Abstract:

Several nanowire devices of mono-crystalline silicon were fabricated using e-beam and optical lithography. The monocrystalline and polycrystalline device characterization was compared and demonstrated with gate and drain voltages. The electrochemical impedance spectroscopy was used to test device stability and sensitivity under various experimental conditions. The stable, selective and well aligned polycrystalline silicon nano-wire have been proposed as an economic alternative to other nano-wire devices. By controlling fabrication conditions results similar to those obtained from monocrystalline silicon and other semiconducting materials. These polysilicon nanowires showed excellent stability with several repeated current voltage test.

Summary of Research:

Nanowire based bio-sensing has been the focus of an intensive ongoing effort from various scientific programs to develop low-cost, ultra-sensitive devices, which perform detections in very little time. Currently, nano devices are becoming ever more sophisticated and reliable. These nanoscale devices can be widely applied in several potential fields including clinical diagnostics, environmental detection, food analysis, bio-agent detection and containment. However, the commercialization has been slow due to various technical difficulties that arise in the materials, surface chemistries, and fabrication processes of these devices. Carbon nanotubes and silicon nanowires have been demonstrated as single molecule biosensors [1,2], but the fabrication methods that have been used for creating these devices are typically not compatible with current process techniques and their integration is technically difficult [3].

The aim of our research is to review nanoscale device fabrication using doped polysilicon as the primary semiconductor. The nanowire was chosen for its easy fabrication and low fabrication cost. Researchers have also shown that polysilicon nanowire devices have superior electrical properties and have better gate controllability than other materials [4,5]. Our current work is a step forward towards addressing these issues. The resolution these issues will greatly benefit the fabrication, and large-scale production of these small sized devices. It will also have a great impact in the future market for polysilicon based nanowire devices.

The detailed fabrication method used in this work is published elsewhere [6]. A 50 nm low boron doped monocrystal silicon nano-wire device with $5 \times 5 \, \mu m$ hole in center shown in Figure 1 was fabricated for detection of shiga toxin. The I-V characterization curves (Figure 2) for this set of monocrystalline nanowire with an Au/Ti interface exhibit a Schottky type of interface. The Schottky nature of these devices especially with Au/Ti metal contact was in good agreement with simulated results. When a boron-doped nanowire is sandwiched between two Ti/Au metal contacts, two back-to-back Schottky diodes are formed. The nanowire has very high resistance, which can be changed using a voltage applied to the wafer substrate. On the other hand, Ohmic contact can be seen in the devices with an Au/Cr nanowire interface (Figure 3 right side). The polysilicon device functionality was tested under different concentration of bacterial samples, with the results compiled as a time vs. impedance plot (Figure 3). A 10 mV sine wave was used as device input. Repeatable results from these devices indicate excellent sensitivity. This will serve as a reference model for ongoing biosensing research.

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References:


Figure 1: A horn shaped image of a nanowire terminal to improve metal contact shown on this figure which is ~ 45 nm wide and ~ 175 nm thin lightly boron doped monocrystalline silicon nanowire separated with 20 µm between two Au/Ti metal contacts.

Figure 2: Most of these devices show repeatable I-V characteristics with the least variation in nanowire current, which is well under 50 nA. This set of devices also show Schottky behavior. Figure on right hand side shows gate voltage vs. drain current profile of these lightly doped devices showing ohmic profile but the main difference was bias voltage and Cr/Au contact for these devices.

Figure 3: A single frequency (1009 Hz) electrochemical impedance spectra of different concentration of bacterial sample solution. 15.0 mV AC was applied between drain to source electrode with 0.0V DC bias. Higher concentration (1E-6 Molar) shows high drop in impedance compare to lower concentration (1E-14 Molar) which indicates clear interaction of samples towards nanowire surface.