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Ordinary Magnetoresistance of Individual Single-Crystalline Bi 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 effective carrier mass $m*$. The magnetoresistance (MR) behavior and long carrier mean free path l in Bi thin films are of particular importance, since they can be exploited for spintronic device applications such as magnetic field sensors and spin-injection devices. With respect to "spintronics", it is expected that Bi can be used as a spin channel in a spin-injection device due to the very long spin diffusion length l_{sd} of a few ten ㎛, following the relation $l_{sd}=(l\upsilon_F\tau_{\uparrow\downarrow})^{1/2}$, where, υ_F is the Fermi velocity and $\tau_{\uparrow\downarrow}$ is the spin relaxation time. In recent years, comprehensive studies have focused on Bi nanowires because of quantum confinement effect. Transport properties in Bi nanowires has been known to depend on the purity and the concentration of crystal defects since a distorted structure compromises the unusual electronic properties of Bi nanowires. Therefore, high crystal quality of Bi nanowires is crucial to investigate unique transport properties of Bi nanowires. In the present work, we report the magneto-transport properties of individual Bi nanowire grown by stress-induced method to prepare single-crystalline Bi nanowires.

Bi thin films were grown on a thermally oxidized 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 base pressure of 5.0×10^{-7}Torr. Rf power of 100W and an Ar working pressure were utilized, yielding a growth rate of 32.7Å/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 400-nm-diameter individual nanowire device was fabricated by a combination of photolithography, electron-beam lithography, and a lift-off process (see Fig. 1A).

Measurements of current versus voltage (I-V) show that the contacts were highly ohmic at 300 K, corresponding to resistivity ρ of $1.29\times10^{-4}\Omega\cdot$cm. Fig. 1B and 1C shows the variation of the transverse and longitudinal ordinary magnetoresistance (OMR) of a 400-nm-diameter Bi nanowire. The largest transverse and longitudinal OMR of 2496 % at T = 110 K and −38 % at T = 2 K in the individual 400-nm Bi nanowire were observed, which is more than 4-times larger than the largest OMR (35 K) of polycrystalline 400-nm-diameter Bi nanowires array grown by electrodeposition. Therefore we are indicating that the Bi nanowire grown by stress-induced method shows the longest mean free paths l, and high-quality, single crystalline. The effect of wire-boundary scattering arising from the reduction of the cyclotron radius caused by a high magnetic field parallel to the axes of cyclotron resonance, occurring in only a single-crystalline nanowire [1, 2] was also observed.

Associated with the crystal quality of the Bi nanowire, mean free path is directly related to the observation of Shubnikov-de Haas (SdH) oscillations. The oscillations masked by impurity scattering is characterized by an exponential decay, $exp(-1/w_c\tau)$, where relaxation time τ is defined $\tau = el/m^*$, and the observation of robust SdH oscillations (see Fig.2) proves that the Bi nanowire is the high quality, single-crystalline. Our results suggest the possibility of exploring the underlying physics in individual high quality single-crystalline Bi nanowires.

