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Advanced fabrication of organic thin-film transistors

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Introducing a photosensitive modification layer between the active and gate dielectric layers of thin-film devices dramatically enhances their charge mobility performance.

Organic and polymeric semiconductors represent a novel class of materials that combine the optical and electronic properties of semiconductors with the processing advantages and mechanical properties of plastics. As a result, organic semiconductors are now suitable for thin-film device technologies, also called organic electronics. Applications include transistors, light-emitting diodes (LEDs), solar cells, sensors, and switches.

The performance of organic thin-film transistors (OTFTs) depends on their constituent semiconductors and dielectrics (insulating materials). In particular, the surface properties of a dielectric layer, such as energy and roughness, represent important factors for potential improvements in the electric characteristics of OTFTs.[1–3] In cases where pentacene is grown on dielectrics with surface-induced morphology, the structure of the first few monolayers is expected to have a strong impact on charge mobility.[2,4] Performance can also be improved by manipulating charge transport in devices. Since carrier transport occurs in a thin layer near the dielectric interface in a typical OTFT configuration, precise interfacial control becomes a crucial element for higher performance.

Many researchers working on OTFTs use polymer materials as a modification layer placed between the silicon dioxide (SiO_2) gate dielectric and the pentacene active layer. Since 2003, our group has also used this approach with the goal of developing high-performance devices. The general structure of one of our OTFTs is shown in Figure 1.[5] We use a photosensitive polyimide (PSPI) not only as a modification layer but also as an alignment layer for the organic semiconductors.[6] Recently, we deposited pentacene films on a PSPI surface characterized by an interesting groove-like morphology (see Figure 2).

Our photoalignment method has already successfully demonstrated anisotropic electrical properties in pentacene OTFTs with enhanced carrier mobilities. Atomic force microscopy and x-ray diffraction studies showed that the pentacene molecules in our active layers were highly oriented along a preferred axis. Our

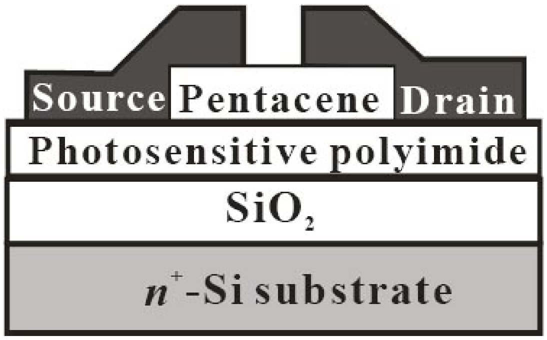

Figure 1. Cross-section of an OTFT in which the silicon substrate also acts as gate electrode. A photosensitive polyimide modification layer is inserted between the gate dielectric and pentacene films. n^+-Si: Highly doped negative-type silicon. SiO_2: Silicon dioxide.

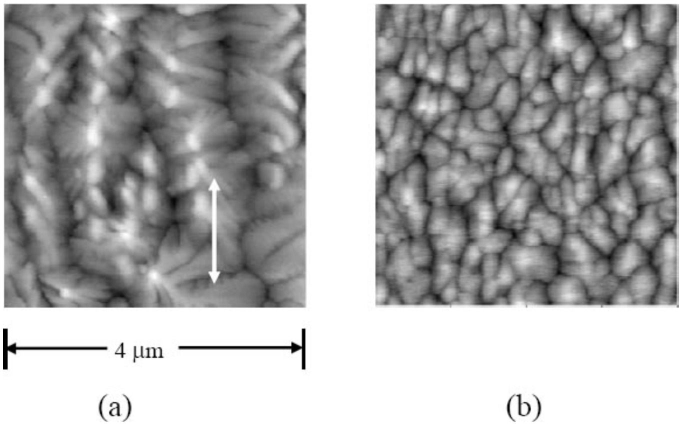

Figure 2. Atomic force microscope images of pentacene films deposited on the surface of (a) PSPI and (b) thermally grown SiO_2. The arrow in image (a) is the alignment direction of the pentacene film. The pentacene layer has an average thickness of 100nm. Reproduced with permission.[6] Copyright 2004 Wiley-VCH Verlag GmbH & Co. KGaA.

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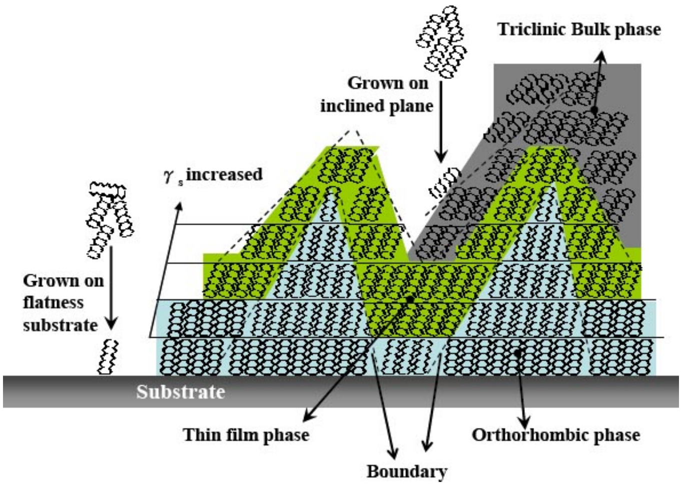

Figure 3. *Schematic evolution of thin-film polymorphs of pentacene film with increasing thickness.* γ_S*: Surface energy in* mJ^{-2}*. Reproduced with permission.*[7] *Copyright 2007 Wiley-VCH Verlag GmbH & Co. KGaA.*

results represent the first measurement of anisotropic electrical behavior in OTFT devices based on pentacene photoalignment technology. These properties could prove very attractive in circuit design, for example, to isolate neighboring components without requiring a large spatial separation or patterning of the organic semiconductor layer. For most organic semiconducting films such as pentacene, the organic active layers deposited on the substrate are often normally conducting and lack a suitable process to pattern the active layer so as to isolate the devices from each other. Our photoalignment method now makes it possible to solve these problems because it enables the fabrication of multiple alignment domains on the organic semiconducting film. We expect that the optimization of photoalignment conditions in OTFT devices should result in further enhancement of their anisotropic electrical properties.

During our experiments, we have also created high-performance pentacene-based OTFTs using PSPI as a modification layer on the gate dielectric. The maximum saturation field-effect mobility exceeded $2.0cm^2/Vs$. Moreover, the PSPI layer has a low surface free energy that can enhance carrier mobility in pentacene-based OTFTs, while increasing crystalline size and also decreasing the crystal disorder of pentacene films.

In other recent work, we have proposed a new growth model that rationalizes the thickness-driven phase transformations in polycrystalline pentacene films in terms of crystal structure, grain size, surface energy, and molecular microstructure (see Figure 3).[7] Our results showed that pentacene grown on PSPI surfaces displays an improved molecular microstructure associated with larger intermolecular interactions as well as enhanced environmental homogeneity and charge mobility.

Our research interests are broad and include several aspects of the fundamental and applied physics of organic semiconductor materials, such as carrier transport, charge, and energy transfer phenomena. A special interest, however, is the development of advanced fabrication techniques for novel organic materials and devices as demonstrated by our recent results. Other on-going research includes the development of novel *n*-type OTFTs using perylene derivatives as active materials.

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