Vertical-type organic transistor advances flexible sheet displays

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Bendable vertical-type organic transistors, with stable high-current and low-voltage operation, provide a building block for electronics and light emitters in next-generation display devices.

Recent developments in organic semiconductors have yielded high-performance electronic and optoelectronic devices, including organic light-emitting diodes (OLEDs), organic field-effect transistors (OFETs), and organic solar cells. Organic materials could potentially be used to create low-cost, large-area, flexible devices. The mobile electronics industry is already anticipating products that incorporate OLED display panels. Researchers have also made rapid progress on OFETs in recent years. Furthermore, combining OLEDs with organic transistors could make all-organic devices possible.

To be practical, however, organic transistors must provide high current density with a drive voltage as low as a few volts and offer sufficient reliability for the application. Conventional OFETs have not achieved these characteristics: they are low-speed, low-power transistors that require relatively high operational voltage. This is mainly due to the low mobility and high resistivity of the organic semiconductors.

To overcome these disadvantages, we developed a number of vertical-type organic transistors. One example is organic static induction transistors (OSITs), which exhibit the high-speed, high-power operation needed for display drivers (see Figure 1). The attractive characteristics of OSITs arise from their vertical structure, which enables a very short channel length between the source, drain, and gate electrodes. Vertical-type organic light-emitting transistors (OLETs), made by combining OSITs and OLEDs, are promising components for flexible sheet displays.

Because no gate insulator is required in fabricating OSITs, they can be made on a flexible substrate in the same way as on glass, and using simple methods such as vacuum evaporation. In our recent research, OSITs fabricated on flexible plastic substrates showed stable electrical characteristics under...
bending conditions. However, for use in the vertical-type OLETs, the OSITs needed a larger on/off ratio and more current. Our recent efforts have focused on improving the performance of OSITs by optimizing the device structure and organic materials. We controlled the interface of vertical-type organic transistors to improve the electrical properties of OSITs, and then used them to demonstrate organic inverters and vertical OLETs for flexible sheet displays.

To enhance the performance of pentacene-based OSITs, our group investigated the effect of the interface control on their behavior. We inserted an ultrathin copper phthalocyanine (CuPc) layer between indium tin oxide (ITO) and a pentacene thin film. We found that these devices achieved both a high on/off ratio of more than 1:1000 and a high current density of more than 1mA/cm$^2$ (see Figure 2). This thin layer is a key factor in the ability of high-performance OSITs to optimize their electronic states, including the hole-injection barrier and band bending at the interface between the organic semiconductor layer and the source electrode. We then used these improved OSITs to fabricate the organic inverters that operate at low voltage. Experimental measurements of the inverter transfer characteristics showed that the operational voltage ranged from –2V to +2V.

We also combined OSITs based on pentacene/CuPc with OLEDs based on tris-(8-hydroxyquinoline) aluminum (Alq3) and 4,4′-bis(N-(1-naphthyl)-N-phenylamino)biphenyl (NPD) to make vertical-type OLETs. These OLETs show typical OSIT characteristics: the current in the OLETs is controlled by a relatively small gate voltage of –1V, and the luminance varies depending on the current voltage. These results show that OSITs are a suitable element for flexible sheet displays. However, much work remains to be done, including developing new materials, device structures, and device fabrication processes. As a next step toward achieving the high current density and high-speed operation required for practical application, I plan to make vertical-type organic transistors using a soluble and air-stable organic semiconductor with high carrier mobility.

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References