Research Assessment Exercise 2020
Impact Case Study

University: The Hong Kong Polytechnic University (PolyU)
Unit of Assessment (UoA): 9 Chemistry

Title of case study: Nano-based Ink Technology against Counterfeiting and Tampering

(1) Summary of the impact

PolyU researchers' breakthrough indelible ink has led to large scale economic, industry and food safety benefits. Enough of this ink is sold annually to print 30 billion food and drink packages. A new company *Xianhong*, launched in 2013 to develop and commercialize the ink, is providing tamper-proof expiry dates and product information for some of China's biggest food and beverage manufacturers. Our patented award-winning ink has enabled *Xianhong* to rapidly grow with over 60 employees now working on ink-related business. *Xianhong* listed on the stock market in 2016. Annual sales revenue was RMB 150M in 2018 generating a net profit of RMB 20.5M. Three of the top dairies in the world (*Nestle*, *Yili*, *Mengniu*) use the ink, and sales cover 14% of the Chinese fast-moving goods industry. Modified ink is used by 23% of China's cable and wire industry for its high rub-resistance.

(2) Underpinning research

Professor Pei Li's fundamental research at PolyU into the design and synthesis of nano- and micro-particles, and particularly her work on nano-coatings, led to the development of a new tamperproof ink formulation. Professor Li's research group developed several new methods of creating core-shell and hybrid polymer particles (for example, hydrophobic cores with hydrophilic shells [1]). This platform technology has a wide range of applications including the creation of antibacterial coatings on various substrates [2, 3].

This research attracted *Hallyuen Holdings'* attention as they had a long-standing industry challenge they wished to solve – how to protect product labels. The company believed that Li's research on materials and interfacial properties could be exploited to develop an ink that would, unlike traditional formulations, permanently bind with a plastic substrate. In 2011, the company funded Professor Li and her team to create a tamperproof ink and printing method that could be applied on plastic substrates such as food packaging.

After more than two years of research and development, Professor Li devised a breakthrough nano-based ink formulation in 2013. The novel feature of the new 'anti-erasing' ink's composition was to include two or more colorants, at least one being hydrophobic. They are able to phase-separate during the printing process. Printing this ink composition on multilayered plastic packaging provides a *double-layered double-coloured* print. The first layer is the surface colorant, which can be removed by an organic solvent. However, the hydrophobic colorant stains non-porous substrates such as low-density polyethylene (LDPE) and therefore remains, leaving a watermark of the surface print which is highly resistant to chemical and physical stress [4-6], see *figure 1*.

Professor Li and her team's subsequent research has expanded on this initial solution to develop a series of ink formulations including indelible inks, migration-resistant inks, oil-resistant inks, alcohol-resistant inks, rub-resistant inks and water-resistant inks and hence a plethora of possible applications.

(3) References to the research

[1] **Pei Li,** Junmin Zhu, Panya Sunintaboon, Frank W. Harris. New route to amphiphilic core-shell polymer nanospheres: Graft copolymerization of methyl methacrylate from water-soluble polymer chains containing amino groups. *Langmuir*, 2002. **18**(22): p. 8641-8646. (*Citations = 124, Scopus, Nov 2019)*
[2] Weijun Ye, Man Fai Leung, John Xin, Tsz Leung Kwong, Daniel Kam Len Lee, **Pei Li.** Novel core-shell particles with poly(n-butyl acrylate) cores and chitosan shells as an antibacterial coating for textiles. *Polymer*, 2005. **46**(23): p. 10538-10543. *(Citations = 135, Scopus, Nov 2019)*
[3] **Pei Li,** Yong Jin. Substrate Coating with Aqueous-Based Multifunctional Core-Shell Particles. United States Patent No. 8993065 B2. 13 Mar 2015.
[4] **Pei Li**, Kin Man Ho, Chun Ho Yam, Kwai Sang Ng, Siu Sun Chan. Inkjet Ink Composition for Printing Irremovable Trace Marks on Substrate for Enhancing Product Authenticity and Traceability. United States Patent No. 9260617 B2. 16 Feb 2016.
[5] **Pei Li,** Kin Man Ho, Chun Ho Yam, Siu Sun Chan, Kwai Sang Ng. Solvent based inkjet ink composition. United States Patent Application, Publication No. 20180155561. 7 Jun 2018. (Application was allowed on 11 Oct 2019)
[6] **Pei Li**, Kin Man Ho, Chun Ho Yam, Siu Sun Chan, Kwai Sang Ng. Solvent based inkjet ink composition. Chinese Patent Application No. 201711259303.5. 21 Aug 2018.

