Test and Modeling of the Electronic Behavior of Carbon Nanotubes High Performances Transistors obtained using Air-Brush Deposition Technique

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Abstract
Using one Single-Walled-Carbon-Nanotube (SWCNT) to achieve high performances transistors presents two important issues. Firstly, we can not predict if SWCNTs are metallic or semiconducting before electrical tests. Secondly, it is quite difficult to identify the position of one single SWCNT using Atomic Force Microscope (AFM) technique and then to deposite metal electrodes. For these reasons, this is not a suitable solution for batch fabrication. Thus, we have focused our work on carbon nanotube field effect transistors (CNTFETs) obtained using SWCNT mats as channels. Indeed, as far as random networks are concerned, it has been shown that, through a percolation effect, overall semiconductor behavior can be obtained for carefully controlled surface densities [1-4]. Only two conditions must be fulfilled: the distance between the two electrodes must be larger than the SWCNT average length (1µm), otherwise metallic nanotubes could cause short-circuit, and the surface density of the SWCNT mat has to exceed slightly the percolation threshold. For too high densities, the conduction reaches an ohmic trend with no gating effect [5]. Our contribution deals with the modeling and the test of CNTFETs obtained using SWCNTs networks as channels. To achieve these ones, we have deposited SWCNT mats using an improved air-brush technique. Firstly, gold electrodes were fabricated using common metal deposition methods on an oxidized Si substrate (used as the gate). The electrodes were designed using interdigited configuration in order to maximize the chance to have SWCNT chains linking the two electrodes, with different channel width D (2, 5, 10 and 15µm). Secondly, using commercial SWCNTs from SouthWestNanoTechnologies, CoMoCat SG65 (90% of semiconducting SWCNTs), we have achieved, after a sonication and a centrifugation step as described in [6 -7], stabilized solutions using N-Methyl-pyrrolidone (NMP) as solvent. These solutions are deposited on the substrate, where the electrodes have been fabricated, using a spray-gun (Fig.1). The substrate is heated at a temperature higher than 202°C (evaporation point for NMP) in order to evaporate instantaneously the solvent droplets hitting the substrate. This last detail allows us to dramatically improve the uniformity of the SWCNTs mats preventing the so-called “coffee ring effect” (deposition of SWCNTs on the borders of the drops evaporated at room temperature) achieving mats with state of the art reproducible characteristics [8]. After electrical test, we have modeled the On/Off current ratio variation of CNTFETs as a function of the electrodes distance, and obtained the formula (1).

\[
\text{Ln}(I_{\text{On}}/ I_{\text{Off}}) = \frac{\pi^{1/2}}{4.236} \left( \frac{L_c}{L_t} \right) \text{Ln}(x / (1-x))
\]

\(L_c=\) channel length
\(L_t=\) SWCNT average length
\(x=\) Semiconducting Nanotubes percentage

This last was defined supposing that the current between electrodes is mainly due to the all semiconducting or all metallic SWCNT chains linking the two electrodes: the mixed paths (composed by semiconducting and metallic SWCNTs) minimally influence the final On/Off current ratio. Finally we have compared the theoretical results with experimental ones and found a close agreement. This result has confirmed that mixed paths have no effect on the overall current flowing in the mat. This is the first time that this hypothesis is confirmed. The impact of our model could be really huge to tailor electronic characteristics of SWCNT mat based devices for industrial applications.
References:

Figures:

Fig. 1: Palladium interdigitated electrodes (a) with SWCNT networks deposited by spray gun technique (b).

Fig. 2: Transfer Characteristics for CNTFETs obtained using Air-Brush technique.

Fig. 3: $I_{on}/I_{off}$ natural logarithm as a function of the channel length.