CARBON NANOTUBES AS ELECTRON SOURCES IN ELECTRON MICROSCOPES

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A research project at Philips Research Eindhoven is aimed at developing a new type of electron source for electron microscopes to improve their resolution [1]. Electron sources were constructed from individual carbon nanotubes by mounting nanotubes on tungsten tips in a scanning electron microscope (SEM) using a nano-manipulator [2]. The electron emission of thin multi-walled carbon nanotubes, as well as nitrogen-doped multi-walled carbon nanotubes has been studied. It was found that the emission process is highly sensitive to small amounts of impurities on the surface of the nanotube. For this reason, the nanotubes were thoroughly cleaned; the presence/absence of impurities was checked by imaging the emission pattern and by recording the emitted current as function of time (Figure 1). Relevant parameters were determined such as energy spread of the emitted electron beam, the angular current density, the current stability level and the brightness. Both the current-voltage characteristics and the energy spread revealed field emission behavior of an emitter with metallic behavior. The field enhancement factor and the emitting area derived from the emission measurements corresponded with calculations based on geometric information as obtained from transmission electron microscopy of the same nanotubes. The workfunction was derived and amounted to 5.0 eV. In addition, *in-situ* electron emission of carbon nanotubes was investigated in a transmission electron microscope (TEM). The morphology of the nanotubes and especially their caps was imaged under the presence of the strong electric field needed for electron emission (Figure 2). Several processes were observed that led to changes in the structure of the nanotube. Our results present important steps in the understanding of the electron emission process of carbon nanotubes and N-doped carbon nanotubes, and in developing a new generation of electron sources for electron microscopy.

References:

[1] N. de Jonge, Y. Lamy, K. Schoots, T.H. Oosterkamp**,** *Nature* **420,** 393 (2002).

[2] N. de Jonge, Y. Lamy, M. Kaiser, *Nano Letters* **3**, 1621 (2003).

Figures

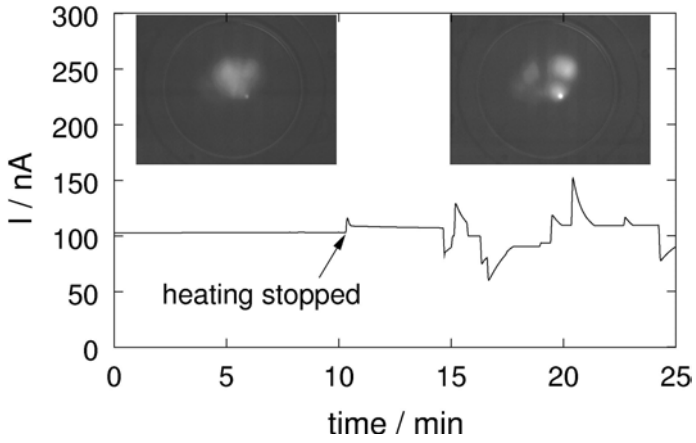
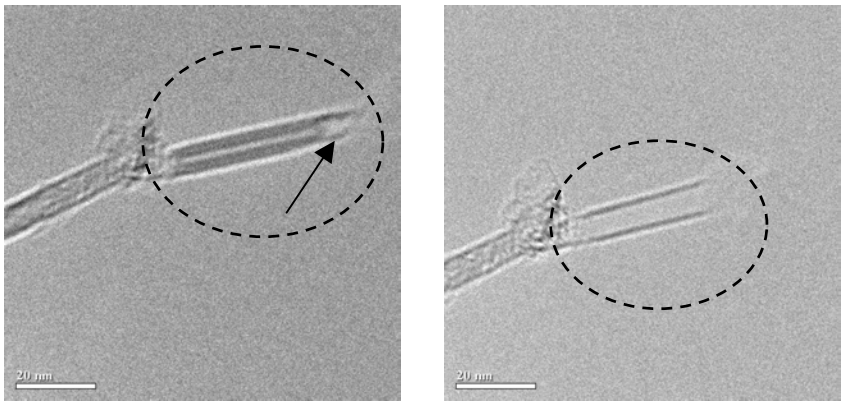


Figure 1. Trace of the emitted current of N-doped nanotube as function of time. The recording started with a stable emission obtained at a temperature of 800 K and an extraction voltage of 359.6 V. Current fluctuations occurred after the heating was stopped as shown at the right side of the plot. The corresponding emission patterns during and after heating recorded with a micro-channel plate and a phosphor screen positioned 1.5 cm in front of the emitter are also shown as insets.



a b

Figure 2. *In-situ* transmission electron microscopy of a degradation reaction of a multi-walled carbon nanotube under the influence of a strong electric field. (a) The open end of a multi-walled nanotube (see arrow), that had been broken-off before, imaged while emitting 8 μA of current at 350 V extraction voltage. (b) The inner walls of the nanotube were removed/destroyed (encircled) and the nanotube continued emitting current of 3 μA at 360 V.