Laser Induced Structural Damage to Multi-walled Carbon Nanotubes in a Controlled-Pressure Environment

Amir H. Khoshaman, M. Chang, A. Nojeh
Department of Electrical and Computer Engineering, University of British Columbia, Vancouver BC, V6T 1Z4, Canada
anojeh@ece.ubc.ca

As a highly anisotropic graphitic material, carbon nanotubes (CNT) inherently exhibit salient physical properties including high aspect ratios, sharp tips (and hence large electric field enhancement coefficients), and high mechanical strength, which make them good candidates for electron sources. To use CNT-based electron sources in practice, their structural stability during emission must be studied.

Electron emission characteristics of multi-walled carbon nanotube (MWCNT) forests via photo- and thermal excitation have been of interest in the recent years. It is common to use a laser beam to generate enough intensity, especially to trigger different excitation mechanisms, for example thermionic as opposed to photo-emission. However, the intensities involved could lead to structural changes to the nanotubes in the presence of oxidants, causing localized calcination on the graphitic surface[1]. In this work, we present a study on the damage threshold of MWCNT forests under localized laser irradiation. Our group has discovered a visible-light-induced "Heat Trap" effect in CNT forests, leading to localized heating and thermionic emission [2]. Here, the issue of stability of CNTs and their structural integrity in the thermionic emission regime is investigated. We used a visible laser to irradiate the sidewalls of aligned MWCNT forests prepared using catalytic chemical vapor deposition, under different environmental pressures. The laser power and exposure time were swept over a wide range from *10-50 mW* and *10-90 min*, respectively. With intensities on the order of only a few W/mm^2, highly localized laser-induced structural deformation was observed (Figure 1). Clear evidence of laser damage to the aligned forest was found with vacuum levels as high as 10^{-6} *torr*. The relationships between the structural changes induced on the CNTs and the laser power, exposure time, and the vacuum level were studied. It was observed that, under low vacuum, a shallow mark is formed on the sidewalls, following the geometrical features of the laser spot, with a diameter of $132\ \mu m$ (Figure 2 (a)). However, at higher vacuums, damage happens only in a small area at the center of the laser spot (Figure 2 (b)). We speculated that at low vacuums, due to the impact of convection, the heat is spread across the laser spot, whereas, at higher vacuum levels the heat spot is more localized, leading to these observations.

---

[1] B. Frank, A. Rinaldi, R. Blume, R. Schlögl, and D.S. Su, Chem. Mater. **22**, 4462 (2010).
[2] P. Yaghoobi, M.V. Moghaddam, and A. Nojeh, Solid State Communications **151**, 1105 (2011).

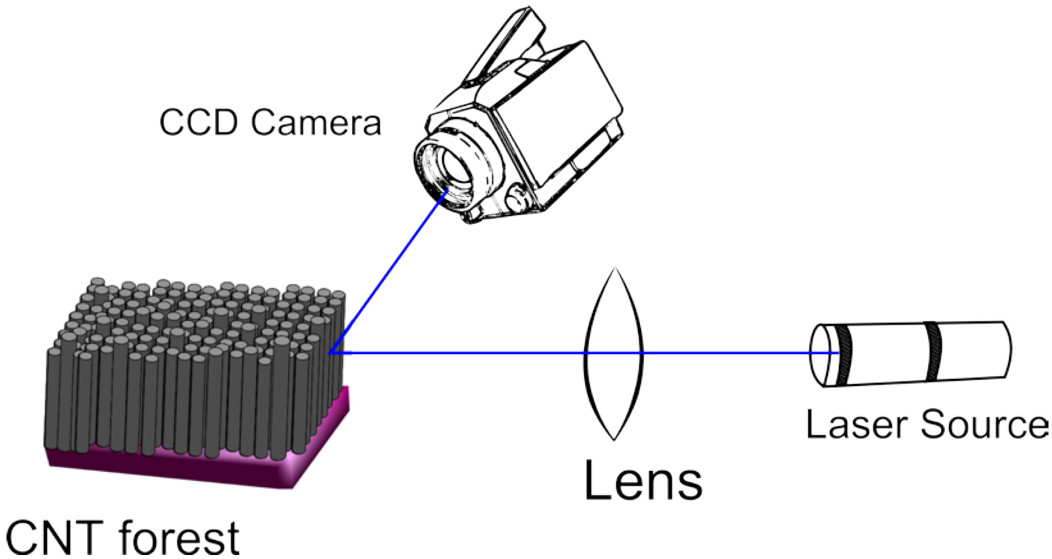

Figure 1: Schematic of the experimental apparatus: the CCD camera was used for calibrating the laser beam spot size. The CNT forest was placed inside a vacuum chamber, and the pressure was monitored by a cold cathode gauge.

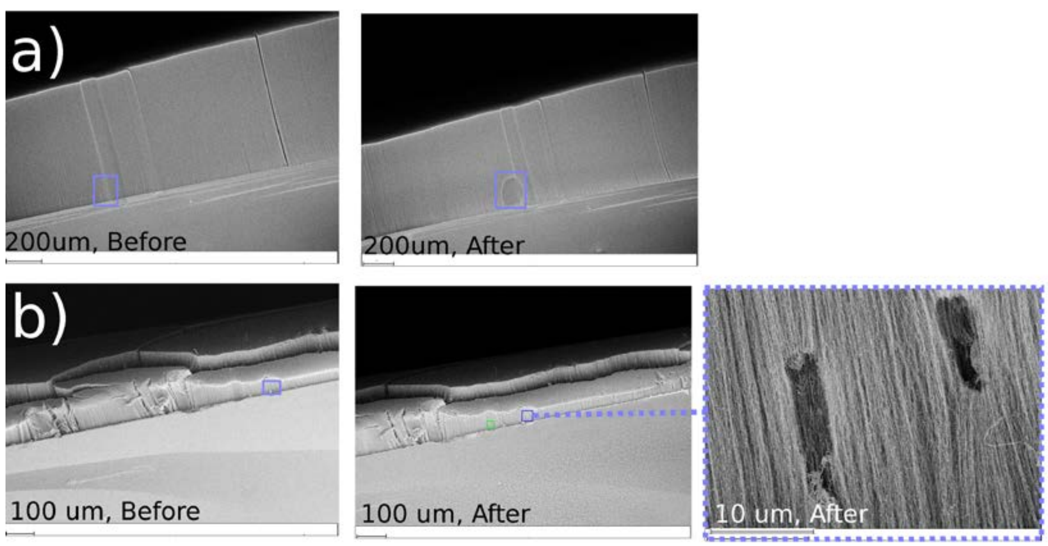

Figure 2: a) Effect of a 466-nm laser beam on MWCNT forests at (a) $2.0x10^{-3}$ torr, (b) $1.0x10^{-6}$ torr. Scanning electron micrographs of the forest sidewalls are presented before and after irradiation with an intensity of *50 mW* for *45* minutes. Note the shallow mark covering the entire irradiated spot in case (a), as opposed to a minor damage only in a very small area (relative to the beam spot size) in case (b).