Novel carbon nanotube based three terminal devices

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Carbon nanotubes since their discovery have created much industrial and scientific interest. Their unique properties in electrical conduction, chemical robustness and the ability to control the growth of aligned CNT films makes them an ideal candidate for high intensity electron sources. Combining these properties with that ability to solubilise CNTs within an aqueous solution further extends the application fields associated with these unique materials.

In this work we will make use of an acid oxidised carbon nanotube ink that has been developed [1] to provide a simple route for controlling threshold fields and the current density in a three terminal device configuration.

The nanotube ink developed in this research project has enabled us to demonstrate threshold fields as low as $0.8 \text{ V}/\mu\text{m}$, by tailoring the underlying substrate morphology.

Furthermore, lithium functionalisation via a wet-chemistry technique has been used to tailor the work function of MWCNTs resulting in even lower threshold fields of $0.25 \text{ V}/\mu\text{m}$ [2]. The inks produced can be inexpensively deposited over large areas (ink jet printing) on a variety of substrates (e.g.: paper, plastic, glass, silicon, etc.).

The Li^+ acid oxidised carbon nanotube ink has been dropped on a piece of filter paper, roughly 1 cm^2 area and it was then placed to dry on a hot plate for 10 minutes in order to evaporate the water. The result was a dark region on the filter paper where the nanotubes formed a conducting mat, as can be seen in Figure 1. Choosing the filter paper as the support substrate for the carbon nanotube solution allows us to easily integrate it in a flexible three terminal device, as will be described.

The three-terminal device was made using a $3 \times 3 \text{ cm}^2$ laminating pouch which had the sheet thickness of $125 \mu\text{m}$. One of the sheets of the pouch was covered by a layer of 100 nm of DC sputtered Au. After the deposition of the Au, a matrix of 4×4 holes was made using a pin to punch through the plastic. Also a channel was cut in the Au covered sheet to allow the contacting of the nanotube mat. The paper covered with the nanotube mat was placed inside the pouch and then laminated using a conventional office laminator. The resulting structure is sketched in Figure 2.

Due to the crude manufacturing technique used, only two out of 4 devices could be used for FE testing mainly because of the way the holes were made. The plastic tended

Figure 1

to cover the holes during the laminating process rendering the structure useless as the emitter would be completely covered.

The field emission tests were performed inside a vacuum chamber at a pressure of 10^{-6} mbar in a triode like configuration as follows. The carbon nanotube mat was contacted through the channel previously cut, using silver paste and it was grounded. The Au gate electrode was kept at a fixed

potential V_g while the spherical anode placed at $300\text{ }\mu\text{m}$ distance from the surface had a potential V_a which was varied in 30 V steps. The data was recorded with the use of a computer and plotted in Figure 3 for various gate voltages. As it can be seen for the first

Figure 3

basis for new generation of flat panel displays.

References:

- [1] H. Ago et al. Phys. Chem. **B** 103, 8116 (1999).
- [2] S. M. Lyth et al. APL **90**, 013120 (2007).

Figure 2

two gate voltages there was no significant current registered at the anode. For the rest of the applied potentials normal FE curves can be seen with a peak current of $5\text{ }\mu\text{A}$. In the light of the method used to manufacture this device the results can only be seen as proof of concept and intense research is currently under way to improve the device.

It can be concluded that flexible FE devices can be manufactured using a cheap process. These devices can easily be integrated in electronic circuits and independently addressed to create the