Extended Abstracts of the 2014 International Conference on Solid State Devices and Materials, Tsukuba, 2014, pp1062-1063

Sub-10 μm Top-Gate Carbon Nanotube Thin-Film Transistors Fabricated by Flexographic Printing Process

Michihiko Maeda[1], Kentaro Higuchi[1], Shigeru Kishimoto[1],
Takuya Tomura[2], Masafumi Takesue[2], Katsuhiko Hata[2] and Yutaka Ohno[1]

[1]Department of Quantum Engineering, Nagoya University,
Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan
Phone: +81-52-789-5387, E-mail: yohno@nuee.nagoya-u.ac.jp
[2]Research and Development Center, Bando Chemical Industries, LTD.,
4-6-6, Minatojimaminamimachi, Chuo-ku, Kobe, 650-0047, Japan

Abstract

Short-channel top-gate carbon nanotube thin-film transistors have been fabricated on a plastic film by the flexography, a type of high-speed printing techniques. Fine patterns were formed on a PDMS plate by micro-process, resulting in printed minimum line width of 11 μm. Top-gate devices with a channel length of 6.2 μm fabricated by this technique showed an ON current of 0.85 mA/mm.

1. Introduction

Among various thin film transistors (TFTs), carbon nanotube (CNT) TFTs have attractive properties such as high mobility, flexibility, transparency, and so on [1-3]. The processability in the thin-film formation is also attractive, i.e., high-mobility channel can be formed by solution [4] and transfer [3] processes. CNT TFTs enable to realize high-performance flexible devices at low cost by introducing high-speed printing process.

In the previous work, we developed a fully lithography-free and non-vacuum process to fabricate CNT TFTs based on flexographic printing technique, one of high speed printing methods [5]. A high mobility of 157 cm^2/Vs was achieved. However, the channel length was as long as 115 μm, which was determined by the fabrication process of the plate for the flexography.

In this work, we have improved the printing resolution for miniaturizing printed CNT TFTs. Flexographic plates have been fabricated by using micro-fabrication process. High-purity semiconductor CNTs were used for the channel. Top-gate CNT TFTs with a channel length of 6.2 μm has been realized.

2. Improvement of printing resolution

We fabricated fine-patterned flexo-plates with polydimethylsiloxane (PDMS) by micro-fabrication process. Figure 1 shows the fabrication process. First, the mold that have patterns to be printed was formed with photoresist (SU-8, 10 μm) on a Si substrate. Then, the PDMS base mixed with a crosslinking agent was spincoated on the substrate. After degasing, PDMS was cured to extend the crosslinking reaction and evaporate solvents. Finally, the plate was obtained by peeling off the PDMS from the mold.

Figure 2(a) shows a top-view micrograph and the cross-sectional profile of a line-and-space pattern with a 20-μm period on a fabricated plate. The width of convex part was 9.4 ± 0.3 μm. R_a and R_z of the surface of the convex part were 30 and 220 nm, respectively, showing sufficiently smooth surface for flexo-plates. Test pattern was printed with the ink of silver nanoparticles. The minimum printed line width was 11 μm.

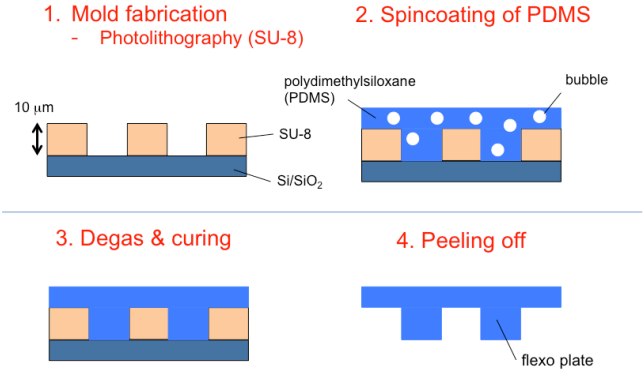

Fig. 1 Fabrication process of flexographic plate.

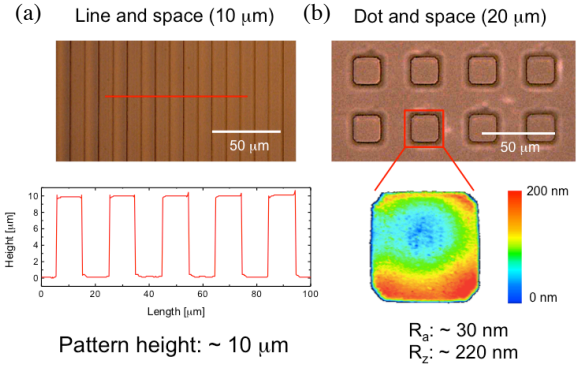

Fig. 2 (a) Micrograph of line-and-space pattern on fabricated flexographic plate and the cross-section profile. (b) Surface profile of the plate.

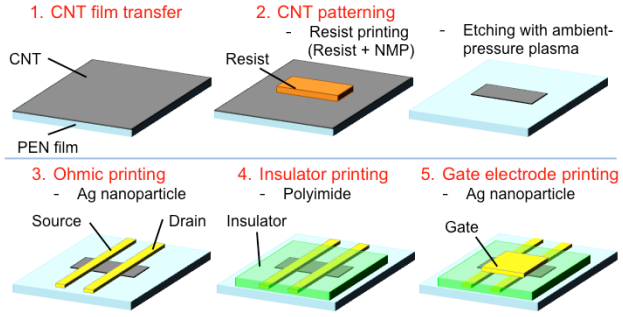

Fig. 3 Device fabrication process.

