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Blending of poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate) with poly (ethyleneimine) as an active layer in depletion-mode organic thin film transistors

Yu-Ju Lin[1], Yu-Chang Li[1], Ten-Chin Wen[2], Li-Ming Huang[2], Hong-Jian Yeh[1], Ying-Kuo Chen[3], Yeong-Her Wang[1,*]

[1]Institute of Microelectronics, Department of Electrical Engineering, National Cheng Kung University, Tainan, 701 Taiwan

[2]Department of Chemical Engineering, National Cheng Kung University, Tainan, 701 Taiwan

[3]Institute of Electro-Optical Science and Engineering, National Cheng Kung University, Tainan, 701 Taiwan

yhw@eembox.ncku.edu.tw

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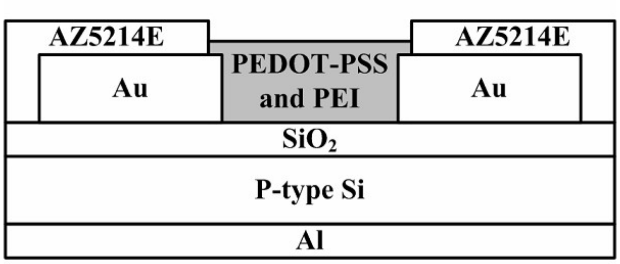
With their high potential in terms of flexibility, easy process, and low cost, organic semiconductor have been developed for thin film transistor (TFT) applications. Doped poly(3,4-ethylenedioxythiophene) (PEDOT) displays conductivities ranging from 1-100 S/cm depending on the counter ions. With poly(styrene sulfonic acid) (PSS) as the counter ion, the conductivity is typically 10 S/cm. PEDOT-PSS are heavily exploited as charge injection layers, optically transparent electrodes in polymer light-emitting diodes, as well as conducting elements in organic transistors. However, no other reports can be found for the modulation of conductivity as transistor active layers. In this work, the modulation of conductivity of PEDOT is applied to organic thin film transistor (OTFT).

Fig. 1 shows the schematic diagram of the proposed OTFT on a Si (100) substrate based on PEDOT-PSS with PEI. Fig. 2 illustrates the current–voltage (I-V) characteristics of OTFT. The gate voltage is from 0 to 100V with 20V per step, while the drain voltage is from 0 to 12.5V. Under V_{gs} = 0 V, the drain current (I_{ds}) rises with the drain voltage (V_{ds}) and shows a large current because the active layer made of high doping of PSS in PEDOT leads to a high conducting state.



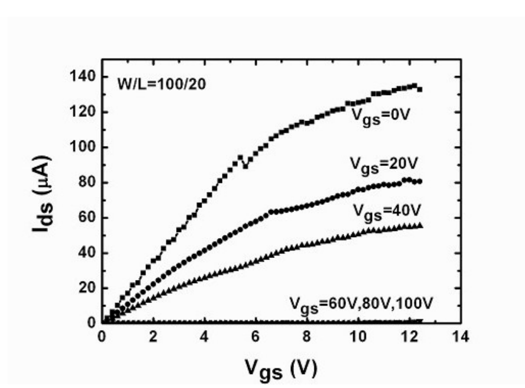


Fig 1. The schematic diagram of the proposed PEDOT-PSS with PEI transistor.

Fig 2. I-V characteristics of the proposed PEDOT-PSS with PEI OTFT.

When a positive voltage is applied to the gate, the currents of the source and drain are decreased. The decreased current for PEDOT-PSS-PEI OTFT is related to the tendency of SO_3^- groups of PSS linking with NH_3^+ of PEI at the applied positive gate voltage as shown in Fig. 3a. When a positive bias is applied to the gate and induces the electric field in the channel, the linked matters (PEI and PSS) are removed from the PEDOT (Fig. 3(b)) and possess low conductivity. This is because the charge carriers have been localized in the sulfur atoms. Therefore, the source-drain current of PEDOT-PSS-PEI-based OTFT is lower than that based on the doped PEDOT under the same source-drain voltage. The stronger the electric fields applied, the more PSS were removed. In other words, applying larger voltages to the gate lowers the presence of source-drain currents. At last, the source-drain currents decreased to 10^{-7}~10^{-8}A under V_{gs}=100V (i.e., the OTFTs based on PEDOT-PSS with PEI operating as depletion-mode transistors) as shown in Fig. 2. The on/off ratios are about 10^3 under the V_{gs} ranging from 0V to 100V. Field-effect mobility and subthreshold slope were evaluated to be about 1.94 $cmVs^{-1}$ and 6.67V/decade.

