Performance Control of High Mobility, Printed Thin Film Transistors Using Semiconducting Nanotube Ink.

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Performance Control of High Mobility, Printed Thin Film Transistors using Semiconducting Nanotube Ink

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In this work, we present progress towards device fabrication using purified, semiconducting-enriched SWNT as the base material. Nanotubes were deposited in different densities (low, moderate, and high density) with different gate length of transistors and effect of each parameter has been studied using DC measurements. It is been shown that the nanotube network density plays a significant role in controlling the performance of such devices. By controlling the density of nanotubes in the network, we laid down a road map to predict and enhance the device performance based on their mobility and on/off ratio. From this work the DC analysis of devices characterization shows a mobility more than 90 cm^2/V-s and also on/off ratios as high as, 10^5 have been achieved. We have demonstrated the first density-control technique over the nanotube network as a key point to modify the transistor's mobility and on/off ratio [1]. When dense network mats of nanotubes were deposited, devices outperformed with higher mobility more than 90 cm^2/V-s, enabling a faster switching speed. While relatively low-density mats yielded devices with on/off ratio of more than 10^5, which makes this technique feasible for low power nanoelectronics. Besides, the effect of various gate lengths have been studied which reveals an interesting trend between the channel length and the mobility.

I. Fabrication

Semiconducting single-walled nanotube (purified 99%) network was deposited on top of Si/SiO_2 substrate. Surface modification (APTES) was also used to ensure the absorption of semiconducting tubes. The nanotube ink was made using density gradient centrifugation process for the separation of nanotubes with different chiralities. Nanotube solution was then poured on wafers. The impact of density of nanotube network was studied for a comprehensive range of densities.

Following the nanotube deposition, the wafer was patterned for source and drain deposition using standard photolithography. We also studied the effect of gate length (10~100 μm) on mobility and on/off ratio.

E-beam evaporation was used to deposit source and drain electrodes (Pd/Au). The Si wafer acts as the back gate and 300 nm of SiO_2 was used as the gate dielectric. Figure 1 shows the schematic of fabrication process and SEM of nanotube network.

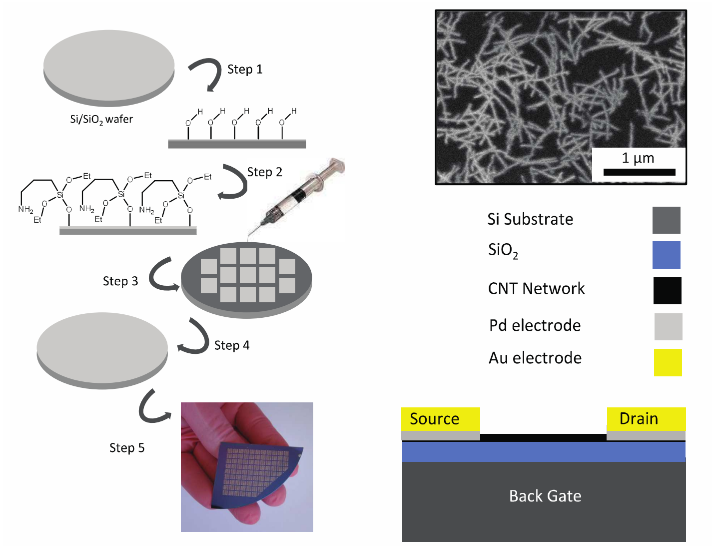

Fig. 1. Fabrication process and SEM image of nanotube network

II. ELECTRICAL MEASUREMENTS

The I_D-V_D extracted from the dc measurement shows that the current-voltage relationship is linear for small V_D ranging from -1 V to 1 V (triode region), indicating good ohmic contact between nanotubes and electrodes (Pd/Au). By applying more negative V_D the devices clearly show saturation behavior. Using 99% semiconducting nanotube network results in high on/off ratio for low and moderate tube densities and low on/off ratio but very high mobility for high-density networks. Mobility also depends on the tube density in the channel. A wide range of mobility from less than 1 to ~90 cm^2/V-s is observed using conventional MOSFET equations and curve fitting the I_D-V_D characteristic. Figure 2 shows the depletion curve (I_{ds} vs V_g) for different V_{ds} voltages and also the I-V characteristic of the device is shown in the inset demonstrating a saturation behavior for high drain-source voltages.

