Research Assessment Exercise 2020
Impact Case Study

University: The Hong Kong Polytechnic University (PolyU)
Unit of Assessment (UoA): 8 Materials Science and Materials Technology

Title of case study: New products and jobs from flexible electronic devices research

(1) Summary of the impact

PolyU materials researchers' investigations into functional materials, device design and the fabrication and characterization of flexible electronics have generated commercial and economic impacts. Using our new technologies, *AdvanPro*, a high-tech spin-off company, has developed their own industrial production line and are designing, producing and marketing mobile-connected wearable monitoring systems for healthcare and sports in China. This company has created 60 new jobs, sold over 32,000 products and has generated approximately HK$22.4 M in total sales during this RAE period. *Aide Inc.*, a second high-tech spin-off based on the same technologies and created by PolyU graduates in 2016, has created 10 jobs and is currently developing products for market.

(2) Underpinning research

Wearable electronics is a huge growth market estimated to reach US$56.8 billion by 2025. However, the underpinning technologies still have problems to be solved. Conductive fibers or fabrics are fundamental to wearable electronics but their performance is often poor due to low conductivity. Furthermore, washing and exposure to sweat corrodes the metal elements, severely limiting product lifespans.

Materials researchers Dr. Yu Wang (2007-2015) and Dr. Yang Chai (2012-present) of the *Department of Applied Physics* have been investigating flexible electronic materials and fiber-based devices, in close collaboration with PolyU's *Institute of Textiles and Clothing*.

Conductive fiber or fabric is an indispensable part of wearable electronics. Conductivity is usually achieved by coating the fibers with very thin metal. To be effective this coating must have negligible effects on the substrate, be compatible with the electronics fabrication process at low temperature, and be stable during mechanical abrasion, bending, twisting and washing.

A magnetron sputtering process can be used to apply nano-scale metal coatings onto fabric. PolyU researchers investigated the critical factors affecting such depositing onto polymeric films, fibers, and fabrics [1, 2]. Research showed that the fibers' surface conditions, including surface roughness and the chemical composition of the fiber materials, cause remarkable differences in the electrical conductance of the finished metal coating. Through our research, we developed new ways to optimally alter a fibres' surface conditions before applying coatings. Our technique produces fabrics with high conductivity and excellent fatigue resistance. The silver coated fabrics can monitor the electrical activity of the human heart (electrocardiogram), comparable to the performance of commercial rigid electrodes, but with far more wearer comfort. This technology can create stretchable sensors, electrical connecting tracks, fabric circuit boards and fabric antenna.

Corrosion, through washing and human perspiration, has been a serious problem for fiber-based wearable electronic devices. To avoid corrosion most fiber-based devices must be packaged in a water- and gas-tight manner. This makes maintaining the metal coating's conductivity and stability extremely challenging. Dr. Chai and his team developed an innovative drape-coating method using highly impermeable graphene as a barrier layer to protect the metal coating. This graphene protection layer reduced the corrosion rate of the metal coating by approximately 66 times [3]. Long-term anti-corrosion performance can further be enhanced by replacing conductive graphene with an insulating boron nitride layer [4]. This method can be extended to protect the semiconductor part of the device which is particularly vulnerable to photocorrosion. Markedly improved photocorrosion resistance was achieved by draping graphene layers over a semiconductor CdS electrode. The lifetime of a three-layer-graphene-draped CdS photocatalyst is 8 times longer than a CdS counterpart without graphene draping [5]. This is in addition to preventing sweat-induced corrosion.

(3) References to the research

Names in bold are PolyU researchers within UoA08

[1] Wang RX, Tao XM, **Wang Y** and Wang GF, 2009. Electrical Properties and Fatigue Resistance of Polyamide 6,6 Fabrics with Nano-crystal Silver Coating, *Journal of NanoScience and Nanotechnology*, 9(5): 3062-3066.

