Current induced degradation of multi-walled carbon nanotube field emitter

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Carbon nanotubes (CNT) have received in the recent years considerable interest as low cost, low threshold field electron emitters. Especially the growth of carbon nanotube as thin films on planar surfaces using chemical vapor deposition has offered the low cost fabrication of field emission cathodes with threshold fields of the order of a few volts per micron.

The performance of such kind of CNT field emitter arrays is however limited by two main parameters: First by the emission inhomogeneity and secondly by the critical emission current per single emitter. We have used scanning anode field emission microscopy (SAFEM) to investigate both properties on CNT cathodes. In the constant current scanning mode we are able to explore the properties of CNT cathodes up to emission site densities of 5e6 cm^{-2} and determine the field enhancement distribution f(β) which can be directly related to the field dependence of the emission site density. Further we can measure the emission properties of individual emitters in planar CNT cathodes and determine the degradation behavior at high emission currents. In contrast to individual MWNT mounted on metallic tips were emission current of 0.1 mA have been reported, we observe that for CVD grown MWNT on p-type Si substrates degradation occurs at much lower emission currents in the range of 100 nA to 10 µA. Based on the measured field enhancement distribution and on the degradation of single emitter we will present a model for the global cathode degradation at high emission currents. The model is based on an exponential field enhancement distribution as observed for CNT thin film field emission cathodes. It then takes into account the successive, field dependent reduction of the actively emitting cathode surface due to local damage because of emitter degradation or emitter disruption events.

Further we will discuss the role of the contact resistance and local heating due to power dissipation in the emitter degradation.

Based on our conclusions on the degradation mechanism we will discuss strategies for the enhancement of the cathode performance using ballast resistor and/or oriented, deterministic growth of CNT.

Figure 1a and 1b show two SAFEM field enhancement maps before and after emitter disruption of a MWNT cathode measured at 11 nA the bright spots correspond to emission sites indicating high field enhancement. The arrow indicates a degradation event of a single emitter, which manifests itself by a reduction of the field enhancement. Figure 2 displays the I-V characteristic of the emitter disruption on the site indicated in fig. 1. The emitter disruption occurs at an applied voltage of 290 V and results in a decrease of the emission current from 2.2 mA to 7 nA. From the I-V characteristic it can be seen that the disruption occurs in the non Fowler-Nordheim like emission regime at high emission currents (above 100 nA). In the low current regime the emission is FN-like (black solid curve). The non FN-like regime can be modeled assuming a resistor limited emission model (gray solid curve in fig.2). The disruption in the resistor-limited emission regime indicates high power dissipation and local heating to be a possible source of the degradation.

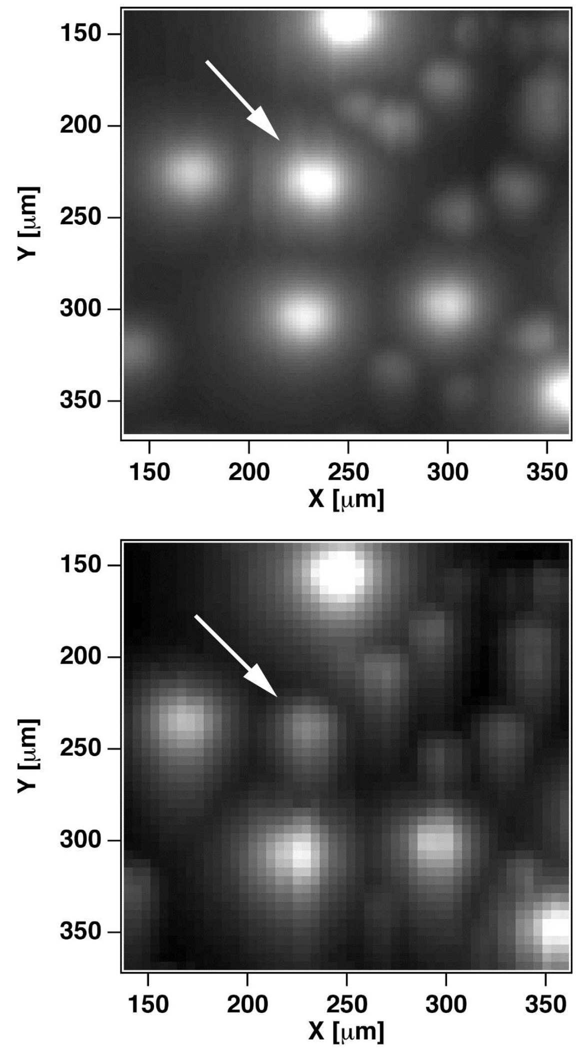

Fig. 1 Single emitter disruption in a MWNT FE cathode

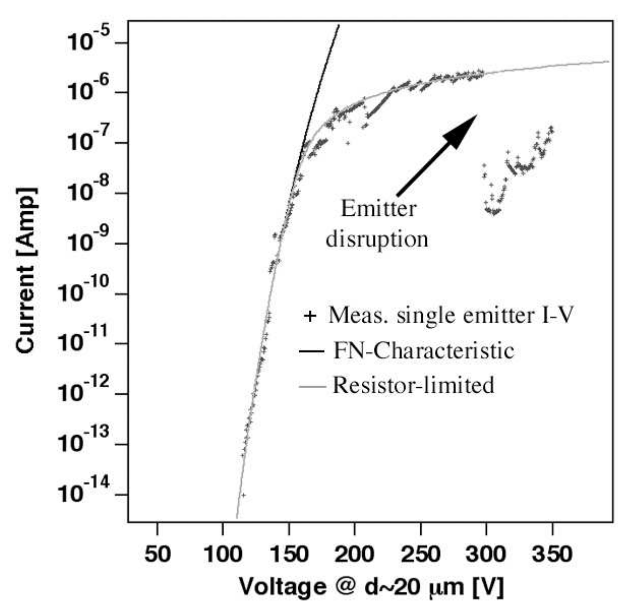

Fig. 2 I-V of the single emitter disruption shown in fig. 1 at a anode cathode separation of 20 µm