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Controlling the characteristics of single walled carbon nanotube network transistors by using metal electrodes with different work functions

Un Jeong Kim, Eun Ju Bae, Yo-Sep Min and Wanjun Park*
Semiconductor device & material Lab., Samsung Advanced Institute of Technology, Yong-In, Kyeongki-Do, 449-712, Korea
*Corresponding to wanjun@samsung.com

***Abstract*— We have fabricated single walled carbon nanotube(SWNT) network transistors using 3 different metal electrodes(*i.e.* Al, Ti/Au and Pd/Au) which have significantly different work functions from each other. We have observed that the barrier height between the SWNTs and metal electrode can change the polarity of the SWNT network FETs.**

Keywords-component; SWNT network FET; work function; polarity

I. INTRODUCTION

Due to its unique 1-dimentional structural nature, singled walled carbon nanotubes(SWNTs) captured the attention of the international research community who investigate their fundamental properties as well as novel devices, e.g. field effect transistors(FETs)[1], sensors[2], field emission devices[3], and etc.

There have been reports that by using the metal electrodes with different work functions the polarity of individual SWNTs can be adjusted[4, 5]. In this work, we show that metal electrodes with different work functions can control the polarity of SWNT network FETs.

II. EXPERIMENTAL

SWNT networks were grown at the pre-patterned catalyst particles on the Si/SiO_2 substrates by PECVD [6]. Then by using photolithography, Ti/Au (100Å/1000Å), Al (500Å), Pd/Au (500Å/200Å) was deposited as source and drain electrodes on the SWNT networks grown on the pre-patterned catalyst particles.

The grown SWNT networks were characterized by Raman spectroscopy (Renishaw 3000) using 633nm laser excitation. The electrical properties of SWNT network transistors were measured by semiconductor parameter analyzer [Agilent 4156C] equipped with a turbo pump.

III. RESULTS AND DISCUSSIONS.

Fig.1 shows a typical set of I_{ds}-V_g curves in air, where I_{ds} and V_g represents the amount of current that flows between the source and drain and the applied voltage to a back-gate electrode. The inset is the typical SEM image of the devices that we studied for this work. The distance between source(S) and drain (D) electrode is 2μm. The density and the size of SWNT bundles between the electrodes were very small to be seen clearly by SEM imaging. However, by resonant Raman scattering, SWNTs were detected easily. For all measurements in this experiment, gate voltage (V_g) was varied from -40V to 40V and the vias between source and drain were varying from -1V to 1V with 500mV step. As well known in the literature, the FET with SWNT network using Ti/Au electrode shows a p-channel behavior under air as shown in Fig.1 [6, 7].

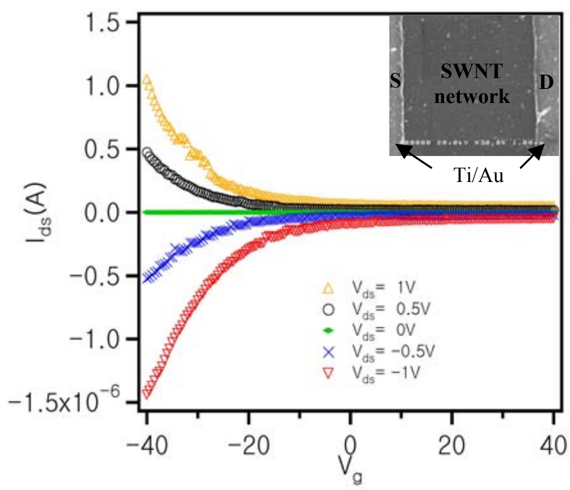

Figure 1. A typical set of I_{ds}-V_g curves measured on SWNT network FET with Ti/Au electrode.

The I_{ds}-V_g curves for the SWNT network FETs using Ti/Au(a)(d), Al(b)(e) and Pd/Au(d)(f) contact electrodes in a logarithmic scale are shown in Fig. 2. The results obtained under air and vacuum are shown at the left and right panel, respectively.

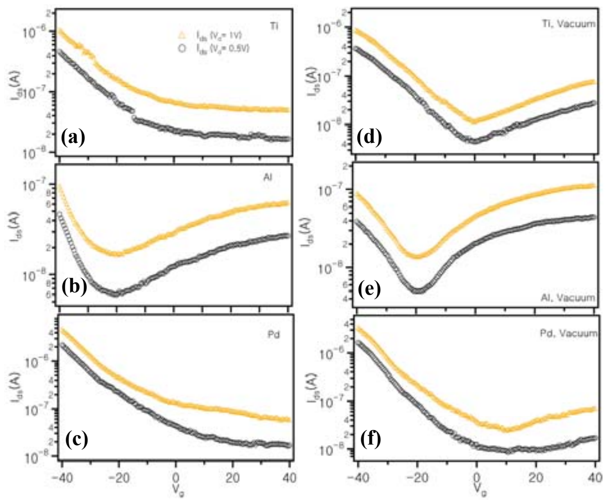

Figure 2. a typical set of I_{ds}-V_g curves in a logarhythemic scale measured on SWNT network FET with Ti/Au(a)(d), Al(d)(e), Pd/Au(c)(f) electrodes under air and vacuum.

CNT network FETs with Ti/Au(a),(d) and Pd/Au(c),(f) electrodes exhibit unipolar and ambipolar behavior under air and vacuum as usual. However, CNT network FET with Al electrodes shows ambipolar behavior with a shifted threshold voltage (V_{th}) to -20V even under air as shown in Fig. 2(b)(e). It has been reported that CNT-FETs usually exhibit unipolar and ambipolar characteristics under ambient air and vacuum, respectively [4, 7]. Unipolar behavior under ambient air was explained by the trapped electrons by the adsorbators (e.g. O_2), whose LUMO level is in the band gap of the CNT, which suppress the n-channel formation on the positive gate voltage [7]. However, additional concept should be introduced to explain the n-channel formation for SWNT network FETs with Al electrodes.

It has been reported that the characteristics of CNT FETs are determined by the barriers at the CNT-metal junctions, which arise due to the differences between metal work function and Fermi level of the CNT[4]. Yang et al.[4] demonstrated that by using metals with different work function, the polarity of CNT-FET can be modified. For example, by using Al contact, they have shown that CNT-FET with Al electrode is n-type since Al has a low work function (~4.0eV) which creates a high Schottky barrier for *p* carriers. Since the work functions of Ti/Au and Pd/Au has a low barrier for p carrier, but for n-carrier, it is natural that Ti/Au and Pd/Au electrodes form p-type transistors under air. Of course, after de-gassing under vacuum, small n-channel will form for the FETs withTi/Au and Pd/Au electrodes as shown in Fig.2(d) and (f).

Yang et al. presented that individual SWNT/Al electrode FET is a completely n-type under air in their report [4]. However, our SWNT network FETs with Al electrode shows ambipolar behavior under air. This result is not understandable if we consider that the typical band gap of semiconducting SWNTs is ~0.4 - ~1.5eV. The work function of Al is too far off from the conduction band energy level even for the smallest nanotubes. By theoretical energy band calculation for the bundled SWNTs[8], van der Walls interaction among nanotubes in bundles widens the band gaps by ~0.2eV. The change in the band gap width ($\Delta E_g \sim 0.2$eV) due to bundling of SWNTs will not change the overall story. We speculate that there must be other factors to govern the polarity of the network FETs. This will require more careful investigation in the future to verify this phenomenon.

In summary, we have demonstrated that the polarity of SWNT network transistor can be modified by using metal electrodes with different work function. However, the ambipolar characteristic of SWNT network FETs with Al electrodes under air remain unexplained.

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