Small-Scale Silicon Wire Device for Biological Sensing

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Abstract:
A small device with nanowires of polycrystalline silicon was fabricated using e-beam lithography. A specific horn shape of nanowire was fabricated to improve the contact with the metal pad. A 5 × 5 µm hole was created in the center of the device to serve as a sensing area, and the rest of the area was insulated to block any conducting path. The two metal contact pads with these nanowires were 10 µm apart, which served as the basis for the electronic sensing. The device characterization was demonstrated with varying gate and drain voltages. Finally, electrochemical impedance spectroscopy was used to demonstrate device-sensing behavior.

Summary of Research:
The motivating force behind the development of nanoscale devices is the fact that they are low-cost, selective, ultra-sensitive, and rapid. However, commercialization has been slow due to various technical difficulties arising in these devices during fabrication and materials. Carbon nanotubes and silicon nanowires have been demonstrated as single molecule biosensors, 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.

A possible solution is to make the devices out of polysilicon. The aim of this project is to review the fabrication process at the nanoscale by using doped polysilicon as the key semiconductor due to a simple fabrication process. One of the focuses we considered was the electrical properties, materials and design considerations of polysilicon nanowire devices for biosensing application.

Nanowires have particular benefits over carbon nanotubes (CNTs) when used as biosensing devices. First, the properties of the material can precisely controlled. Second, there is a wider class of well-developed fictionalization and blocking chemistries by modifying nanoscale layer outside as well as inside of nanowires. Another huge attraction towards polysilicon nanowire-based biosensors is that they have the potential of achieving ultrafast detection at femtomolar concentration. Several researches have also shown that nanowire devices have superior electrical properties and have better gate controllability than conventional MOSFET.

All nanowire devices were fabricated at the Cornell NanoScale Facility (CNF), Cornell University, Ithaca, NY, USA. The electron transport properties of these polysilicon nanowires are important for understanding the carrier transport mechanism in these nanowire devices. It has been widely reported that crystallized nanowires demonstrate both ballistic and diffusive electron transport mechanisms, depending on the wire length and diameter. Another issue is the nature of the nanowire – metal contact. Depending on parameters such the metal used to make the contact, residual silicon oxide in the contact area, and nanowire dopant concentration, the result may be a Schottky rather than an ohmic contact.

The nanowire has very high resistance, which can be changed using a voltage applied to the wafer substrate. The improved ohmic contact can be seen in our devices (Figure 1) with an Au/Cr nanowire interface as predicted from I-V characterizations (Figures 2 and 3). The device functionality was tested under different pH levels (Figure 4), with the results compiled as a time vs. impedance plot. A 10 mV sine wave was used as device input. Repeatable results from these devices indicate excellent sensitivity and this will serve as a reference biosensing model for ongoing research on bio-agents detection. Our current work is a step forward to address these issues which will not only benefit the fabrication of process but also small in size and would have a huge potential in the future market of polysilicon based nanoscale sensing devices.
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References:


Figure 1: An another well improved SEM image long horn shaped ~ 50 nm wide and 75 nm thin high boron doped polysilicon nanowire separated with 10 µm between two Pt/Cr metal contacts.

Figure 2: Most of these devices show repeatable I-V characteristics with the least variation in nanowire current which is well under 1 µA (for single nanowire) and 6 µA (5 array nanowire). We can easily see from the I-V profile that no Schottky behavior exists in the device.

Figure 3: Gate voltage vs. drain current profile of these medium high doped devices recorded with potentiostat showing excellent gain with small drain to source bias AC voltage (-25 mV to -250 mV) at 503 Hz.

Figure 4: A single frequency (1009 Hz) electrochemical impedance spectra of different pH solution on top of 2-5 nm silicon oxide insulated 50 nm polysilicon nanowire area containing 5 x 5 µm hole in the nanowire center of device. 15.0 mV AC was applied between drain to source electrode with 0.0V DC bias. Higher pH shows high drop in impedance compare to lower pH which indicates clear interaction of ions towards nanowire.