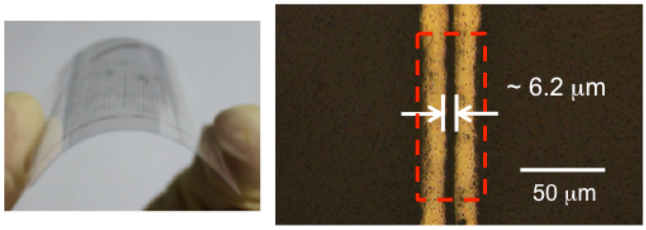

Fig. 4 (a) Photograph of printed CNT TFT on PEN. (b) Micrograph of the channel.

3. Printed short-channel CNT TFTs

Device fabrication process

Top-gate CNT TFTs were fabricated on a polyethylene naphthalate (PEN) film with a thickness of 100 μm. Figure 3 shows the device fabrication process. First, a thin film of semiconductor CNTs was formed by the transfer process. High-purity semiconductor CNTs purified by gel chromatography technique [6] was used in this work. The CNTs dispersed in surfactant solution were collected on the membrane filter by suction filtration, and then transferred on the substrate. Then, the CNT film was patterned by printing the resist material and subsequent etching with ambient-pressure plasma of O_2/Ar. Here, we used a resist ink mixed with a low-volatile solvent. After removing the resist, the source and drain electrodes, gate insulator, and gate electrode were printed. Silver nanoparticle (Bando Chemical Industries, FlowMetal SW1026-x1) and polyimide (Taiyo Holdings, IJPR TR64861) were respectively used for the electrodes and insulator.

Figure 4 shows (a) a photograph of fabricated CNT TFTs and (b) a micrograph of the channel regime before printing the gate stack. The channel length and width were 6.2 and 108 μm respectively. The channel length is the shortest for CNT TFTs fabricated by printing processes to our knowledge [5,7,8]. The average thickness of the gate insulator was measured to be 1.5 μm by a laser microscope. The gate leakage current was less than 2 pA at 100 V. The transfer characteristics of a fabricated device showed *p*-type conduction with an on/off ratio of ~10^3 as shown in Fig. 5. The mobility was estimated to be 3.3 cm^2/Vs. The ON current density was 0.85 mA/mm at V_{DS} = −10 V.

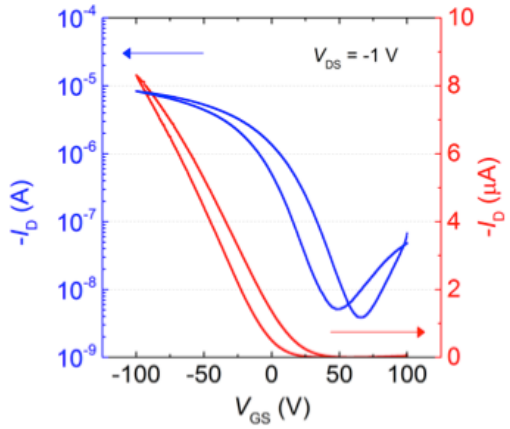

Fig. 5 Transfer characteristics of printed CNT TFT.

4. Conclusions

We have fabricated short-channel top-gate CNT TFTs on a plastic film by using flexographic printing technique. The printing resolution was improved down to 11 μm by fabricating flexo-plates with micro-fabrication processes. The channel length of the printed TFTs was 6.2 μm, which was among the shorted length for printed CNT TFTs. The devices showed an on/off ratio of ~10^3, a mobility of 3.3 cm^2/Vs, and ON current density of 0.85 mA/mm.

Acknowledgements

This work was partially supported by ALCA-JST, SICORP-JST, and Grant-in-Aid of MEXT.

References

[1] E. S. Snow, J. P. Novak, P. M. Campbell, and D. Park, *Appl. Phys. Lett.* **82** (2003) 2145.

[2] 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** (2008) 495.

[3] D.-M. Sun, M. Y. Timmermans, Y. Tain, A. G. Nasibulin, E. I. Kauppinen, S. Kishimoto, T. Mizutani, and Y. Ohno, *Nature Nanotech.* **6** (2011) 156.

[4] M. C. LeMieux, M. Roberts, S. Barman, Y. W. Jin, J. M. Kim, and Z. Bao, *Science* **321** (2008) 101.

[5] K. Higuchi, S. Kishimoto, Y. Nakajima, T. Tomura, M. Takesue, K. Hata, E. I. Kauppinen, and Y. Ohno, *Appl. Phys. Express* **6** (2013) 085101.

[6] H. Liu, D. Nishide, T. Tanaka, and H. Kataura, *Nature Commun.* **2** (2011) 309.

[7] P. Chen, Y. Fu, R. Aminirad, C. Wang, J. Zhang, K. Wang, K. Galatsis, and C. Zhou, *Nano Lett.* **11** (2011) 5301.

[8] J. Noh, M. Jung, K. Jung, G. Lee, S. Lim, D. Kim, S. Kim, J. M. Tour, and G. Cho, *Org. Electron.* **12** (2011) 2185.