

## Polarization-sensitive photodetectors based on electric field-aligned semiconductor nanowires

A. Singh, R. Zhou, V. Protasenko, H.-C. Chang, M. Kuno, H. Xing, and D. Jena  
University of Notre Dame, Notre Dame, IN 46556  
Phone: 574 631 8835, Fax: 574 631 4393, email: djena@nd.edu

Various semiconductor nanostructures, including nanotubes and nanowires have been grown and studied recently. The primary growth technique has been chemical vapor deposition (CVD)-based, such as the rather popular vapor-liquid-solid (VLS) technique. [1] Growth techniques utilizing solution-based synthesis, on the other hand, have a number of advantages over the CVD technique such as low cost, scaling of production, ability to passivate the semiconductor surface chemically during growth, and the ease of transfer to any substrate. One such synthetic method is the solution-liquid-solid (SLS) technique, which has been used by various groups to produce colloidal quantum dots or nanocrystals.[2] Rudimentary photodetectors have been demonstrated using closed-packed “solids” of the SLS-grown nanocrystals. Though photon absorption and electron-hole pair generation in nanocrystals is efficient, the extraction of carriers is difficult, involving hopping transport between the dots before being collected by the electrodes.

In this work, we demonstrate photodetectors based on CdSe nanowire networks, or “quantum-wire solids”. Nanowires allow band-transport along their axes, therefore potentially offering a drastic improvement over nanocrystals for the efficient collection of optically generated carriers. To evaluate the transport properties of the nanowires, we have fabricated field-effect transistors using both single nanowires and networks of nanowires as channels on SiO<sub>2</sub>/Si substrates with back gates. For single nanowire FETs, focused ion beam has been employed to define Pt source-drain contacts. Typical nanowire diameters are 10nms, and lengths vary from 1-10 microns. For multiple nanowire channels, we have used ac dielectrophoretic alignment for precise placement of the nanowires between the source-drain contacts (Figure 1, right).[3] The nanowires FETs thus fabricated require a negative gate bias for pinch-off indicating that the wires are n-type, and drain-source current on/off ratios of 10<sup>5</sup> are observed for FETs with dense nanowires network channels, as opposed to ~10 for single nanowires FETs (Figure 2, right). In the presence of optical excitation, the photocurrent exceeds the dark current by several orders of magnitude, exhibiting the strong photoconductivity of the nanowires.

Metal-semiconductor-metal photodetector devices are then fabricated using conventional optical lithography and metal deposition. The photodetectors are found to have very low dark currents (~ 10 nA at 5 V), indicating very few free carriers in the nanowires at room temperature. The spectroscopic photoresponse of these photodetectors is measured using a xenon lamp coupled with a monochromator, and a lock-in amplifier in a photon energy range of 1.4 - 3.5 eV. We observe a sharp turn-on in the photocurrent, at 1.80 eV, near the absorption edge of the nanowires measured independently using an UV-Vis spectrophotometer (Figure 3, left). The photoresponse is estimated to be higher than 50 mA/W at a bias of 5 V at 550 nm (2.25 eV) illumination. With increasing photon energy, the responsivity of the NW-based photodetectors shows a very slow decrease, ~ 18% drop at 3.4 eV compared to that at 2.25 eV. This is in sharp contrast to traditional photodetectors, where the photoresponse decays rapidly with increasing photon energy. In another metal-nanowire-metal photodetector structure, the nanowires were aligned between the metal electrodes by dielectrophoresis. In Figure 3 (right), we plot the photocurrent through such a MSM photodetector as a function of the angle that the polarization direction of the incident light (at 488nm) makes with the nanowires axis. The large anisotropy of the absorption coefficient leads to a ~10% modulation of the photocurrent.

In conclusion, we have demonstrated that solution-synthesized semiconductor nanowires can be used as channels in traditional FET structures, and their high optical absorption and high quantum efficiencies can be exploited for fabrication of photodetectors. In addition, by using aligned nanowires in MSM structures, polarization sensitive photodetectors can be achieved. With solution synthesized narrow bandgap semiconductor (PbS, PbSe) nanowires, the photodetector spectral range can be extended into the IR regime, and can be transferred to flexible substrates in the future.[4]

[1] Y. Huang, Duan X., Y. Cui, L. Lauhon, K.-H. Kim, and C. Lieber, *Nature (London)* **294**, 1313 (2001).

[2] C. B. Murray, C. R. Kagan, and M. G. Bawendi, *Annu. Rev. Mater. Sci.* **30**, 545 (2000).

[3] R. Zhou, H.-C. Chang, V. Protasenko, M. Kuno, A. Singh, and D. Jena, unpublished (2006).

[4] H. Petersson, J. Tragardh, A. I. Persson, L. Landin, D. Hessman, and L. Samuelson, *Nano Letters* **6**, 229 (2006).

