Proc. Int. Symp. Super-Functionality Organic Devices
IPAP Conf. Series 6 pp.146-149

Flexible AMOLED Backplane Technology Using Pentacene TFTs

Ryu-Gi Seong, Yong-Hun Xu, Hyun-Sook Byun, and Chung-Kun Song

Dept. of Electronics Eng., Dong-A University, Busan, Korea

We fabricated a panel consisting of an array of organic TFTs (OTFT) and organic LEDs (OLED) in order to demonstrate the possible application of OTFTs to flexible active matrix OLED (AMOLED). The panel was composed of 64 x 64 pixels on 4 inch size PET substrate in which each pixel had one OTFT integrated with one green OLED. The panel successfully displayed some letters and pictures by emitting green light with a luminance of 20 cd/m^2 at 6 V, which was controlled by the gate voltage of OTFT. In addition, we also developed fabrication processes for pentacene TFT with polyvinylphenol (PVP) gate on poly-ethylene-terephehalate (PET) substrate. The OTFTs produced had a maximum mobility of 1.2 cm^2/V.sec and an on/off current ratio of 2x10^6.

KEYWORDS: organic-TFT, organic LED, polyvinylphenol gate, poly-ethylene-terephelate

1. Introduction

The flexible AMOLED is attracting much attention because it enables a lighter and thinner display. Since it is also highly rugged and not prone to breakage, it enables new applications such as conformable and rollable displays [1, 2]. In addition, large area displays can be made cheaply because of the low temperature process used and their possible roll-to-roll manufacturing. However, the flexible AMOLED display is at the proof-of-concept stage for conformable and rollable displays.

For the flexible AMOLED, the driving transistors, which should be able to supply sufficient current to OLED, should have high compatibility with plastic substrate. At present, there are three types of transistors available for flexible AMOLED. Low-temperature poly-silicon TFT produces high mobility of 100 cm^2/Vs but its plastic compatibility is very poor due to the high temperature process [3]. Amorphous silicon TFT is a workhorse of the well established active matrix liquid crystal display industry, and has a mobility of about 1 cm^2/Vs [4]; however, its plastic compatibility is not yet good enough for use in the flexible AMOLED. OTFTs have recently been well developed to exhibit mobility of ~ 3 cm^2/Vs at the discrete-device level [5]. The process temperature is very low (~ 100^{o}C), resulting in low cost and an excellent compatibility with plastic substrate. In this work we chose OTFT for flexible AMOLED test panel because of its excellent plastic compatibility.

Several groups are working on flexible AMOLED. DuPont and Honeywell demonstrated flexible AMOLED using a-Si on glass as well as plastic substrate [6]. Lehigh University also fabricated flexible AMOLED on stainless substrate using poly-Si [7] and Philips chose polymer TFT to drive E-ink [8]. To our knowledge, flexible AMOLED panels driven by organic TFTs have not yet been reported.

In the work reported here, we fabricated an array of 64 x 64 pixels on 4 inch size PET substrate in which each pixel was composed of one OTFT and one OLED. The purpose of this panel was to investigate the current driving capability of OTFTs for OLEDs and to develop the fabrication process for flexible AMOLED. The OTFTs used PVP for gate insulator and pentacene for organic semiconductor. For OLED, two layers of Alq3 and TPD were employed to generate green light. In this letter we will discuss the fabrication process and characteristics of PVP gate on PET substrate and the issue of pentacene film thickness on OTFT performance since thickness uniformity is an important factor for a large-area panel. Finally, the integration process and operation results of the array will be discussed to consider the possible application of OTFTs to flexible AMOLED.

2. Experimental

2.1 PVP Gate Insulator

For the gate insulator, we tried several materials such as sputtered SiO_2 and organic materials. PVP produced the best performance. PVP gate has been reported in the literature [9] concerning PVP process on Si wafer. However, in our work, PVP process was developed for PET substrate. The PVP organic gate material consisted of PVP polymer and cross-link agent (CLA), and propylene glycol monomethyl ether acetate (PGMEA) as a solvent. We found that the optimum ratio of components was 10wt% of PVP mixed with 5wt% of CLA in 100wt% of PGMEA. The CLA was activated by thermal heating and the optimum temperature was found to be 200^{o}C.

