Effect of alignment Layer on Pentacene Molecular Orientation and Organic Thin-Film Transistor performance

Hyun Doo Hwang[1], Chang Ho Kim[2], Chang-Jae Yu[1], and Jae-Hoon Kim[1, 2*]

Dept. of Electronics and Communications Engineering, Hanyang University, Seoul, Korea
Research Institute of Information Display, Hanyang University, Seoul, Korea
e-mail: jhoon@hanyang.ac.kr

We have studied the effect of surface ordering on the molecular orientation and performance of organic thin-film transistors (OTFTs). Rubbed polyimide (PI) and liquid crystal polymer (LCP) material that is normally used as display devices was used to create the surface ordering. LC molecules were aligned to rubbing direction and pentacene molecules on LC layer were ordered to same direction. When introduced in OTFTs, they were found to enhance the saturation current by a factor of 2.

1. Introduction

Pentacene, a fused-ring polycyclic aromatic hydrocarbon, is one of the most intensively investigated systems among various organic semiconductors due to great mobility and good semiconducting behavior. The electrical conductivity in this material strongly depends on the direction of applied electrical field to its long molecular axis. Also, it is known that the vertical alignment of pentacene molecules to the gate insulator surface provides a strong π-π^* overlap and increases the electrical conductivity in the direction of perpendicular to the long-axis. These have motivated several studies of the effects of pentacene molecular orientations on the performance of OTFTs.

LC is materials which have wide technological applications. Generally, when a liquid crystal is used in a display device, a uniform alignment of the LC molecules is achieved by rubbing treatment or photoirradiation on polymer layers[1-3] as well as by self assembled monolayers.[4] Considering that pentacene is a rigid rodlike molecule similar to the structure of a liquid crystal, it is expected that similar surface-induced order can also be imposed on pentacene. In this paper, we use different alignment layers to investigate their effects on pentacene molecular orientation and the concomitant performance of organic TFTs.

2. Experimental

OTFTs with the cross-linked poly (4-vinylphenol) (cPVP) insulator layer were fabricated. cPVP layer was spin-coated and baked at 180°C for 1 hour in a vacuum dry oven. Its thickness was about 3000 Å confirmed by α-step profilemeter. For the fabrication of morphological alignment layer, PI (RN1199a, a product of Nissan Chemical Industries, Ltd.) films were formed by spin-coating on cPVP insulator layer and then rubbed in the parallel and vertical directions to conducting channel in OTFTs. LCP material was used for the fabrication of molecular alignment layer. LC molecules were aligned in the parallel and vertical directions to channel direction.

Pentacene was purchased from TCI and used without any further purification. Films were grown by vacuum evaporation at a pressure of under 10^{-5} Torr on glass at room temperature. The rate of deposition was of the order of 0.6 Å/s and the final film thickness was 600 Å. Channel length (L) and width (W) of fabricated OTFTs were 90 μm and 300 μm, respectively

3. Results and Discussion

We investigated the microscopic images under crossed polarizers of LCP layer spin-coated on rubbed PI to confirm ordering characteristic of LCP layer (see Fig.1). Light can pass through crossed polarizer on LCP layer spin-coated on rubbed PI because LCP layer was ordered to rubbing direction.

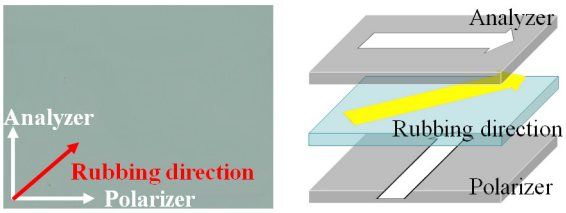

Figure 1 Microscopic image of LCP layer on rubbed PI

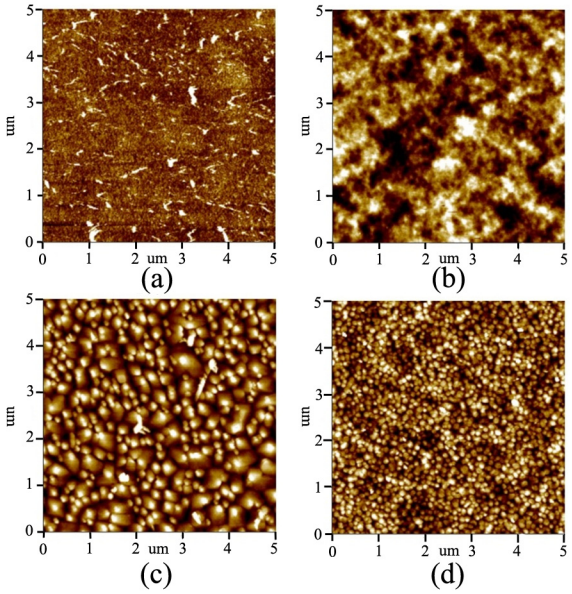

Figure 2 AFM images of LCP layer on PI (a) without and (b) with rubbing treatment. The grain size of pentacene deposited on (c) disordered and (d) ordered LCP layer was changed

LCP layer can ordered the LC molecules to same ordering direction. We expected that similar ordering characteristics can be imposed on pentacene because of the rodlike molecule structure similar to the liquid crystal.

