SILICON NANOWIRES AS BIOLOGICAL SENSORS AND HIGHLY EFFICIENT THERMOELECTRIC MATERIALS

Thesis by

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Abstract

Silicon nanowires are of significant interest because of their novel properties which afford new functions. Here, we study silicon nanowires fabricated via a well established top down approach called superlattice nanowire pattern transfer (SNAP). In the first part of the thesis, nanowires are utilized for biological sensing of DNA and proteins in an electrolyte solution. Important electronic and surface properties are considered as means to optimize the device sensitivity. The removal of silicon-oxide interface is shown to improve the limit of detection by two orders of magnitude. The sensitivity can be further improved by the reduction of the doping level to 10^{17} cm^{-3}. In this way, sub-femtomolar concentration of oligonucleotides in physiological conditions can be detected. While the Debye screening is circumvented by the electrostatic adsorption of primary DNA on the amine-terminated monolayer, the detection of proteins is limited by the size of the antibodies. In low ionic strength solution, ~10μM, human IL2 cytokine is detectable at 1 to 10pM concentrations. Furthermore, a model is developed which allows the determination of kinetic parameters and absolute analyte concentrations from the real-time resistance of the nanowires. This model is consistent with Langmuir model, and could, in principle, be used to determine the amount of low abundance biological molecules at concentrations below those detectable with other label-free methods, such as surface plasmon resonance technique. In addition, a novel electrochemical technique is developed which allows the spatially-selective functionalization of silicon nanowires and the construction of a small library of proteins. In the second part, the discovery of highly efficient thermoelectric materials based on silicon nanowires is discussed. A relatively simple, scalable, and single component system of silicon nanowires with figure of merit of ~1 at room temperature is

developed. ZT can be tuned at various temperatures to exceed unity by varying nanowire size and/or impurity doping level. Such enhancement in ZT compared to the bulk value is achieved by significantly perturbing the phonon-mediated heat transport in a nanowire. Decreased thermal conductivities and longer lifetimes of long-wavelength phonons in a nanowire are major reasons for an increased thermoelectric efficiency of these structures.

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