(4) Details of the impact

Tampering with product information, such as food and drink expiry dates, is an increasing consumer problem in China and other major global markets [C1]. Traditional printing onto food packaging is vulnerable to tampering, as traditional inks can be easily removed with a solvent. This is not only a major food safety issue as unscrupulous vendors sell products that would otherwise need to be thrown away, but for major Chinese dairies such as Mengniu lack of label durability can also cause major supply chain problems and economic losses.

Concerned about this major industry challenge, *Hallyuen Holdings* (a Hong Kong company) approached Professor Li at PolyU to develop a chemical solution to enhance product identification, authenticity and traceability. Upon development of our breakthrough ink, *Hallyuen Holdings* launched a new company, *Xianhong,* in China in July 2013 to commercialize the work: "*the research carried out by Professor Pei Li was essential to the foundation of Inner Mongolia Xianhong Science Co. Ltd*" [C2].

Creation of a new business, jobs and profits
Our ink and the company were an immediate commercial success, aided by early recognition through several national and global awards including the *2013 Best Innovation Award* from China's Enterprise in Code and Marking Industry and a *Gold Medal* at the *2015 World Invention Innovation Contest*. Between the first and second year of trading, *Xianhong's* customer base grew by 168%, accompanied by a 310% sales volume increase and 12,225% increase in profits (from RMB 41.6k to RMB 5.1M) [C2].

This rapid growth enabled *Xianhong* to list on the Beijing NEEQ stock exchange after just 3 years, in May 2016. With the investment generated, they acquired another business, expanding *Xianhong* to offer integrated manufacturing solutions. This expansion helped them achieve ***sales of RMB 150M and generate a RMB 20.5M profit in 2018.*** *Xianhong* have stated that "*although the business has now*

expanded and diversified far beyond nano-functional ink and its related products, the relationship with ink customers was the foundation from which to develop and grow our service business model". ***Total sales and profit for the period 2014-2018 were RMB 431M and RMB 85.2M respectively*** [C2].

Xianhong now has ***over 280 employees*** [C2] and has established ***7 major R&D institutions***, including a nano-functional ink R&D center, big data R&D center, RFID R&D center, intelligent manufacturing R&D center, laser machine R&D center, instrumentation R&D center and nano material testing center [C3].

In 2017 the ink-related business accounted for 27% of *Xianhong's* total revenue, of which 85% was net profit. *Xianhong* have created jobs across greater China specifically related to ink R&D, production and sales, including their Hong Kong R&D center, a pilot scale lab in Shenzhen, and a production site in Inner Mongolia. Almost ***60 employees are working on ink-related business*** in 2019 [C2].

PolyU continues to support the company through R&D and consultancy: "*Professor Li and her lab have provided our business with sustained R&D, and enabled us to develop over 20 new products to retain our competitive edge and grow the business… Furthermore, we have employed five former PhD students and three former undergraduates from Hong Kong Polytechnic University*" [C2].

German inkjet printer manufacturer *Paul Leibinger GmbH & Co* have also benefited commercially from our ink. *Xianhong* partnered with *Leibinger* to sell printers in China which can deploy our ink. *Leibinger* also act as sole agent for sales of some of the ink outside China. The Area Sales Manager states this has "*opened up new market opportunities for our company. In our industry it is of major importance to have good inks and especially having inks with unique features... This ink has helped us a lot in the Chinese market and we have sold a large quantity of printer units [as a result]*" [C4].

