Fabrication of an Integrated Pixel with an Organic Light-Emitting Diode Driven by Copper Phthalocyanine Organic Thin Film Transistors *

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An organic integrated pixel with organic light-emitting diodes (OLEDs) driven by organic thin film transistors (OTFTs) is fabricated by a greatly simplified processing. The OTFTs are based on copper phthalocyanine as the active medium and fabricated on indium–tin–oxide (ITO) glass with top-gate structure, thus an organic integrated pixel is easily made by integrating OLED with OTFT. The OTFTs show field-effect mobility of 0.4 cm^2/Vs and on/off ratio of 10^3 order. The OLED is driven well and emits the brightness as large as 2100 cd/m^2 at a current density of 14.6 $\mu A/cm^2$ at −19.7 V gate voltage. This simple device structure is promising in the future large-area flexible OLED displays.

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Organic light-emitting devices (OLEDs) are one of the most promising next-generation low cost full colour flat panel displays alterative to liquid crystal-based ones.[1−5] Great efforts have also been paid to addressing issues of high information content displays based on such LEDs. The active matrix organic light emitting diodes (AMOLEDs) are considered to have the largest market potential because it affords high information content as well as the advantages of thinner, portable, light-weight and low power consumption.[6,7] The active addressing schemes have been proposed.[8−10]

For AMOLEDs, the driving transistors should be able to supply sufficient current to drive OLEDs and also have high compatibility with OLEDs' substrate. Organic thin film transistors (OTFTs) have attracted attention for use in a number of large area applications where high switching speeds are not essential.[11−13] Taking account of the performance and processing temperature, the OTFTs are taken as the most promising candidate. Significant progress has been achieved in the performance of organic thin film transistors (OTFTs) in the last decade, and state-of-the-art OTFTs have already reached a status comparable with hydrogenated amorphous silicon (α-Si) transistors.[14]

In most cases, the OTFTs were fabricated with organic semiconductors (OSCs) as the active component and inorganic oxides as the gate dielectrics, such as SiO_2, Ta_2O_5, Al_2O_3 on a Si wafer.[15−17] However, these hybrid devices are hardly suitable for the organic display application requiring low cost, and large area coverage because of their complicated manufacture processing and limited size.

We have demonstrated the potential of fluoride materials as gate dielectrics for OTFTs.[18] The fabricated transistors show good electrical characteristics, and the same method used to form the organic semiconductor and fluoride gate dielectric films by thermal evaporation greatly simplified the fabrication process of devices. This provides a convenient way to produce high-performance OTFTs on large scale and should be useful for integration in organic displays.

In this study, we fabricated optoelectronic integrated pixels consisting of an OLED driven by an OTFT via the full evaporation method on glass substrates. The OTFTs have nylon 6/CaF_2 two-layer gate dielectrics. It can be seen that the OTFTs can drive OLEDs well, thus an integrated pixel consisting of an OLED and an OTFT is realized.

The smart pixels were fabricated on indium tin oxide (ITO) coated glass substrates. ITO as source and drain electrodes were patterned by photolithography. OTFTs were firstly fabricated. After usual cleaning, a 50-nm-thick copper phthalocyanine (CuPc) active layer was thermally deposited on the patterned ITO substrates through the first shadow mask. The evaporation ratio was about 0.1 nm/s at the vacuum pressure of 10^{-4} Pa. Then, a 10-nm nylon 6 and 300-nm calcium fluoride (CaF_2) gate insulating layer was thermally deposited on the top of the CuPc active layer at an evaporation rate of 3–5 nm/s through the same shadow mask. Then OLEDs were fabricated. NPB (50 nm), Alq_3:C545T(30 nm), Alq_3(30 nm) and

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LiF(1 nm) layers were orderly thermally deposited on the top of the ITO anode by another shadow, and finally 100-nm Al as the gate electrode and cathode was formed by the third shadow mask. The emission area of the OLED is $500 \times 500\,\mu m^2$. Three masks were changed in vacuum. The substrates were held at room temperature during the deposition. A schematic of the cross section of the smart pixel is shown in Fig. 1.

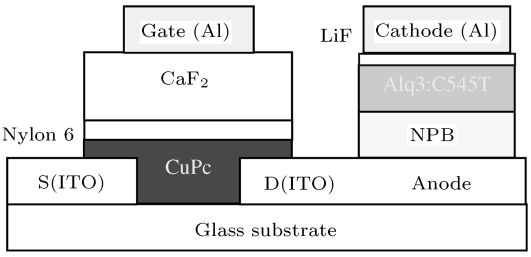


Fig. 1. Schematic diagrams of the integrated OTFT and OLED device.

The electrical characteristics of OTFTs were measured by using two Keithley source meters (Keithley 2400). The current–brightness–voltage characteristics of OLEDs were measured by using a Keithley source measurement unit (Keithley 2400 and Keithley 2000) with a calibrated silicon photodiode. All the measurements were carried out under ambient condition.

