High Gain ZnO Nanowire Phototransistor

Arthur Zhang, Cesare Soci, Bin Xiang, Jung Park, Deli Wang, Yu-Hwa Lo
Department of Electrical and Computer Engineering, Jacobs School of Engineering, University of California, San Diego
9500 Gilman Drive, MC 0407, La Jolla, CA 92093
Email: ayzhang@ucsd.edu

Abstract: We demonstrate the potential of nanowires as phototransistors with internal gain. Two-terminal single ZnO nanowire devices have been fabricated, which under UV illumination, show high photoconductive gain (approaching 10^{10}) due to hole-trapping at surface states.

OCIS codes: (040.7190) Ultraviolet detectors; (160.5140) Photoconductive materials

1. Introduction

The photoconductive properties of ZnO nanowires (NWs) have been investigated in the past [1,2]. Although high photocurrent has been previously observed in such devices, and the role of hole-trapping due to oxygen related deep levels is well understood, it has not yet been recognized that such properties can lead to substantial internal photoconductive gain. Here we evaluate the gain associated with the ZnO NW photoresponse and demonstrate their potential as phototransistor devices with high internal gain.

2. Experimental methods

ZnO NWs were grown using a simple tube furnace CVD at 925°C with a mixture of ZnO powder and graphite as source materials [3]. The as-grown ZnO NWs are typically 100-200nm in diameter and 5 to 10μm in length. The NWs were transferred onto a thermally oxidized Si substrate (600 nm SiO_2) and Ti/Au (20nm/160nm) electrodes with 2μm finger spacing were patterned on top of the NWs through optical lithography. A characteristic SEM image of a single ZnO NW device is shown in the inset of Fig. 1. Figure 1 shows a schematic of the setup used to measure single NW IV characteristics in dark and under illumination. An external bias was applied to the NW and a low-noise current preamplifier (Ithaco 1211) was used in conjunction with a digital acquisition board (NI PCI-6030E) to record the data. The excitation source consisted of a Hg vapor lamp. Monochromatic UV illumination was obtained with a band-pass filter centered at 390nm (± 50nm). The beam was attenuated through neutral density filters to achieve the desired optical power, and finally focused onto the device with a spot size of 0.25cm^2.

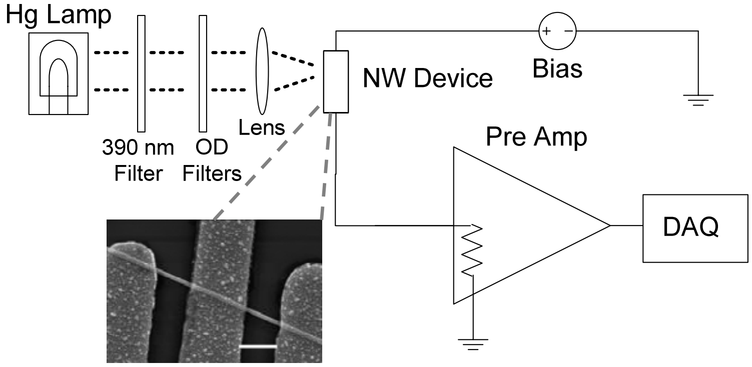

Fig. 1. Single ZnO NW photoconductivity measurement setup. An external bias is applied to the NW, and the signal recorded through a low-noise preamplifier and digital acquisition board. The device is illuminated using a Hg lamp filtered to 390nm (±50nm) and attenuated using multiple neutral density filters. The beam is focused onto the device with a spot size of 0.25cm^2. (Inset) SEM image of single ZnO NW device. Scale bar is 2μm.

3. Results and discussion

A comparison of the I-V curves for a single NW device obtained in dark and under illumination is shown in Fig. 2. Even at the lowest light intensity used (1.6μW/cm^2), the current shows an increase of more than three orders of magnitude as compared to the dark current of the order of 10nA seen in the inset of Fig. 2. The photocurrent and gain vs. absorbed photon flux, measured at 3V bias after saturation (2 min waiting time under applied bias and illumination), are plotted in Fig. 3. The absorbed photon flux is estimated by assuming a 20% absorption of the incident power in the ZnO NW having a cutoff wavelength of 365 nm. This assumption is based on an estimate of 30% surface reflection and 70% absorption in 200nm diameter ZnO NW at 3.5eV. With this estimate a DC gain approaching 10^{10} is obtained.

The gain of a phototransistor is determined by the ratio of recombination time of the trapped carriers (τ_n) and the transit time of the free carriers in the NW channel (τ_t), i.e. τ_n/τ_t [4]. The transit time along the NW is determined by the charge carrier mobility, electrode spacing and applied bias. Hole-trapping due to oxygen-related defects at ZnO NW surfaces leads to extremely long carrier recombination lifetime (of the order of several seconds)[5], which results in the high internal gain observed. This effect is strongly enhanced in NWs due to the large surface to volume ratio and the built-in potential that drives holes towards the surface states and confine electrons within the channel. Even higher gains are expected if a similar surface-state trapping mechanism is combined with higher mobility semiconductor NWs.

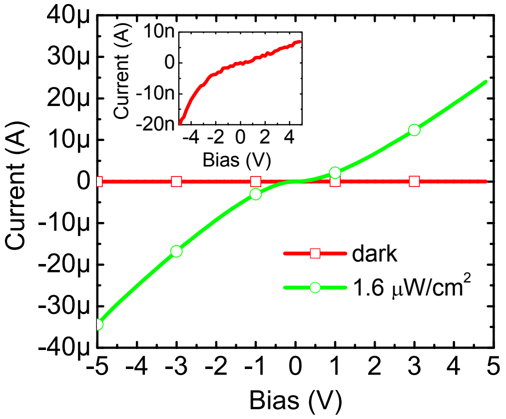

Fig. 2. I-V curves of single NW photoresponse. The photocurrent vs. bias measured in dark and under illumination is plotted. The device shows photocurrent increase by more than three orders of magnitude above dark current level even at the lowest excitation intensity used. (Inset) The dark current is shown on a smaller scale.

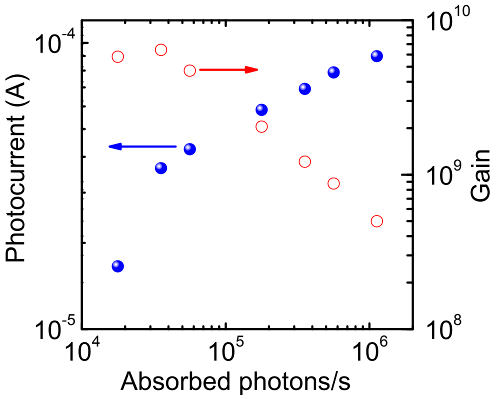

Fig. 3. Photocurrent/Gain dependence on photon flux. The photon flux is estimated from the measured excitation power and the gain calculated as the ratio of electron and photon flux.

4. Conclusion

Fabricated ZnO NW devices are shown to act as UV phototransistors. High internal gain is produced in these devices from charge separation of carriers, which significantly increase their recombination time. This shows the potential of photoconductive NWs as a new generation of phototransistors for sensing, imaging, and other applications where high gain and low operation voltage are desired.

5. References

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