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Ferroelectric P(VDF-TeFE) Gate FET Memory

Tomohiro Watanabe[1], Hiroyuki Miyashita[1], Takeshi Kanashima[1] and Masanori Okuyama[1,2]
[1]Department of Systems Innovatin, Graduate School of Engineering Science, Osaka University
Machikaneyama, 1-3, Toyonaka, Osaka 560-8531, Japan
Phone: +81-6-6850-6331, fax: +81-6-6850-6341, E-mail: t_watanabe@semi.ee.es.osaka-u.ac.jp
[2]Institute for NanoScience Design, Osaka University

1. Introduction

Recently, much attention has been paid to organic electronics, which devices are flexible, light in weight and transparent. Moreover, costs of the devices are low as they can be fabricated by using low temperature on cheap and abundant substrates such as organic plates and metal films. If memory characteristics are added to the organic devices, they should be expanded to vast applications such as smart card, display panel devices and telecommunication. 1T-type FET memory whose gate insulator is organic ferroelectrics has a lot of attention.[1,2,3] FET memory, MFS FET fabricated by combining organic semiconductor and organic ferroelectrics, has many advantages such as flexibility, lightweight, transparency and low cost. Here, poly-vinylidene fluoride/trifluoroethylene (P(VDF-TrFE)) is widely used as a ferroelectric material among the organic ferroelectrics, because it has good characteristics. However, polymerization reaction of VDF-TrFE is much difficult in production, and the supplier of P(VDF-TrFE) is limited. So, it is worthful to research the alternative organic ferroelectric materials of P(VDF-TrFE). On the other hand, polyvinirydene/tetrafluoroethylene can be produced easily and abundantly and its electronic application is expected very much.

We have focused on poly-vinylidene fluoride/tetrafluoroethylene (P(VDF-TeFE)) copolymer which is more available than P(VDF-TrFE). Analysis of FET characteristics whose gate insulator is P(VDF-TeFE) has been reported [4], but objective of this is the analysis of turnover of spontaneous polarization in P(VDF-TeFE). So, memory characteristics are not optimized, and retention characteristic is not reported. In this paper, we have prepared the ferroelectric gate FET memory by using P(VDF-TeFE) thin film as ferroelectrics, and improved the memory characteristics such as drain current-voltage and memory retention by optimizing processes.

2. Fabrication of P(VDF-TeFE) Film Gate FET

P(VDF-TeFE) thin films were deposited on Pt(120 nm)/Ti(20 nm)/SiO_2(1 μm)/Si substrate by spin coating method using the solution of 5 wt% P(VDF-TeFE) 80/20 mol% solved in methylethylketone (MEK). Pt/Ti is deposited as gate electrode by sputtering. Typically, P(VDF-TeFE) solution was spin-coated at 1500 rpm for 10 sec. After spin coating, the thin films were annealed at 170^{o}C for 2.5 hours in air. Pentacene used as an organic semiconductor was prepared on P(VDF-TeFE). Au electrodes as source and drain were formed by vacuum evaporation with shadow mask. Figure 1 shows the structure of P(VDF-TeFE) FET memory and the thicknesses of fabricated organic ferroelectrics and organic semiconductor thin films are 570 and 50 nm, respectively.

3. Results and Discussions

Chemical structure of deposited P(VDF-TeFE) thin film is characterized by FT-IR. IR absorption spectra result that this film has the peaks which are specific to beta-phase poly crystalline.[5] So, it is expected that P(VDF-TeFE) thin films have ferroelectric properties.

Ferroelectric properties of P(VDF-TeFE) were characterized by using metal-ferroelectric-metal (MFM) structure. Thickness of P(VDF-TeFE) thin films is 280 nm. Its *P-E* hysteresis is measured at 100 Hz. Remanent polarization (P_r) in as-deposited film is only 1 μC/cm^2, which is much smaller than the reported maximum polarization (P_m). Moreover, this value is much inferior to P_r of 8~12 μC/cm^2 of P(VDF-TrFE).[1,3] However, P_r of P(VDF-TeFE) can be enhanced by poling in which alternative high electric field is applied to the film. Figure 2 shows the *P-E* curve of P(VDF-TeFE) thin film after poling. Maximum applied voltage is ±60 V.

P_r is increased after poling, and ferroelectric hysteresis is clearly observed. 4 μC/cm^2 of P_r is obtained. It is thought that high electric field influenced molecular orientation of ferroelectric beta-phase structure and/or its orientation rearrangement may occur, or small weak leakage spot may be removed, pinned domain or locked polarization may be released.

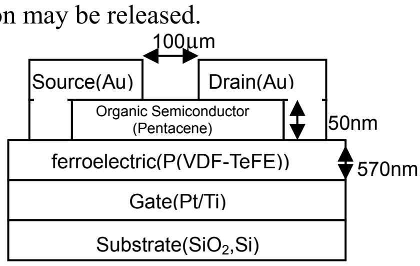

Fig. 1. Structure of P(VDF-TeFE) FET memory.

