Received 29 July 2020; accepted 14 August 2020. Date of publication 19 August 2020; date of current version 2 September 2020. The review of this article was arranged by Editor X. Guo.

Digital Object Identifier 10.1109/JEDS.2020.3017873

# Novel Green Temporary Bonding and Separation Method for Manufacturing Thin Displays

### JU-TE CHEN<sup>10</sup> 1,2 AND SHENG-HSIUNG YANG<sup>2</sup>

1 Industrial Technology Research Institute, Hsinchu 31040, Taiwan 2 Institute of Lighting and Energy Photonics, College of Photonics, National Chiao Tung University, Tainan 71150, Taiwan

CORRESPONDING AUTHOR: J.-T. CHEN (e-mail: jutechen@gmail.com)

**ABSTRACT** Owing to the rapidly growing popularity of portable products, there is an increasing demand for lightweight devices with thin displays. Glass substrates contribute substantially to the thickness and weight of display panels, and therefore, it is important to minimize their thickness. However, thin glass substrates are too fragile to be supported on their own and used directly. Thicker glass substrates are therefore used to fabricate display panels, and the substrate thickness is then reduced through etching and surface grinding. This approach is time-consuming, involves the use of highly hazardous chemicals, and produces acidic liquid waste. Thus, countries in which thin panels are produced have experienced severe environmental pollution problems related to their manufacture. In addition to the pollution produced, existing panel-thinning methods cannot satisfy the demand for increasingly thinner panels, and as a result, there is an urgent need for new panel-thinning technologies. This article proposes a novel green temporary bonding and separation method that allows thin glass substrates to be carried to directly produce thin panels. This method makes possible the rapid manufacture of thinner glass display panels for foldable and flexible displays. This method does not use any chemicals and does not produce any polluting waste and thereby contributes to environmental protection.

INDEX TERMS Carrier bonding, foldable displays, flexible displays, thin glass, temporary bonding.

#### I. INTRODUCTION

In recent years, owing to the rapidly growing popularity of portable products, the demand for thin, lightweight devices with thin displays has become increasingly apparent. According to a report published by the market research agency IHS Technology [1], the demand for thinner displays has been increasing annually. Among such displays, amorphous silicon thin-film transistor liquid crystal displays ( $\alpha$ -Si TFT LCD) account for more than half of the market share, owing to their low production-defect rate, high stability, and cost-effectiveness.

Fabricating a thin LCD panel requires thinning of the glass substrate, which is the primary contributor to the thickness and weight of the overall panel. The thickness of the glass substrate in a thin display should be 0.2 mm or less to be in line with current industry standards. However, a glass substrate with a thickness of less than 0.3 mm is too thin to be transferred between pieces of equipment in

the production line and therefore cannot be use directly in existing display panel fabrication processes. Currently, the only way to fabricate a thin LCD panel is to use a glass substrate with a thickness of 0.5 mm for fabrication and then transport it to a thinning factory to reduce the thickness of the glass substrate, as shown in Fig. 1. This process is very time-consuming, requiring an average of 3 to 5 days. In addition, this thinning is done using chemical etching and surface grinding, which involve the use of hazardous chemicals and lead to the production of various liquid wastes for which there is no effective disposal method. Consequently, countries that produce thin panels experience severe environmental pollution problems.

As an alternative, Byun and Lee [2] proposed the use of fluoride-based chemicals as etchants, but this still involves the use of high-risk chemicals and produces pollutants that are difficult to handle. In addition to the contamination issues involved, the existing panel thinning methods



**FIGURE 1.** Schematic illustration of thin display panel manufacturing process.





FIGURE 3. Bonding principle of glass on carrier.

**FIGURE 2.** Schematic illustration of thin glass substrate bonded to a carrier to produce a thin display panel.

are limited to thinning a glass substrate to a thickness of 0.15 mm, which does not meet the requirements for ultrathin display panels. For example, the thickness of the glass substrates used in foldable mobile phones need to be less than 0.1 mm. Because of this problem, foldable mobile phones with glass substrates did not appear until 2020. For these reasons, new technological solutions are urgently needed to make thinner panels using more environmentally friendly processes.

Glass substrate suppliers have proposed another concept for thin panel manufacturing, shown in Fig. 2, which involves bonding a 0.2 mm thick glass substrate to a carrier glass substrate [3], [4]. This approach solves the problem of production line equipment being incapable of transporting glass substrates with thicknesses less than 0.3 mm. This type of glass-on-carrier (GoC) substrate can be introduced directly into the original panel fabrication process, after which the carrier is removed, using a separation method, to obtain a thin panel. This approach can significantly reduce the manufacturing processes and time required to produce thin glass substrates.

