

Fabrication and Characteristics of Field-Effect Transistors having Pentacene/Vanadium Pentoxide Co-evaporated Layer

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1. Introduction

Organic field-effect transistors (OFETs) have been attracting significant interest because of their various advantages such as flexibility; further, their fabrication processes are simple. However, OFETs have many drawbacks. One of the major drawbacks of OFETs is that their mobility and conductivity are lower than those of inorganic thin film transistors. To such a situation, efforts are being made to improve these properties by using organic materials with high crystallinity [1], or monocrystalline materials [2], for the active layer. The OFETs used in the driving circuit of high-brightness OLED displays have to supply a large current to the displays. Therefore, it is very important to develop OFETs with high mobility, which will also aid in reducing the electric power consumption of OLED displays and other devices.

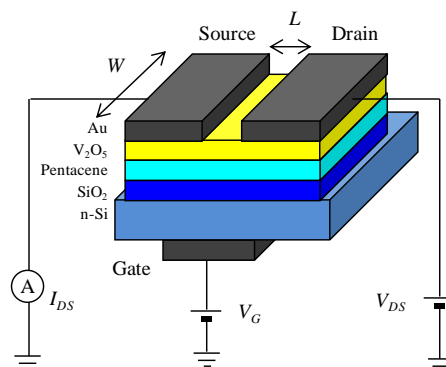
In this study, OFETs using pentacene and vanadium pentoxide (V_2O_5) evaporated films as an active layer were fabricated, and the device properties were investigated. It is known that pentacene is an excellent hole transporting material and can be used for the fabrication of OFETs [1]. Additionally, it has been reported that V_2O_5 , which is one of a Lewis-acid material, can remarkably improve a luminance efficiency of OLEDs [3]. We characterized the OFET having a stacked pentacene and V_2O_5 layer as an active layer, and attempted to improve the field effect mobility. Moreover, we also fabricated the OFETs having a mixed layer of a pentacene and V_2O_5 as an active layer, and discussed the effect of mixing pentacene and V_2O_5 molecules to the improvement of the device performance.

2. Experimental

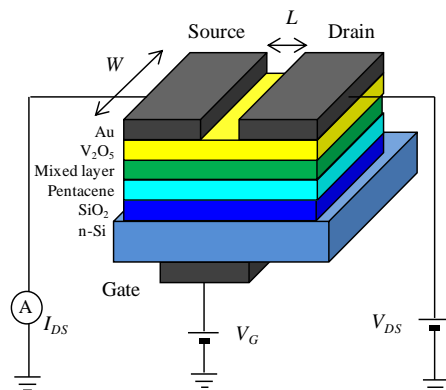
In order to confirm the interaction between pentacene and V_2O_5 molecules at the interface, we measured the UV-vis absorption characteristics of an evaporated pentacene layer, V_2O_5 layer, and co-evaporated layer comprising pentacene and V_2O_5 in a 1:1 molar ratio on quartz glass substrate. In addition, we prepared some top-contact OFETs, as shown in Fig. 1. Each OFET was essentially fabricated on heavily doped n-type Si wafers, which were oxidized to form a 100-nm-thick SiO_2 layer on the surface. Device 1 is the OFET having a stacked pentacene and V_2O_5 layer: Al gate electrode / n-type Si substrate / SiO_2 / 50-nm-thick pentacene / 20-nm-thick V_2O_5 / S and D electrodes structure. Inserting V_2O_5 layer between a pentacene and S-D electrodes aims the improvements of OFET prop-

erties. Moreover, the OFETs having a co-evaporated layer of a pentacene and V_2O_5 as an active layer were also fabricated as device 2: Al gate electrode / n-type Si substrate / SiO_2 / (50-x/2)-nm-thick pentacene / x-nm-thick co-evaporated layer / (20-x/2)-nm-thick V_2O_5 / S and D electrodes. The mixing ratio of pentacene and V_2O_5 molecular in a co-evaporated layer was adjusted to 1:1 mol%, approximately. The pentacene and V_2O_5 layers, and S, D electrodes were fabricated by vacuum evaporation method in these devices.

Characteristics of the devices were investigated by using a semiconductor parameter analyzer (Hewlett-Packard, 4145B) in nitrogen atmosphere at a room temperature.



(a) Device 1 has 50-nm-thick pentacene and 20-nm V_2O_5 layers as an active layer.



(b) Device 2 has (50-x/2)-nm pentacene, x-nm co-evaporated layer and (20-x/2)-nm V_2O_5 layers as an active layer.

Fig. 1 Schematic diagram showing structure of fabricated organic field-effect transistors.

3. Results and discussion

Figure 2 shows the UV-vis absorption of a pentacene layer, V_2O_5 layer, and co-evaporated layer composed of pentacene and V_2O_5 molecules in a 1:1 mol% ratio. Changes in the absorption spectrum resulting from the molecular interactions were observed at a wavelength of approximately 1,000 nm. The appearance of new absorption bands corresponds approximately to the radical cation absorption of pentacene [4]. Therefore, it was predicted that electrons in a pentacene layer transferred to a V_2O_5 layer. This suggests the formation of charge transfer (CT) complexes at the interface between the pentacene and V_2O_5 layers in the co-evaporated layer.

