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Improvement of transfer characteristics for PZT-CNT-FET by ionic liquid

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1. Introduction

Ferroelectric-gate field effect transistors (FETs) offer potential advantages as non-volatile memory elements. Hysteresis transfer properties obtained on the ferroelectric gate FETs are expected to correspond to the polarization of the ferroelectric gate. We have reported that single-wall carbon-nanotube FETs (CNT-FETs) with polycrystalline ferroelectric $PbZr_xTi_{1-x}O_3$ (PZT) thin films as gate insulators show the expected hysteresis transfer properties based on the ferroelectric properties of PZT [1], where the hysteresis loop shows clockwise manner corresponding to the PZT polarization, while, for usual CNT-FET with SiO_2 gate, the hysteresis loop shows anticlockwise manner. Recently, we have pointed out that the operation of PZT-CNT-FET depends on both the polarization characteristics of PZT domain under the CNT and the adhesion between CNT and PZT [2]. As a result, the device performance is fluctuated and some devices show no expected hysteresis transfer characteristics. Similar results have been reported from other group even on the epitaxial PZT which has a flat surface than the polycrystalline PZT film [3]. In this study, we have investigated the transfer characteristics of the PZT-CNT-FETs with application of ionic liquid (1-Buty-l-3-methylimidazolium tetrafluoro-borate) to the CNT channel in order to improve the transfer characteristics.

2. Device fabrication

PZT thin films with a thickness of 300 nm were prepared by sol-gel method on Pt/Ti/SiO_2/Si substrates. The source solution of PZT was spin-coated, dried at 150 ^oC for 1 min, and baked at 300 ^oC for each coating. After crystallization annealing at 670 ^oC for 10 min, polycrystalline PZT films were obtained. The PZT films had a (101) preferred orientation by X-ray diffraction and showed a P-E hysteresis loop with a remanent polarization of 20 μC/cm^2 as shown in Fig. 1. Single-wall CNTs were dispersed in 2 % of sodium dodecyl sulfate (SDS) and mixture was applied on the PZT films. The electrodes of Pt were fabricated on the CNTs by photolithography. Ionic liquid was dropped between the source-drain electrodes of the FET channel with a length of 1 μm. The CNT channel was covered with the ionic liquid as shown in Fig. 2. To evaluate I_d-V_g (drain current-gate voltage) hysteresis of the FETs, the V_g was swept from 1 to -1 V and from -1 to 1 V at V_{sd} = 0.1 V. To evaluate the CNT channel after the application of the ionic liquid, we have performed contact mode AFM through the ionic liquid, where the AFM probe tip was immersed in the ionic liquid. As shown in Fig. 3, the CNT channel was clealy obseved by the contact mode AFM even after the application of ionic liquid.

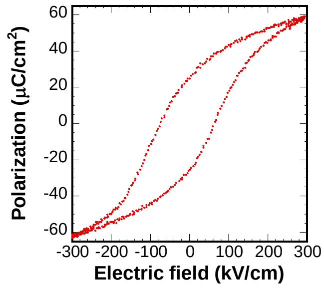

Fig. 1 Polarization-Electric field loop of PZT gate film.

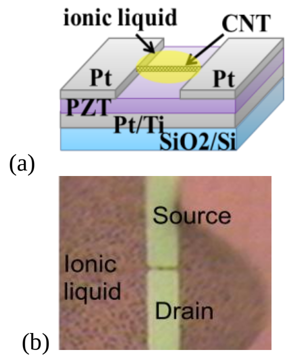

Fig. 2 (a) Schematic device structure and (b) optical microscopy image of FET channel covered with ionic liquid.

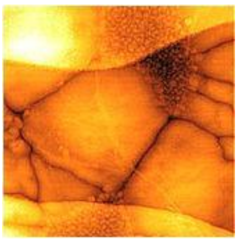

Fig. 3 AFM image of CNT channel taken through the ionic liquid covering the channel. The gap between source and drain electrodes is ~ 1 μm.

3. Results and Discussions

Figure 4 shows the transfer characteristics of

PZT-CNT-FETs for the CNT channel including the metallic CNTs (namely m-FET). The hysteresis loop for some of the PZT-CNT-FETs before dropping ionic liquid showed the small anticlockwise hysteresis loop as shown in Fig. 4(a), where arrows indicate the sweep direction of V_g. It is noted that the direction of the hysteresis is the same for usual CNT-FETs with SiO_2 gate. The transconductance (g_m) of the PZT-CNT-FETs was ~ 50 nS. As shown in Fig. 4(b), the transconductance, g_m, just after applying the ionic liquid was increased to 150 nS. This implies that the gate voltage was effectively coupled to the CNT channel through the ionic liquid. In this case, however, the hysteresis loop still showed anticlockwise manner. When this device was left for three days, the g_m improved further, up to 180 nS and the hysteresis characteristics showed the expected clockwise manner as shown in Fig. 4(c). These improvements of g_m for the m-FETs were observed for 5devices per examined 7 devices. Thus, the highly efficient capacitive coupling between the gate voltage and the CNT channel has been realized by the application of the ionic liquid.