Although panel makers have purchased laminated glass from glass substrate suppliers and have attempted to use it in the manufacture of thin display panels [5], it remains difficult to separate the carrier after the panel is processed. This is because the bonding force of the laminated glass increases significantly throughout the panel fabrication process. Furthermore, the separation method, which applies suction to the carrier and the panel by means of a vacuum chuck to pull them apart, damages the panel. Therefore, better bonding and separation methods are needed to make this thin-display panel manufacturing concept viable.

In this article, a new green temporary bonding and separation method was developed to implement the production concept illustrated in Fig. 2. This method was verified by temporarily bonding an ultra-thin glass substrate with a thickness of 0.1 mm to a 0.5 mm thick glass carrier substrate to produce a prototype ultra-thin  $\alpha$ -Si TFT LCD panel.

# II. GREEN CARRIER BONDING AND SEPARATION METHOD

#### A. BONDING GLASS SUBSTRATE ON CARRIER (GOC)

The laminated GoC substrate must be able to withstand the various processing environments through which an LCD panel passes, including being soaked in various chemicals and subjected to temperatures as high as 350 °C. Furthermore, it must be possible to separate the carrier from the GoC substrate after the LCD panel fabrication process is complete. In this article, we propose a novel temporary carrier bonding method to meet the above requirements. This method was implemented as follows. Thin alkali-free glass substrates (model OA-10G) were obtained from the NEG Corporation for use as the thin glass substrates (360 mm  $\times$  460 mm; thickness: 0.1 mm) and carrier plates (370 mm  $\times$  470 mm; thickness: 0.5 mm). Next, a diamond drill bit with a diameter of 1.5 mm was inserted into a micro air grinder to drill a hole at 58,000 rpm in the center of the carrier glass. A continuous flow of water was used for cooling the drill bit and preventing cracks in the glass. Then, the surfaces of the thin glass substrate and the carrier glass were cleaned and dried to remove impurities and moisture. Finally, the thin glass and carrier substrates were bonded face to face in a cleanroom by the application of pressure at 0.8 kgf/cm<sup>2</sup> and heating to a temperature of 250 °C. The glass-on-carrier bonding principle is illustrated in Fig. 3. The elevated temperature induces the reaction of hydroxyl groups between the ultra-thin glass and the carrier to form covalent bonds. An appropriate bonding force can be generated through this process. This bonding step takes less than 2 min and does not require an adhesive. A photograph of the resulting GoC is shown in Fig. 4, and a schematic illustration of the design is shown in Fig. 5. This green bonding technology involves few production processes and has a fast production time.

The idea of this method was derived from wafer direct bonding technology [6], [7], [8], [9], [10], [11]. However, this particular method differs from this technology since the wafer direct bonding technology involves permanent and firm bonding of a silicon wafer to another silicon wafer, whereas the proposed method produces only a temporary bond. The



FIGURE 4. Photograph of a thin glass substrate bonded to a carrier.



FIGURE 5. Schematic illustration of thin glass substrate bonded on carrier.



FIGURE 6. Schematic illustration of the crack opening method.

temporary bonding method that we propose can be used to temporarily bond a glass substrate to another glass substrate from which it can later be separated. Because the manufacturing processes and the results of the two methods are different, the method we propose is unique.

#### **B. MEASURING THE PEELING FORCE OF GOC**

The peeling force required to separate the GoC substrate after heating to different temperatures needs to be determined. The peeling force required to separate the GoC substrate was measured using the crack opening method employed in a previous study [12]. As illustrated in Fig. 6, a blade is inserted into the bonding interface of the two substrates, and the peeling force is calculated using Eq. (1).

$$F = \frac{Ewd^3h}{4c^3} \tag{1}$$

In Eq. (1), F is the peeling force, E is the Young's modulus of the thin glass (73 GPa), d is the thickness of the thin glass substrate (0.1 mm), h is the blade thickness (0.4 mm), c is the separation distance between the thin glass and the carrier from the blade end, and w is the width of the GoC substrate test piece (50 mm).

To perform the crack opening method, the GoC substrate was first cut into 35 pieces 50 mm  $\times$  100 mm in size. The

TABLE 1. Peeling force F of GoC after various heating temperatures calculated using the crack opening method.