Figure 3 shows plots of the drain current (I_D) vs. drain-source voltage (V_{DS}) for devices 1 operating at various negative gate voltages (V_{GS}). When a negative V_G was applied, typical I_D - V_{DS} curves were observed. From the $|I_D|^{1/2}$ vs. V_G characteristics, the apparent mobility (μ) was estimated $0.33 \text{ cm}^2/(\text{Vs})$ —approximately twice that of the conventional pentacene OFET. We have already confirmed that an OFET with only a 70-nm-thick V_2O_5 layer as an active layer did not exhibit any typical FET characteristics. Therefore, we believed that the improved properties were the result of the formation of CT complexes at the interface between the pentacene and V_2O_5 active layers, which dissociate under the gate voltage and thus contribute to the formation of an effective channel. The increase of the channel charge should result in the large apparent mobility.

The I_{DS} - V_{DS} plots for the OFET with co-evaporated layer of pentacene and V_2O_5 (device 2) operated at various negative V_{GS} is shown in Fig. 4. In this OFET, a larger drain current was observed than device 1. The calculated apparent mobility was $1.4 \text{ cm}^2/(\text{Vs})$ —approximately four-fold that of the device 1, and 10 times higher than that of conventional pentacene OFET. The reason of these improvements was estimated that a region where CT complexes were formed would be expanded by a mixing of a pentacene and V_2O_5 . A much of carriers would generate by a V_G applying in the co-evaporated layer, and contribute to a formation of an effective channel.

Acknowledgements

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References

- [1] C. R. Kagan and P. Andry, *Thin-Film Transistors* (2003) 318.
- [2] V. C. Sundar, J. Zaumseil, V. Podzorov, E. Menard, R. L. Willett, T. Someya, M. E. Gershenson, and J. A. Rogers, *Science* **303** (2004) 1644.
- [3] J. Kido, T. Matsumoto, T. Nakada, J. Endo, K. Mori, N. Kawamura, and A. Yokoi, *SID Int. Symp. Dig. Tech. Pap.* **34** (2003) 964.
- [4] J. Szczepanski, C. Wehlburg and M. Vala, *Chem. Phys. Lett.* **232** (1995) 221.

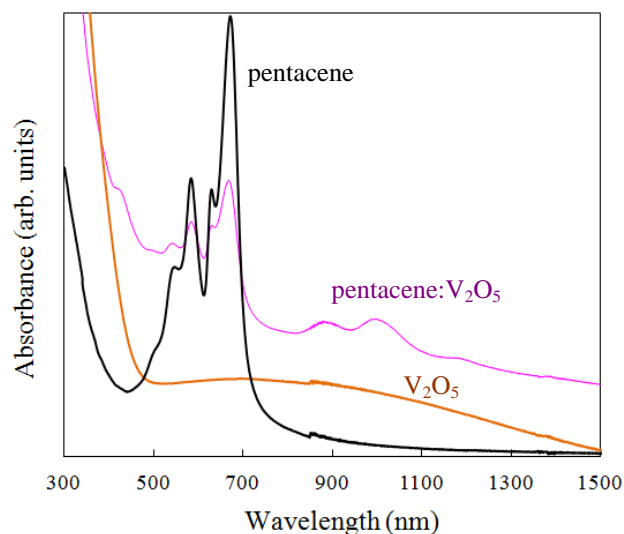


Fig. 2 Absorption spectra of evaporated single layers of pentacene and V_2O_5 and a co-evaporated layer of pentacene and V_2O_5 (at 1:1 molar ratio) on quartz glass substrate.

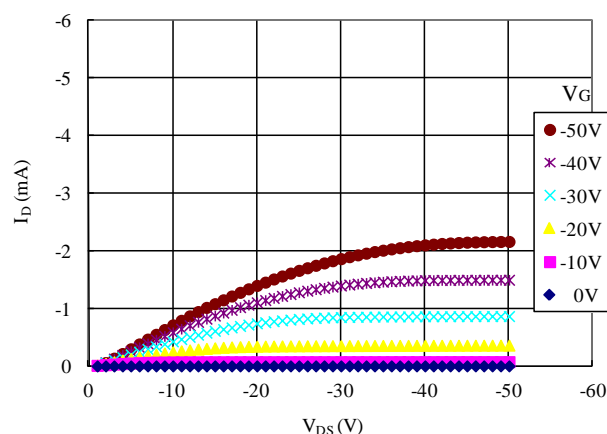


Fig. 3 I_D against V_{DS} characteristics under various values of V_{GS} for device 1, shown in Fig. 1 (a).

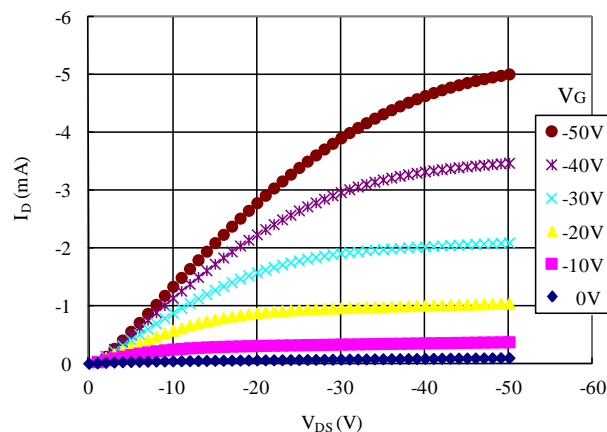


Fig. 4 I_D against V_{DS} characteristics under various values of V_{GS} for device 2, shown in Fig. 1 (b).