WAFER-SCALE ASSEMBLY OF NANOTUBE NETWORK DEVICES USING DIELECTROPHORESIS

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Variations of the electrical resistance of carbon nanotubes upon changes in gas concentrations has developed into a well-established method with many potential applications. Detection of ppt levels of NO_2 have been demonstrated experimentally using individual single walled carbon nanotubes [1]. Such devices could develop into commercial applications provided suitable methods for mass-production could be found. For assembly of single-walled carbon nanotubes onto microelectrodes, AC dielectrophoresis offers a cheap, quick, room temperature assembly method which may readily be adapted to wafer scale.

We demonstrate here an approach for simultaneously forming single walled carbon nanotube networks with comparable characteristics. The advantage of using networks is to average out large fluctuations due to variations in contact properties and in individual nanotube electronic characteristics. Nanotubes dispersed in SDS and ultrasonicated for 4 hours were distributed on a 10 cm^2 area of a full wafer containing 50 devices. Using an assembly voltage 10V@1 MHz, 70% of the electrode gaps contained a network with thousands of individual nanotubes, spread out between the electrodes along the electrical field lines (see Figure 1).

We report here on the response of 40 such networks to oxygen, temperature, as well as light and electron irradiation. The resistances were typically in the range from 0.8 kΩ to 10 kΩ, with decreasing resistance when assembled at larger frequencies (see Figure 2). In scanning electron microscopes we found the structures to be much more ordered at high frequencies. An explanation is that at high frequencies, only carbon nanotubes feel the electrical field, as these have superior conductance compared to for instance amorphous carbon.

The networks behave surprisingly identical to light irradiation, even for different base resistances. A brief illumination with visible light caused the resistance of the networks to increase rapidly, as reported for individual nanotubes in Ref [2]. Depending on whether the devices were held in atmospheric or nitrogen environment the resistance dropped rapidly, or slowly, respectively, upon turning off the light source, as shown in Figure 3. This result supports the idea that adsorbed oxygen on the nanotube surface determines the resistance, explaining why the resistance is nearly stable after removing the oxygen by the light in an oxygen-depleted environment. Measurements of the resistance increase as a function of temperature support the hypothesis of oxygen desorption. Finally, we observed a remarkable increase of the resistance upon SEM irradiation. Although the resistance decreased substantially after 5 days, it had not returned to the original levels even 40 days after the SEM exposure.

In conclusion, we will show that carbon nanotube devices made by dielectrophoresis, a method requiring only simple equipment and taking less that a few seconds to apply, are comparable in their performance as single nanotubes contacted by other more complex methods.

References:

[1] Pengfei Qi, Ophir Vermesh, Mihai Grecu, Ali Javey, Qian Wang, and Hongjie Dai, NanoLetters 3(3):347-351,2003

[2] Robert J. Chen, Nathan R. Franklin, Jing Kong, Jien Cao, Thomas W. Tombler, Yuegang Zhang, and Hongjie Dai, Applied Physics Letters 79(14):2258-2260, 2001

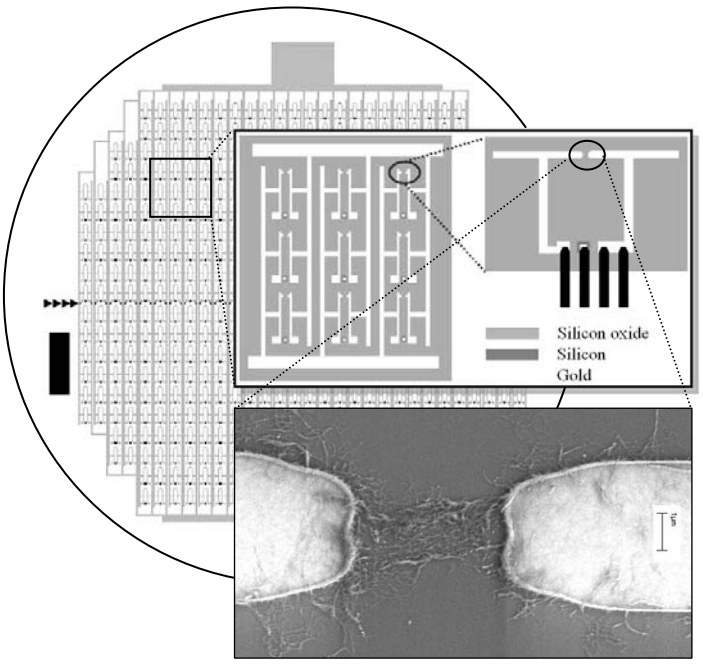

Figure 1. The wafer-scale concept and results. A single wafer contains more than 500 identical chips where voltage can be applied at the same time. The top inset shows how this is possible and the bottom inset shows a typical networks obtained.

