Electronic Properties of Bismuth Nanowires

Personnel

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We have successfully fabricated arrays of bismuth nanowires with narrow diameter distributions, which can be varied between 7-120nm and can be made up to 100mm in length (see Figure 15(a)). The nanowire arrays are produced using a non-lithographic fabrication technique of filling an electrochemically grown anodic alumina template with molten Bi (see Figure 15(b)). The Bi crystallizes with the same crystallographic structure of bulk Bi with wire densities of about $10^{10}/cm^2$. Bi wires doped with Te and alloyed with Sb have also been fabricated. I-V measurements have been made both on wire arrays in the template and on individual Bi nanowires, which have been removed from the alumina template. In this measurement on the individual wires, a pattern of four electrodes are affixed on top of a single Bi nanowire using electron beam lithography (see Figure 16), using the facilities available in Professor H.I. Smith's NanoStructures Laboratory.

Bismuth's extremely small effective mass (~$0.001m_0$)) and extremely large mean free path in the bulk (~0.4mm at 4K) make Bi nanowires an interesting system for studying quantum conduction. In addition, our group has predicted very good thermoelectric properties for wires with small diameters (10nm). Bismuth in bulk form is a semimetal and therefore not a good thermoelectric material because of the approximate cancellation of hole and electron contributions to the Seebeck coefficient. However, quantum confinement can be introduced by making bismuth in the form of small diameter nanowires, thus moving the lowest conduction subband up in energy and the highest valence subband down in energy to get a one dimensional semiconductor. A theoretical model for the transport properties of these nanowires based on the basic electronic structure of bulk Bi has been developed to predict the dependence of the transport properties of bismuth on nanowire diameter, crystalline orientation , isoelectronic antimony concentration and temperature. This model is being applied to interpret the transport measurements in the Bi nanowires.

I-V measurements on a 70nm Bi nanowire using a 4-point method show the room temperature resistivity to be 9 times higher than for bulk Bi. We attribute this increase in resistivity to a reduction in the carrier mobility due to increased scattering of electrons at the wire boundary and by grain boundaries within the nanowire.

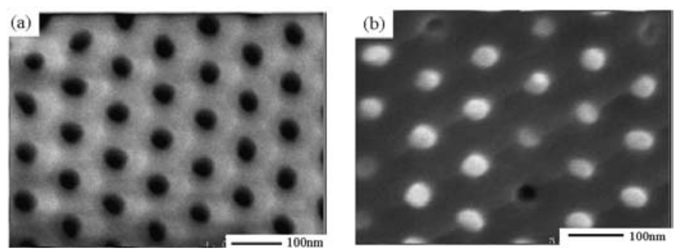

Fig. 15: SEM image of an anodic alumina template with 40nm diameter pore size (a) unfilled and (b) filled with bismuth.

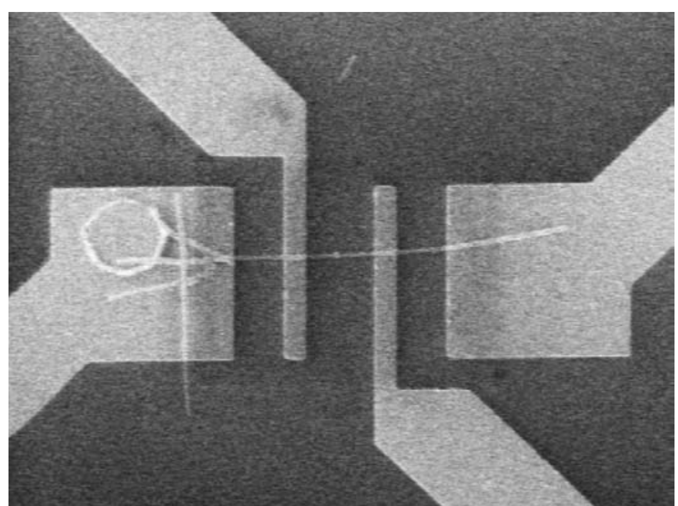

Fig. 16: SEM image of a 70nm Bi nanowire with four gold electrodes. Electrodes were patterned using electron beam lithography. Note the 1µm scale bar. The circle on the left electrode is one of the lithographic markers used to locate the wire and to attach the electrodes to the wire.