Ultrafast field emission from carbon nanotubes

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High brightness, ultra-fast electron sources with spatially structured emission from nanoscale solids are of fundamental interest for next-generation free-electron lasers, compact coherent X-ray sources, electron diffractive imaging, and attosecond science[1]. Due to their high aspect ratio, small tip radius, unique electronic structures, impressive structural stability, and high thermal conductivity; carbon nanotubes exhibit widely promising properties as mediators for enhanced electron sources, and as such have attracted tremendous attention in the past two decades. Here, we expanded the field of ultrafast optical field emission from metal nanostructures to carbon nanotubes.

Here, we study the performance of carbon nanotube as an optical field emitter and attempt to reach into strong field and sub-cycle regime in the visible (410 nm) and near-infrared (820 nm) fields. Three CNT emitters with different tip radius and morphology were studied, as shown in Fig. 1a, b, c. All samples consisted of vertically aligned arrays of few-walled CNTs (Fig. 1a, b, radius of ~3nm, high and medium β) and multi-wall CNTs (Fig. 1c, radius of ~10nm, low β) which were grown by chemical vapor deposition. In the present study, femtosecond pulses were focused onto the CNT arrays mounted in a cryogenically cooled ultra-high vacuum.

Fig.1(d, e, f) displays the photocurrent as a function of incident peak intensity for different tip radii. At similar laser intensity, the emission current from the CNTs with high β is two order of magnitude greater than that from the low β CNTs, and one order of magnitude from that of the medium β CNTs; results which are in good agreement with the predicted field-enhancement in Fig.1. The maximum emission current from a single CNT cluster in Fig. 1a (yellow circle) reached up to 40 nA, corresponding to a time average current density of a 4 A/cm^2 (estimated emission area of ~1 μm), and a very high instantaneous current density of 4×10^6 A/cm^2. This is much higher than the current density obtained from CNT emitters during static field excitation, and is also much higher than that from metal emitters excited at optical frequencies[2].

The adiabatic electron emission at ultra-short periods and ultra-low temperatures may contribute to the extremely high current density. Though still largely unclear, we tentatively attribute the electron emission in this optical field to sub-nanometric localized fields, which are lattice enhanced by the ultra-low temperature across the ultra-short timescales, all of which make it possible to, for the first time, to empirically probe new mechanisms of field driven electron emission, which we hope will attract further study.

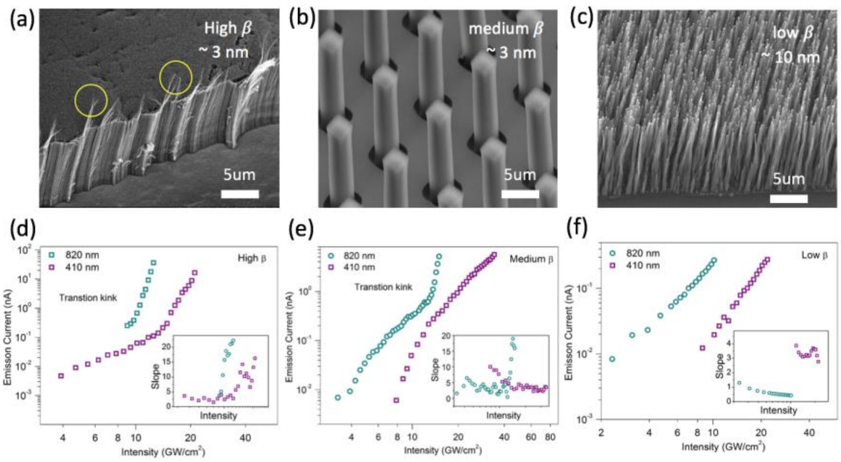

Fig.1 ultrafast field emission from three different carbon nanotube emitters.

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