The thermally cross-linked PVP provided a hydrophobic surface with the contact angle of 61.9^o corresponding to a surface energy of 48 dyne/cm, compared with the non-cross-linked PVP polymer film which had the contact angle of 52.1^o and surface energy of 53 dyne/cm.

The low surface energy of the cross-linked PVP supplied a good surface condition for well-ordering of pentacene molecules. In addition, PVP cross-linked at a high temperature such as 200^{o}C exhibited a higher chemical resistance than when baked at a lower temperature such as 160^{o}C as shown in Fig. 1.

PVP baked at 160^{o}C produced similar transfer characteristics to PVP baked at 200^{o}C without acetone treatment. However, after acetone treatment, PVP baked at 160^{o}C was seriously degraded while PVP at 200^{o}C was sustained. Therefore, the high temperature thermal process is required to obtain stable PVP gate for the subsequent chemical processes.

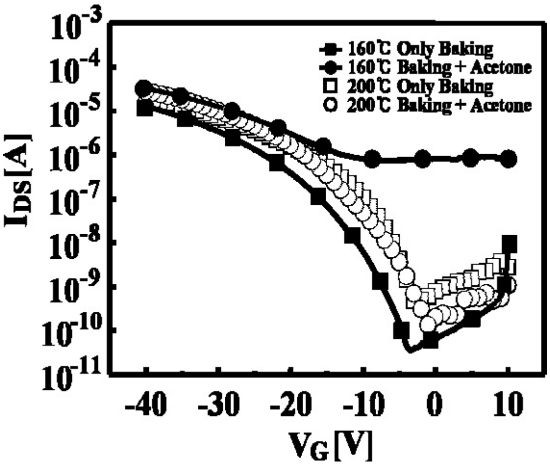

Fig. 1 The results of baking temperature and chemical resistance test of PVP gate.

2.2 Deposition of Pentacene Thin Film

Another issue is the uniformity of pentacene film in terms of thickness as well as crystallinity. It is important to obtain a uniform pentacene film over the entire area since the performance of OTFT depends on pentacene thickness and thus determines the panel performance. As shown in Fig. 2, the field effect mobility depended on pentacene thickness. It increased with thickness, reaching a maximum value at 50 nm. The low mobility of thin pentacene film was caused by the gaps existing between grains as shown in Fig. 2.

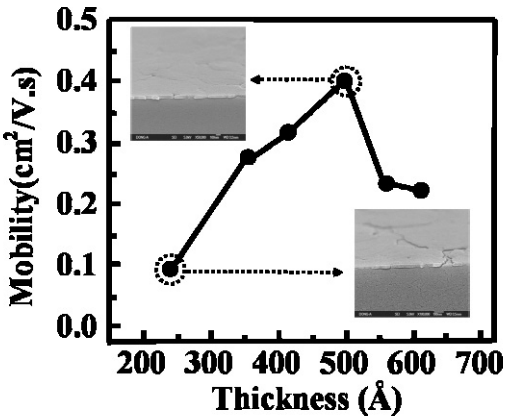

Fig. 2 The thickness dependence of mobility of pentacene TFTs.

These gaps were reduced as the thickness increased and completely filled at 50 nm, producing the high mobility. The largest grains were obtained at the cell temperature of 190°C, giving high mobility. However, the grain size was reduced as the cell temperature increased or decreased from 190°C as shown on Fig. 3.

