Two-photon Photoemission from Carbon Nanotube Arrays under Low-power Ultraviolet Illumination

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Light-induced electron emission can happen due to photoemission, photo-field-emission, optical field-emission and thermionic emission. Multi-photon photoemission[1,2] is of particular interest as it enables electron emission using photon energies below the cathode workfunction. The emitter temperature plays an important role in photoemission and the relative weight of various multi-photon phenomena.[3] Such effects are typically observed using the high intensities delivered by pulsed lasers, which can also induce a noticeable rise in lattice temperature or at least in the electronic temperature of the cathode.

Here, we report one- and two-photon photoemission from an array of millimeter-long, vertically-aligned carbon nanotubes (a nanotube forest) using low-power, continuous-wave laser. A ultra-violet laser beam (wavelength: 266 nm) is focused on the side wall of the nanotube forest (Figure 1(a)) onto a spot of ~ 125 µm in diameter. The intensity is limited to a maximum of 500 W/cm^2, orders of magnitude below typical intensities used in pulsed-laser multi-photon photoemission experiments on bulk emitters. We show that in various ranges of laser power (corresponding to various intensities for a fixed spot size), different mechanisms are dominant. At low intensities, electrons are emitted due to simple one-photon photoemission. In this region, the electron emission current increases linearly with laser intensity (Figure 1(b)). As the intensity gradually increases, a two-photon photoemission process seems to dominate, as suggested by the fact that the slope of the log-log plot of current vs. intensity is equal to 2 in this region (Figure 1(b)), indicating a second-order process. The temperature of the irradiated spot may be playing a key role here. We have previously shown that, through a so-called Heat Trap effect, even a low-power laser beam can locally heat a spot on the sidewall of a nanotube forest by thermally isolating the spot from the surroundings, easily raising its temperature to hundreds or thousands of degrees.[4] As the intensity is further increased, gradually a fully thermionic process takes over (Figure 1(b), beyond the region with slope 2). Surprisingly, we also observe that the laser polarization has little effect in the two-photon photoemission region, while it has a significant effect as the power is increased and thermionic emission dominates (Figure 2).

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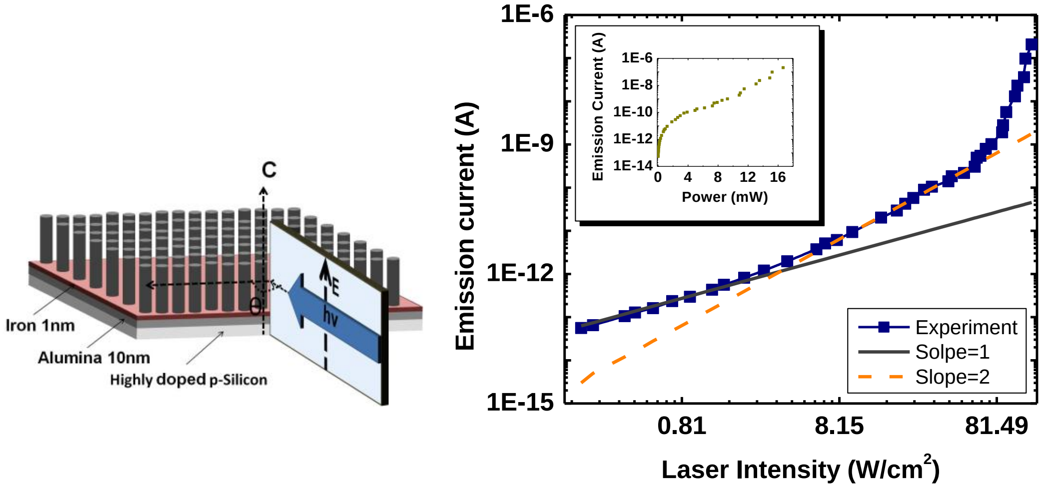

(a) (b)

Figure 1: (a) Schematic of the experimental configuration. The laser beam is s-polarized (electric field parallel to the nanotubes' axis) and focused on the side wall of the nanotube forest onto a spot of ~ 125 µm in diameter (drawing not to scale). (b) Log-log plot of the photoemission current vs. laser intensity under perpendicular incidence. Inset shows the current vs. laser power.

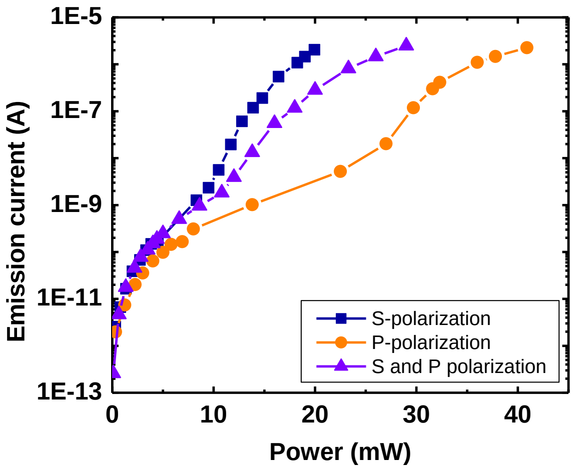

Figure 2: Photoemission current as a function of laser power for different polarizations of the laser beam. The angles of incidence for the s- and p-polarized beams are ~ 0° and ~ 8° respectively, and both have the same plane of incidence. In the case of the combination of s and p polarizations (violet), the unpolarized beam has first been split into s and p halves using a polarizing beamsplitter, which have then been combined again onto the same spot on the forest side wall.