Determination of Mechanical, Electrical and Surface Properties of an Individual Carbon Nanotube by Single Measurement

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A few years ago, a method called force-distance measurement to determine the interaction between individual gecko lizard spatula and the tipless AFM cantilever was presented[1]. We have extended this method to determine properties of vertically aligned carbon nanotubes (VACNTs) grown on electrically conducted substrate. Here we have used metal coated tipless AFM cantilever (see Fig. 1) for force-distance measurement method.[2] The cantilever was electrically biased with 0.2 V while the substrate with VACNTs was electrically grounded. During force spectrum measurement we also monitored electrical current flowing through the forest of CNTs. Presented method is a simple way to determine mechanical, electrical and surface properties of a single CNT without necessity of tedious sample preparation such as careful placement of the CNT at the measurement system or using high vacuum tools such as SEM or TEM.

The force spectrum (see Fig. 2) provided information about number of CNTs in contact with the cantilever at any point of time as well as determined the CNT stiffness and adhesion force between the cantilever and the CNT. Once we know length and diameter of the CNT, we can also determine its Young's modulus. A force spectrum (Fig. 3 left axis) combined with measuring of current spectrum (see Fig. 3 right axis) provided information about CNT conductivity and thus its resistance. One can see that the jump-off location (force) is affected by applied voltage. This finding suggests that the water bridge formation is affected by external voltage.

The presented method is simple allowing statistically significant number of measurements to be performed. We could then build a histogram of the most probable value eliminating a random measurement error. The only requirement of presented method is having both CNT and AFM cantilever with similar stiffness as they have to influence each other. Further, the cantilever has to be coated with metal for electrical measurement and the CNT has to be grown from electrically conductive substrate.

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[1] Sun, W. X., Neuzil, P., Kustandi, T. S., Oh, S. & Samper, V. D. The nature of the gecko lizard adhesive force. *Biophys. J.* 89, L14-L17, doi:10.1529/biophysj.105.065268 (2005).

[2] Cappella, B. & Dietler, G. Force-distance curves by atomic force microscopy. *Surface Science Reports* 34, 1-109, doi:10.1016/s0167-5729(99)00003-5 (1999).

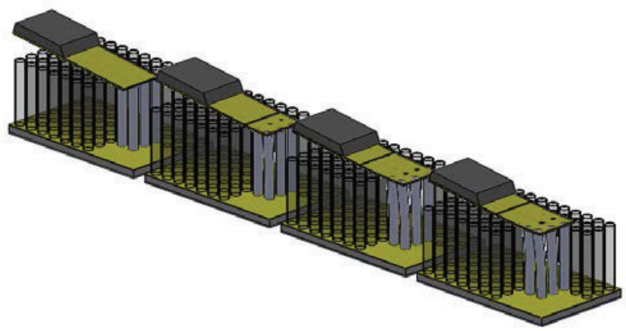

Figure 1 Schematic drawing of interaction between cantilever and VACNTs. From top left to bottom right: No interaction, interaction with one, two, and three CNTs.

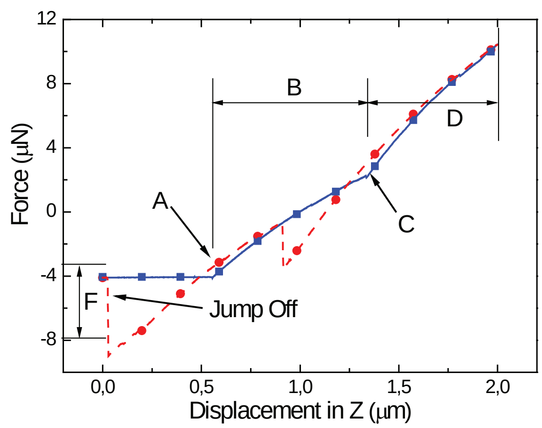

Figure 2 Typical force-distance curve between relatively soft nanotubes (with the respect to the stiffness of applied AFM cantilever) and an AFM cantilever. Blue and red arrows show direction of the curve. At point A, the cantilever snapped to the CNT in the closest proximity due to sudden water bridge collapse and was then pushed against the CNT (region B).

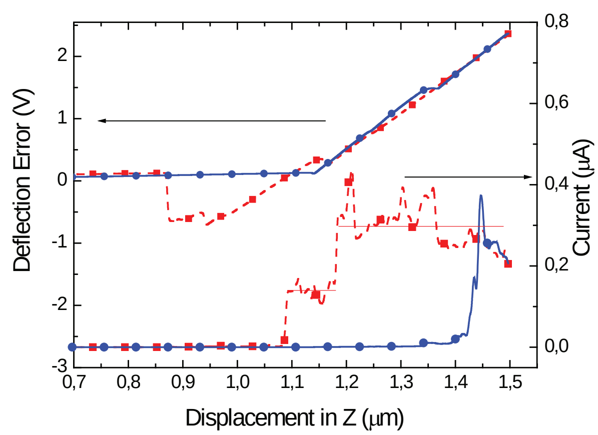

Figure 3 Force-distance measurement (left axis) and electrical measurement (right axis).