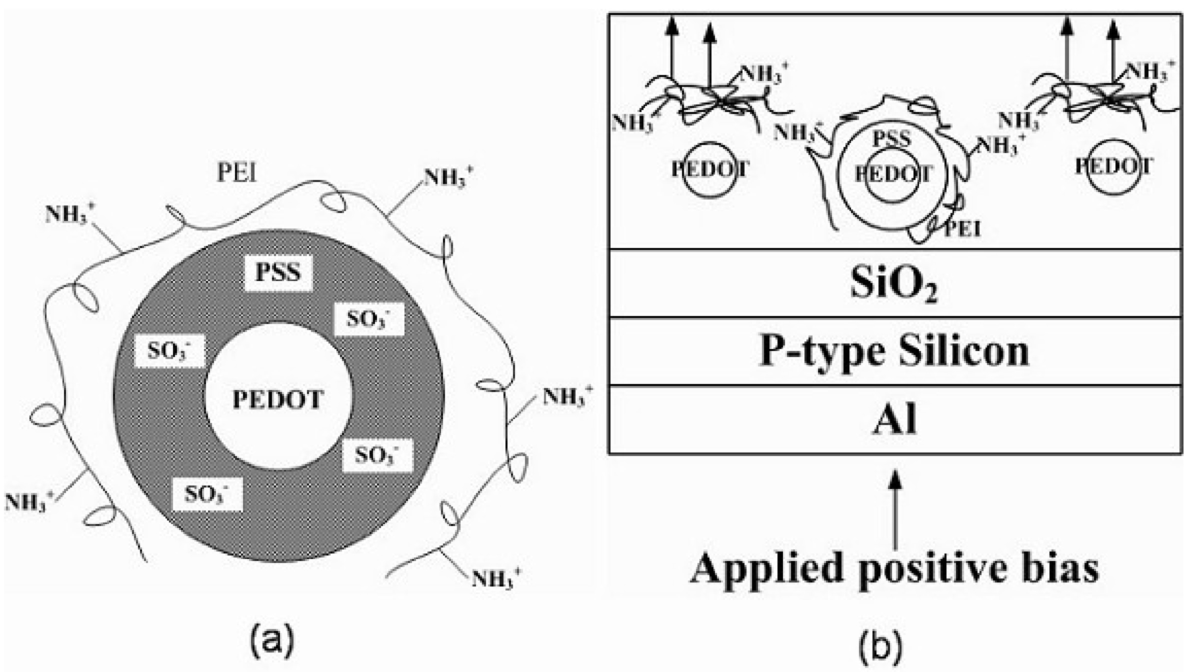


Fig 3. (a) The synthesized structure of PEDOT-PSS with PEI, (b) Operation mechanism of the depletion-mode OTFT.

In order to investigate the role of PEI, devices based on PEDOT-PSS were fabricated. Fig. 4 shows the I-V characteristics of devices without PEI. It is obvious the I-V characteristics have a resistor instead of a transistor behavior. Compared with the I-V characteristics of devices based on PEDOT-PSS with PEI, the source-drain currents of devices without PEI were larger. The low source-drain current for PEDOT-PSS-PEI based on OTFT was attributed to the SO_3-H^+ groups of PSS, which were electrostatically linked with the NH_3^+ groups of PEI as the PEI was mixed with PEDOT-PSS. The charge carriers were localized in the sulfur atoms.

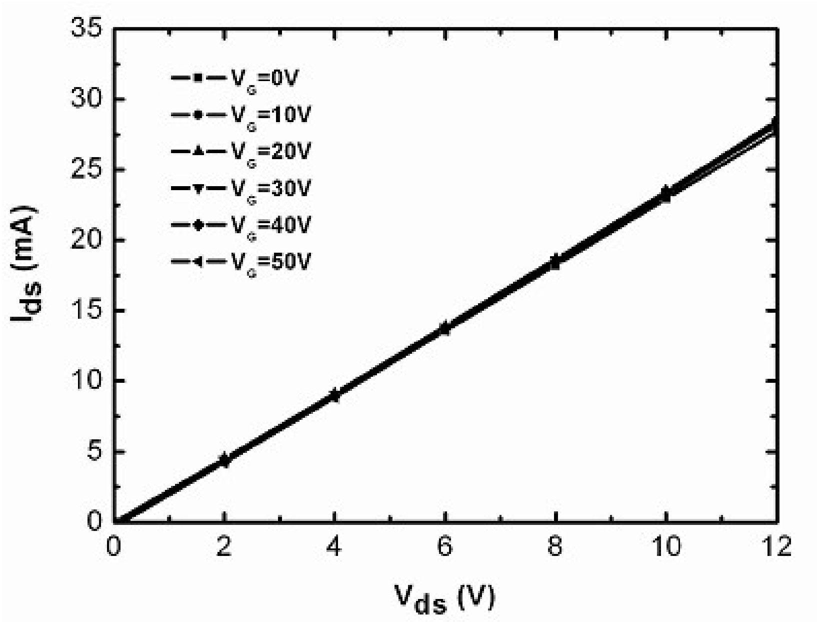


Fig 4. I-V characteristics of OTFT based on PEDOT-PSS without PEI. It only indicates the resistor.

In summary, the depletion mode of OTFTs based on PEDOT-PSS with PEI has been demonstrated. The devices with large current could be applied in electric circuits with large currents. The on/off ratio is about 10^8. Field-effect mobility and subthreshold slope were evaluated to be about 1.94 $cmVs^{-1}$ and 6.67V/decade. Without the incorporation of PEI in PEDOT-PSS, a very high conductivity can be observed in PEDOT-PSS which only indicates the resistor behavior. The role of the PEI in the PEDOT-PSS is found to be the key issue in modulating the layer conductivity.

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