T (°C)	c' (mm)	F (N)
250	8.59	0.57538
300	8.58	0.57783
350	8.57	0.58073
400	8.55	0.58419
450	8.53	0.58865
500	8.47	0.60083
550	8.30	0.63823



FIGURE 7. Peeling force F of the GoC, measured using the crack opening method, after heating to various temperatures.

test pieces were divided into seven groups of five pieces each. The seven groups of test pieces were heated to 250 °C, 300 °C, 350 °C, 400 °C, 450 °C, 500 °C, and 550 °C for 30 min before being cooled to room temperature (to simulate the various display panel heating processes). A blade was then plunged into the interface between the thin glass and the carrier from the 50 mm end of the GoC, and the GoC was then allowed to stand for 5 min. The separation distance *c* between the thin glass and the carrier from the blade end was subsequently measured. After *c* for each piece was measured, the average separation length *c'* was calculated for the five pieces in each group, as shown in Table 1.

Using the average separation length c' for each group as c in Eq. (1), the peeling force F for the GoC at each of the various heating temperatures was calculated. These values are shown in Table 1 and plotted in Fig. 7. The results show that higher heating temperatures make the GoC separation more difficult. However, the GoC formed using our bonding method could be separated even after being heated to 550 °C for 30 min. When the GoC is used to make a display panel, the peeling force F in Table 1 can be used as a basis for separating the GoC.

#### C. GREEN CARRIER SEPARATION METHOD

The separation methods proposed to date all involve the use of a pulling force to separate the carrier from the panel. Such separation methods often cause damage to the fragile parts of the display panel, such as the thin glass edges or



FIGURE 8. Schematic illustration of separation using a pulling force.



FIGURE 9. Schematic illustration of separation by gas injection.

seal agents, as shown in Fig. 8. Therefore, these previously proposed temporary bonding methods are not actually used to produce thin display panels at the present time.

As shown in Fig. 7, the bonding force of our proposed carrier bonding method is so small that the carrier can be separated from the display panel without further reducing the bonding force. However, in order to ensure that the process of separation of the carrier from the display panel does not damage the display panel, we have developed a method for injecting gas through the hole of the carrier to separate it from the display panel. This method generates a gas thrust that pushes the carrier away from the display panel so that it will not cause damage to the display panel, as shown in Fig. 9.

However, when the gas was injected through the hole, it was found that the gas could not flow between the ultrathin glass and the carrier. Hence, it was necessary to create a small gap between the ultrathin glass and the carrier before injecting the gas. In order to be able to implement this method to manufacture ultrathin  $\alpha$ -Si TFT display panels, we designed a separation machine, shown in Fig. 10, and developed a separation process, illustrated in Fig. 11, for use with the machine.

In this separation machine, the following two mechanisms for making gaps are particularly noteworthy.

## C.1. GROOVE DESIGN IN THE MIDDLE OF THE PLATFORM

As shown in Figs. 12 and 13, a circular groove is formed in the center of the platform. The groove has a diameter R of 160 mm and an intermediate depth d of 3 mm, which becomes shallower toward the circular periphery. Thus, a gap is maintained when the GoC substrate is placed on it.



FIGURE 10. Separation machine design diagram.



FIGURE 11. Flowchart of the separation process steps.

## C.2. GAS INJECTION MECHANISM WITH PRESS DOWN FUNCTION

As shown in Fig. 14, the gas injection mechanism is fixed under the upper base and forms a clearance fit with a vertical



FIGURE 12. Cross-sectional view of the groove on the platform.



FIGURE 13. Photo of separation machine groove.

sliding distance of 1 cm. A rod-type tension gauge is positioned directly above it, and the thrusting end of the rod-type tension gauge presses vertically against the upper end of the gas injection mechanism, through the upper base.

When the gas injection needle head is lowered into the hole of the carrier glass in Step 3 with the lowering of the upper base, the gas injection needle makes contact with the thin glass substrate and presses it down to create a gap. The rod-type tension gauge has a thrust display scale that indicates the magnitude of the thrust. The spring inside the rod-type tension gauge provides a cushioning effect when the head of the gas injection needle touches the GoC substrate, allowing the applied thrust to be gradually increased and greatly reducing the rupture.

While the gas injection needle head presses down on the thin glass substrate to create a gap, the function of the platform groove is to provide the required space, as shown in Fig. 15. By these two mechanisms, a gap is created so that gas can be injected between the thin glass substrate and the carrier.

