

Carbon Nanotube Field Electron Emitter

Oliver Gröning, EMPA Thun & University of Fribourg, Switzerland

Research Group

The research group Nanotech@Surfaces has been established on the 1.1.2003 as division 127 at the Swiss Federal Laboratories for Material Testing and Research (EMPA) in Thun. It has been formed out of members of the solid state physics research group of Prof. Louis Schlapbach of the University of Fribourg and is headed by Dr. Pierangelo Gröning.

The research of the group focuses on self-assembly and characterization of organic molecules at surfaces, plasma-enhanced chemical vapor deposition of plasma polymers and carbon nanostructures as well as on fundamental aspects of the electronic properties of carbon nanotubes and their application as field electron emitter.



Corresponding Author:
Dr. Oliver Gröning
Oliver.Groening@empa.ch

Results

Figure 1 shows a SEM-image of a typical layer of multiwalled CNT (MWNT) on a Si-Wafer grown by chemical vapor deposition (CVD) [2]. The individual tubes are randomly oriented with typical diameter of 20 nm and length of up to a few μm . Figure 2 shows a SAFEM map of a $270 \times 270 \mu\text{m}^2$ region the sample depicted in Figure 1. The map shows the voltage $V(x,y)$ required to obtain a field emission current of 11 nA as a function of the lateral position of a tip-shaped anode. The vertical distance between the sample and the anode is 4–5 μm . The circular dips in the voltage map represent the emission of individual, strongly emitting (high field enhancement) nanotubes. The right region has been strained only with small emission currents of 11 nA and represents the genuine emission of the sample. The regions on the left hand side have been strained with higher emission currents of 1.5 μA and 2.0 μA . The degradation of the emission properties is evident from the higher voltages needed to get the

Carbon nanotube (CNT) field emitter can be regarded as the second-generation electron sources following the metal and silicon micro-tips. Due to high aspect ratio, chemical inertness, good conductivity and simple production methods CNT have attracted great interest as field emission (FE) electron sources. The successful development of CNT FE-cathodes requires the characterization of single emitter in the cathode as well as the investigation of the global emission properties which we achieve using a homebuilt scanning anode field emission microscope (SAFEM). We have identified bad contact to the CNT as being one of the major hindrance in the performance of planar CNT FE-cathodes[1].

Introduction

Just about one decade after their discovery by S. Iijima CNT have become a unique model system in the domain of nanomaterials. This is due to outstanding physico-chemical properties, e.g. singlewalled CNT exhibit an axial tensile strength 50 times higher than of high grade steel. Further they show metallic or semiconducting electronic behavior. The wide range of favorable properties qualifies CNT for many different applications from reinforcement of composite material to field effect transistors. In this respect electron field emitter might be the CNT application closest to make in to the consumer market, e.g. Samsung is currently developing a CNT based 42" field emission flat panel display (FED) for the home entertaining market.

The potential of CNT to serve as field emitter resides in their high aspect ratio leading to strong enhancement of an applied electric field at their apex. This effect enables the local generation of electric fields of the order of 3000 MV/m needed to field emit electrons using applied electric fields of only a few MV/m.

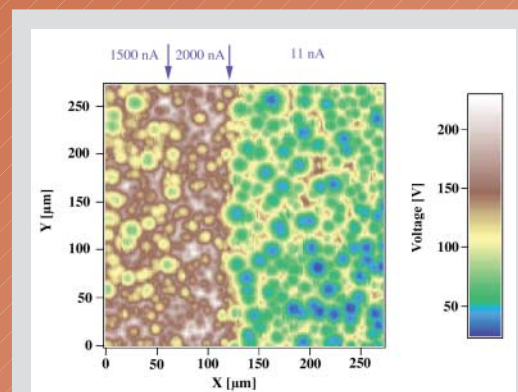


Fig. 2. Scanning anode field emission voltage map $V(x,y)$ of a partially high current stressed MWNT film. The measurement is performed at a constant emission current of 11 nA and a anode-sample distance of 4–5 μm .

emission of 11 nA as compared to the unstrained region. For CVD grown CNT FE-cathodes we consistently observe emitter degradation for emission currents below 5 μA per single emitter. This is remarkable as for single MWNT emitter mounted on metallic tips emission degradation occurs only for currents above 100 μA [3]. Detailed inspection of the current-voltage characteristic on single emitter shows in many cases a deviation of the usually expected Fowler-Nordheim emission behavior before abrupt emitter degradation occurs. This deviation can be modeled using a resistor limited emission model suggesting a voltage drop in the contact to the nanotube of a few volts [1]. One has to be aware that the field emission current density at the emission site (the apex of the nanotube in this case) can be of the order of 10^6 Acm^{-2} . Due to the cylindrical shape of the nanotube one will find the same current density at the substrate-nanotube contact. With a voltage drop of 10 V in the contact and an emission current of 2 μA the dissipated energy can be estimated to be of the order of 20 mW. Due to the small cross section of the contact (~20–30 nm) this is sufficient to melt the substrate as observed by SEM and leads to emitter failure.

Outlook

The rather low critical emission current before failure together with an unfavorably large spread in the field enhancement distribution are today the major hindrances to the full exploitation of the potential of CNT field emission cathodes. We are currently involved in different projects to overcome these problems and achieve high emission current density and homogeneity for applications in travelling wave tubes (Thales S.A.), X-Ray tubes (Comet AG) and displays.

References

- [1] O. Gröning et al., *Chimia* **56** (2002), 553.
- [2] O.M. Küttel et al., *Appl. Phys. Lett.* **73** (1998), 2113.
- [3] J.M. Bonard et al., *Solid-State Electronics* **45** (2001), 893.

A basic introduction on electron emission is given at the beginning of the Newsletter.

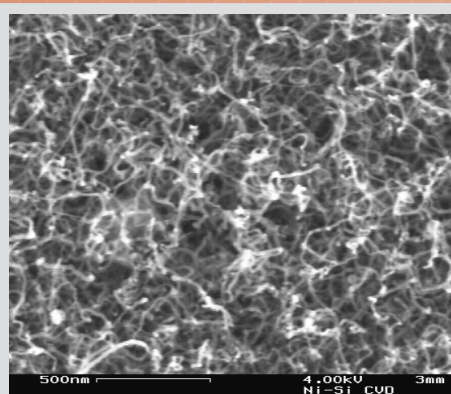


Fig. 1. SEM image of a MWNT thin film on silicon