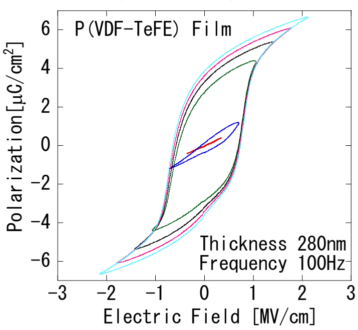

Fig. 2. *P-E* curve of P(VDF-TeFE) thin film measured at 100 Hz after poling. Thickness is 280 nm, and maximum applied voltage is ±60V.

This effect gives us enough P_r which enables to make ferroelectric FET memory device with P(VDF-TeFE).

Drain current-drain voltage(I_D-V_D) characteristics of FET fabricated using pentacene/P(VDF-TeFE) are shown in Fig. 3. Gate width W and length L are 100 μm and 100μm, respectively. Since drain currents are linearly proportional to drain voltage in the low voltage region, this behavior is very similar to a p-channel MIS FET fabricated using pentacene, and good FET is obtained. Moreover, drain current is not so large, but it is thought that they can be improved by optimizing the device parameters and film thickness. Figure 4 shows the drain, source and gate currents as a function of gate voltage, V_G. Gate leakage current is below 1 nA, and is very small in all gate voltage region. Moreover, drain and source currents in Off state are very small, too. The drain current is almost equal to the source current. Memory window is about 40V, which is wide and indicates good memory characteristics. Threshold voltage of the center of hysteresis curves is around 0V, and this FET memory can realize normally on and normally off operation corresponding to P(VDF-TeFE) polarization. On/Off ratio is 830 and calculated mobility is 0.11 cm^2/Vs. The shift of threshold voltage was observed when electrical characteristics were measured many times. Such instability is often reported in many works of organic transistor by exposing the device to the air.[6] The gate insulator which contains polarization charge is used in pentacene/P(VDF-TeFE) FET, and voltage induced by these charges is constantly applied. Therefore, it is thought that this device has much sensitivity for the threshold voltage shift. In order to solve this problem, surface treatment or encapsulation to avoid air exposure is important.

Figure 5 shows the retention characteristics of pentacene/P(VDF-TeFE) FET memory. Measurement was done in vacuum below 1 Pa. These On and Off states are memorized at V_G=±70 V. On/Off ratio of drain current is about 100 in the initial stage. Gate voltage is 0 during retention measurement. On/Off ratio is slowly decreased, but On/Off ratio remains 55 after 16 hours. So, this result shows that memory states can be kept for a long time.

4. Conclusions

Organic FET memory whose gate insulator is P(VDF-TeFE) has been fabricated and characterized. This FET has good memory characteristics. On/Off current ratio is 830 and mobility is 0.11 cm^2/Vs. Moreover, memory retention time is over 16 hours. These results show the possibility of P(VDF-TeFE) ferroelectric material substituting for P(VDF-TrFE).

Acknowledgements

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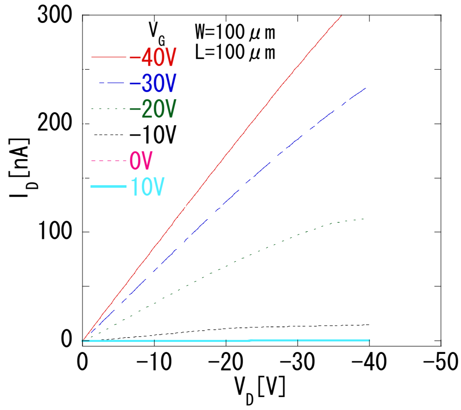

Fig. 3. I_D-V_D characteristics of MFS FET fabricated using pentacene/P(VDF-TeFE). Thickness of P(VDF-TeFE) is 570 nm, and W=L= 100 μm.

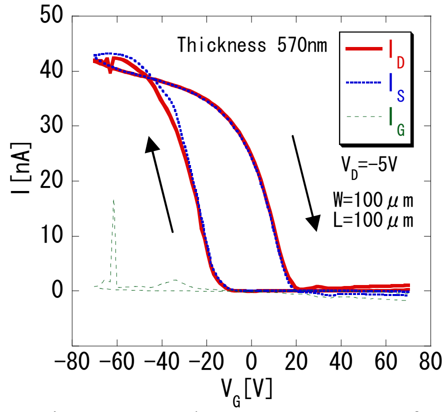

Fig. 4. Drain, source and gate currents as a function of gate voltage in pentacene/P(VDF-TeFE) FET. Drain voltage is -5 V.

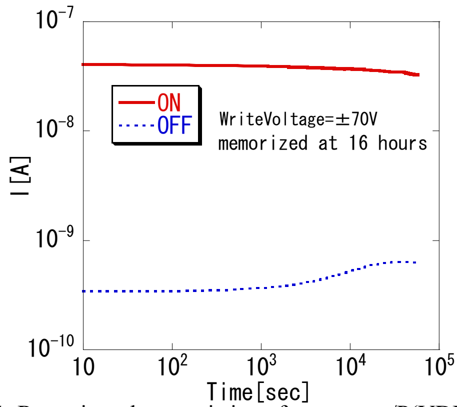

Fig. 5. Retention characteristics of pentacene/P(VDF-TeFE) FET memory. Drain voltage is fixed at -5 V

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