Field-effect Transistors Based on Poly(*p*-phenylenevinylene) Derivatives

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Field-effect mobilities and on/off current ratios have been determined for the organic field-effect transistors (OFETs) based on three kinds of poly(*p*-phenylenevinylene) derivatives. The best transistor performance has been obtained for poly(2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylenevinylene) (MEH-PPV). The hole mobility and the on/off ratio obtained for the MEH-PPV OFET are 3.6×10^{-4} cm^2/Vs and 1.5×10^6, respectively. These OFETs operate stably in the atmosphere as well as in vacuum.

Field-effect transistors fabricated with organic materials have recently received increasing interest because of their potential applications in low-cost, flexible, and large-area devices.[1] Conjugated polymers represent promising candidates for these organic field-effect transistors (OFETs). Among OFETs fabricated with conjugated polymers, the highest hole mobility of 0.1 cm^2/Vs has been demonstrated for the OFET based on regioregular poly(3-hexylthiophene).[2] However, the current on/off ratio of the OFET is not high in the atmosphere. Although poly(*p*-phenylenevinylene) (PPV) derivatives are incorporated as the active materials in light-emitting diodes, few papers[3–5] have been reported for the transistor properties of these polymers. In this paper, we report the properties of OFETs fabricated with PPV derivatives: poly(2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylenevinylene) (MEH-PPV), poly(2,5-dioctyloxy-1,4-pehylenevinylene) (DOO-PPV), and poly(2-[4-(3,7-dimethyloctyloxy)phenyl]-1,4-phenylenevinylene) (DMOP-PPV). The chemical structures of these polymers are shown in Figure 1.

The schematic structure of a bottom-contact OFET and the circuit for measuring OFET characteristics are shown in Figure 2. A highly doped n^+-silicon plate was used as the gate electrode on which the SiO_2 layer with the thickness of about 600 nm was formed by thermal oxidation. The interdigital Au(20 nm)/Cr(10 nm) electrodes, which consisted of 25 pairs with 25 µm in spacing and 6 mm in width, were prepared on the surface and used as the source and drain electrodes. Thus the length (L) and the width (W) of the channel region were 25 µm and 294 mm, respectively. PPV derivatives were synthesized according to the previous methods.[6] A film of each PPV derivative was prepared by casting or spin-coating from a $CHCl_3$ solution of the sample. The concentrations of the MEH-PPV, DOO-PPV, and DMOP-PPV solutions were 0.16, 0.5, and 0.33 wt %, respectively. The thicknesses of the films were about 100 nm. The drain current (I_D) versus the drain-to-source voltage (V_D) characteristics for various values of gate voltage (V_G) were measured in vacuum (1.0×10^{-2} Pa) and in the atmosphere.

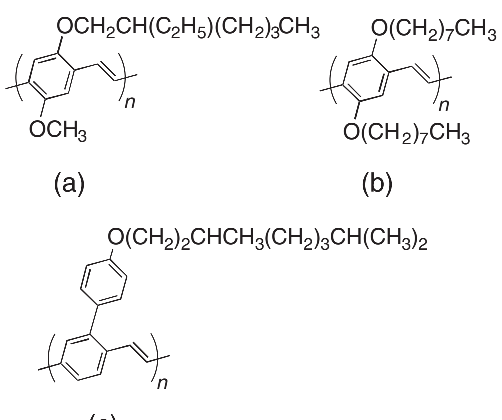

Figure 1. Chemical structures of PPV derivatives: (a) MEH-PPV; (b) DOO-PPV; (c) DMOP-PPV.

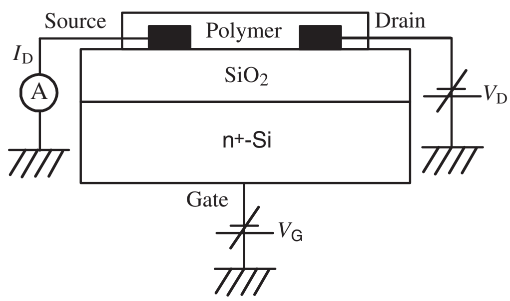

Figure 2. Schematic OFET structure.

