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Development of FET type photorewritable memory using photochromic interface layer

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1. Introduction

It has been known that the performance of organic field effect transistor (OFET) is strongly affected by interfacial states between the gate dielectric and the semiconductor layers. For example, it has been often reported that the surface state of the dielectric layer, which can be modified by an over-coated SAM layer, govern the FET performance [1,2]. In this study, we inserted an interface layer of which physical properties can be controlled by the light irradiation, and studied about the effects due to energy level changes of the interface layer on the FET characteristics.

Diarylethene derivatives are known to be a representative photoisomerizable material. Not only the absorption spectra but also other molecular properties change reversibly, such as refractive indices, dipole moments, oxidation-reduction potentials and electronic characteristics during photoisomerization. And they are the promising materials for developing information-recording devices by photon mode because of having the characteristics of good thermal stability, high fatigue resistance and rapid response[3]. We intended to develop an organic field effect transistor having photo-memory function using diarylethene derivatives.

2. Experiment

Fig.1 shows the cross-sectional illustration of our newly developed FET-type photorewritable memory structure that was fabricated as following procedure. An Indium Tin Oxide (ITO) glass was employed as a substrate and a transparent gate electrode. ITO glasses were carefully cleaned before the fabrication of FET devices. A PMMA film was spincoated on the ITO glass as a gate insulator (thickness = 800nm). The DAE (1,2-Bis(2,4-dimethyl-5-phenyl-3-thienyl) perfluorocyclopente was deposited onto the PMMA film as a photochromic interface layer (thickness = 85nm). A pentacene film (thickness = 50 nm) was deposited onto the DAE layer. Pentacene was train-sublimated 5 times for purification. After that, Au DS electrodes were deposited through the patterned metal mask (channel width W: 5mm, channel length L: 20µm). All thin film depositions are carried out by using thermal evaporation method at a pressure of ca. 10^{-6} Torr (deposition rate = 0.1~0.2 nm/s). Electrical measurements were carried out by using two sourcemeters (Keithley 6430 + 2420).

Diarylethene has two type photoisomers, open and closed-ring isomers [4]. One isomer can be reversibly

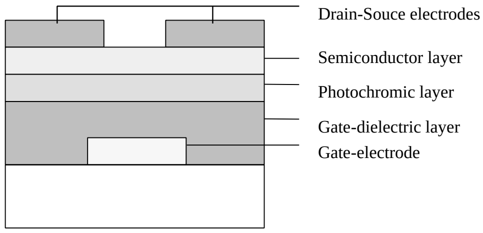

Fig.1 Schematic diagram of the OFET having photoswitching function.

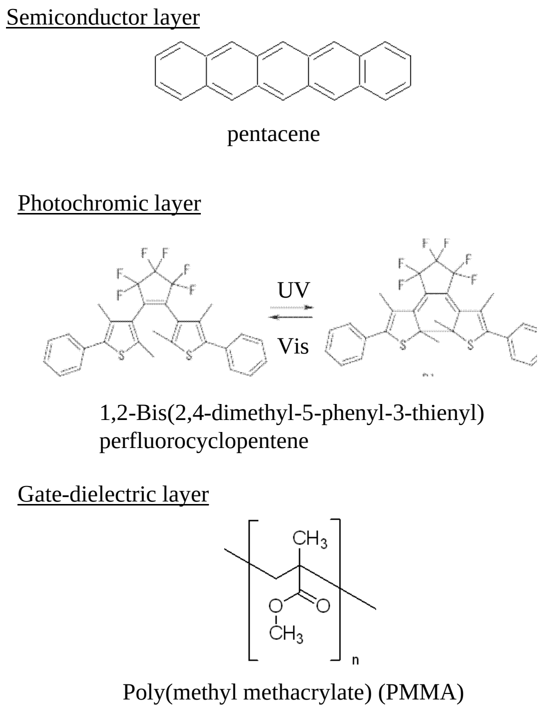

Fig.2 Chemical structures of the molecules included in each layer of the OFET.

switched to the other isomer by Vis or UV light irradiation (Fig.2). Transistor properties of the FET were measured under dark condition after Vis (>520nm) or UV light (<340nm) irradiation, respectively.

3.Results and Disucussions

Figs.3 show the $I_{DS}^{1/2}$-V_{GS} plot of the FET having the DAE photochromic layer. In figs.3, the left and right figures show the switching behaviors of the transistor characteristic at the timing of the first and second photoisomerizations, respectively. The field effect mobility values (μ_{FETs}), threshold voltages (V_{ths}) apparently change by the photoisomerization (the closed-ring isomer <-> the open-ring isomer). Figs.3 show also a good reversibility of photoswitching behavior.