[2] Wang RX, Tao XM, **Wang Y**, Wang GF, Shang SM, 2010. Microstructures and electrical conductance of silver nanocrystalline thin films on flexible polymer substrates, *Surface & Coatings Technology*, 204(8) 1206-1210. (The Research Grant Council, Hong Kong SAR Government (grant number: PolyU 5277/07E))

[3] **Zhao YD, Xie YZ, Yeung YH, Tang LB, Jie WJ,** Jiang YF, Xu L, **Lau SP**, **Chai Y**, 2013. Highly impermeable and transparent graphene as an ultra-thin protection barrier for Ag thin films, *Journal of Materials Chemistry C*, 1: 4956-4961.

[4] **Shen LT, Zhao YD, Wang Y, Song RB**, Yao Q, Chen SS, **Chai Y**, 2016. A long-term corrosion barrier with an insulating boron nitride monolayer, *Journal of Materials Chemistry A*, 4, 5044-5050. (Research Grant Council of Hong Kong (grant number: PolyU 252001/14E))

[5] **Wang MY, Cai LJ, Wang Y, Zhou FC, Xu K,** Tao XM, **Chai Y**, 2017. Graphene-Draped Semiconductors for Enhanced Photocorrosion Resistance and Photocatalytic Properties, *Journal of the American Chemical Society*, 139(11): 4144-4151. Research Grant Council of Hong Kong (grant number: PolyU 252001/14E)

(4) Details of the impact

Smart wearables for health, medicine and sports is a huge new market growing at 11% a year and estimated to reach US$56.8 billion by 2025. Market opportunities abound for those who can provide products that are more effective and integrate better with clothing and shoes than their competitors.

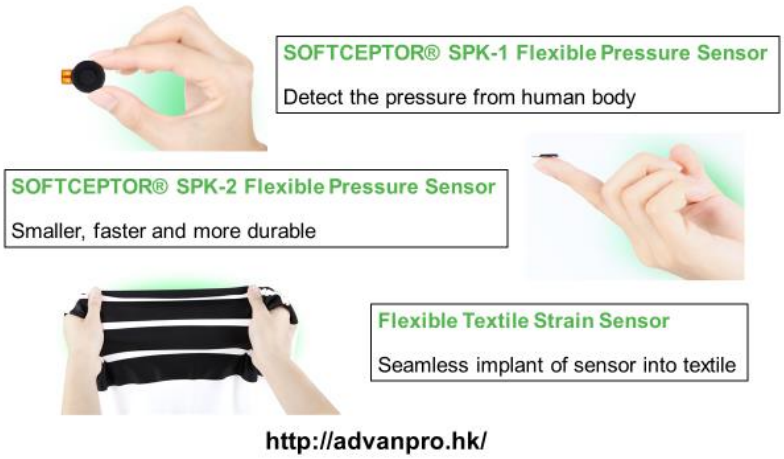
Since 1 October 2013, our high-tech spin-out company *AdvanPro*, established to exploit the above research findings, has [A]:

- created 60 new jobs (growing the company from 10 to 70 employees),
- raised nearly RMB 40 M (HK$44.9 M) in investment,
- sold over 32,000 products
- reached an annual sales value in 2018 of ~ RMB 10 M (HK$ 11.2 M), with total sales in the period of ~RMB 20 M (HK$ 22.4 M)

The *AdvanPro Technology Company Ltd* (*AdvanPro*) was formed by PolyU graduates and a former PolyU postdoctoral assistant in 2010. Supported by PolyU in its earliest stages, it received a HK$100 K *Micro Fund* award as seed funding in 2012, and training workshops and mentoring support through our *Institute for Entrepreneurship* (IfE). *AdvanPro* continues to receive advice and support from PolyU academics to the present day, and received informal support from IfE after 1 October 2013.

The innovative nature of PolyU conductive fibers has enabled *AdvanPro* to develop and commercialize soft, flexible fiber-based strain sensors and pressure sensors [A, B]. By themselves these fibers would not be suitable for commercial wearable sensors as they would suffer from moisture- and sweat-induced metal corrosion. Conventional protective plastic shells would be electrically insulating and relatively bulky. But PolyU's graphene coating solution is highly impermeable, electrically conductive, effectively protecting metal coating from reacting with oxygen or moisture as well as being lightweight. This technology greatly enhances the sensors' reliability and has enabled the company to develop products that are both comfortable and highly reliable.

