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A field effect transistor based on an individual single-crystalline Bi nanowire with extraordinary mobility

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Semimetallic bismuth (Bi) is known to be expected to us in new class of thermometric devices with high thermoelectric figure-of-merit ZT values. In present work, we report on the observation of the gate effects in an individual single-crystalline Bi nanowire at room-temperature, demonstrating extraordinary mobility and mean free paths in a Bi nanowire.

In growing Bi nanowires, a Bi thin film was first deposited on Si(100) substrate in a dc/rf magnetron sputtering system. Interestingly, uniform and straight Bi nanowires with high aspect ratio were found to be extruded from the surface of the as-grown films after heat treatment at 270 ˚C for 10 hours. High-resolution transmission electron microscopy (HRTEM) studies revealed that a Bi nanowire is single crystalline and its axis are oriented along the trigonal direction[001]. A 10 nm-thick Bi oxide layer was also found to form on the outer surface of the nanowire.

The dependence of conductance on gate voltage was found in a field effect transistor (FET) based on the individual single-crystalline Bi nanowire with d = 120 nm, exhibiting three regions with different slopes. This enables us to determine the carrier concentration of the individual 120-nm-diameter Bi nanowire. The largest electron mobility μ (~ 76,900 cm2/Vs) and the longest mean free path L (~ 1.35 ㎛) were observed at room temperature. The results show that the mobility and concentration are 3 and 2 order of magnitude is larger, respectively, for our single-crystalline Bi nanowire relative to polycrystalline Bi nanowire, and this value exceeds those for all known semiconductors, including semiconducting carbon nanotubes (>100,000 cm2/Vs).

These results imply that large thermoelectric power (S) can be obtained by high μ of the single-crystalline Bi nanowire, where μ is defined $\mu \propto dG/dV_g$ according to Mott's formula. Our results provide motivation for the potential use of the single-crystalline Bi nanowires in high-performance thermoelectric devices.