Figure 3 shows the I_D–V_D characteristics in vacuum for an OFET fabricated with a solution-cast film of MEH-PPV. When the gate electrode is biased negatively with respect to the source electrode, the OFET operates in the accumulation mode and the accumulated charges are holes. The observed results indicate MEH-PPV behaves as a p-type semiconductor. Saturation behaviors in the drain current are observed. The hole mobility μ_h and the threshold voltage V_T have been calculated from the saturation current $I_{D,sat}$ by using the following equation:[7]

$$I_{D,sat} = \frac{WC\mu_h}{2L}(V_G - V_T)^2 \quad (1)$$

where C is the capacitance per unit area of the gate insulator. The capacitance is 5.75 nF/cm^2. The square root of $-I_{D,sat}$ is plotted against V_G in Figure 4. By using the least-square method, the hole mobility has been obtained to be 7.3×10^{-5} cm^2/Vs and the threshold voltage −33 V. The on/off current ratio (R) means the ratio of the drain currents between $V_G = 0$ and $V_G = -100$ V at the drain-to-source voltage of −100 V. The on/off ratio has

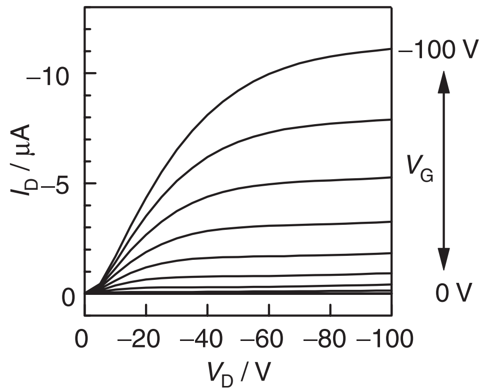

Figure 3. Plot of the drain current (I_D) versus the drain-to-source voltage (V_D) for gate voltages at every 10 V from 0 to −100 V for an MEH-PPV OFET.

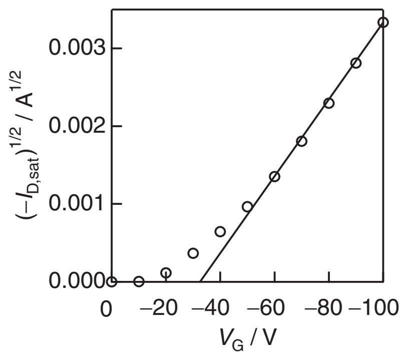

Figure 4. Plot of the square root of the drain current in the saturation regime ($I_{D,sat}$) as a function of the gate voltage for a fixed drain-to-source voltage of −100 V. The straight line is a least-square fit to the points above −60 V.

been determined to be 2.8×10^7. For positive gate voltages the behavior of an n-type semiconductor has not been observed. In the OFETs fabricated with DOO-PPV and DMOP-PPV, these polymers show the behaviors of a p-type semiconductor, but not n-type. By using the procedures used for the MEH-PPV OFET, the hole mobilities, the threshold voltages, and the on/off current ratios of these OFETs have been determined. The best properties obtained for these three kinds of OFETs are listed in Table 1. Field-effect mobilities, on/off ratios, and threshold voltages do not significantly depend on the method of film preparation. The transistor properties of these OFETs are stable even in the atmosphere. In particular, the on/off ratios are high. Tzeng et al.[5] reported the transistor properties of MEH-PPV; the field-effect mobility is 4.3×10^{-4} cm^2/Vs and the on/off ratio is 390. The present on/off ratio is much higher than the reported. The observed high on/off ratios are intrinsic to the PPV derivatives. Probably, PPV derivatives are not doped with the oxygen in the atmosphere, because of their high ionization potentials. The number of carbon atoms in the side chains of a PPV derivative becomes small in the order of DMOP-PPV, DOO-PPV, MDMO-PPV, and MEH-PPV. In this order, the field-effect mobility obtained becomes high. Thus, it is expected that higher field-effect mobility will be obtained for a PPV derivative having smaller side chains.

Table 1. Hole mobilities (μ_h), on/off current ratios (R), and threshold voltages (V_T)

Polymer	Film[a]	μ_h/cm^2 V^{-1} s^{-1}	R	V_T/V
MEH-PPV	spin	3.6×10^{-4}	1.5×10^6	−22
DOO-PPV	sol	1.6×10^{-5}	4.1×10^5	−23
DMOP-PPV	sol	1.8×10^{-6}	2.3×10^5	−22

[a] Spin, spin-coated film; sol, solution-cast film.

In summary, the transistor properties of MEH-PPV, DOO-PPV, and DMOP-PPV have been studied. The MEH-PPV transistor has shown the best performance: the field-effect mobility of 3.6×10^{-4} cm^2/Vs and the on/off ratio higher than 10^6.

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