The μ_{FET} value of the open-ring state is larger than that of the close-ring state as shown in Table 1. This result would be explained as follows. As for the energy levels of molecular orbital of DAE molecule, the HOMO levels of the closed-ring and open-ring states are 6.3 eV and 5.5 eV, respectively. The LUMO levels of the closed-ring and open-ring states are 3.7 eV and 3.2 eV, respectively. In the case of pentacene, the HOMO level is 5.6eV and the LUMO level is 3.7 eV. These energy levels were calculated by using UV-vis absorption spectrum (Fig.4) and the onset potential of cyclic voltammogram (not shown in this paper) for each molecule. The energy level diagram for each state are shown in Figs.5. In the case of the open-ring state, energy difference between the HOMO levels of pentacene and DAE is relatively large, and then the holes in the pentacene layer are not injected into the DAE layer. Therefore, the DAE layer works as an insulator. On the other hand, in the case of the closed-ring state, the energy difference between the HOMO levels of pentacene and DAE becomes very small, and then the holes in the pentacene layer are easily injected into the DAE layer. The hole transport property of the DAE layer is very poor, therefore, the holes injected into the DAE layer are immobilized.

3.Conclusion

We have shown the good photoswitching and photomemory behaviors of the OFET having the DAE photochromic interface layer.

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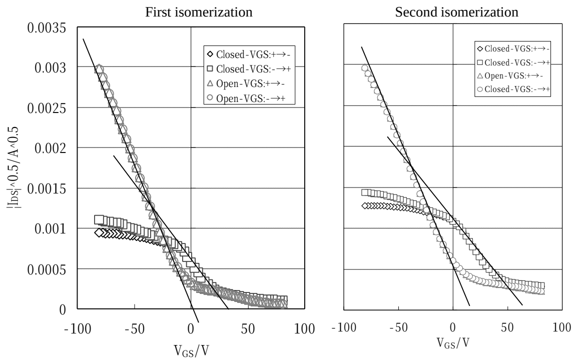

Figs.3 $I_{DS}^{1/2}$-V_{GS} plots of the FET having the diarylethene photochromic layer(left : first isomerization, right : second isomerization).

Table 1. Transistor parameters of the FET having the diarylethene photochromic layer at each state.

	First isomerization		Second isomerization	
State	closed	open	closed	open
μ_{FET}(cm²/Vs)	4.4×10^{-4}	1.6×10^{-3}	4.6×10^{-4}	1.2×10^{-3}
Vth (V)	35V	0V	60V	20V

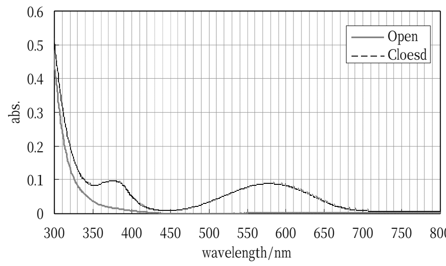

Fig.4 UV-vis absorption spectra of diarylethene (―open and -----closed).

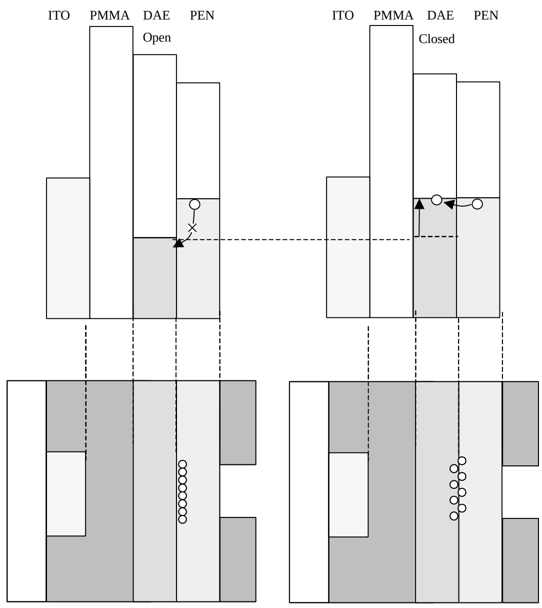

Fig.5 Energy level diagrams and cross-sectional images of the FET having the diarylethene (DAE) photochromic layer. (left: open, right closed)