Figure 2(a) and (b) show the atomic force microscopy (AFM) image of disordered and ordered LCP layer, respectively. The morphology of disordered LCP layer was very smooth that has the root-mean-square (RMS) value of roughness 2.3 nm. The roughness of ordered LCP layer is also as low as disordered LCP layer. There is no morphological difference between ordered and disordered LCP layer surface, but it has a significantly difference on the pentacene grain size deposited on LCP layers. The grain size of pentacene deposited on ordered LCP layer was smaller than another. It strongly influences the conduction properties and in particular the saturation current. Decreased grain size can induce the decreased width of pentacene grain boundary, it means that the potential barrier between grain boundaries will be decreasing. This result observed in pentacene TFTs deposited on hydrophobic surface to improve the device performance.

Figure 3 shows typical source–drain current versus source–drain voltage curves from three devices prepared side by side, with ordered and disordered LCP layer. The triangles and circles are data from devices with LCP layer ordered vertical and parallel to the direction of current flow in the channel, respectively. The filled circles are data from the device with the disordered LCP layer. The device with the vertical rubbing direction shows the saturation current that is over 1.5 times larger than the disordered device. On the other hand, the device fabricated on ordered LCP layer to the vertical direction of current flow was found to have a poor influence on the saturation current.

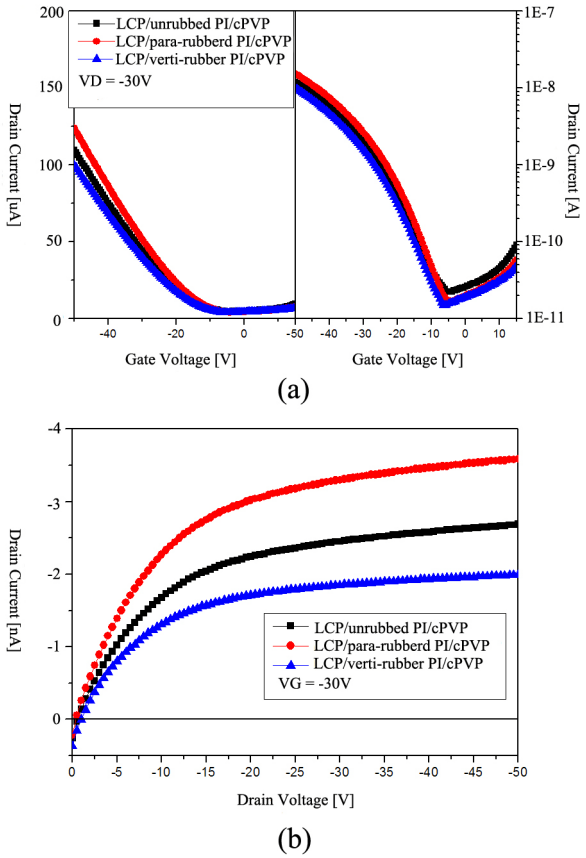

Figure 3 The (a) transfer and (b) output curve of OTFTs having different rubbing conditions

The electric characteristic of OTFTs have the only rubbed PI layer exhibited an increase in the drain current compared to the device without rubbing treatment, independent on the rubbing directions. Dichroic ratio of the drain current was about 1.2, which is defined as the ratio of current for the device with the parallel aligned PI layer to that with the vertical aligned PI layer. On the other hand, the electric characteristic of OTFTs with the LCP layer that has effectiveness on molecular alignment showed a significant dependence of drain current on the ordered direction: the drain current in the parallel direction to current flow of channel region increased compared with that for the device with disordered LCP layer, but the drain current in the vertical direction to current flow of channel region even deteriorated. In this case, dichroic ratio was about 2.1. These results indicate that the morphological effect on the pentacene molecular orientation is intrinsically different from that of a prior molecular orientation.

4. Conclusion

We use ordered LCP layers to investigate their effects on pentacene molecular orientation and the concomitant performance of OTFTs. We controlled pentacene molecular orientation by effect with pentacene molecules and LCP molecules. When we introduced LCP layer in OTFTs, they were found to enhance the saturation current by a factor of 2.

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