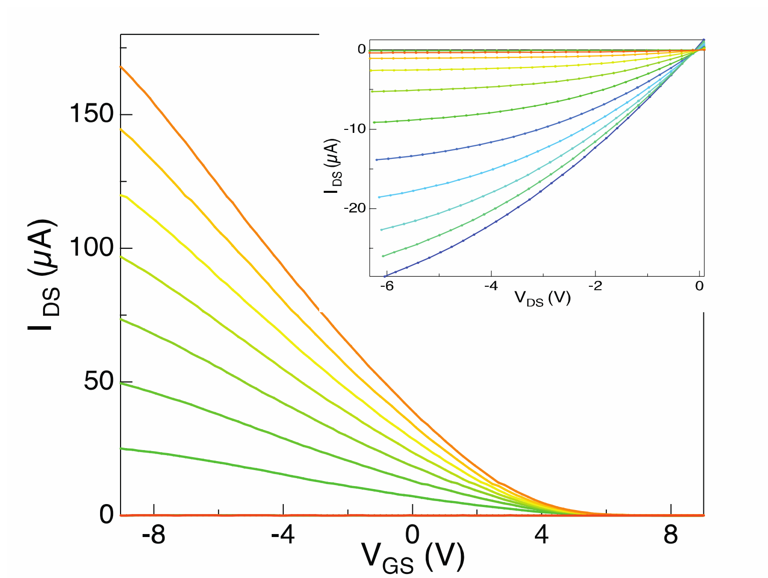

Fig. 2. Depletion curve (V_G from +10 ~ -10 V, with 2 V increment, V_{DS} from 0~7 V with 1 V increment). I_{DS}-V_{DS} in the inset

Figure 3 depicts the trend between the notmalized transconductance and the channle length.

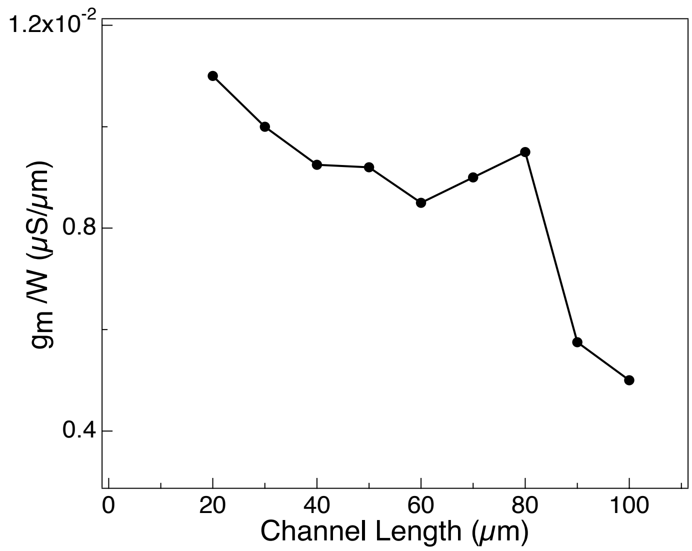

Fig. 3. Transconductance vs. Channel length

Mobility and on/off ratio are two most important figures of merit for evaluating the devices' performance. As mentioned above, here for the first time we present a trend between the network density and the mobility for purified semiconducting nanotube transistors (Figure 4). As it is shown, by increasing the tube density, mobility will increase as well.

Moreover, we found a trend between tube density and on/off ratio. Increasing the density will increase the number of pass-ways from source to drain electrodes therefore increases the number of metallic tubes in the channel as well. This in fact enhances the off current and as a result the on/off ratio will decrease.

Besides, our measurements show an inverse relationship between mobility and on/off ratio of such devices as it can be seen in figure 5. More details can be found in [1].

