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Air-Stable *p*-Type and *n*-Type Carbon Nanotube Field-Effect Transistors with Top-Gate Structure on SiN_X Passivation Films Formed by Catalytic Chemical Vapor Deposition

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1. Introduction

Carbon nanotubes (CNTs) extremely attract attentions in terms of their unique mechanical, chemical, and electronic properties. They are quasi one-dimensional conductors with properties such as high current carrying capabilities. It is dependent on their chirality that they may be either semiconducting or metallic. Semiconducting CNTs can operate as the active elements of field-effect transistors (FETs), in particular, for highly sensitive biosensors.[1] In order to fabricate high performance of CNTFETs with top-gate structures, the passivation films are absolutely necessary. However, it is a great problem that the conventional formation process of passivation films introduces damages in CNT channels. For instance, plasma-enhanced chemical vapor deposition has been a widely used technique to obtain passivation films with high quality. However, the passivation films are formed by collision between energetic electrons and molecules of source gases, resulting in introduction of defects into CNTs by plasma. In this paper, we have fabricated CNTFETs with top-gate structures on SiN_X passivation films formed by catalytic chemical vapor deposition (Cat-CVD). In this method, source gases are decomposed by catalytic cracking reactions with a heated catalyzer placed, so that the films are deposited at low temperatures, which do not introduce damage in CNT channels.

2. Sample Structure

Figure 1 shows a schematic structure of the CNTFET with top gate structure on a SiN_X passivation film. A p^+-type Si wafer with thermally oxidized SiO_2 (150 nm) was used as a substrate. Firstly, a metal catalyst consisting of a layer of Co (2 nm) was patterned on the substrate using conventional photolithography and metal lift-off processes. Next, the CNTs were synthesized by thermal chemical vapor deposition (CVD) at 900 °C for 10 minutes, using C_2H_5OH as a source gas. Ti/Au (3 / 100 nm) electrodes were formed both on the patterned catalysts and on the backside of the substrate. The gap distance between the source and drain was 5 µm. Next, SiN_X films (50 nm) were formed on the CNTFET devices by Cat-CVD. The surface temperature of the substrate was 65 °C and 270 °C, measured by a thermocouple when depositing SiN_X films on the CNTFET devices. Finally, Ti/Au (5 / 80 nm) electrodes, as top-gate electrode, were formed on SiN_X passivation films. In this experiment, the I_D versus drain-source bias (V_{DS}) and the drain current versus gate-source bias (V_{GS}) characteristics of the CNTFETs at room temperature were measured using a semiconductor parameter analyzer.

3. Results and Discussion

Figures 2a and 2b show the liner I_D-V_{DS} characteristics in vacuum for the CNTFETs with SiN_X passivation films fabricated at 65 °C and 270 °C, using gate biases as parameters, respectively. For this measurement, the back-gate bias V_{BGS} was changed from –5 V to 5 V with a 2 V step. For the CNTFETs with SiN_X passivation films formed at 65 °C shown in Figure 2a, the I_D decreases with the increase in V_{BGS}, indicating that the carriers in the channel are holes (*p*-type). On the other hand, for CNTFETs with SiN_X passivation films formed at 270 °C shown in Figure 2b, the I_D increases with increase in V_{BGS}, indicating that the carriers in the channel are electrons (*n*-type). This indicates that adsorbed oxygen on the CNTs sidewalls, which results in *p*-type characteristics, is removed during the formation process of the SiN_X passivation films at 270 °C. Hence, we have controlled the type of carrier of CNTFETs only by the substrate temperature during SiN_X passivation film deposition.

