

Photoalignment Process of Optical Anisotropic Pentacene Thin Film for Organic TFTs

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Abstract

We report on the photoalignment process of pentacene thin film with optical anisotropy on treated buffer layers. The photopolymer, showing an anchoring transition, was used as a buffer layer to control the structural order of the pentacene molecules. Using the photoelastic modulator, it was found that the grain size and the optical anisotropy of the pentacene thin film were strongly correlated with each other.

1. Introduction

Organic semiconducting materials, such as conjugated polymers and oligomers, have attracted great interest for advancing flexible electronics where large area coverage, mechanical flexibility, low-temperature processes, and overall low-cost are required [1-3]. Especially, organic thin-film-transistors (OTFTs) based on the pentacene have been extensively studied due to their superior performances such as high field-effect mobility and large current on/off ratio [4-6]. It is generally believed that the intermolecular transport occurs via hopping or tunneling mechanism dependent on sharing the electron clouds between molecules [7]. Thus, the collective molecular ordering and recovery of void sites in thin films of organic semiconducting materials play an important role on the device performances.

Considering that the pentacene molecule has a rod-shape like a liquid crystal (LC) molecule, it is expected that the structural ordering of the pentacene molecules can be induced on an aligning layer of the LC molecules through anisotropic surface anchoring. Recently, some aspects of molecular ordering of the pentacene molecules on a surfactant-treated surface were shown to increase the grain size and the mobility in the pentacene-based devices such as the OTFTs [5,6]. However, the underlying physics behind the surface-induced ordering and the resultant surface morphology have not been reported so far.

In this work, we report on the photoalignment process of pentacene thin film with optical anisotropy on treated buffer layers which can be also served as a

gate dielectric layer. The exposure of a linearly polarized ultraviolet (LPUV) light onto the photoaligning buffer layer is capable of controlling precisely the surface orientation of the pentacene molecules into the quasi-planar alignment. Using the atomic force microscope (AFM) and a photoelastic modulator (PEM), the surface morphology and the optical anisotropy were determined for the substrates with photoalignment buffer layers showing the anchoring transition.

2. Configurations

Figures 1(a) and 1(b) show schematic diagrams of the surface orientation of the pentacene molecules, having a rod-shape like the LC molecule, on two different substrates coated with the photoaligning polymer of the polymethylmethacrylate (PMMA) moiety, one of which was treated with the LPUV light. Note that the PMMA photopolymer was known to align the LC

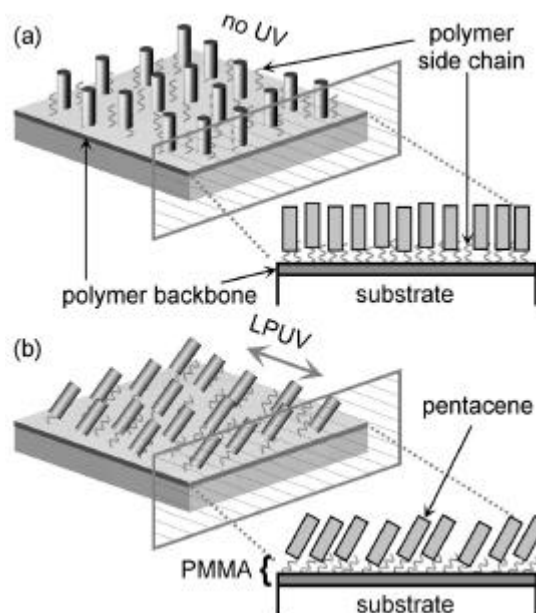


Fig. 1 Schematic diagrams of the surface orientation of the pentacene molecules on (a) the PMMA buffer layer with no UV treatment and (b) the PMMA buffer layer exposed to the LPUV light.

homogeneously by the illumination LPUV light and vertically under no UV light [8]. Another point is that the dielectric constant of the PMMA polymer used was found to be about 3.8, and thus it can be used as a gate dielectric layer for fabricating the OTFTs.