AdvanPro used this conductive textile, and anti-corrosion coating to devise three innovative sensors: *Softceptor SPK1*, *Softceptor SPK2*, and the *Fabric Strain Sensor*. These sensors provide the foundation of the business, but the company takes an integrated approach and is focusing on providing whole solutions to other business customers: they design products, integrate both hardware and software, process and analyze acquired physiological signals.



Early sales were focused on sensors, but rapid growth in 2018 has seen success with two new products leading to ***annual sales now around RMB 10 M (HK$11.2 M)*** and ***total sales in the period of approximately RMB 20 M (HK$22.4 M)*** [A].

The two main customers benefiting from *AdvanPro*'s sensors and integrated solutions are *Nuojin Enterprise* and *Shandong Lafeng*.

Nuojin manufactures and sells smart wearable devices. Working with AdvanPro offers them access to their sensors which they say: "*have a large measuring range, high sensitivity, good elasticity, low modulus similarly to skin, excellent stability and long-term fatigue performance. The safe material system makes it very suitable for the measurement of strain and pressure in the fields of health case, sports, industrial measurement and so on*" [C].

For *Nuojin, AdvanPro* has developed an '*intelligent breathing trainer*' using their strain sensor, enabling them to bring a new product to the Chinese domestic market. This product helps pregnant women to use the *Lamaze* breathing technique to aid labour which can reduce stress, and therefore the need for assisted deliveries. This product is ***the world's first wearable device that provides real-time monitoring to aid Lamaze training***, with software tutorials and coaching. *AdvanPro* explain "*because (we are) the only company in China that can design, manufacture, integrate software and hardware*

technologies, analyze the output signals, and construct the interface directly for users; it greatly saves time and cost for customers like Nuojin". *Nuojin* ***bought over 24,000 units*** *from AdvanPro* in 2018 [A].

Shandong Lafeng is a clothing company with over 400 employees that exports to Japan, South Korea, and the United States among others. *AdvanPro* have developed '*Intelligent Pants for Breathing' –* ***trousers with smart sensors able to monitor steps, breathing and even falls.*** This product, which integrates Softceptor pressure sensors, first went on sale in 2018, and *Shandong* have ***purchased around 8,000 pairs*** to date.

As well as developing and selling products to other businesses, *AdvanPro* aim to start selling their own brands and have developed a *Smart Running Insole* [E] which they will bring to market in 2020. Already recognized as an innovative product, it won the iF Design Award *(Product)* in 2018 [**F**] for its ability to accurately track activity in addition to providing accurate gait analysis based on real-time pressure distribution on the sole and heel of the foot.

A prototype breathing belt built by *AdvanPro* won 'Best Lifestyle Award' at the 2016 *Hong Kong ICT Awards* [D].

AdvanPro has grown to be successful during this RAE period, ***increasing staffing from 10 to 70*** with around ***50 employees in highly skilled R&D roles*** and ***obtaining nearly RMB 40 M (HK$44.9 M)*** from angel investors and venture capital funds since 1 Oct 2013 [A].

This investment has enabled the company to ***build the world's first wearable sensor automatic production line*** for pressure sensors. This production line enables rapid mass production, ***with a capacity of 16 million items annually***. The automation means that only 2 employees are required for manufacturing, a ***cost saving that can be passed on to AdvanPro's customers*** [A].

Based on PolyU's conductive fiber research, a ***second start-up, Aide Inc,*** was founded in 2016. Currently ***employing 10 staff, it has a number of Smart ECG products in trial production*** for medical certification and is developing more [G, H].

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

[A] Letter from Managing Director of AdvanPro, September 2019
[B] AdvanPro website with sensor information (archived November 2019)
[C] Nuojin Enterprise website discussing earlier prototype product and their partnership with AdvanPro (archived November 2019)
[D] AdvanPro website announcement about Smart Breathing award (archived April 2019)
[E] AdvanPro website featuring smart insole (archived April 2019)
[F] iF Design Award, 2018, website (archived April 2019)
[G] Letter from CEO, *Aide Inc*, October 2019
[H] *Aide Inc* product website (archived April 2019)