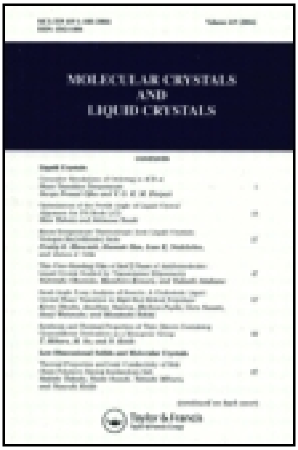

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Electrical Characteristics of All Polymer Based Thin Film Transistor using Poly (3,4-ETHYLENEDIOXYTHIOPHENE) and Polypyrrole

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ELECTRICAL CHARACTERISTICS OF ALL POLYMER BASED THIN FILM TRANSISTOR USING POLY (3,4-ETHYLENEDIOXYTHIOPHENE) AND POLYPYRROLE

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We report the electrical characteristics of all polymer based thin film transistor (TFT). Conducting poly (3,4-ethylenedioxythiophene) (PEDOT) and polypyrrole (PPy) were used for gate electrode and active layer, which were made by photolithographic micro-patterning. Polyvinyle cinnamate and epoxy were used for insulating layer through spin coating. From the current (I)-voltage (V) characteristics of all polymer based TFTs, the source-drain current (I_{ds}) of the devices dramatically decreased with increasing positive gate bias (V_g), indicating p-type TFT. We analyze these results based on the "bottle-neck" effect, which implies the distinct depletion mode of the field effect region on the gate electrode with positive V_g. With negative V_g, the I_{ds} of the devices weakly increases. Depending on the channel length between the contacts of source and drain electrodes, the on-off current ratio (I_{on}/I_{off}) was changed.

Keywords: polypyrrole; poly (3,4-ethylenedioxythiophene); thin film transistor (TFT)

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1. INTRODUCTION

Organic π-conjugated materials with unique electronic properties have attracted considerable attention for new microelectronic devices. The performance of the organic optical and electronic devices such as light emitting diode (LED) and thin film transistor (TFT) has been improved due to the development of new organic π-conjugated materials and their process. The organic TFTs can be used for active driver of flat panel display [1,2]. They have advantages such as low temperature process and light weight [3,4]. The OTFTs have been fabricated through the photolithography pattern made by inorganic insulating layer such as SiO_2 and Si_3N_4 and typical metal electrodes, which causes the limitation for the development of flexible and transparent OTFT.

In this study, we newly fabricated flexible and fairly high transparent TFT based on conducting polymers as gate electrode and active layer by using photolithographic micro-patterning. The electrical characteristics of all polymer based TFT such as dc conductivity (σ_{dc}) of active layer and source-drain current (I_{ds}), were measured. We observed the p-type nature of the devices and the variation of σ_{dc} and I_{ds} with V_g. We analyze the results using the "bottle-neck" effect.

2. EXPERIMENTAL

All polymer based TFT was fabricated by using conducting poly (3,4-ethylenedioxythiophene) (PEDOT) and polypyrrole (PPy) as gate electrode and active layer, which were made by photolithographic micro-patterning. The solution of ferric p-toluenesulfonate (FTS) as an oxidant and polyvinyl alcohol (PVA) as a matrix polymer was spin-coated on flexible and transparent polyethyleneterephthalate (PET) or polyimide (PI) substrate. The oxidant film was exposed to UV light ($\lambda = 365\,\text{nm}$) with the intensity of $10\,\text{mW/cm}^2$ for 10 minutes through a photomask. The patterned oxidant film was then exposed to pyrrole or 3,4-ethylenedioxythiophene (EDOT) vapor for 5 to 30 minutes, resulting in polymerization of pyrrole or EDOT only on the unirradiated area. The thickness of PEDOT or PPy as an active layer was $\sim 4000\,\text{Å}$. It is noted that the source, drain, and active layer are in the one-body type as shown in Figure 1(a). Polyvinyle cinnamate (PVCN) or epoxy was used as an insulating layer by spin-coating. The thickness of dielectric layer was $\sim 3000\,\text{Å}$. The channel length and width of the devices were $1\,\text{cm} \sim 1\,\text{mm}$ and $20\,\mu\text{m} \sim 100\,\mu\text{m}$, respectively. The schematic diagram of the device is presented in Figure 1(a). Flexible and (semi) transparent all polymer based TFT was fabricated as shown in Figure 1(b). The electrical characteristics of the OTFT devices were

