Ambipolar Behavior in All-Carbon-Nanotube Field-Effect Transistors by Poly(Vinyl Alcohol) Coating

Shinya Aikawa[1], Taiki Inoue[1], Erik Einarsson[1,2], Theerapol Thurakitseree[1], Shohei Chiashi[1], and Shigeo Maruyama[1]

[1]*Department of Mechanical Engineering, The University of Tokyo*
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
[2]*Global Center of Excellence for Mechanical Systems Innovation, The University of Tokyo*
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

§1 Introduction

Flexible and transparent high-performance integrated circuits using single-walled carbon nanotube thin-film transistors (CNT-TFTs) have recently been developed[1-3]. However, these devices limit optical transparency and mechanical flexibility because they use opaque metal electrodes or brittle oxide dielectrics. To stabilize device operation when applying high physical stresses, we suggest that robust carbon electrodes (CNT network or graphene) and flexible polymer dielectrics should be used as device materials. Poly(methyl methacrylate) (PMMA) or an epoxy such as SU-8 is typically employed as a polymer insulator, but the influence of device properties due to the interaction between CNTs and polymers has not been examined.

In our previous work, we found that the conduction type of CNT-FETs can be changed to ambipolar behavior by poly(vinyl alcohol) (PVA) coating[4]. PVA is a considerably effective dielectric polymer because it has a relatively high dielectric constant compared with other polymers. Here, we examine this conduction type conversion of CNT-FETs by PVA coating.

§2 Experiments

The fabrication process of CNT-FETs is as follows. Patterned catalyst deposition (Co thickness: 0.2 nm) was performed on a Si substrate (t_{ox}: 300 nm) by conventional photolithography and lift-off processes. Single-walled carbon nanotubes (SWNTs) were synthesized by alcohol catalytic chemical vapor deposition (ACCVD)[5]. PVA solution with 10% concentration was dropped onto the channel region as shown in Fig. 1 and then dried at 65 °C for 10 min. Various kinds of PVA solution (e.g. different molecular weight, different solvent, etc.) were used in this study. The devices were characterized using a semiconductor parameter analyzer (Agilent 4156C) at room temperature under ambient conditions.

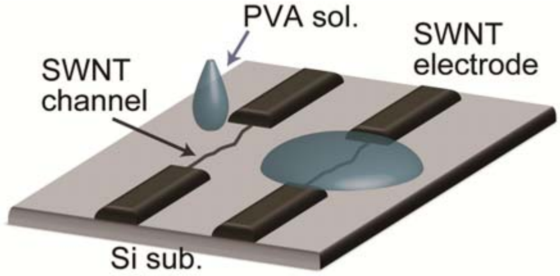

Fig. 1 Schematic of device structure.

§3 Results and discussion

Figure 2 shows typical transfer characteristics of as-fabricated (solid line) and PVA-coated (dashed line) devices. In both cases electrical properties were measured employing a Si substrate as a back-gate electrode at $V_{DS} = -10$ V. The uncoated device showed typical p-type conduction, whereas the PVA-coated FET showed ambipolar behavior. The reason for this change might be attributed to the suppression of charge transfer from the SWNT. When an SWNT channel is exposed to air, electrons are transferred to surrounding oxygen or water molecules[6], thus the electron conduction through the channel is suppressed. However, the PVA layer may act as a potential barrier, allowing electrons to pass through the channel at positive gate voltages.

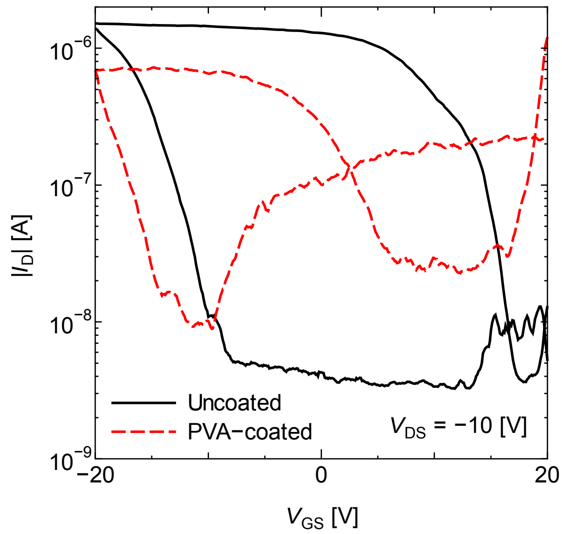

Fig. 2 Influence of PVA coating on the device transfer characteristics. Solid and dashed lines indicate as-fabricated and PVA-coated devices, respectively. Both were measured at $V_{DS} = -10$ V using a Si substrate as a back-gate electrode.

§4 Summary

We observed electron conduction in CNT-FETs by PVA coating under ambient conditions. Because carriers are injected from the electrodes but not from PVA, ambipolar conduction implies that charge transfer can be suppressed by PVA coating. Other results including SWNT diameter distribution, capacitances of PVA film, and *I-V* characteristics when coating by other PVA solutions will be discussed.

References

1. Q. Cao, H. S. Kim, N. Pimparkar, J. P. Kulkarni, C. Wang, M. Shim, K. Roy, M. A. Alam and J. A. Rogers, *Nature* **454**, 495 (2008).
2. D. M. Sun, M. Y. Timmermans, Y. Tian, A. G. Nasibulin, E. I. Kauppinen, S. Kishimoto, T. Mizutani and Y. Ohno, *Nat. Nanotechnol.* **6**, 156 (2011).
3. C. Wang, J. C. Chien, K. Takei, T. Takahashi, J. Nah, A. M. Niknejad and A. Javey, *Nano Lett.* (2012) doi: 10.1021/nl2043375.
4. S. Aikawa, E. Einarsson, T. Thurakitseree, S. Chiashi, E. Nishikawa and S. Maruyama, *Appl. Phys. Lett.* **100**, 063502 (2012).
5. S. Maruyama, R. Kojima, Y. Miyauchi, S. Chiashi and M. Kohno, *Chem. Phys. Lett.* **360**, 229 (2002).
6. C. M. Aguirre, P. L. Levesque, M. Paillet, F. Lapointe, B. C. St-Antoine, P. Desjardins and R. Martel, *Adv. Mater.* **21**, 3087 (2009).

Corresponding Author: S. Maruyama
Email: maruyama@photon.t.u-tokyo.ac.jp