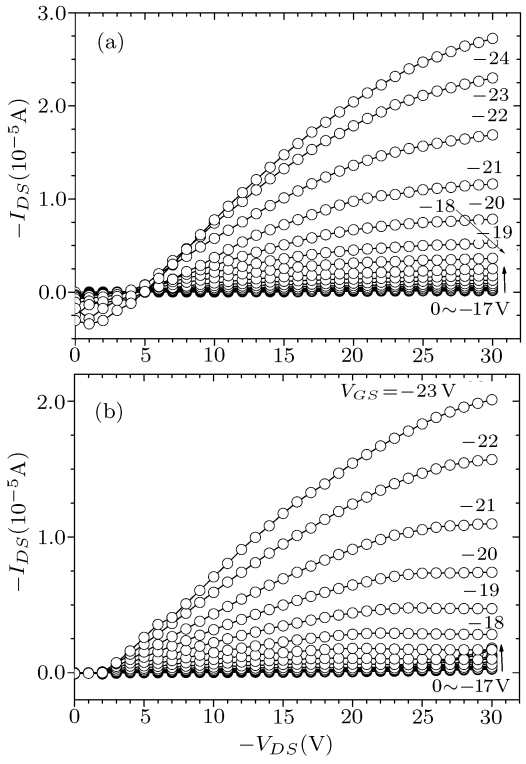


Fig. 2. Output characteristics of the CuPc OTFTs with (a) CaF_2 and (b) organic nylon 6/CaF_2 gate dielectric.

From comparison of the output characteristics of OTFTs with the CaF_2 single layer gate insulator and the nylon 6/CaF_2 two-layer gate insulator, as shown in Fig. 2, the gate leakage current was greatly reduced from 10^{-6} A to 10^{-8} A due to the addition of nylon 6, which is favour of driving OLEDs. The field-effect mobility extracted from the OTFT device characteristics was $0.4\,cm^2/Vs$ at $V_G = -25$ V and the ON/OFF current ratio is 10^3 order.

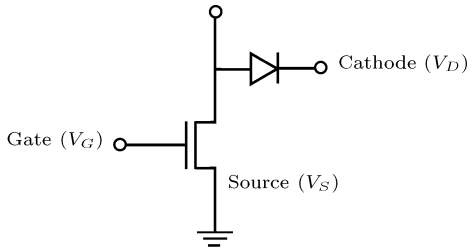


Fig. 3. Equivalent circuit diagram of integrated OTFT and OLED.

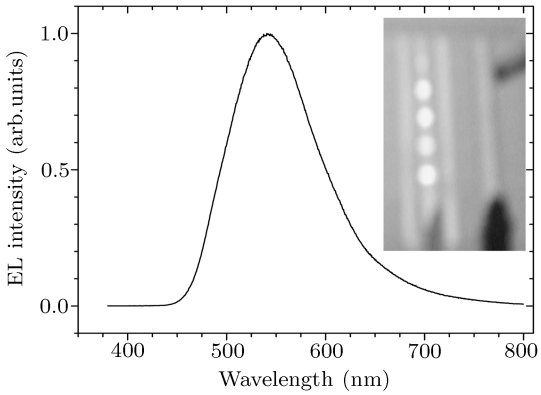


Fig. 4. Electroluminescence spectrum of the OLED and the photograph of the devices.

Figure 3 shows the equivalent circuit diagram of integrated OTFT and OLED. As OTFT is switched to ON-state, there is current to flow from the OTFT source electrode to the OLED cathode. Consequently, the OLED can be switched on and off by changing the OTFT gate voltage. Figure 4 gives the electroluminescence spectrum of the OLED and the photograph of the devices. Light emission from the OLEDs can be clearly seen with the naked eye. It can be seen that the OLED generated green light with a wavelength of 530 nm. The current-brightness-voltage characteristics of the device was measured by varying the gate voltage V_G, at a fixed drain-source voltage $V_{DS} = -30$ V. From Fig. 5, the OTFT supplied a current density of $0.466\,\mu A/cm^2$ at turn-on voltage of $V_G = -11.5$ V and the OLED brightness of $14.2\,cd/m^2$, and at $V_G = -19.7$ V, the OTFT supplied a current density of $14.6\,\mu A/cm^2$ to the OLED resulting in a brightness of $2100\,cd/m^2$. The brightness of $300\,cd/m^2$, which is necessary for a conventional display, was achieved at a current density of

$5.44\,\mu A/cm^2$ at the gate voltage of $-14.9\,V$. Single OLED test showed that the turn-on voltage is 2.5 V and the current efficiency is 15.4 cd/A, compared to the reported values. It can be concluded that the brightness of OLEDs should increase if the OTFT can provide larger current. The top-gate structure permits us to markedly increase the W/L ratio using comb-shape source and drain electrodes, but without increasing the area of OTFT, thus the output current of OTFT should be greatly increased.

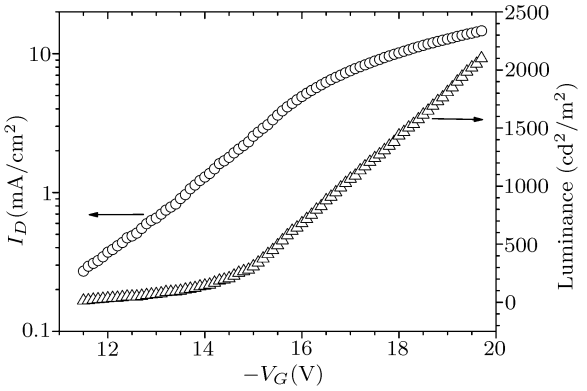


Fig. 5. Current-brightness-voltage characteristics of the device. The OLED device structure is ITO/NPB(50 nm) /Alq:C545T(0.5 1%)(30nm)/Alq(30 nm)/LiF(1 nm)/Al.

In conclusion, we have fabricated an organic integrated pixel with OLEDs driven by OTFTs via greatly simplified processing and device structure. The OTFTs show better electrical properties with field-effect mobility of $0.4\,cm^2/Vs$ and the on/off of 10^3 order, and provided sufficient current to drive OLEDs. The driven OLEDs emit brightness as large as $2100\,cd/m^2$ at a current density of $14.6\,\mu A/cm^2$ at the gate voltage of $-19.7\,V$. This kind of simple device structure is promising for future large-area flexible OLED displays.

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