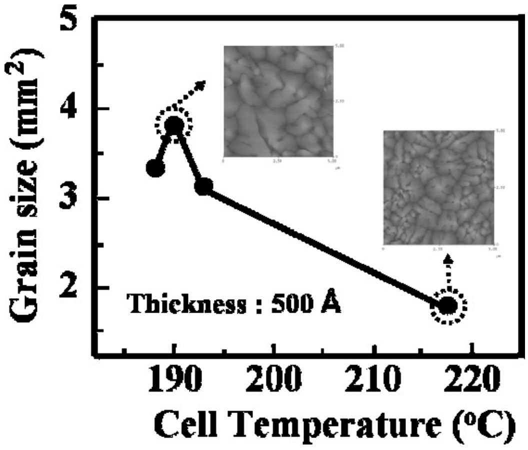

Fig. 3 The deposition temperature dependence of grain size of pentacene film.

Therefore, in order to make a high performance display panel it is important to sustain pentacene thickness at 50 nm over the large substrate and also to obtain the large grains by maintaining the temperature at 190°C during the deposition period.

Using such an optimized PVP gate and pentacene deposition process on PVP gate, we fabricated pentacene TFTs on PET substrate, which produced mobility of 0.9 ± 0.3 cm^2/Vs, a sub-threshold slope of 0.27 V/dec and an on/off current ratio of 2 x 10^6 as shown in Fig. 4.

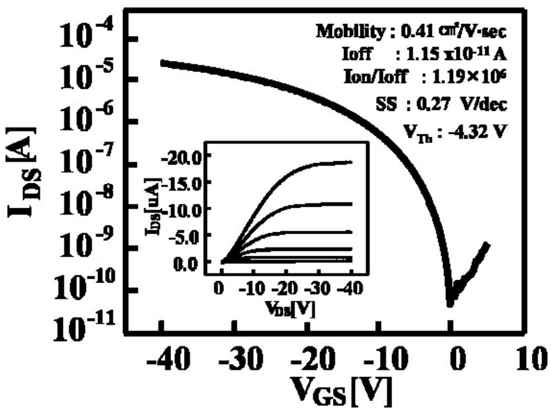

Fig. 4 The electrical characteristics of pentacene TFT using PVP gate.

The overall performance was good enough for application to AMOLED display. Thus, we fabricated an array of OTFTs with a resolution of 64 x 64, in which each OTFT was integrated with one green OLED, on 4 inch size

PET substrate. We examined the driving capability of OTFT for OLED using the developed integration process. An OLED with an area of 200 μm x 200 μm produced luminance of 20 cd/m^2 at 6 V. Note that OTFTs should operate in saturation mode to drive OLED so that the W/L(width/length) ratio must be larger than 20 with a channel length of 10 μm, and also the supply voltage should be larger than 19 V.

2.3 Fabrication of Display Panel

The fabrication process was as follows. ITO(Indium thin oxide) on PET substrate was first patterned for the anode of OLED, and then an Al gate was deposited and patterned. Subsequently, PVP gate dielectric was deposited as described above and patterned by the conventional photolithography process. In this step, the edges of the anode were covered by a PVP layer to avoid the degradation caused by the edge field. Then pentacene was evaporated through a shadow mask, above which the source and drain electrodes were deposited to complete the pentacene TFTs. For OLED, TPD and Alq3 were sequentially deposited followed by deposition of an Al cathode. Finally, an Al interconnection metal connected OTFT to OLED. In Fig. 5, the final panel with an array of pixels and an enlarged view of the pixels is shown. The OLED generated green light with a wavelength of 530 nm. The intensity was controlled by the gate voltage and also the drain-source voltage of OTFT as shown in Fig. 6a. As a demonstration, the panel displayed some letters and the logo of Dong-A university as shown in Fig. 6b.

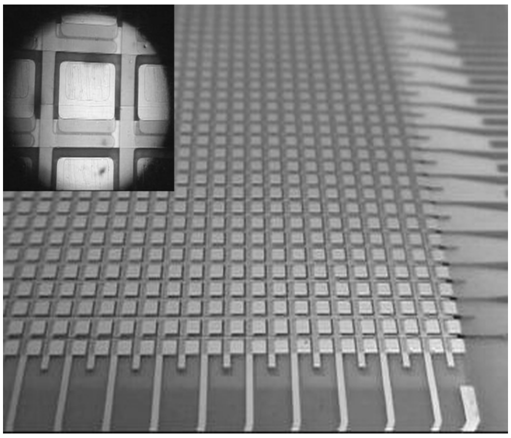

Fig. 5 The Flexible AMOLED panel on PET substrate and an enlarged pixel.