Protecting sales and enhancing food safety for the food and drink industry

Indelible marking on packaging materials is one of the most effective and economic ways of combatting counterfeit products and ensuring accurate product tracking along supply chains. The fast-drying ink is easily applied to rapid packaging production lines. The ink's *double-layer double-colour* nature makes it impossible to hide tampering as the second layer will look different to the first. Before this ink was available, tampering not only risked consumers' health, but also caused huge financial losses [C2]. China's large and stratified market means the same products sell for substantially different prices in different geographic regions (e.g. RMB 12 for milk in Beijing, RMB 6 for milk in Inner Mongolia). By removing and replacing printed location information, distributors could buy cheaply in lower priced markets and transport to higher priced markets and sell at a profit, undercutting companies:

> *"There has always been a problem of tampering in the market. Unscrupulous distributors and proprietors alter information code on the packaging and then reprint new information on our products, thus greatly disrupt the market order and cause immense economic loss to our company.*
>
> *The adoption of nano anti-erasing ink by our company has* ***solved the tampering problem that has existed for a long time.*** *It has not only protected the information code on our product packaging but also improved traceability*

Fig. 1) Drink carton with nano-ink: tampering has revealed orange double layer

which in turn ***safeguard the interest of our company as well as public health.*** *It also brings forth substantial economic and social benefits. Our company has applied Xianhong's anti-erasing ink to different products and production lines in various production bases. Results are considered to be remarkable"* Mengniu Dairy [C5].

Xianhong estimate that they have captured ***14% of the ink market for fast-moving consumer goods in China*** (valued at RMB 152M per annum) [C2]. Three of the top ten dairies in the world by turnover, *Nestle, Yili* and *Mengniu,* use the ink in their production lines. Other food and drink manufacturers using our ink include the world's largest pork company (*WH Group*) and China's largest beverage company (*Wahaha*). Our ink sells in global markets including Germany, Switzerland, Brazil, Vietnam, and Singapore [C4]. Around ***78,000 litres of nano-functional ink are sold to the fast-moving consumer goods industry*** each year [C2]. With manufacturer product information and best-before dates requiring only a few microliters to print per package, we estimate this is enough to print over 30 billion packages annually.

Providing solutions for a broad range of industries

The *Xianhong* and PolyU relationship continues, with Professor Li and her team working on a series of ink formulations, for example temperature resistant ink, anti-migration ink, color changing ink, UV-resistant security printing ink and highly adhesive ink, to meet the needs of different industries [C6].

Cables are often bundled together and the friction thus caused, and/or any tape used to hold them, can erase normal inks making cable identification extremely difficult. Since 2014, the wire and cable industry has become a major customer for highly adhesive, high rub-resistant ink for power cables, communication cables and optical fibers. *Xianhong* estimate that they now have ***23% of the ink market for China's wire and cable industry*** (valued at RMB 91M per annum) [C2]. Companies benefiting from these problem solving products include *Yangtze Optical Fibre and Cable Joint Stock*, a leading global optical fibre and cable manufacturer employing over 4000 staff, selling products in over 70 countries, and using our ink in 19 of their production lines; and also the *HengTong Group*, the world's second largest cable manufacturer who use the ink on 25 production lines [C2].

Further applications include an ink developed for the electronics industry that is indelible and invisible on components and products made of glass fiber or silicon. Customers include *BoE*, the world's third largest display manufacturing company. We have also developed an ink for the motor industry that can be printed onto airbags, brake pads and engine parts (*Lear Corporation*, *DELPHI*), ink for household packaging such as personal care products and cosmetics (*AMWAY, BIOSLIM*) and ink for the pipe industry (*Fischer Tubetech, The Plansee Group*) [C7].

(5) Sources to corroborate the impact

[C1] Example of tampering from news report: Reuters, China (website archived April 2019)
[C2] Letter from Chief Technical Officer and Director, *Xianhong Science Company Ltd*, 23 Sept 2019
[C3] Online news article published by Mongolia Technology Department, Science and Technology Promotion Center (archived April 2019)
[C4] Letter from Area Sales Manager Asia & Oceania, *Paul Leibinger GmbH & Co*, 20 Sept 2019
[C5] Letter from *Mengniu Dairy (Group) Company Ltd*, 2019
[C6] Xianhong company website: http://marker.xhsim.com/category/nano-functional-ink/
[C7] Xianhong website detailing industry applications (archived July 2019)