Extended Abstracts of the 2003 International Conference on Solid State Devices and Materials, Tokyo, 2003, pp. 770-771

C-7-4

Measurement of Lateral Carrier Mobility in Organic Thin Films Using Time of Flight Method

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1. Introduction

Organic materials have been attracted much attention because of applications to devices such as field-effect transistors [1,2], light-emitting devices (LED) [3], photodetectors [4] and gas sensors [5]. Carrier transport in organic materials for these applications plays important roles for devise performances. Hence it is importance to investigate carrier transport in organic films.

Time-of-flight (TOF) technique is useful for investigation of carrier transport in organic films [6,7]. In the TOF method, carrier mobility and diffusion are analyzed from photocurrent generated by carrier transport in an organic film between electrodes. In general, the vertical current in TOF method is observed because the organic layer is sandwiched between the electrodes. The measured vertical carrier mobility is useful for devices in which carrier vertically transport as organic LED. However, it is necessary to investigate lateral carrier transport concerning devices in which carriers laterally transport as organic thin-film transistors (TFTs). Because differences between vertical and lateral carrier transport are predicted from anisotropy of organic films.

In this study, we have demonstrated measurements of lateral carrier mobility in organic films by TOF technique using a micro-excitation system. The organic layer was copper phthalocyanine (CuPc), which is used for organic TFT [8] and gas sensor [5]. In order to compare measured carrier mobility to field-effect mobility, we fabricated organic TFTs with CuPc as a channel material.

2. Experimental

Figures 1(b) shows schematics of TOF measurement system. The measurements were carried out with a cw Ti:sapphire laser light, which was focused onto the samples by the objective lens. The laser light was modulated by an acousto-optic modulator (AOM), which is controlled by a pulse generator. The waveform of control voltage had a rectangular form with a pulse width of 1 μs. The cw laser power was about 100 mW, and wavelength is variable in the range of 700 to 900 nm. The photocurrent of the CuPc layer is obtained less than 770 nm. The sample surface and irradiation pattern were observed through the same objective lens by using a charge-coupled device (CCD). Therefore, irradiation position is adjustable.

The schematic illustration of measured sample and electric circuit is shown in Fig. 1(b). The CuPc layer of 100 nm was deposited on a glass substrate at a rate of 0.02 nm/s by thermal evaporation. Aluminum electrodes were patterned by shadow mask. The distance between the electrodes is 10 μm. The sample was encapsulated in a glove box under dry nitrogen to avoid degeneration of the organic material (not illustrated). The organic layer was excited through the glass substrate by the Ti:sapphire laser. The aluminum electrodes were connected in a circuit with a voltage source and a resistance. The TOF measurement was carried out under electric field in the range of 10 to 60 kV/cm. The current transient of TOF was observed with a voltage amplifier and a digital oscilloscope.

We fabricated the organic TFTs so as to compare carrier mobility and field effect mobility. Organic transistors were fabricated on a glass substrate. The device structure consisted of a chromium gate, a 150-nm-thick SiO_2 gate insulator with a capacitance of 20 nF/cm^2, and Cr/Au layer for drain and source electrodes. The shapes of electrodes were defined by photolithography and conventional lift-off process. A 60-nm-thick CuPc layer was deposited on the same condition to compare the mobilities.

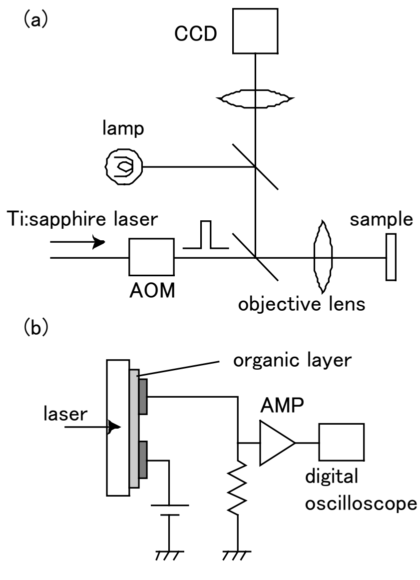
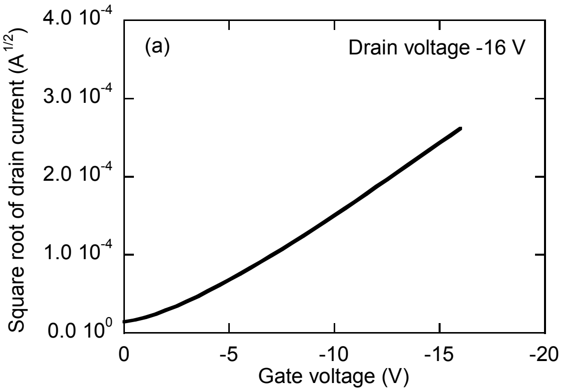


Fig. 1 TOF measurement system. (a) A micro-optical system for excitation of carrier in organic films. (b) Illustration of a sample and an electric circuit.

