Fabrication and characterization of *p-i-p* top-gate carbon nanotube FETs

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1. INTRODUTION

Carbon nanotubes (CNs) are promising materials for the nano-scale electron devices such as CN field-effect transistors (CNFETs). In order to fully develop the potential of CNs, it is necessary to optimize the device structure [1]. In this study, we have fabricated *p-i-p* top-gate (TG-) CNFETs, where the access region was doped with F_4TCNQ (tetrafluorotetracyano-*p*-quinodimethane) as *p*-type dopant [2]. This results in the improvement of device performance.

2. EXPERIMENTS

The schematic device structure and SEM image of the fabricated *p-i-p* TG-CNFETs are shown in Fig. 1 and Fig. 2, respectively. The single-walled carbon nanotubes were synthesized on a p^+-Si wafer with SiO_2 (100 nm) by alcohol catalytic chemical vapor deposition [3]. After the formation of the source and drain electrodes, Au/Ti/AlO_x top-gate structure was formed by electron-beam lithography, electron-beam evaporation, and lift-off process. The gate length (l_G), gate insulator thickness (t_{ox}), and source-drain distance (l_{SD}) are 200 nm, 10 nm and ~3 μm, respectively. Finally, the access regions between the source and gate and between the drain and gate were doped with F_4TCNQ as *p*-type dopant. The wafer was soaked in chloroform solution of F_4TCNQ (3.6 mol/l) for 1.5 hours. We have confirmed the effectiveness of the F_4TCNQ doping using back-gate-type (BG-) CNFETs. Figure 3 shows the I_D-V_{GS} characteristics of BG-CNFETs before and after the F_4TCNQ doping. The threshold voltage (V_{th}) shifted ~5 V toward positive V_{GS}, and the on-current was increased 350% by the doping. The positive V_{th} shift shows the effectiveness of F_4TCNQ as a *p*-type dopant. The increase in on-current would be attributed to an increase of channel conductivity and/or a reduction of resistance of the Schottky contacts.

Figure 4(a) shows I_D-V_{GS} characteristics of CNFETs; BG-CNFET (dotted line), undoped TG-CNFET (broken line), and *p-i-p* TG-CNFET (solid line). Here, the substrate bias (V_{sub}) was floating for the TG-CNFETs. In the case of both TG-CNFETs, subthreshold slope (*s*-factor) was improved to be 200 mV/dec as compared to that of BG-CNFETs (s ~ 1000 mV/dec). Another attractive property of the present TG-CNFETs is smaller hysteresis than that of BG-CNFET. In the case of BG-CNFETs, the large counterclockwise hysteresis has been related to water molecules [4] and organic contamination [5] around the CN channel. In the present TG-CNFETs, the active region is passivated by the gate oxide, resulting in the suppression of hysteresis. By the F_4TCNQ doping, the on-current of TG-CNFETs was increased by one order of magnitude, and consequently, the I_{on}/I_{off} was improved to be 10^3 as shown in Fig. 4(b). The schematic energy band of *p-i-p* TG-CNFET is shown in Fig. 4(c). The F_4TCNQ doping increases hole concentration in the access region. This results in a reduction of serial resistance of the access region.

3. SUMMARY

We have successfully fabricated F_4TCNQ doped *p-i-p* TG-CNFETs. The top-gated device structure improved *s*-factor and reduced hysteresis, and the doping into the access region improved current driving capability.

REFERENCES

[1] J. Appenzeller *et al.*, IEEE Trans. Electron Devices **52**, 2568 (2005).
[2] T. Takenobu *et al.*, Adv. Mater. **17**, 2430 (2005).
[3] Y. Ohno *et al.*, Jpn. J. Appl. Phys. **42**, 4116 (2003).
[4] W. Kim *et al.*, Nano Lett. **3**, 193 (2003).
[5] H. Shimauchi *et al.*, Jpn. J. Appl. Phys. **45**, 5501 (2006).

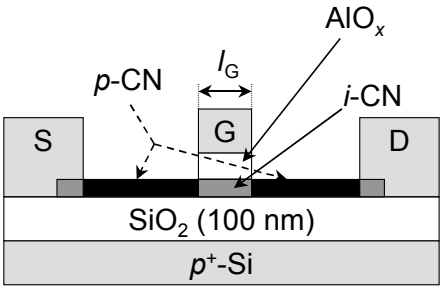

Fig. 1 The schematic device structure of F_4TCNQ doped *p-i-p* top-gate (TG-) CNFETs.