The effect of various environments on the characteristics of CNTFETs with SiN_X passivation films was then investigated. Figure 3a shows I_D-V_{BGS} characteristics of the *p*-type CNTFETs with SiN_X passivation films formed at 65 °C preserved in vacuum for 1 hour, 10 hours, and in air. Figure 3b shows *n*-type CNTFETs with SiN_X passivation films formed at 270 °C preserved in vacuum for 1 hour, 11 hours, and in air. V_{DS} is set at 1 V. The source-drain current of both for the *p*-type and *n*-type CNTFETs does not vary over time in vacuum (for 1 hour and 10,11 hours) or in air. Therefore, the CNTFETs could be completely protected by the SiN_X passivation films from further effects of ambient gases.

Figure 4 shows the top-gate bias V_{TGS} dependence of I_D for *p*-type CNTFETs at V_{DS} = 1 V. Good pinch-off characteristics with a threshold voltage of –1 V were obtained. Transconductance $g_m = | \Delta I_D / \Delta V_G |$ is 0.154 µS. Consequently, we have succeeded in fabricating air-stable *p*-type and *n*-type CNTFETs with top-gate structures on SiN_X passivation films formed by Cat-CVD.

4. Conclusions

The fabrication and electrical characteristics of CNTFETs with the top-gate structure on SiN_X passivation film by Cat-CVD have been investigated. We controlled the type of carrier of CNTFETs by the substrate temperature during SiN_X passivation films deposition. Moreover, we have succeeded in fabricating air-stable *p*-type and *n*-type CNTFETs with top-gate structures on SiN_X passivation films formed by Cat-CVD.

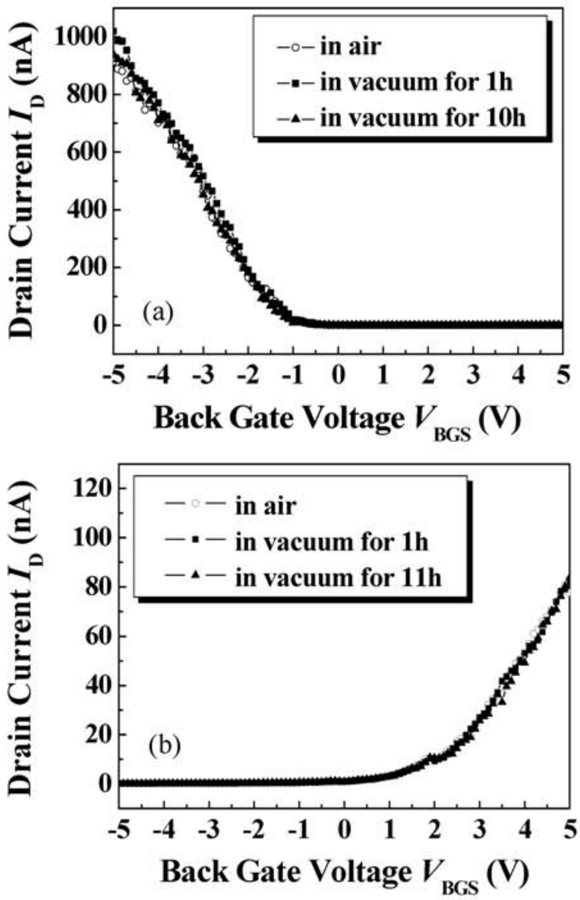

Fig. 3. (a) I_D-V_{BGS} characteristics of a *p*-type CNTFET with SiN_X passivation films formed at 65 °C preserved in vacuum for 1 hour (closed squares), 10 hours (closed triangles), and in air (open circles). (b) I_D-V_{BGS} characteristics of the *n*-type CNTFET with SiN_X passivation films formed at 270 °C preserved in vacuum for 1 hour (closed squares), 11 hours (closed triangles), and in air (open circles).

