Ultrafast laser-induced field emission from a single carbon nanotube based nanotip

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Abstract: We present the first demonstration of ultrafast laser-induced field emission from a carbon nanotube based nanotip, and measurement of the energy distribution of the electrons.

OCIS codes: 020.4180, 240.6675.

Laser-induced electron emission from sharp tips has been observed when exploring various strong-field phenomena including multiphoton ionization (MPI) [1–3], above threshold photoionization (ATP) [4,6], and optical field emission [5]. The large optical field enhancement due to the sharp tip geometry greatly reduces the laser intensities needed to reach these strong regimes and therefore alleviates the need for high-power, low-repetition rate lasers. An additional DC field applied to the tip can be adjusted to modify the electron emission and in combination with differing laser parameters, different regimes of photoemission are attained. Investigations of the thermal response of the illumination are also studied for a variety of parameters.

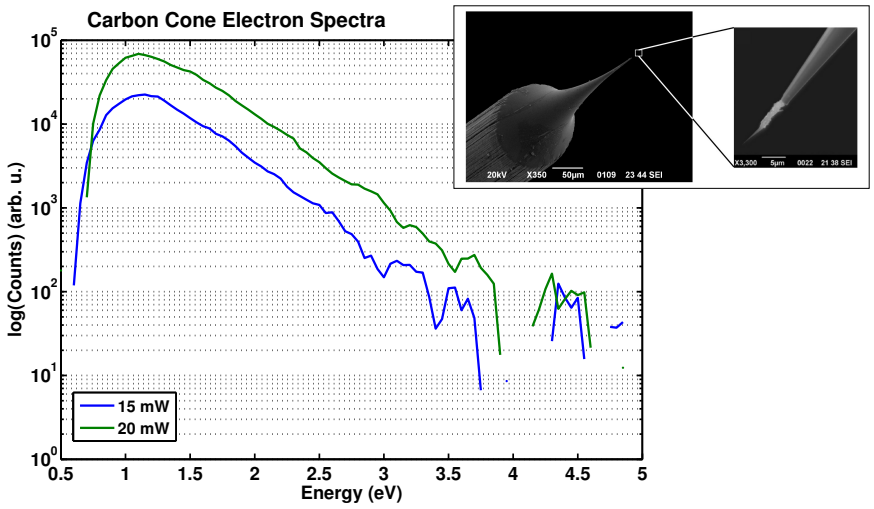

Fig. 1. Typical photoelectron spectrum for the case of a CNT based nanotip (inset) for different laser powers. An increase in laser intensity shows a broadening of the spectrum.

Our new experimental setup extends upon studies performed on conventional tungsten or gold tips, by using a new innovative tip based on a single carbon nanotube [7, 8]. This recently developed nanotip raises high expectations for advances by implementation in electron microscopy [7]. The carbon cone is grown onto a single multi-wall carbon nanotube (CNT) with an apex diameter of a few nm, and mounted on a tungsten tip with a focused ion beam, as shown in the inset of Fig. 1. The use of this CNT-based nanotip (CCnT) has several advantages over W and Au nanotips. The mechanical strength of the carbon bonds is larger, increasing robustness and stability. The aspect ratio of the carbon cone is sharper and the apex size can be smaller, which can lead to a higher field enhancement in the vicinity of the

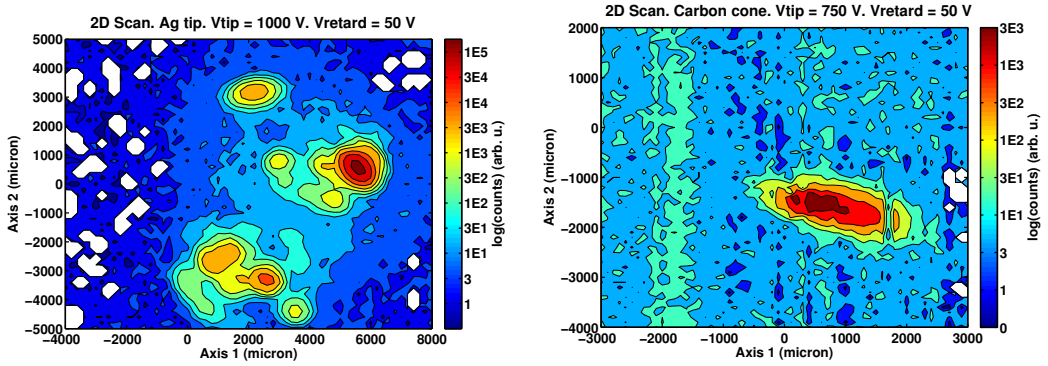

Fig. 2. The left panel shows the electron emission from a conventional silver tip demonstrating the faceted emission from the metallic crystalline structure. Right panel shows the single emission spot from the central carbon nanotube of a CCnT.

apex. The growth of the carbon cone is completely controlled, which allows modification of the electronic structure by doping or filling the CNT with other elements.

In our experiment, the direct output of a Ti:sapphire laser oscillator with a center wavelength of 800 nm, $\sim$20 fs duration and 80 MHz repetition-rate is focused onto the apex of a nanotip with a power density on the order of 10^{11} W/cm^2 in an ultra high vacuum chamber with a pressure on the order of 10^{-10} mbar. Additionally, a small DC field (15 V) is applied to the tip. The laser polarization and intensity are carefully controlled. A field retarding spectrometer based on a mesh grid with an adjustable voltage combined with a double stage Micro Channel Plate (MCP) measures the kinetic energy distribution of the electrons with a resolution of dE/E $\sim 10^{-3}$. The entire spectrometer ensemble is mounted on a 2-dimensional translational nano-positioner to enable 2D imaging of the electron emission. Electron emission is measured in two different cases: static emission, in which emission is induced by a large voltage applied directly to the tip, and dynamic laser emission, in which emission is induced by an ultrafast laser pulse.

Preliminary 2D scans of static electron field emission from the nanotips show the difference in emission patterns from a CNT based nanotip and a conventional metal. As seen in the left panel of Fig 2, due to the faceted nature of the crystalline structure of a conventional metallic nanotip, electron emission can be seen from the different facets of the the tip apex. Since the CCnT is based around a central nanotube, electron emission only originates from this central apex, thus one spot appears in the emission pattern.

We also observed the first laser-induced field emission from a CNT-based nanotip. Fig. 1 shows several photoelectron spectra with different average laser power (15 mW and 20 mW). The broadening of the spectra with respect to laser power shows the dependency of the electron spectrum on laser intensity. The signature of ATP (peaks in the spectrum spaced by the photon energy) in the carbon spectra has not yet been clearly demonstrated. These first results are encouraging for further studies of electron emission from this innovative CNT-based carbon nanotip.

We thank A. Arbouet and M. Monthioux for their important scientific input, S. Faure and L. Polizzi for their technical support. ANR contract labex NEXT No 11 LABEX 075 and the region Midi-Pyrénées are gratefully acknowledged for funding support.

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