NANOPHOTONICS WITH NANOWIRES

K. Nilsson[1], M. T. Borgström[1], M. Graczyk[1], M-E. Pistol[1], L. Samuelson[1], F. Capasso[2], M. Magnusson, J. Leene[3] and H. Pettersson[1,4]

[1]Solid State Physics/Nanometer Structure Consortium, Lund University, Box 118, S-22100 Lund, Sweden
[2] Division of Engineering and Applied Science, Harvard University, Cambridge, Massachusetts, USA
[3]SolVoltaics AB, Lund , Sweden
[4]Center for Applied Mathematics and Physics, Halmstad University, Box 823, S-30118 Halmstad, Sweden

There is a growing market for infrared detectors with applications e.g. single-photon detection for secure low-power inter-chip communication to focal plane array chips for infrared heat cameras for security, medicine and environmental mapping. An emerging interesting candidate that in addition offers direct integration on silicon substrates is semiconductor nanowires.

1. Introduction

Self-assembled nanowires (NWs) are needle-like nanostructures made of semiconductor materials, e.g. indium arsenide (InAs), indiumphosphide (InP) or silicon (Si). The wires are fabricated in a self-assembled process, i.e. they grow spontaneously from seed particles (e.g. gold) deposited on a suitable substrate using electron-beam lithography, nanoimprint lithography or, more simply, with an aerosol technique if no requirements of ordering exists. The subsequent epi-growth process results in a very large density of remarkably homogeneous wires with respect to composition and dimensions (Figure 1 below). Typical dimensions of NWs are a diameter of 10-100nm and a length of 1-10μm. Semiconductor NWs have the interesting property that radically different chemical compositions can be formed along the wire (so called hetero-structures). Nanowires are potentially interesting for a variety of devices e.g. transistors, LEDs and photodetectors. Nanowire photodetectors are expec-ted to offer higher speed, gain and detectivity due to their extremely compact size and large surface-to-volume ratio.

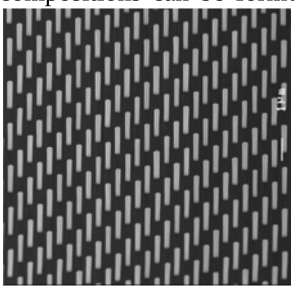

Fig. 1 *SEM image of InAs NWs grown on GaAs.*

2. Single NW device layout and results

Our group recently published the very first spectrally resolved photocurrent data on single NW photodetectors for the MWIR region with included heterostructures that facilitates a tailoring of the wavelength window, as well as a drastically reduced dark current, both very important parameters for photodetectors. Subsequently we changed our focus to study photoexcitation in NW p-n junctions and Schottky junctions. Figure 2 shows a scanning electron microscope image of n^+p diodes in indium phosphide (InP), while Fig. 3 shows the current-voltage (I-V) characteristics for similar diodes under variable laser excitation (to be published). Presently we are also studying the photoresponse from nanoscale Schottky junctions formed between the gold seed particle and a GaAs NW (to be published). The small size of NW-based p-n diodes effectively reduces the dark current and the noise. A further advantage is found for pixel cells made of multiple NWs. Here individual nanowires acts as electrical circuit breakers in the case of an electrical shock, resulting in a higher reliability and extended life-time as compared to conventional planar pixel elements where the same electrical shock would destroy the complete pixel element. Furthermore, the small foot print of NWs facilitates growth of NWs directly on cheap silicon substrates which is vitually impossible for conventionally fabricated planar photodetectors, thus reducing the cost dramatically.

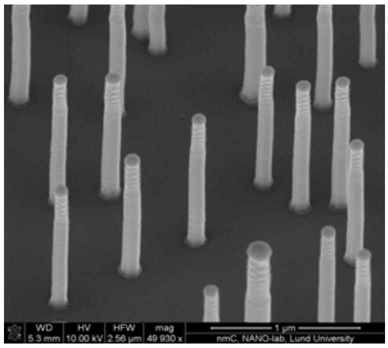

Fig. 2 *SEM image of InP n^+p diodes on InP.*

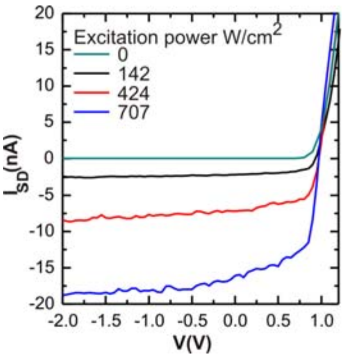

Fig. 3 I-V characteristics of InP n^+p diodes

3. Novel proposed multi-NW detector designs

In this proposal we intend to study two distinctly different detector geometries – axial and radial- as schemat-ically depicted in the Figure 4 below. The device physics is similar for the two geometries, with the added benefit for the radial p-i-n structure being that the interface extends along the length of the nanowire and that the crucial carrier separation takes place in the radial direction. The collection distance is expected to be small and thus the photogenerated carriers can reach

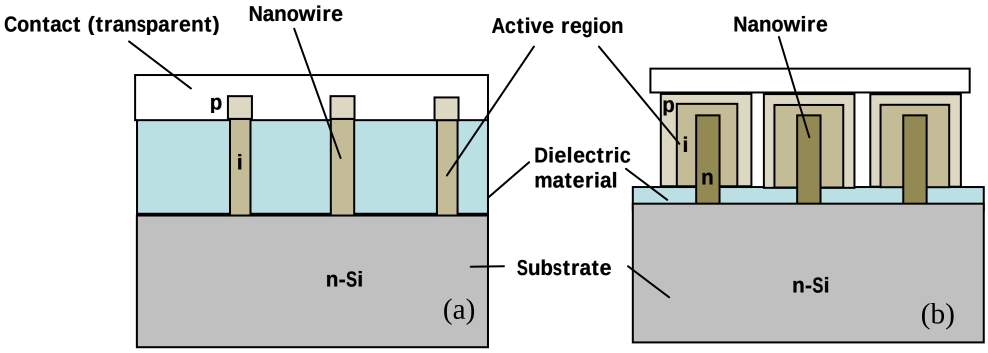

Fig. 4 Axial (a) and radial (b) photodetector designs based on InGaAs nanowires grown on silicon

the p-i-n junction with very high efficiency without substantial bulk recombination. Since the nanowires will be grown directly on silicon, it is very important that the interface between the InGaAs nanowire and the silicon substrate is carefully characterized with respect to band-offset and detrimental interface states.

There is a well-known trade-off between quantum efficiency and response speed for p-i-n photodetectors that depends on the device length. Due to a built-in gain, avalanche photo detectors (APDs) offer both large quantum efficiency and a high response speed since the light collecting volume (device length) can be reduced. A novel nanowire-based APD design with expected sensitivity down to single-photon detection has recently been invented. A key advantage of this design is that the high field multiplication region is physically separated from the lower field absorbing (optically active) region, which decreases the generation of undesirable dark current due to breakdown effects in the absorbing region.

Publications

[1] *Infrared Photodetectors in Heterostructure Nanowires*
H. Pettersson, J. Trägårdh, A. I. Persson, L.Landin, D. Hessman and L. Samuelson
NanoLett. **6**, 229 (2006).

[2] *Single p-Type/Intrinsic/n-Type Silicon Nanowires as Nanoscale Avalanche Photodetectors*
C. Yang, C. J. Barrelet, F. Capasso and C. M. Lieber
NanoLett. **6**, 2929 (2006).