the cutting-edge knowledge about the advanced technologies in this field, promoting their growth and benefiting the company."* [B].

(5) Sources to corroborate the impact

[A] SIUI Company profile (archived webpage, July 2019)
[B] Letter from Director & Deputy General Manager, SIUI (October 2019)
[C] Product details for Apogee 6500 (archived webpage, July 2019)
[D] Testimony from the Department of Medical Equipment, Nanchang County Peoples Hospital (October 2019)
[E] Apogee 6500 launch (archived webpage, Nov 2019)