In Fig. 1(a) where the side chains of the PMMA photopolymer are oriented vertically on the substrate, the pentacene molecules will arrange themselves along the direction perpendicular to the photoaligning buffer layer under no LPUV light. Under the LPUV illumination, the photosensitive side chains experience the anisotropic photoreaction along the polarization direction of the UV beam which is perpendicular to the pentacene molecules as shown in Fig. 1(b). Then, the pentacene molecules on the LPUV treated substrate will incline toward a certain direction dependent on the polarization direction of the illuminated UV beam. Such molecular inclination tends to pack the pentacene molecules in a more ordered state whose optical anisotropy can be accurately measured with the PEM. The PEM method is powerful for measuring an extremely small optical anisotropy such as the phase retardation through a rubbed aligning layer for the LC [9].

3. Experiments

The photosensitive PMMA buffer layer of LGC-M1 (LG Cable Co., Korea) was used for producing the anisotropic anchoring forces for the pentacene molecules. The PMMA photopolymer is known to produce dual-alignment of the LC molecules dependent on the LPUV exposure. After glass substrates were coated with the PMMA photopolymer, they were baked at 150 °C for 30 minutes. In order to generate the anisotropic anchoring forces for the pentacene molecules, the LPUV light was exposed to the photosensitive PMMA buffer layer at 12 mW/cm² for 3 minutes. We used a broadband UV source of a high pressure Hg lamp for photo-aligning the pentacene molecules. The pentacene thin films were deposited by thermal evaporation in a vacuum chamber under a basal pressure of 10⁻⁶ mbar at room temperature. The pentacene powder with high purity of 99.8% (Sigma-Aldrich Co.) was used. The deposition rate was maintained to be 0.5 Å. The thicknesses of the buffer layer and the pentacene thin film were measured as 500 nm and 60 nm, respectively.

The surface images and the morphological profiles of the pentacene film samples on two different substrates

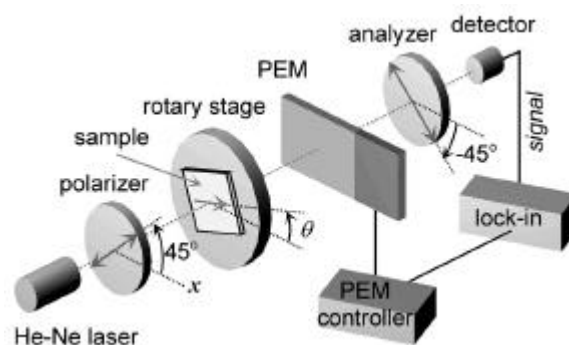


Fig. 2 The experimental setup to measure the optical anisotropy of the pentacene thin films. The pentacene sample is placed in a rotary stage system.

were observed with the AFM. The phase retardation through each pentacene sample, placed in a rotary stage system (495B and PMC200, Newport Co.) under crossed polarizers [9], was measured using the phase retardation technique [10] as shown in Fig. 2. The azimuthal angle-dependent birefringence (phase retardation) of the pentacene sample was determined using the PEM (PEM90, Hinds Instruments) and lock-in amplifier (SR830, Stanford Research System).

4. Results and Discussion

The AFM images and the morphological profiles of the pentacene film samples on two different substrates are shown in Fig. 3. Here, the morphological profiles were obtained along the white dashed-lines shown in

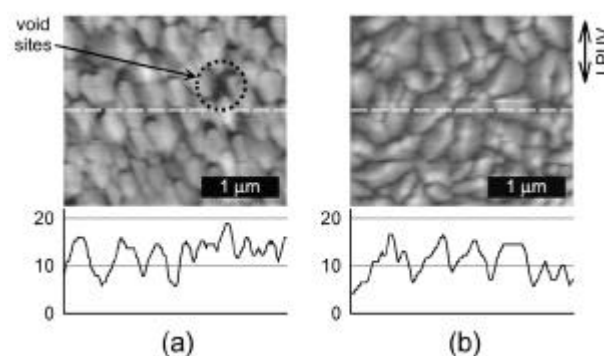


Fig. 3 The AFM images and the morphological profiles of the pentacene thin films on (a) the PMMA buffer layer with no UV treatment and (b) the PMMA buffer layer exposed to the LPUV light. The morphological profiles were obtained along the white dashed-lines in the AFM images. Dotted circles represent the void sites with deep valleys in the pentacene thin films.

the AFM images. In Figs. 3(a) and 3(b), the standard deviations in the morphological profiles of the pentacene samples were measured as 4.06 nm and 3.73 nm, respectively. As shown in Figs. 3(a) and 3(b), void sites with deep valleys, marked by dotted circles in Fig. 3, were not observed in the pentacene sample on the LPUV treated buffer layer. This indicates that as shown in Fig. 3(b), the tilted arrangement of the pentacene molecules play a significant role in the recovery of the void sites since the molecular inclination tends to pack the pentacene molecules in a more ordered state.

