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Magnetoresistance and Shubnikov-de Haas Oscillations in an Individual Single-Crystalline Bismuth Nanowire Grown by On-film Formation of Nanowires

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Semimetallic bismuth (Bi) has been extensively investigated over the last decade since it exhibits very intriguing transport properties due to their highly anisotropic Fermi surface, low carrier concentration, long carrier mean free path l, and small carrier effective mass m*. In particular, Bi nanowires attract great attention in light of the development of nanowire fabrication methods and the opportunity for exploring novel low-dimensional phenomena. They are also important from the point of practical applications in such fields as magnetic field sensors and spin-injection devices. In the present work, we report magneto-transport properties and Shubnikov-de Haas (SdH) oscillations of individual Bi nanowires.

Bi thin films were grown on a SiO_2/Si substrate in a radio frequency (rf)-sputtering system with a Bi target of 99.999%. The deposition of Bi was carried out in a vacuum chamber with a working pressure of 2.0×10^{-3}Torr. Rf power of 100W and an Ar working pressure were utilized, yielding a growth rate of 32.7 Å/sec. For growth of the Bi nanowires, the sputtered-Bi thin films were transferred to a furnace for heat treatment at 270 ˚C for 10 hours.

A representative device based on a 400 nm diameter individual Bi nanowire was fabricated by a combination of photolithography, e-beam lithography, and a lift-off process. Measurements of current versus voltage (I-V) show that the contacts are highly ohmic at both temperatures of 2 K and 300 K, corresponding to resistivity ρ of 1.02×10^{-4} and 6.77×10^{-5} Ω • cm, respectively. The variation of the transverse and longitudinal ordinary magnetoresistance (OMR) of Bi nanowire with d=400 nm can be observed. From the individual Bi nanowire, the largest transverse and longitudinal OMRs were measured to be 2496% at T = 110K and －38% at T=2K , indicating that the Bi nanowire grown by our stress-relief method shows the longest mean free paths l with high quality single crystallinity.

The variation of the observed SdH oscillations with transverse and longitudinal magnetic fields to the axis of the Bi nanowire is consistent with the geometry of the highly anisotropic Fermi surfaces of Bi, and in turn, reveals the growth direction and the high crystal quality of the nanowires. A small misalignment of the longitudinal magnetic fields with respect to the axis of the nanowire results in an increase of the SdH period, showing that its axis is oriented along the trigonal direction and electrons are the majority carriers. Our results demonstrate the vast potential of high quality single crystalline Bi nanowires both for a variety of device applications and for fundamental investigations such as quantum transport.