Broadband Light-Induced Thermionic Electron Emission from Arrays of Carbon Nanotubes using Laser Pointers

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Photocathodes either require high-energy photons (ultra-violet) or have to be made from semimetals/semiconductors combined with alkali metals to have low workfunction in order to operate with visible light.[1] The former suffer from the challenges associated with ultra-violet sources and the latter are highly unstable and can only operate in ultra high vacuum conditions (better than 10^{-10} Torr). High-power pulsed lasers (with a few GW/cm^2 of light intensity) are also used for thermionic emission from metals, but again require a sophisticated and expensive light source. In this work, we show that a photocathode made from an array of carbon nanotubes (a nanotube forest) can address all these challenges.

We have previously reported thermionic emission from carbon nanotube forests induced by collimated and focused beams of continuous-wave, visible lasers.[2,3] In those studies, we had used research grade lasers (an argon ion laser and a solid-state laser) with a small range of wavelengths (488 nm – 532 nm). In the present work, we demonstrate electron emission from nanotube forests using continuous-wave, battery-operated, hand-held lasers with four different wavelengths in a broad visible/infra-red range (405 nm, 532 nm, 650 nm, and 1064 nm).

Figure 1 illustrates the electron emission current as a function of laser power for the four different wavelengths. In addition to showing that nanotubes can be used for extremely inexpensive photocathodes, which, given their mechanical strength and chemical stability, opens the way to various applications, the figure reveals the remarkable property that significant emission takes place regardless of the laser wavelength, suggesting that even a regular wide-spectrum light source could be used. This has important implications for bringing photocathodes to mainstream applications such as solar energy conversion and displays.

The temperature of the emission spot can be estimated using a power equilibrium equation (incident laser power = power loss due to black body radiation, electron emission and heat conduction to the surroundings). Figure 2 shows the emission current as a function of the temperature estimated in this manner. A theoretical estimate based on the Richardson-Dushman equation for thermionic emission is also shown, providing a reasonable fit to the experimental data.

[1] J. S. Escher, G. A. Antypas, and J. Edgecumbe, Appl. Phys. Lett. **29**, 153 (1976).
[2] P. Yaghoobi, M. Vahdani Moghaddam, M. Michan, and A. Nojeh, J. Vac. Sci. Technol. B (in press).
[3] P. Yaghoobi, M. Vahdani Moghaddam, and A. Nojeh, (submitted).

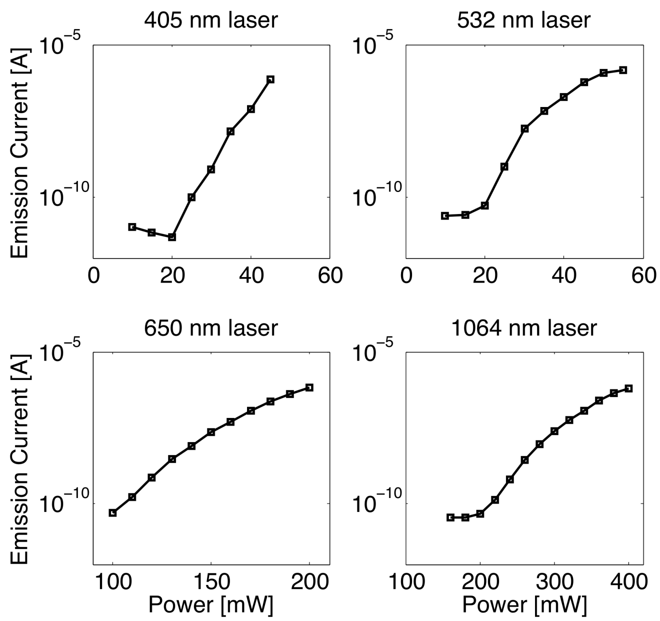

Figure 1: Electron emission current as function of laser power for laser wavelengths of 405 nm, 532 nm, 650 nm, and 1064 nm. In all cases the laser was focused to a spot in the range of 200 – 600 μm in diameter. Since this emission process is dependent on the light intensity, the beam shape of the laser can greatly affect the emission current for a given laser power. In the 650 nm and 1064 nm cases, the laser beams were overall wider, less circular and more difficult to focus, and therefore more laser power was needed for electron emission.

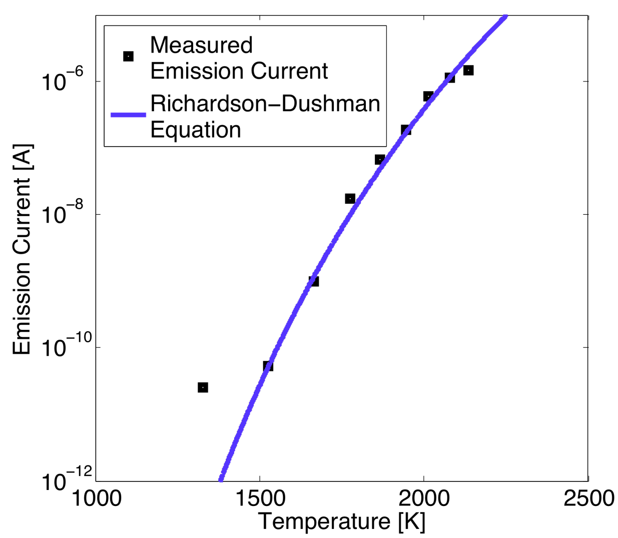

Figure 2: Electron emission current as a function of estimated temperature using a power equilibrium equation. The measured behavior follows the thermionic emission behavior predicted by the Riachardson-Dushman equation.