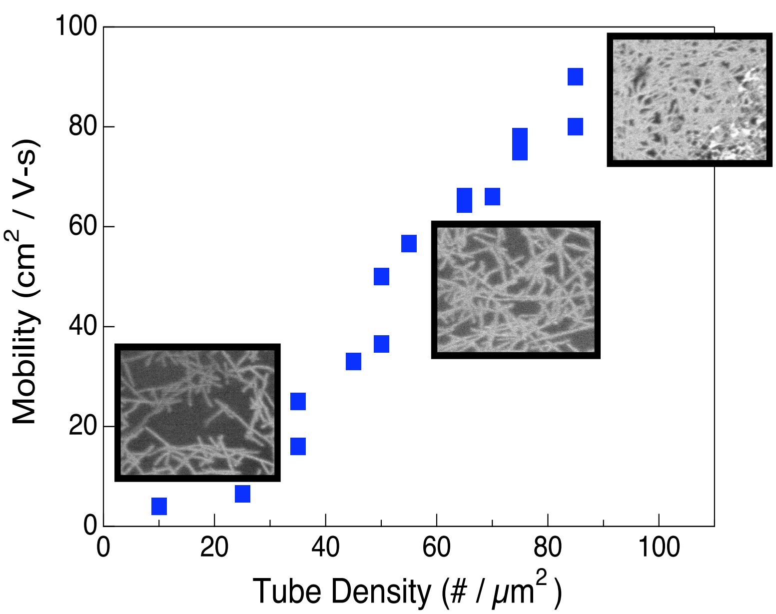

Fig 4. Mobility vs nanotube network density for a wide range of densities from less than 10 tube.μm^{-2} to around 90 tube.μm^{-2}. The inset shows SEM image of three different (low, moderate, and high) network densities.

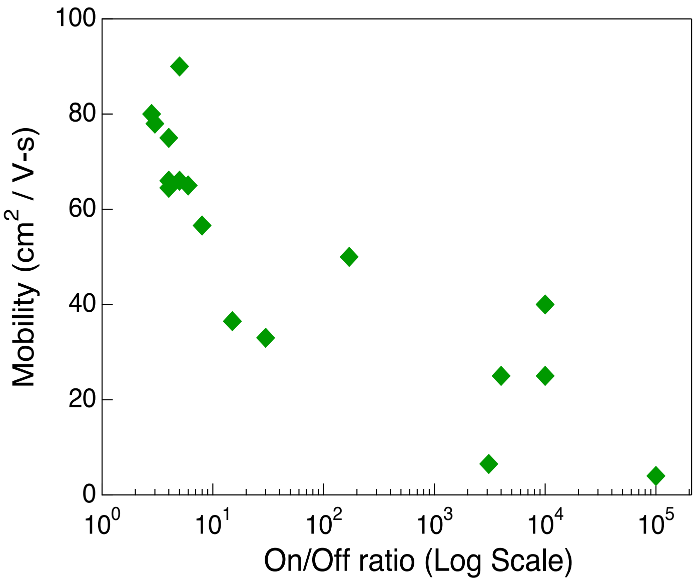

Fig. 5. Mobility vs. On/Off ratio

III. Conclusion

In summary we reported thin film transistors fabricated using semiconductor-enriched carbon nanotubes. The dc electrical measurements show a great improvement in terms of mobility (~90 cm^2/V-s), on/off ratio (more than 100,000), and transconductance compared to previous works. Moreover, for the first time the density dependence and control of the devices' performance has been demonstrated. Since these are some of the first all semiconducting nanotube-ink devices ever made, the initial results are indeed quite promising for thin film transistors and RF electronics. In addition, the density control provides the first comprehensive roadmap towards a wide variety of large-area printed electronics.

IV. Reference

[1] N. Rouhi, D. Jain, P. J. Burke, "Fundamental Limits on the Mobility of Nanotube-Based Semiconducting Inks", *Advanced Materials*, 23, 94-99, 2011.