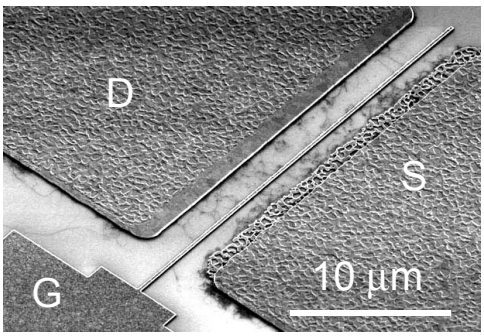

Fig. 2 SEM image of fabricated F_4TCNQ doped *p-i-p* TG-CNFETs.

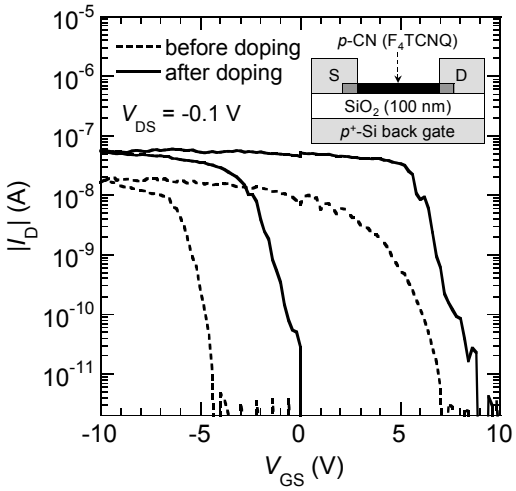

Fig. 3 I_D-V_{GS} characteristics of back-gate (BG-) CNFET before and after F_4TCNQ doping. A V_{th} Shift toward positive V_{GS} and an increase in on-current were observed. Inset is the schematic device structure of *p*-doped BG-CNFETs.

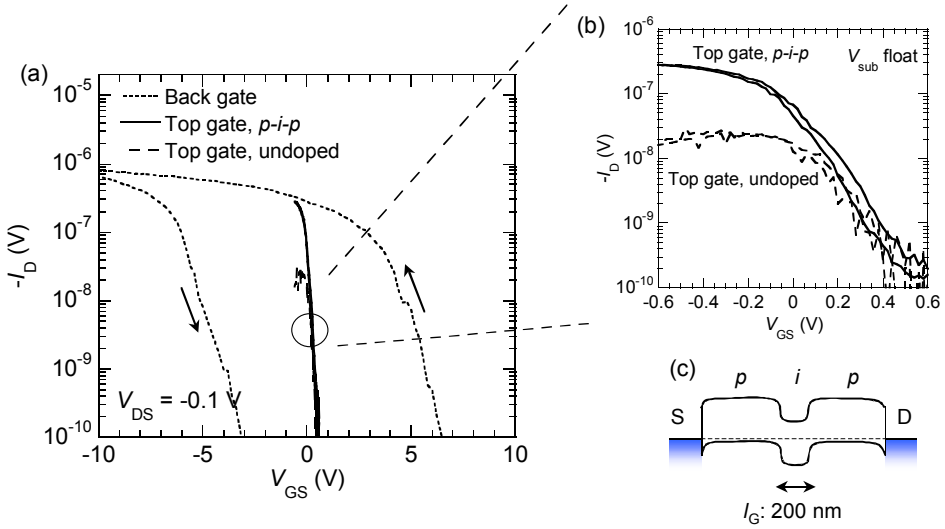

Fig. 4 (a) I_D-V_{GS} characteristics of CNFETs; BG-CNFET (dotted line), undoped TG-CNFET (broken line), and *p-i-p* TG-CNFET (solid line). (b) I_D-V_{GS} characteristics of TG-FETs. (c) Schematic band structure of *p-i-p* TG-CNFET. Subthreshold slope was improved and hysteresis were reduced by introducing the top-gate structure. The on-current of TG-CNFETs was increased by one order of magnitude by F_4TCNQ doping.