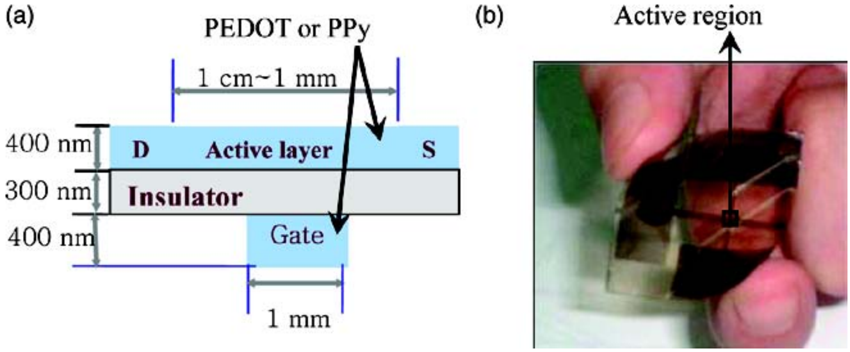

FIGURE 1 (a) Schematic diagram and (b) photograph of all polymer based flexible and (semi) transparent TFT.

measured by using Keithely 237 SMU with home made PC interface programs. For σ_{dc} of the active layer with and without V_g, we used 4-probe method in order to eliminate contact resistance. We used various electrical adhesives such as silver paste, carbon paste, or thermally evaporated gold for electrical contact.

3. RESULTS AND DISCUSSION

Figures 2(a) and (b) show the *I–V* characteristic curves with gate dependence of PEDOT and PPy based OTFTs, respectively. The insulating layer of the device was PVCN or epoxy. The channel length between the contacts of source and drain electrodes was 1 cm. We observed that I_{ds} of the devices decreased with increasing positive V_g, indicating *p*-type OTFT operating in a depletion mode. Holes are the major charge carriers in the PPy and PEDOT active layer. The results are analyzed by "bottle-neck" effect as shown in Figure 2(e), in which charge transport of the active layer is determined by the area of the active region (i.e., overlap of active layer and gate electrode). The threshold voltage of the devices using PEDOT and PPy samples was found to be $\sim$30 V and $\sim$60 V, respectively. From the slope of the I_{ds} vs V_g at $V_{ds} = 20$ V as shown in Figures 2(c) and (d), the trans-conductance of the devices using PEDOT and PPy was estimated to be $-0.5\,\mu$A/V and $-0.3\,\mu$A/V, respectively. The on-off current ratio (I_{on}/I_{off}) was exceed $\sim 8.3 \times 10^2$ in both PEDOT and PPy based TFTs.

Figures 3(a) and (b) show the *I–V* characteristic curves with gate dependence of PEDOT/PVCN/PEDOT TFT devices with the channel length (L) of $\sim$3 mm and $\sim$1 mm, respectively. It should be noted that