Once the gas injection needle head supports the gap between the thin glass substrate and the carrier, the gas injection at separation process Step 4 is performed, shown in Fig. 16. In this process, the input pipe of the gas injection mechanism is connected to the gas regulating valve and the pressure gauge. The gas pressure is controlled by the regulating valve, and the pressure gauge instantly displays



FIGURE 14. Diagram of gas injection apparatus.



FIGURE 15. Diagram of the separation machine.

the input gas pressure. Thus, gas can be injected at a stable pressure. The gas injection pressure is converted into thrust to push the thin glass substrate and carrier apart. Because of the characteristics of gas flow, the flow of gas from the central injection hole to the edge of the glass plate separates the entire thin glass substrate from the carrier.

The gas injection hole has a diameter of 1.5 mm, and the area A of the injection hole is  $1.767 \text{ mm}^2$ . The gas pressure required to separate the GoC can determined from the peeling force F from Table 1. The gas input pressure P corresponding to the peeling force F is calculated from the pressure formula P = F/A. As shown in Table 2, the peeling force F can thus be used as a reference value for the gas injection pressure for the separation of the GoC. This



Ultra thin glass



TABLE 2. Peeling force F corresponding to gas input pressure P.

T (°C)	F (N)	P (kgf/cm <sup>2</sup> )
250	0.57538	3.32039
300	0.57783	3.33453
350	0.58073	3.35126
400	0.58419	3.37122
450	0.58865	3.39697
500	0.60083	3.46727
550	0.63823	3.68312

finding related to the two-stage separation process is similar to the concepts of static friction force and sliding friction force in classical physics.

#### **III. VERIFICATION OF RESULTS AND DISCUSSION**

The  $\alpha$ -Si TFT array process is the most complicated and difficult process in the manufacture  $\alpha$ -Si TFT panels. A flowchart of the process, which is quite mature, is shown in Fig. 17 [13].

Thirty sheets of GoC substrates were manufactured using the bonding method described in Section II-A and were sent to a panel factory for the  $\alpha$ -Si TFT array process for display panel fabrication. All 30 sheets of GoC substrates successfully passed through the  $\alpha$ -Si TFT array process.

Before performing the separation process, two parameters must be set on the separation machine: the amount of thrust applied to the GoC substrate by the gas injection needle in Step 3 and the gas injection pressure used in Step 4. First, five sheets were taken from the 30 sheets of GoC substrates and placed on the separation machine, where the thrust applied to the GoC substrate by the gas injection needle was manually adjusted. As the gas injection needle head pressed down and caused a gap in the bonding interface of the GoC, there was an observable change in the refractive



**FIGURE 17.** Flowchart of the  $\alpha$ -Si TFT array process.

index of the light. After several manual tests, it was found that when the thrust of the rod-type tension gauge was greater than 88 g, a gap was created in the bonding interface of the GoC substrate. Thus, the thrust of the gas injection needle of the separation machine was set to 88 g. Second, as the maximum temperature of the  $\alpha$ -Si TFT array process was 350 °C, the gas injection pressure of the separation machine at Step 4 was set to 3.36 kgf/cm<sup>2</sup>, in accordance with Table 2.

After the two parameters were set, the other 25 GoC substrates were placed one by one onto the separation machine, as shown in Fig. 18, to perform the separation process according to the steps shown in Fig. 11. The results show that all 25 sheets of the GoC that were subjected to the  $\alpha$ -Si TFT panel fabrication process at 350 °C were successfully separated. The separation process was completed for each GoC within 90 s, and an  $\alpha$ -Si TFT array panel with a thickness as thin as 0.1 mm was obtained, as shown in Fig. 19. This temporary bonding process was very fast in comparison to the current thin display panel manufacturing process.

There are a few points to be made about drilling holes of good quality on the glass carrier. First, you must choose a diamond powder drill bit, which has hardness greater than that of glass, to drill holes smoothly. Second, the drilling speed should be higher than 58,000 rpm. If it is lower than this speed, the glass carrier is easy to crack. Third, since heat is generated by friction during drilling, the drill bit must be cooled with water to prevent glass cracks due to thermal stress. Fourth, the drill bit will wear out. After each drill bit has drilled 25 holes, the drill bit needs to be replaced to maintain the drilling quality. We have gained the above four insights after many failed drilling attempts. Holes that are drilled on glass carriers in accordance with the above four points are of good quality without additional polishing or grinding.