Figure 5 shows the transfer characteristics of PZT-CNT-FETs for the semiconductive CNT channel (namely s-FET). As described in the m-FETs, the transfer characteristics before the application of the ionic liquid showed the anticlockwise manner as usual CNT-FET with SiO_2 gate. As shown in Fig. 5(b), although the application of the ionic liquid to the s-FETs induces the efficient improvement of g_m, the direction of the hysteresis was still the same even after 3 days of the application of ionic liquid.

It is noted that the sweep range of the gate voltage is smaller than that for the coercive electric field of the PZT. In general, the polarization change of the PZT should not be occurred in this voltage range for both types of PZT-CNT-FETs. However, the m-FETs show the hysteresis loop induced by the polarization change of the PZT. It is noted that the CNT channel examined here is likely to be the bundled CNTs including the metallic CNTs. Thus, the electric field just beneath of the CNT channel was efficiently concentrated and enhanced to the electric field stronger than the coercive electric field of the PZT. On the contrary, the s-FETs have smaller amount of the charge density in the channel, so that the electric flux line could not be terminated sufficiently to change the polarization direction of the PZT. Thus, the mixture of the metallic CNTs are effective to have the hysteresis loop induced by the polarization change of the PZT. Furthermore, lower operation voltage of the device has much advantageous to prevent the device failure induced by the fatigue of the PZT.

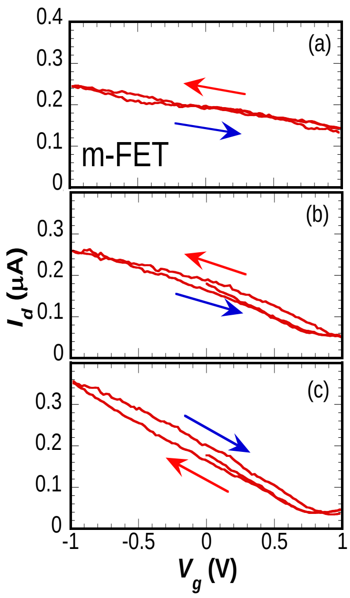

Fig. 4 I_d-V_g hysteresis characteristics (m-FET) (a) before, (b) just after dropping ionic liquid, (c) three days after dropping ionic liquid

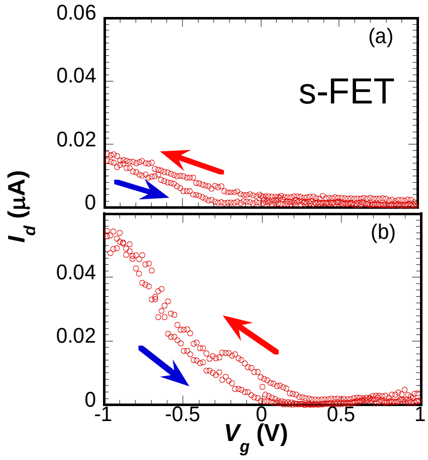

Fig. 5 I_d-V_g hysteresis characteristics (s-FET)
(a) Before, (b) after dropping ionic liquid

3. Conclusions

We have found the improvement of transfer characteristics for the PZT-CNT-FET by the ionic liquid application. In addition, the hysteresis loop of m-FET after applying the ionic liquid showed clockwise hysteresis manner due to the polarization reversal of PZT gate. On the other hand, the hysteresis of s-FET after applying the ionic liquid showed anti-clockwise hysteresis, which is similar behavior observed for the usual CNT-FET with SiO_2 gate. Thus, the metallic CNTs in the channel are crucial to improve the performance of PZT-CNT-FET by applying the ionic liquid to the CNT channel.

Acknowledgements

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References

[1] T. Sakurai, T. Yoshimura, S. Akita, N. Fujimura and Y. Nakayama: Jpn. J. Appl. Phys. **45** (2006) L1036.

[2] S. Kataoka, T. Arie, and S. Akita: Proc. of MNC2010, 12B-9-5 (2010).

[3] P. Paruch, A.-B. Posadas, M. Dawber, C. H. Ahn, and P. L. McEuen: Appl. Phys. Lett. **93** (2008) 132901.