Resistor limited electron field emission in regular oriented carbon nanotube arrays

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The use of carbon nanotubes (CNT) as electron emitters in field emission might be the closest to market application of these carbon nanostructures with a big economic impact. The reason for this can be found in the fact, that the use of CNT allows the fabrication of planar electron emission cathodes using relative simple and low cost approaches like direct growth in chemical vapor deposition (CVD) or screen printing of CNT-Matrix pastes. The economic fabrication of large area cathodes is a major advantage of CNT emitter over the classical Spindt type metal micro-tips, especially for field emission flat panel displays (FED).

Depending on the application the requirements towards the emission performance of the cathodes can be very different. In the case of FED applications the main figure of merit for the cathode is the emission site density, which should amount to 10^6 cm^{-2} with an emission current density of 10 $mAcm^{-2}$. In high current applications such as high-frequency amplifier tubes (e.g. travelling wave tubes) the use of field emitter can lead to more compact devices with lower power consumption. For HF-devices the cathode should deliver an emission current density of 1 Acm^{-2}, where the emission site density is less important and can be as low as 10^4 cm^{-2}.

A vital problem of field emitter arrays is the achievement of a homogenous emission under the action of a globally applied electric field. In the case of randomly oriented CNT thin film emitters the stochastic distribution of length, diameter and orientation of the CNT leads to a exponential type frequency distribution of the field enhancement values $f(\beta)=C_1\exp(-C_2\beta)$, where C_1 and C_2 are positive constants [1]. This yields low threshold fields around 1-2 $V\mu m^{-1}$, but at low emission site densities typically smaller than 100 cm^{-2}. The consequence of the exponential type field enhancement distribution is that the emission current is usually carried only by a very small number of emitters. We will briefly discuss experimentally and theoretically the implications of the exponential type field enhancement distribution on the emission site density as well as on the global emission current density.

In order to achieve best emission performance the situation of only a minority of emitter being active needs be changed to the situation were the majority of emitters is active. This can be attained by controlling the emitter geometry with regard to length, diameter, orientation and position, this leads to a control of the field enhancement distribution. A further amelioration of the emission properties can be achieved by using ballast resistors to limit the emission current in a certain range. We have used a dc-PE CVD process to grown regular arrays of carbon nanotubes[2] (see fig. 1), using a TiN interlayer between the Si substrate and the CNT an effective resistor limitation of the emission current is achieved (see fig. 2). By scanning anode field emission microscopy (SAFEM) we will demonstrate local emission site densities of 6.25 mio. cm^{-2} and global emission site densities of 2.2 mio. cm^{-2}. We will experimentally show and discuss in detail the effect of the ballast resistor on the emission homogenization and demonstrate the prospects of achieving global emission current densities above 1 Acm^{-2} for CNT field emission cathodes. We will further show that using the SAFEM measurement of the microscopic emitter properties for regular CNT arrays (field enhancement distribution, single emitter I-V characteristic and measurement of critical current for degradation) the global emission properties as measured e.g. in a plane parallel configuration can be accurately simulated.

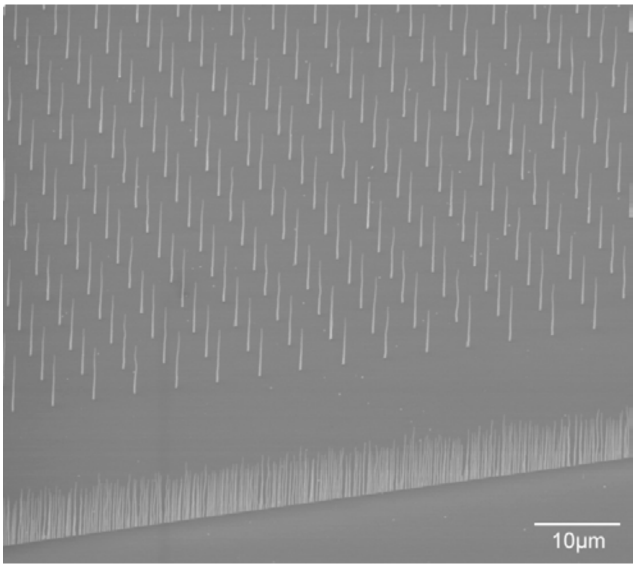

Figure 1

Well ordered array of CNT grown by DC-plasma enhanced CVD

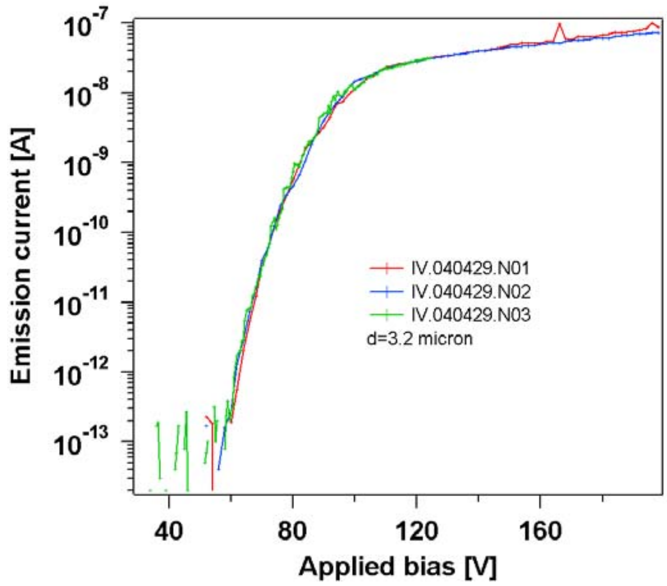

Figure 2

Single CNT emitter resistor limited I-V characteristic showing an emission plateau in the current range from 20-100 nA.

References:

[1] L. Nilsson, O. Gröning, et al. "Microscopic characterization of electron field emitter", JVST B, 20(1), p. 326 (2002)

[2] K.B.K. Teo, et al. "Plasma enhanced chemical vapor deposition carbon nanotubes / nanofibers – how uniform do they grow?", Nanotechnology 14(2), p. 204 (2003)