Because the ultra-thin glass is smaller than the carrier, there is a residue on the carrier that prevents it from being



**FIGURE 18.** Photo of  $\alpha$ -Si TFT array panel with thickness of 0.1 mm on separation machine.



**FIGURE 19.** Photo of  $\alpha$ -Si TFT array panel with thickness of 0.1 mm.

used again. In the future, if ultra-thin glass and carrier pieces of the same size can be bonded, the carrier can be used multiple times.

We evaluated the transfer characteristics of  $\alpha$ -Si TFT before and after separation from a carrier substrate. The change in transfer characteristics was negligible, as shown in Fig. 20. The results indicate that the separation process did not cause damage.

We summarize our contribution and scientific findings as follows. First, we have presented a green temporary bonding method based on wafer direct bonding technology. We changed the original manufacturing process to change its function from permanent bonding technology to a new temporary bonding technology. By analyzing two glass substrates bonded using this temporary bonding technique, we were able to measure the peeling force after treatment at various temperatures. We found that the higher the treatment



FIGURE 20. Transfer characteristics of  $\alpha$ -Si TFT before and after separation from carrier substrate: a) log I<sub>DS</sub> vs V<sub>GS</sub> b) linear I<sub>DS</sub> vs V<sub>GS</sub>.

temperature is, the more difficult it is to separate the two substrates. The measurement results also show that the peeling force is still in the detachable range even after temperature as high as 550 °C. The proposed new method has potential for use in making various thin electronic devices that require high-temperature processes. This finding is important because the current temporary bonding technology that can withstand temperatures exceeding 550 °C relies on LLO (laser lift off), a temporary bonding technology that uses a laser to separate the carrier board, which is a complicated and expensive process.

Second, because of the fragility of ultra-thin glass, we designed a separation machine and established the for the separation process using this machine. We demonstrated the separation of the ultra-thin glass substrate and the carrier that had passed through the  $\alpha$ -Si TFT array process production line of the panel factory. The separation principle involves push the two bonded glass substrates away from each other by blowing a gas between them. The separation machine has undergone many revisions in both its hardware and software

to make it possible to achieve positive results. We found that setting the blowing pressure of the machine according to the measured value of peeling force was not sufficient to separate the ultra-thin glass substrate from the carrier. We therefore made significant modifications to the machine—specifically, to the "gas injection mechanism with press-down function" that is described in this article. This mechanism creates a gap into which gas is injected to push the two glass substrates apart. The gas injection pressure after creation of the gap can adopt the value measured by the peeling force. This finding related to the two-stage separation process is similar to the concepts of static friction force and sliding friction force in classical physics.

Third, this thinning process can provide a thinning solution for various flexible electronics. This is useful because not all products can be soaked in hydrofluoric acid (HF) for thinning.

Fourth, if our green technology can be applied to mass production, the amount of chemical waste produced will be significantly reduced.

#### **IV. CONCLUSION**

In this article, a green temporary bonding and separation method is proposed for manufacturing thin displays. This method has been shown to be able to produce an ultrathin display panel of an  $\alpha$ -Si TFT array on a glass substrate with a thickness of 0.1 mm in a panel factory. This thickness cannot be achieved by the original panel thinning technology while maintaining the quality. This green alternative solution allows thin display panels of better quality to be produced faster and allows for thinner panel thickness to be achieved. If the method described in this article is implemented in a panel factory in the future, there will be no need for the panels produced to be transported to a thinning factory for chemical grinding. This will save time, reduce costs, and avoid the use of hazardous chemicals and production of contaminated waste, all of which will facilitate the quick and safe manufacturing of flexible electronics.

In the future, this thin display panel manufacturing solution is expected to be used to produce thinner versions of new types of displays, such as organic light-emitting diode (OLED) and micro light-emitting diode (micro LED) displays, which cannot be produced by the traditional thinning method without damage to the structure of the OLED or micro LED display. This temporary bonding method can be further applied to other processes, such as thin wafer handling in semiconductor processing [14], [15]. However, at present, it has only been verified that the proposed method can withstand a 350 °C processing temperature. Some display panel fabrication and semiconductor process environments involve higher temperatures, and whether this method can withstand higher process temperatures remains to be verified.

We believe that the proposed method not only addresses the demand for products with thinner display panels but also contributes significantly to the protection of the environment.

