Optimization of copper nanocones for field emission cathodes

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We have optimized the fabrication of copper nanocones (Cu-NCs) for flat structured field emission (FE) cathodes [1]. Stacks of three polycarbonate foils (PC ~30 µm) were irradiated with ^{238}U or ^{136}Xe ions (11.1 MeV/u, 10^6-10^7 cm^{-2}). The ion tracks were asymmetrically etched in a 40:60 mixture of 9 M NaOH and methanol. Depending on the etching time, conical pores of different size were obtained. The membrane surface with the large pore opening (2-4 µm) was sputter-coated with ~60 nm Au, reinforced with ~20 µm Cu, and glued on an Al plate, to obtain a flat template for the electrochemical deposition of NCs as described in detail in [2, 3]. Flat cathodes of 25 mm^2 size with mechanically stable Cu-NCs were achieved (Fig.1).

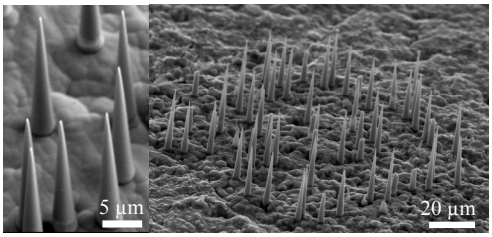

Figure 1: SEM images (60° view) of Cu-NCs with sharp tips (left) and of a patch (right) (PC irradiated with ^{136}Xe).

The average values and standard deviations of the NC tips on various cathodes derived from SEM images are summarized in Fig. 2. A systematic increase of the mean tip diameter with etching time is obvious up to 17 min, and the aging of the etchant is considered to be responsible for the rather low values for the 20 min etching which was performed one day later. As expected for the different total energy loss, the complete pore opening required a longer etching time for ^{136}Xe (~20 min) than for ^{238}U ion tracks (~15 min). Moreover, there is some evidence for a weak dependence of the NC size on the stack position. It is most remarkable that the sharpest Cu-NCs were grown in the ^{136}Xe ion tracks.

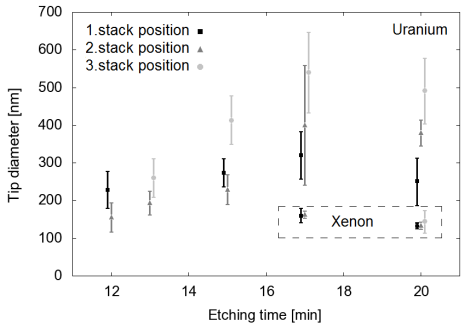

Figure 2: Mean tip diameter of Cu-NCs as function of the polycarbonate (PC) etching time for three stack positions. The dashed rectangle marks the data for ^{136}Xe ion tracks.

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The FE homogeneity of selected Cu-NC cathodes was measured before and after sputter-coating with Au by means of the FESM as described in [1]. W anodes with small tip diameter $Ø_a$ and gap Δz were used to obtain high resolution maps. In Fig. 3 the best result is given showing at least 8 emitters/patch (of ~180 µm diameter) for the bare Cu-NCs grown in etched Xe-ion tracks, and ~20 % more after 60 nm Au coating probably due to less oxide.

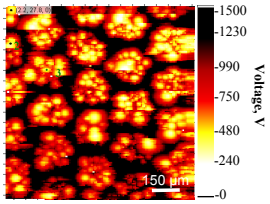

Figure 3: High resolution voltage maps (1 nA FE current, $Ø_a$=12 µm, Δz = 30 µm) of bare (left, ~1 mm^2) and 60 nm Au-coated (right, ~0.9 mm^2) structured Cu-NC cathodes.

The integral FE properties of selected Cu-NC patches were measured with a truncated-cone anode of adjusted size ($Ø_a$ = 150 µm). The typical current-field curve of a Au-coated patch in the left Fig. 4 confirms a rather stable Fowler-Nordheim (FN) behavior up to 90 µA at 43 V/µm with a field enhancement factor of ~338. Current jumps occurred on all patches, but at higher current levels for the Au-coated CuNCs as shown in the right Fig 4. Correlated SEM images revealed a partial destruction of the CuNCs by FE currents of ~20 µA for bare and ~100 µA for the Au-coated ones. On average these patches yielded 151 µA at 50 V/m, i.e. much higher FE current carrying capability as compared to Au nanowire patches. In conclusion, these results are very promising for high current FE devices based on Au-NC cathodes grown in ^{136}Xe ion tracks.

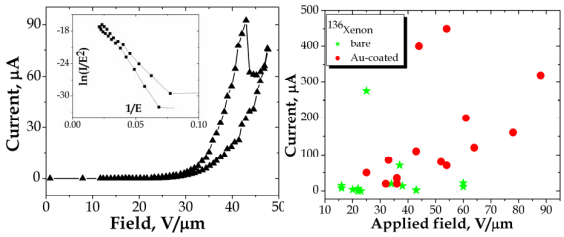

Figure 4: Typ. I(E)-curve and FN-plot (inset) of a patch in the right map of Fig. 3 (left) and maximum current vs. field for all measured patches of various Cu-NC cathodes.

References

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