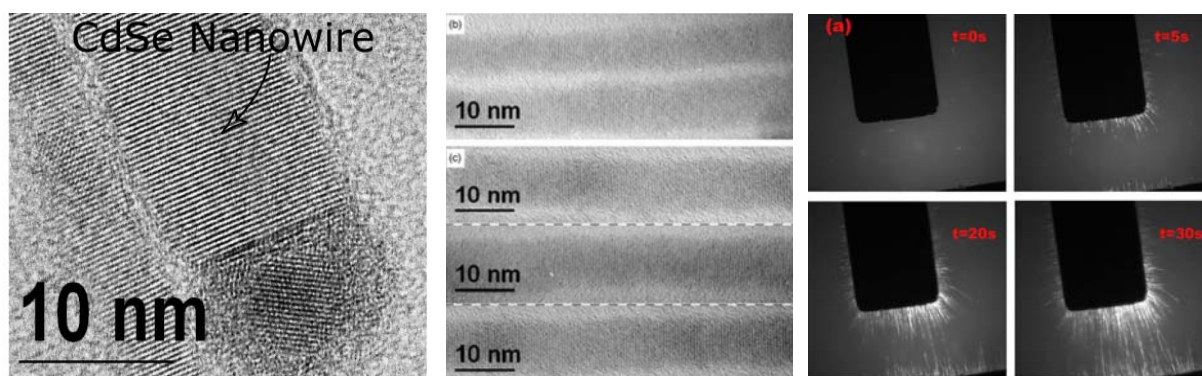


Fig. 1: Solution-synthesized CdSe nanowires (left, center), and their ac electric-field assisted dielectrophoretic alignment between contact pads in solution (right).

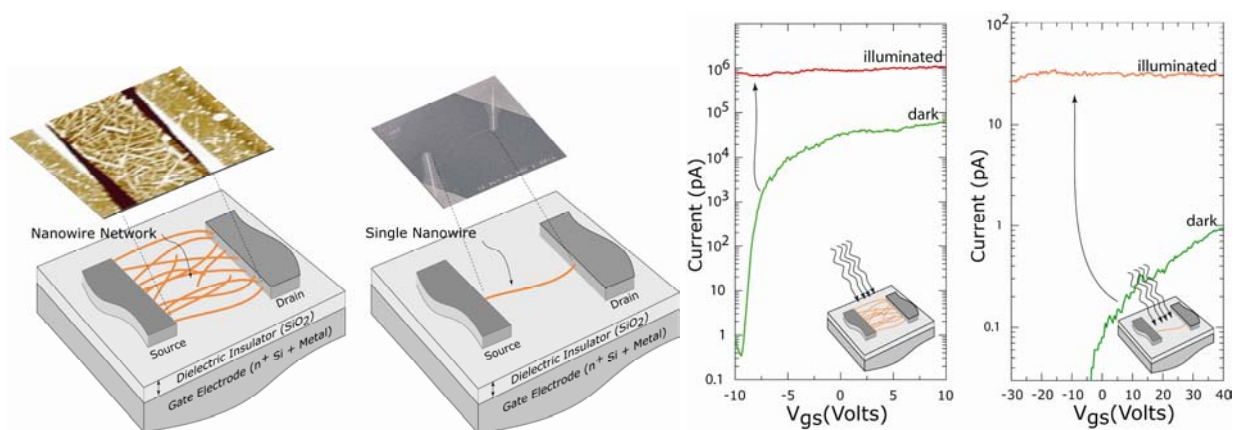


Fig. 2: AFM & SEM images of (left) multiple nanowires FET and (center) single nanowires FETs assembled on conductive Si/SiO<sub>2</sub> substrates with back-gates. The single nanowires FETs are fabricated by focused-ion-beam inscribed Pt contacts written from isolated wires to larger metal pads. The figure on the right compares the current-voltage characteristics of the two FETs in dark and under illumination.

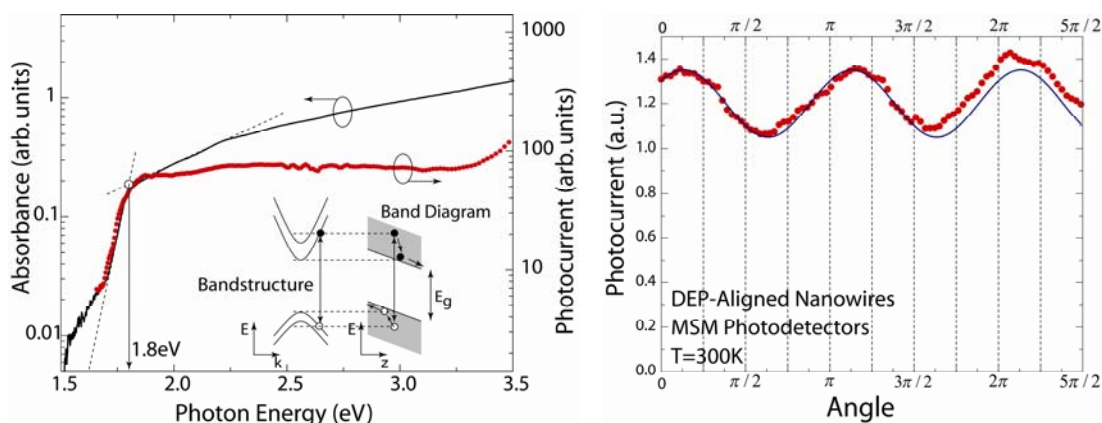


Fig. 3: (Left): 300K photocurrent spectra superposed on the absorption spectra of the nanowires showing sharp band-edge onset of photocurrent. The photoresponse does not decrease with increasing photon energy in sharp contrast to bulk semiconductor photoconductive photodetectors. (Right): Polarization sensitive photocurrent as a function of angle of polarization of incident light (488nm) w.r.t the nanowires axis.