The more ordered, tilted arrangement of the pentacene molecules having a rod-like shape produces a non-zero optical anisotropy, and thus the phase retardation through each pentacene sample is measured. Figs. 4(a) and 4(b) show the measured optical anisotropies of the pentacene film samples on the PMMA buffer layer with no UV treatment and the PMMA buffer layer exposed to the LPUV light. Here, the azimuthal angle represents the rotation angle of the pentacene sample under crossed polarizers.

On the PMMA buffer layer with no UV treatment, the structural ordering of the pentacene molecules exhibits isotropic symmetry since the non-treated PMMA buffer layer produces nearly vertical alignment of the pentacene molecules as shown in Fig. 4(a). Under the LPUV exposure on the PMMA buffer layer, however, the pentacene molecules become unidirectionally tilted and packed in a more ordered state due to the anisotropic anchoring forces generated in the photoaligning buffer layer by the LPUV treatment. As shown in Fig. 4(b), an optical anisotropy exists in such more ordered configuration

of the rod-like pentacene molecules. Note that in a uniaxial medium, the optical anisotropy can be determined from the optical intensity measured as a function of the rotation angle of the optic axis under crossed polarizers. In this case, the optical anisotropic pattern should have 4-fold symmetry since the uniaxial medium has the fast and slow optic axes. The direction of the optical anisotropy coincides with the polarization direction of the exposed UV light. This means that the structural order of the pentacene molecules can be precisely controlled by the polarization of the LPUV light. Moreover, the magnitude of the optical anisotropy and the grain size are primarily governed by the strength of anisotropic surface anchoring of the pentacene molecules on the PMMA buffer layer.

5. Conclusion

In conclusion, we presented the photoalignment process of the pentacene thin film to control its surface-induced molecular order and the associated optical anisotropy on the photoaligning PMMA buffer layer. The PMMA photopolymer, used as a gate dielectric layer for fabricating the OTFTs, possesses an anchoring transition from the vertical alignment to the quasi-planar alignment by the LPUV light. It was found that the void sites with deep valleys were recovered in a more ordered state of the pentacene molecules on the LPUV treated buffer layer. Moreover, the structural order of the pentacene molecules can be precisely controlled by the polarization of the LPUV light. The results presented here provide a basis for controlling the mobility and the grain size in the pentacene thin film for flexible electronics.

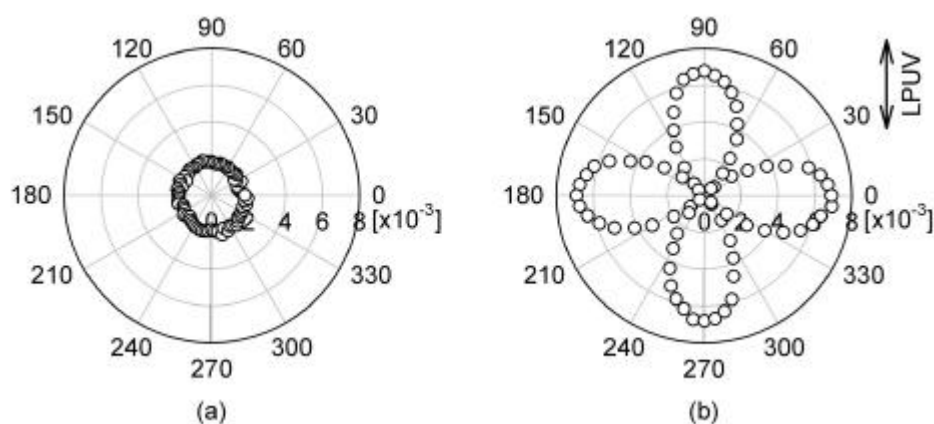


Fig. 4 The optical anisotropies of the pentacene thin films on (a) the PMMA buffer layer with no UV treatment and (b) the PMMA buffer layer exposed to the LPUV light.

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7. References

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