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Carbon Nanotube Electrical Interfaces

Himanshu Mishra
Birck Nanotechnology Center, School of Mechanical Engineering, School of Materials Engineering, and School of Electrical and Computer Engineering, Purdue University, hmishra@purdue.edu

Timothy Fisher
Birck Nanotechnology Center, School of Mechanical Engineering, School of Materials Engineering, and School of Electrical and Computer Engineering, Purdue University, tsfisher@purdue.edu

Timothy D. Sands
Birck Nanotechnology Center, School of Mechanical Engineering, School of Materials Engineering, and School of Electrical and Computer Engineering, Purdue University, tsands@purdue.edu

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1. Motivation: To investigate the current flow through the interface between two mating carbon nanotube arrays, in order to assess and design applications for high-performance dry electrical interface materials. Moderate electrical contact resistance between two metal substrates has been reported when one of the two surfaces was covered with a multiwall carbon nanotube (MWCNT) film. The motivation behind this work is to study the effects on electrical contact resistance between two metal substrates with strong adhesion to the substrate.

2. MWCNT array synthesis on sapphire substrate: Vertically aligned, high number density MWCNT arrays with strong adhesion to the substrate were synthesized by a plasma-enhanced CVD process. Standard photolithographic processes were employed to obtain patterned metal tri-layers [Ti (1µm), Au (10nm), Ti (0.1µm)] of different widths on double-side polished (DSP), transparent sapphire substrates. MWCNT arrays were synthesized by the microwave plasma-enhanced chemical vapor deposition (PECVD) process. The reaction conditions during PECVD process were 900°C substrate temperature, 10 torr chamber pressure and 200 W plasma power. Methane and hydrogen were the feed gases with flow rates of 10 sccm and 50 sccm respectively.

3. CNT-CNT array specific contact resistance measurement: Sheet resistivity of the 1µm thick metal under-layers was calculated by four-probe measurement on the test structures patterned on the substrates by Cascade Microtech’s Summit 1175SB-HT Femtometer. Sheet resistivity values of the metal traces varied significantly from the bulk resistivity value at room temperature. Specific contact resistance was calculated as the product of the mating area of the metal traces and the difference of the total resistance and the sheet resistance for that individual circuit. The observed specific contact resistance value was two orders of magnitude lower than the specific contact resistance value reported in literature for singlewalled carbon nanotubes arrays. (Ref: Najafipour et al., Rev. Sci. Instrum. 77, 065105 (2006))

4. Theoretical model: Both diffusive and ballistic transport characteristics are expected to be important in understanding the nature of interfacial electrical conduction. The arrays were assumed to be perfectly vertically aligned with one tube contacting only one from the opposing array. The deformation of an individual MWCNT, when pressed against the substrate, was predicted to be \( L = 3 \mu m \pm 5\% \). The number density of tubes used in the analysis was estimated to be \( 10^{10} \text{mm}^{-2} \) by an image processing and analysis software program and manually counting the number of tubes in a representative area. Average length and diameter of the MWCNT’s was observed by scanning electron microscopy, 50 µm and 40 nm respectively. The material properties of MWCNT’s were taken from the literature. (Ref: S. Dresselhaus, G. Dresselhaus, Ph. Avouris Carbon Nanotube Electrical Interfaces, Springer (2001), ISBN3-540-41086-4)

Figure 1. Patterned metal layers on DSP sapphire wafers. (a) Magnified view of the top wafer pattern. (b, c) Field emission scanning electron microscope images of the MWCNT arrays. (d) Top view of the MWCNT array.