Dimensionality, Heat Transfer and Light-activated Cathodes

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Localized light-induced heating of conductors is intriguing from a fundamental point of view and has significant prospects for thermionic cathode applications in multi-electron-beam system[1] as well as in thermionic electricity generation[2]. Previously, our group reported this unique phenomenon in arrays of vertically-aligned carbon nanotubes (VA-CNTs), where localized heating with a high temperature gradient of > 1,000K/mm and peak temperatures in excess of 1,000 K was achieved in this conducting material, using a laser beam with low optical intensity.

Here, we investigate the distinctiveness of this particular phenomenon to the specimen's dimensionality which gives rise to limited local thermal dissipation. The schematic of the experimental apparatus is shown in *Figure 1*. Neither a similarly localized temperature response, nor any significant increase in temperature could be induced in bulk materials as opposed to the scenario where one-dimensional materials were illuminated with the same laser intensity as the nanotubes: alumina and tungsten slabs were used as examples of bulk materials, under ~6μW/μm² of laser intensity. In the case of alumina, a maximum temperature difference of 6 K was observed. A result similar to alumina (absence of prodigious temperature gradient) was also observed for tungsten, as well as pyrolytic graphite (a two-dimensional material). It appears that the dimensionality of the illuminated sample plays a key role in this localized light-induced heating, as we have observed the thermal response on niobium nanowires similar to that on VA-CNTs, and comparable temperature levels and gradients could be attained under the same level of optical intensity, as seen in *Figure 2*. We also report the peak temperature at varying levels of pressure (*Figure 3*). It remains generally stable in the range from 10^{-7} to 10^{-1} Torr and abruptly declines to 600K from 1,400K at 10^{2} Torr, due to heat loss through convection.

[1] M. V. Moghaddam, and A. Nojeh, 57th International Conference on Electron, Ion, and Photon Beam Technology and Nanofabrication 1A-5 (EIPBN 2013), Nashville TN, USA.
[2] P. Yaghoobi, M. V. Moghaddam, and A. Nojeh, AIP Adv., **2**, 0421392(2012)

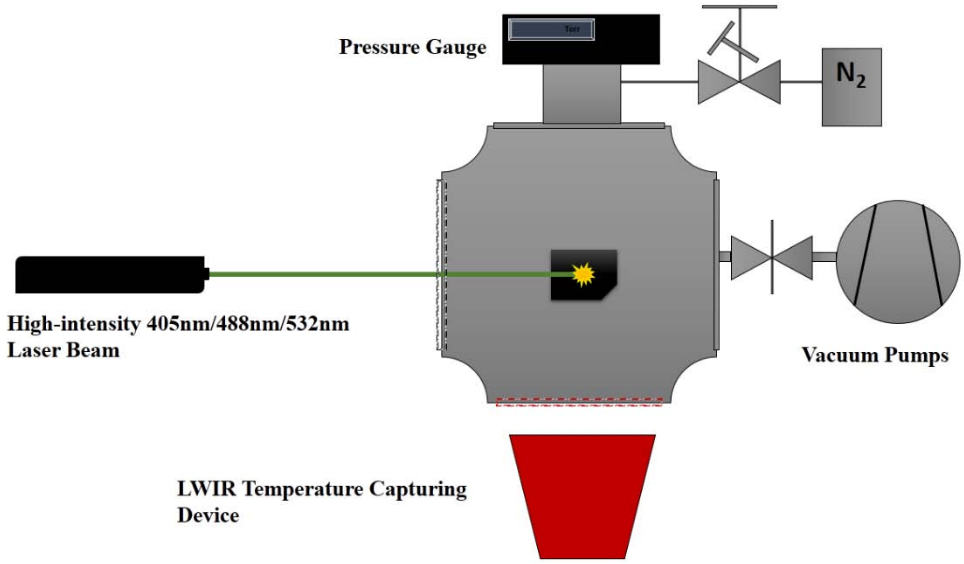

Figure 1: General experimental setup. For the pressure sweep, nitrogen was leaked through a high-precision leak valve to a chamber pre-pumped to 10^{-7} Torr.

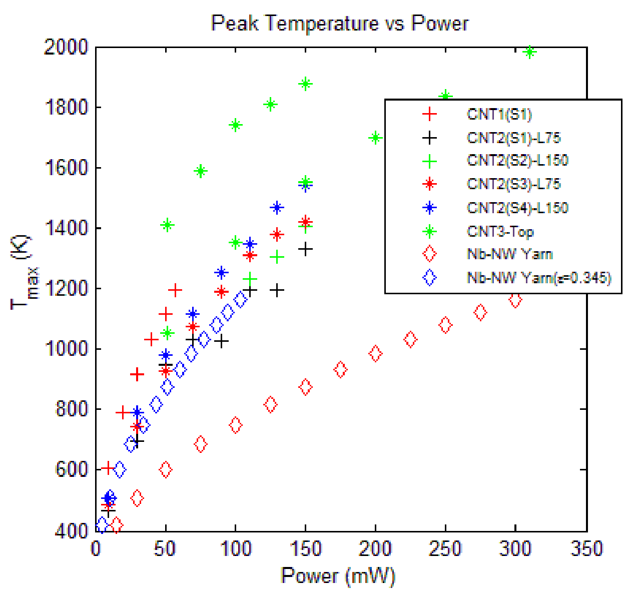

Figure 2: Peak temperature under different laser powers: The peak temperature of VA-CNT forests' thermal response to a focused 532/488nm laser beam with an estimated beam radius of 67.5µm to 104.9 µm. Dataset collected on Nb-nanowire yarns is plotted with a normalized optical power along with the original dataset.

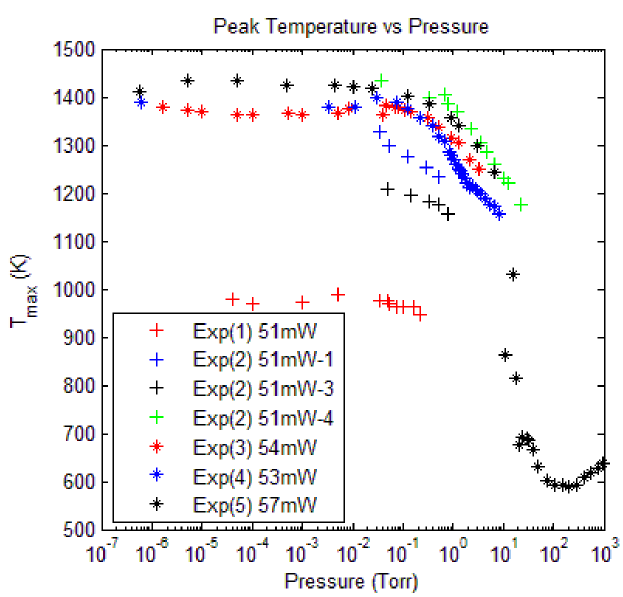

Figure 3: Peak temperature at varying vacuum conditions. Different sets of experiments were conducted at different spots on the VA-CNT forest sidewalls. The lower temperature achieved in Exp(1) was attributed to the under-ranged calibration configuration on the temperature capturing device.