Polarization-Sensitive Visible-Light-Induced Thermionic Electron Emission from Carbon Nanotube Forests

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Carbon nanotubes (CNTs) have been studied for use as electron sources in a variety of devices due to their unique and attractive electrical, mechanical and thermal properties.[1,2] Unlike conventional thermionic sources operated using high-power pulsed lasers, we have shown that cathodes based on CNT forests (arrays of vertically aligned CNTs) can be heated to thermionic emission temperatures simply using low-power visible lasers in both collimated and focused forms.[3,4] However, much remains to be learnt on this front. In particular, due to the geometrical structure of CNTs, which leads to optical anisotropy, the polarization of incident light could play an important role. In this work, the results of thermionic electron emission experiments from a CNT forest as a function of polarization are reported for an incident wavelength of 488nm (visible) from an argon ion laser. The multi-walled carbon nanotube forest, with lateral dimensions of ~5x5 mm^2 and a height of ~1 mm, was synthesized using ethylene-based chemical vapor deposition. The forest was placed inside an ultra high vacuum chamber with a sapphire viewport to allow laser illumination. The laser beam was incident on the sidewall of the forest, perpendicular to its surface and focused onto a circular spot of ~ 0.5 mm in diameter. We confirmed that the reflectance from the viewport was negligible for incidence angles within 0-45 degrees.

We observed that when the electric field of the laser beam was polarized parallel to the axis of the CNTs in the forest, the emission current was about two orders of magnitude higher than the case where the electric field of the laser was perpendicular to the CNTs' axis. Figure 1 shows this remarkable difference in emission current as a function of laser power for both polarizations. We attribute this behavior to the significantly stronger absorption of parallel-polarized light and, therefore, more efficient heating of the cathode. Our optical simulations confirm the stronger absorption of parallel-polarized light. We also measured the emission current as a function of polarization angle at fixed incident power (Figure 2). It can be seen that most of the change happens within the 0-60 degree range, and the current saturates beyond 60 degrees. We believe this is due to the wavy nature of the CNTs and their imperfect alignment in the forest, as confirmed by electron microscopy.

[1] Y. Saito, Ed. Carbon nanotube and related field-emitters - Fundamentals and applications, Wiley-VCH 2010.
[2] P. Liu *et al*., Phys. Rev. B, **73**, 235412 (2006).
[3] P. Yaghoobi, M. Vahdani Moghaddam, M. Michan, and A. Nojeh, J. Vac. Sci. Technol. B (in press).
[4] P. Yaghoobi, M. Vahdani Moghaddam, and A. Nojeh, (submitted).

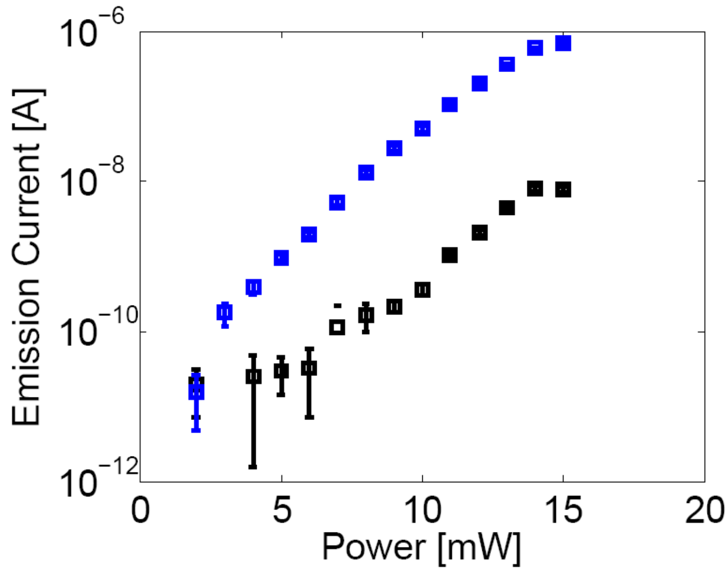

Figure 1: Thermionic emission current from a CNT forest as a function of laser power for the cases where the electric field of the laser was parallel and perpendicular to CNTs axis (blue and black squares, respectively). The laser wavelength was 488 nm and the beam was perpendicular to the surface of the sidewall of the forest, focused to a spot of approximately 0.5 mm in diameter.

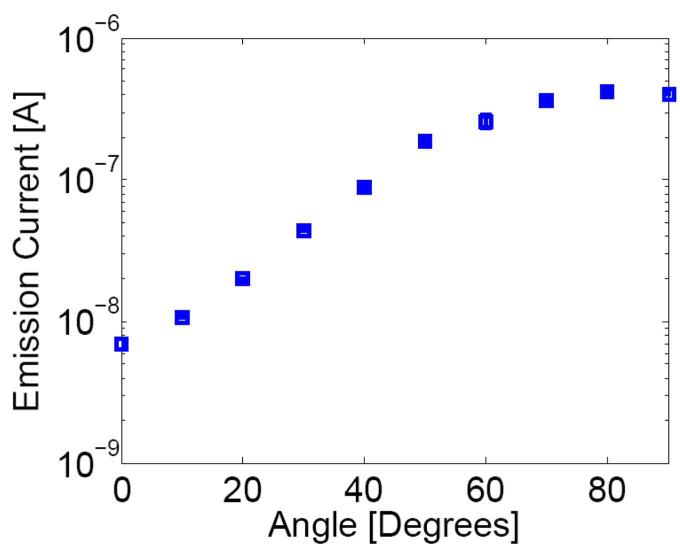

Figure 2: Thermionic emission current as a function of angle of polarization of the laser, where 0 degrees indicates the case where the electric field of the laser beam is perpendicular to the axis of the CNTs. The laser power was 14 mW and the spot was approximately 0.5 mm in diameter. The laser wavelength was 488 nm.