3. Conclusion

In conclusion, we developed a fabrication process of pentacene TFT with PVP gate on PET substrate and successfully fabricated an array of 64 x 64 pixels consisting of OTFTs and OLEDs. The panel demonstrated that the performance of pentacene OTFTs was good enough to drive OLEDs in an array on a large panel and is thus applicable to flexible AMOLED. However, there exist some challenges in backplane process development such as dimensional instability due to shrinkage of plastic substrate caused by high temperature process of PVP thermal baking, and due to the differential thermal expansion coefficients between the substrate and thin films used in the panel.

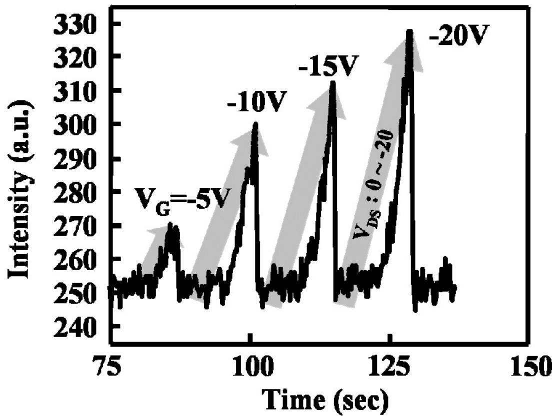

Fig. 6a The light intensity controlled by V_{GS} and V_{DS} of pentacene TFT.

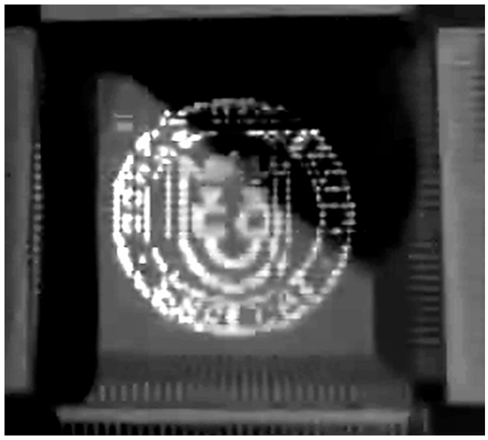

Fig. 6b The logo of Dong-A University displayed on the panel.

Acknowledgement

This work was supported by the Information Display R&D Center, one of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology of Korea.

1) A. N. Krasnov, *Appl. Phys. Lett.*, vol.80, pp.3853-3855, MAY 2002.
2) A Sugimoto, H Ochi, S Fujimura, *IEEE J. Select. Topics Quantum*

Electron., vol.10, pp.107-114, JAN.-FEB. 2004.
3) J.Jang and B.C.Lim, *SID 99 Digest*, pp.728-731, 1999.
4) T. Nishibe, *Mat.Res. Soc. Symp. Proc*., vol.685E, pp.D6.1., 2001.
5) T. W. Kelley, D. V. Muyres, P. F. Baude, T. P. Smith, T. D. Jones, in *Proc. 2003 MRS Spring Meeting*, 2003, pp. 226.
6) K. R. Sarma, presented at 3rd Annual Flexible Displays & Microelectronics Conf. Flexible Backplane Technologies, Phoenix,
7) M. Troccoli, T. Afentakis, T. Chuang, M. Hatalis, J. Hartzell, presented at 3rd Annual Flexible Displays & Microelectronics Conf. Flexible Backplane Technologies, Phoenix, USA, 2004.
8) P. V. Lieshout, presented at 3rd Annual Flexible Displays & Microelectronics Conf. Display Technologies: Applicatons & The Electro-Optic Front Plane, Phoenix, USA, 2004.
9) H. Klauk, M. Haik, U. Zschieschang, G. Schmid, W. Radlik, *J. Appl. Phys.,* vol.92, pp.5259, 2002.