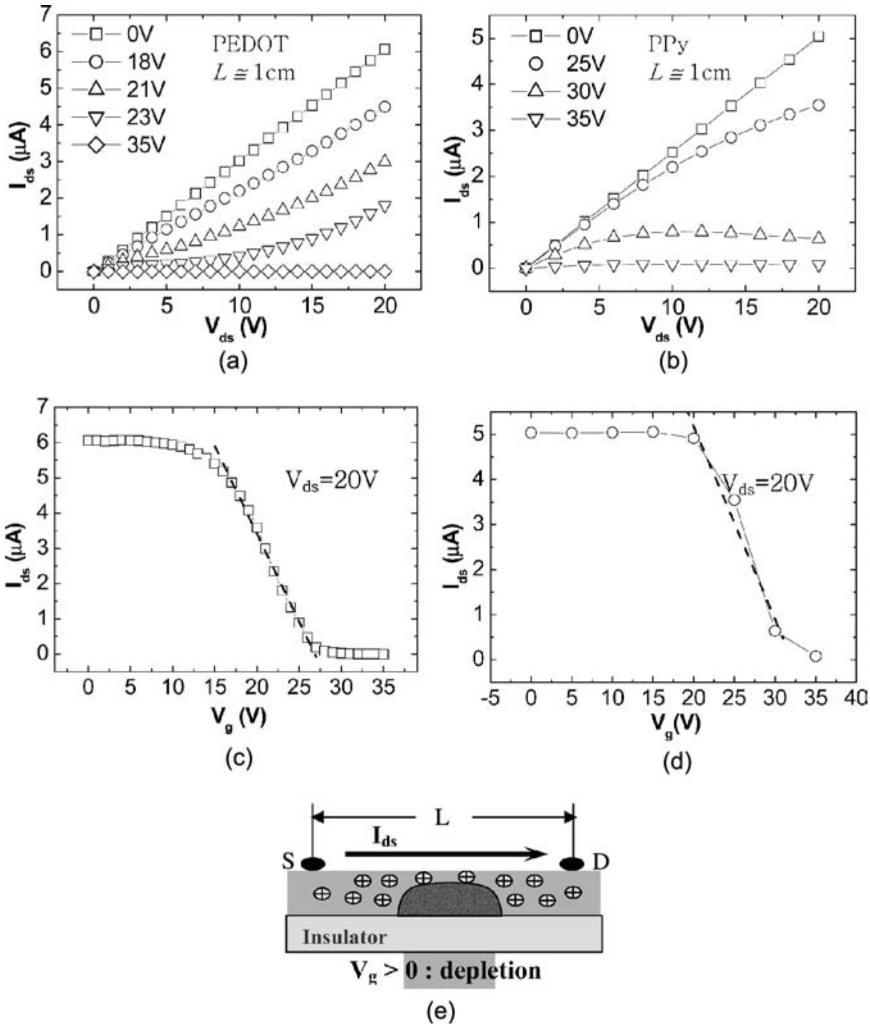

FIGURE 2 I_{ds} of (a) PEDOT/PVCN/PEDOT and (b) PPy/epoxy/PPy OTFT devices, as a function of V_{ds}, and I_{ds} of (c) PEDOT/PVCN/PEDOT and (d) PPy/epoxy/PPy OTFT devices, as a function of V_g, and (e) schematic diagram of the depletion mode based on the "bottle-neck" effect.

the L is the channel length between the contacts of source and drain electrodes. We observed that I_{ds} of the devices dramatically decreased with increasing positive V_g indicating p-type OTFTs operating in depletion mode. With negative V_g, we clearly observed that I_{ds} weakly increased