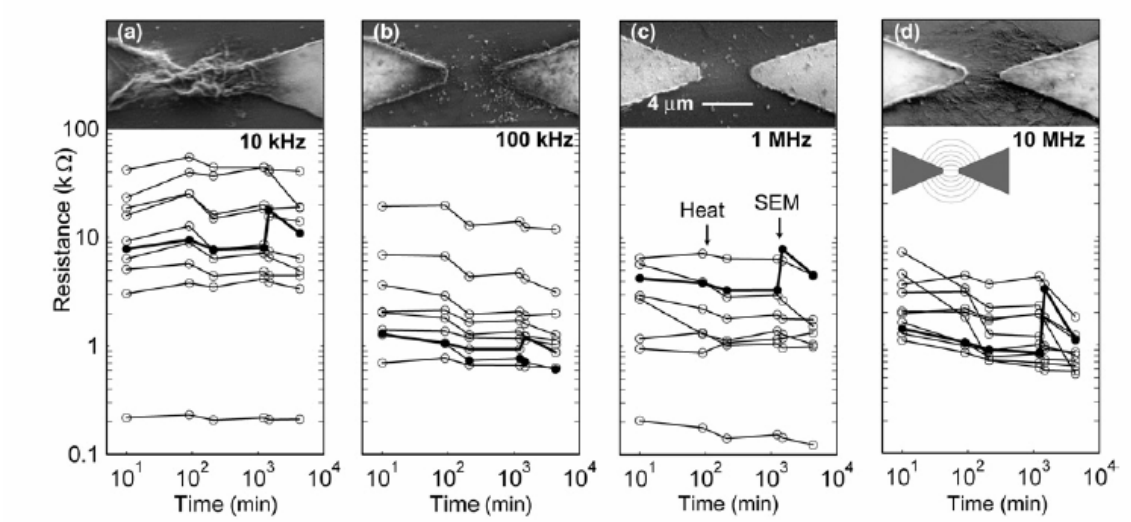

Figure 2. Measurements of the resistance of the assembled networks in a period of 24 hours for all samples, and for the four frequencies 10 kHz, 100 kHz, 1 MHz and 10 MHz. The filled markers represent samples that were imaged in SEM (shown as insets). The field lines calculated for a similar electrode geometry is shown as an inset in (d).

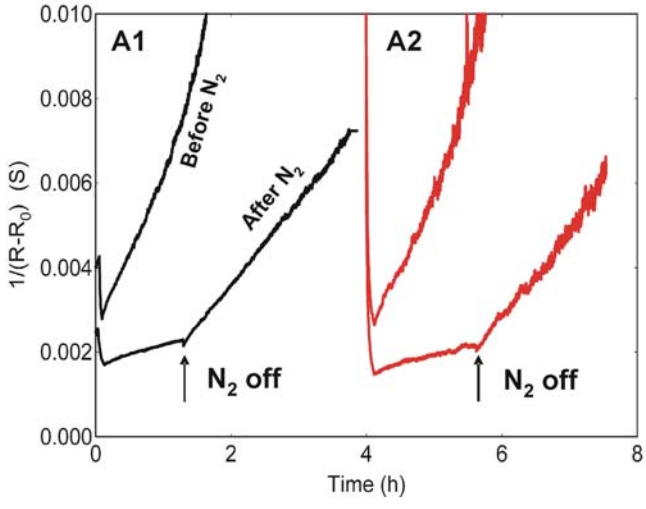

Figure 3. The response of two nanotube networks to illumination with a cold light source in atmospheric and nitrogen environments. The results can be explained by oxygen desorption and adsorption.