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Extremely Efficient Multiple Electron-hole Pair Generation in Carbon Nanotube Photodiodes

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The efficient generation of multiple electron-hole (e-h) pairs from a single photon could improve the efficiency of photovoltaic solar cells beyond standard thermodynamic limits [1] and has been the focus of much recent work in semiconductor nanomaterials [2,3]. In single walled carbon nanotubes (SWNTs), the small Fermi velocity and low dielectric constant suggests that electron-electron interactions are very strong and that high-energy carriers should efficiently generate e-h pairs. Here, I will discuss observations of highly efficient generation of e-h pairs due to impact excitation in SWNT p-n junction photodiodes [4]. To investigate optoelectronic transport properties of individual SWNT photodiodes, we focus a laser beam over the device while monitoring the electronic characteristics. Optical excitation into the second electronic subband $E_{22} \sim 2\ E_{GAP}$ leads to striking photocurrent steps in the device $I - V_{SD}$ characteristics that occur at voltage intervals of the band gap energy E_{GAP}/e. Spatially and spectrally resolved photocurrent combined with temperature-dependent studies suggest that these steps result from efficient generation of multiple e-h pairs from a single hot E_{22} carrier. We conclude that in the SWNT photodiode, a single photon with energy greater than$2E_{GAP}$ is converted into multiple e-h pairs, leading to enhanced photocurrent and increased photo-conversion efficiency. [1] W. Shockley, and H. J. Queisser, *Journal of Applied Physics* **32**, 510 (1961). [2] R. D. Schaller, and V. I. Klimov, *Physical Review Letters* **92** (18), 186601 (2004). [3] R. J. Ellingson, et al, *Nano Letters*, **5** (5), 865-871 (2005). [4] Nathaniel M. Gabor, Zhaohui Zhong, Ken Bosnick, Jiwoong Park, and Paul McEuen, *Science*, **325**, 1367 (2009).