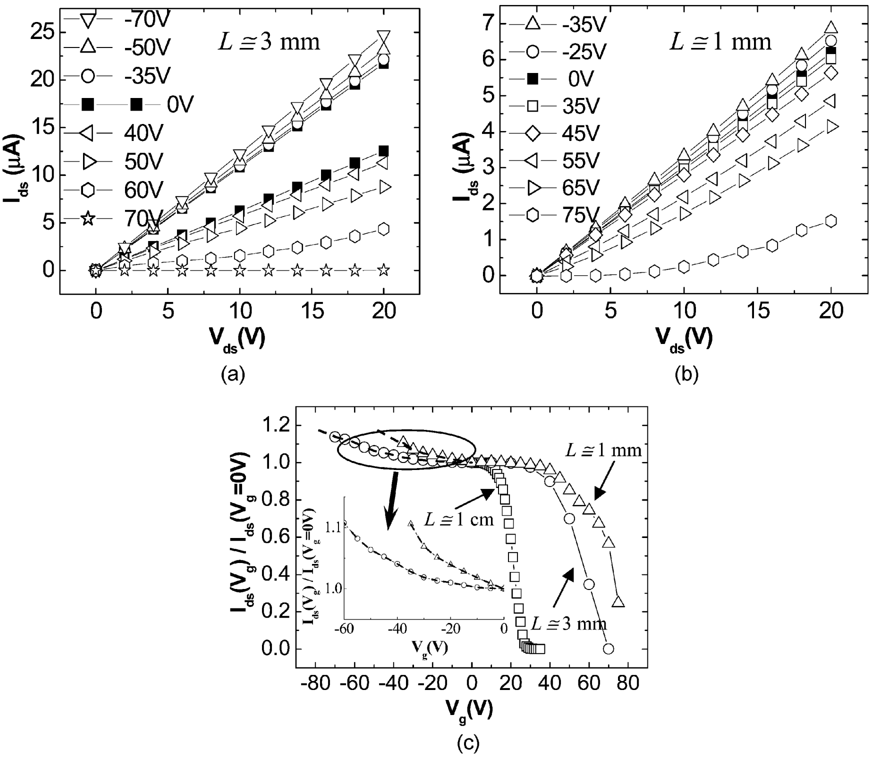

FIGURE 3 (a) I_{ds} vs V_{ds} of PEDOT/PVCN/PEDOT devices with $L \cong 3$ mm, (b) I_{ds} vs. V_{ds} of that devices with $L \cong 1$ mm, (c) $I_{ds}/I_{ds}(V_g = 0)$ of the devices with $L \cong 3$ mm and $L \cong 1$ mm at $V_{ds} = 20$ V. Inset: Magnification of I_{ds} with negative V_g.

for the devices with the $L = 3$ mm and 1 mm, as shown in Figures 3(a), (b) and (c). This implies the operation of the devices in accumulation mode also. As shown in the inset of Figure 3(c), with negative V_g, the I_{on}/I_{off} of the devices with the $L = 1$ mm was larger than that with the $L = 3$ mm. mm. When we defined the rate of current increment with negative V_g as $[I_{ds}(V_g = 0\ V) - I_{ds}(V_g = -35\ V)]/I_{ds}(V_g = 0\ V) \times 100$, the estimated rate of current increment of the devices with the $L \cong 3$ mm and 1 mm was $\sim$1.3% and $\sim$10.6%, respectively, at $V_{ds} = 20$ V. In the accumulation mode with negative V_g, we observed the dependence of I_{ds} on the contact length between source and drain electrodes.

Figure 4 shows the variation of σ_{dc} of the active layer of PEDOT based OTFTs. The normalized conductivity $[\sigma(V_g > 0)/\sigma(V_g = 0)]$ of the active layer of OTFT devices with $V_g = 2$ V, 4 V, and 8 V for 40 sec, was about 0.991, 0.943, and 0.939, respectively. We observed that the $\sigma(V_g > 0)/$

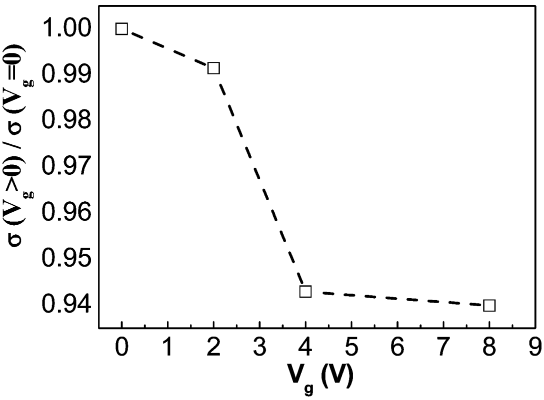

FIGURE 4 Normalized conductivity [$\sigma_{\rm dc}(V_g > 0)/\sigma_{\rm dc}\ (V_g = 0)$] of active layer of the PEDOT based TFTs with various V_g's for 40 sec.

$\sigma(V_g = 0)$ decreased with increasing positive V_g. This can be explained by the "bottle-neck" effect, i.e., the shortening of current path between source and drain due to the broadening of depletion region with increasing positive V_g, as shown in Figure 3(e).

4. CONCLUSION

We fabricated all polymer based thin film transistor by using conducting poly (3,4-ethylenedioxythiophene) (PEDOT) and polypyrrole (PPy) as gate electrode and active layer, which were made by photolithographic micropatterning. Polyvinyle cinnamate or epoxy was used as insulating layer by spin-coating. All polymer based TFTs show the p-type characteristics operating in depletion mode, while the accumulation mode with negative V_g was weakly observed. The results were analyzed by the "bottle-neck" effect, in which charge transport of the active layer is determined by the area of the active region, the contact length of source and drain electrodes, and the polarity of V_g.

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