#### REFERENCES

- IHS Electronics and Media. Accessed: Apr. 30, 2020. [Online]. Available: https://technology.ihs.com/api/binary/441559?attachment= true
- [2] J. Y. Byun and K. W. Lee, "59.4: A novel route for thinning of LCD glass substrates," in *Soc. Int. Display (SID) Symp. Dig.*, 2006, pp. 1786–1788.
- [3] T. Higuchi, Y. Matsuyama, K. Ebata, D. Uchida, and S. Kondo, "A novel route for thinning of LCD glass substrates," in *Soc. Int. Display (SID) Symp. Dig.*, 2012, pp. 1372–1374.
- [4] S. M. Garner *et al.*, "Cholesteric liquid crystal display with flexible glass substrates," *J. Display Technol.*, vol. 9, no. 8, pp. 644–650, Aug. 2013.
- [5] C. C. Kuo, Y. C. Chen, B. S. Chiou, J. Y. Chiou, Y. T. Lee, and Y. Y. Huang, "Ultra thin glass for flexible display," in *Proc. Int. Display Workshop*, 2012, pp. 1497–1500.
- [6] Q.-Y. Tong, G. Cha, R. Gafiteanu, and U. Gosele, "Low temperature wafer direct bonding," *J. Microelectromech. Syst.*, vol. 3, no. 1, pp. 29–35, Mar. 1994.
- [7] C. B. Eom, L. Hunag, R. A. Rao, Q. Y. Tong, and U. Goesele, "Fabrication of double sided YBa/sub 2/Cu/sub 3/O/sub 7/ thin films on 2 inch diameter LaAlO/sub 3/ wafers by direct wafer bonding," *IEEE Trans. Appl. Supercond.*, vol. 7, no. 2, pp. 1244–1248, Jun. 1997.
- [8] X. X. Zhang and J.-P. Raskin, "Low-temperature wafer bonding: A study of void formation and influence on bonding strength," J. Microelectromech. Syst., vol. 14, no. 2, pp. 368–382, Apr. 2005.
- [9] G. Liao, Y. Shi, T. Shi, and L. Nie, "Dynamics of contact wave in silicon wafer direct bonding," *IEEE Trans. Adv. Packag.*, vol. 33, no. 2, pp. 348–352, May 2010.
- [10] K. K. Ryu, J. C. Roberts, E. L. Piner, and T. Palacios, "Thin-body N-face GaN transistor fabricated by direct wafer bonding," *IEEE Electron Device Lett.*, vol. 32, no. 7, pp. 895–897, Jul. 2011.
- [11] K. H. Lee *et al.*, "Monolithic integration of Si-CMOS and III-V-on-Si through direct wafer bonding process," *IEEE J. Electron Devices Soc.*, vol. 6, pp. 571–578, Dec. 2017.
- [12] W. J. Clegg. Materials & Structures, in Natural Sciences Tripos, Part IB, 2010, DH53-DH56. Accessed: Apr. 30, 2020. [Online]. Available: https://zh.scribd.com/document/288795420/Equilibrium-crack-lengthin-wedging
- [13] C. Y. Hsu, C. F. Chien, and K. Y. Lin, "Data mining for yield enhancement in TFT-LCD manufacturing: An empirical study," *J. Chin. Inst. Ind. Eng.*, vol. 27, no. 2, pp. 140–156, Feb. 2010.
- [14] J. Hermanowski, "Thin wafer handling—Study of temporary wafer bonding materials and processes," *presented at the IEEE Int. Conf. 3D Syst. Integr.*, San Francisco, CA, USA, Sep. 2009, pp. 1–5.
- [15] H. Mizuno et al., "UV laser releasable temporary bonding materials for FO-WLP," Presented at the Int. Conf. Electron. Packag. iMAPS Asia Conf. (ICEP-IAAC), Mie, Japan, Apr. 2018, pp. 252–256.





**JU-TE CHEN** is currently pursuing the Ph.D. degree with the Institute of Lighting and Energy Photonics, College of Photonics, National Chiao Tung University, Tainan, Taiwan.

He served as the Principal Investigator with the Industrial Technology Research Institute, Hsinchu, Taiwan, from 2005 to 2014. His research interests include flexible electronics, flexible displays, and temporary bonding.

**SHENG-HSIUNG YANG** received the first Ph.D. degree in applied chemistry from the National Chiao Tung University, Hsinchu, Taiwan, and the second Ph.D. degree in materials science from the University of Nantes, Nantes, France, in 2004.

He is currently an Associate Professor with the Institute of Lighting and Energy Photonics, College of Photonics, National Chiao Tung University (Tainan campus), Taiwan. His major field of study is synthesis of conjugated polymers for light-emitting application. His research

interests include synthesis of light-emitting and ionic conjugated polymers, preparation of nanostructured metal oxides, perovskite-related materials, and conventional/inverted photovoltaic and light-emitting devices.