References

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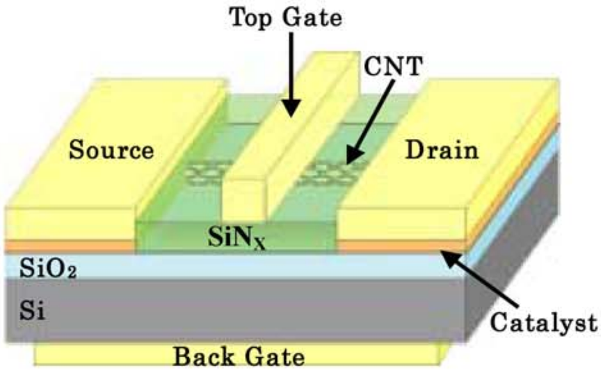

Fig. 1. Schematic sample structure of CNT-FET with top gate structure on SiN_X passivation films.

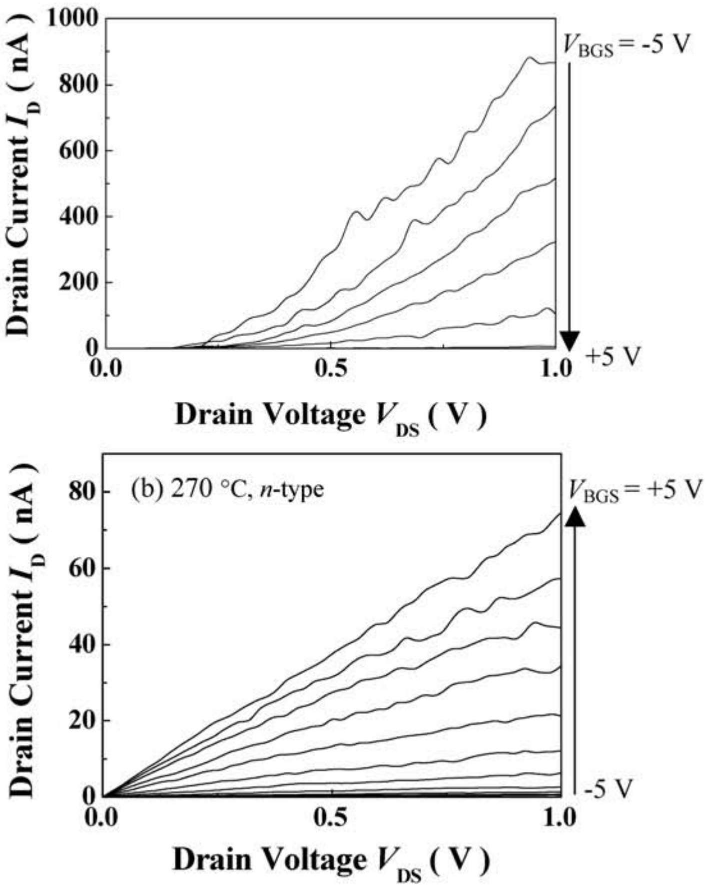

Fig. 2. (a) I_D-V_{DS} characteristics of the *p*-type CNTFET with SiN_X films formed at 65 °C, and (b) I_D-V_{DS} characteristics of the *n*-type CNTFET with SiN_X films formed at 270 °C. V_{BGS} is changed from –5 to 5 V with 2 V steps.

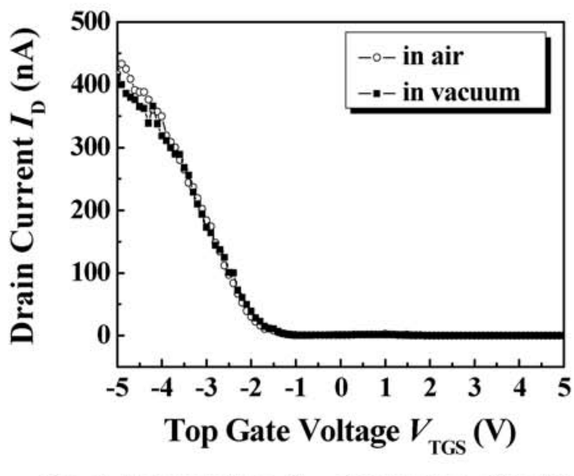

Fig. 4. Top-gate bias V_{TGS} dependence of I_D for *p*-type CNTFET preserved in vacuum and in air.