3. Results

Figure 2 shows the square root of drain current and the drain current characteristics of the CuPc TFT. The channel width and length of the transistor were 250 μm and 4 μm, respectively. The transistor acts as a p-type transistor. The saturation region was observed at high drain. The square root of the drain current was proportional to the gate voltage in the range of –9.5 to –15 V, as seen in Fig. 2(a). The field-effect mobility is estimated to be 5.6×10^{-4} $cm^2/(Vs)$.



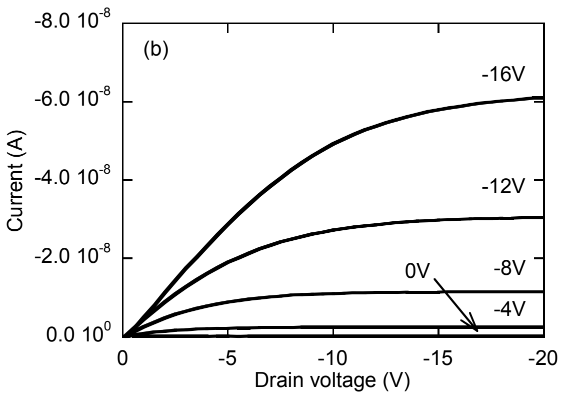


Fig. 2 Characteristics of a CuPc TFT. (a) Square root of drain current versus gate voltage at a drain voltage of –16 V. (b) Drain current-voltage characteristic at various gate voltages.

Figure 3 shows transient current signals at different electric fields, which was obtained from excitation at the center between electrodes with a distance of 10 μm. The CuPc film was exposed at the laser light of a 733 nm wavelength between 10 and 11 μs. The photocurrent increased linearly with time for several micro-second just after incidence of the laser light. The initial spike was not observed in the current signal. The measured signal is slightly different from typical TOF signal for vertical carrier transport. However, plateau region with constant current was observed. The existence of the plateau region indicates that the mean of the carrier (hole) velocity is constant at a constant applied voltage. The proportionally relation between the velocity and electric field is approximately satisfied since the current at the plateau region was roughly proportional to electric field. The carrier mobility is estimated to be 2×10^{-4} $cm^2/(Vs)$ from a fitting to the experimental data. The value is less than that of the CuPc transistor. This may be due to the existence of electrons excited at the same time with hole.

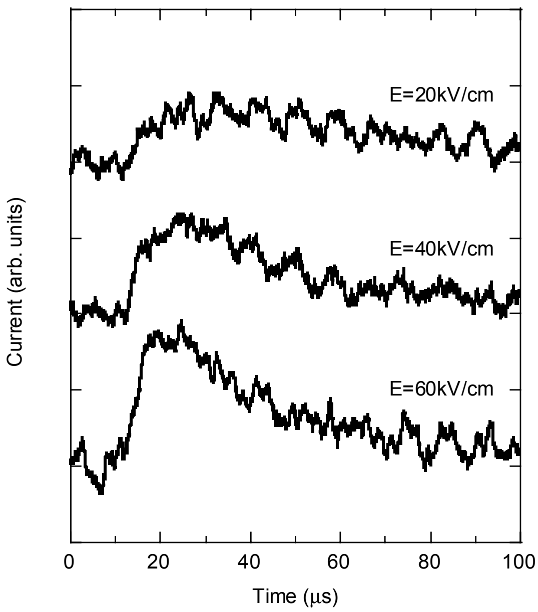


Fig. 3 Time-of-flight photocurrent signal at different electric field.

4. Conclusions

We demonstrated the measurement of lateral carrier mobility in the organic films using the TOF technique. The lateral TOF method will be suitable to investigate carrier transport in organic films for device applications involving lateral carrier transport.

Acknowledgements

This work was supported in part by the IT Program and Grant-in-Aid for COE Research (#12CE2004) from the Ministry of Education, Culture, Sports, Science and Technology.

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