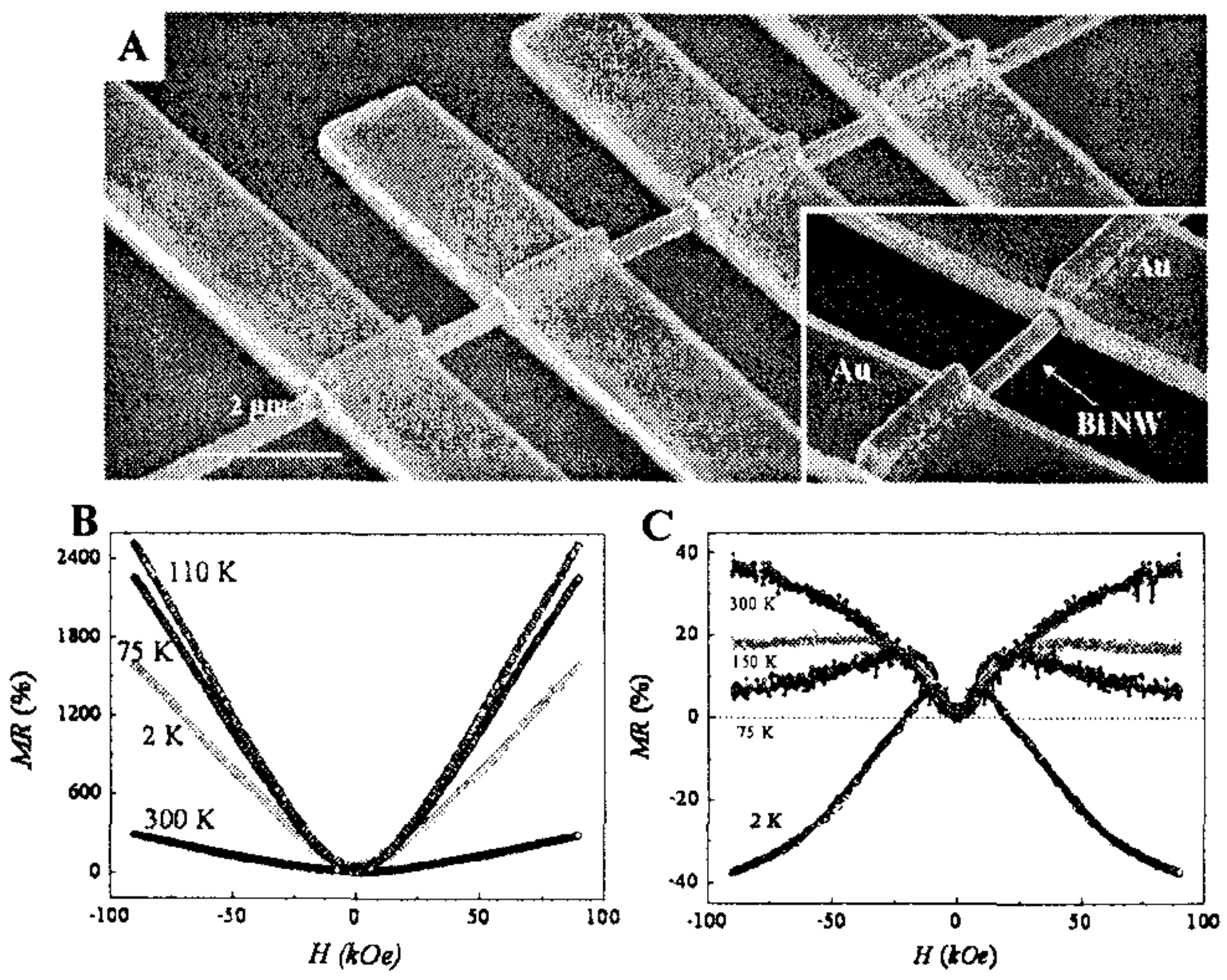

Fig. 1. (A) A SEM image of an individual Bi nanowire device. The OMR of the 400-nm-diameter Bi nanowire: (B) transverse and (C) longitudinal geometry.

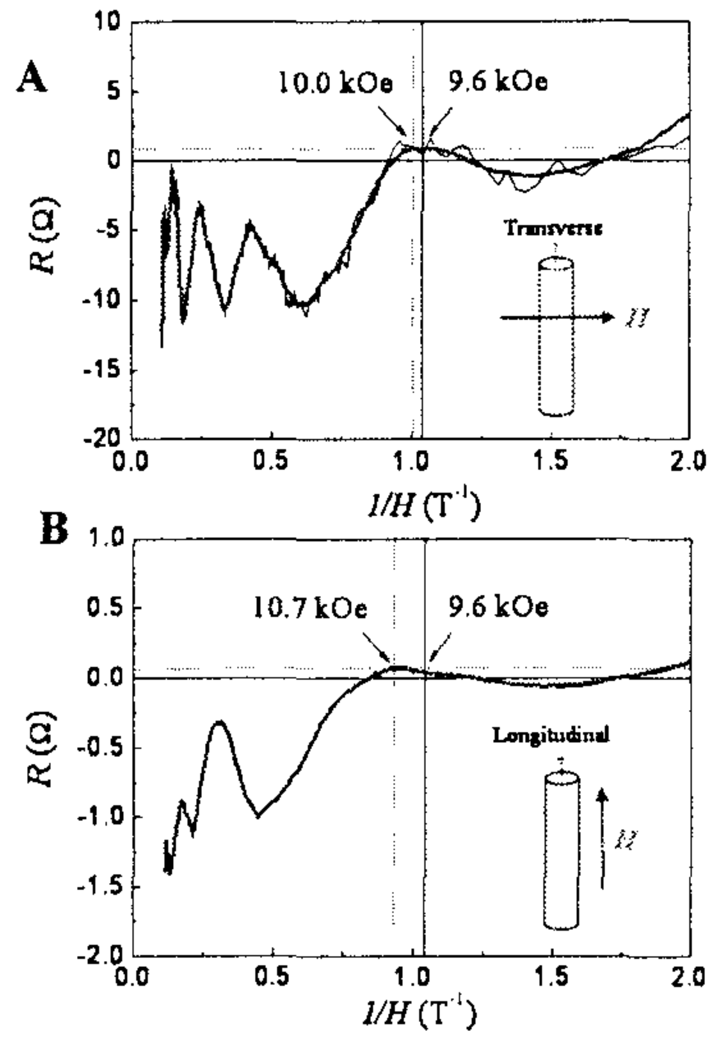

Fig. 2. SdH oscillations obtained by the external field of (A) transverse and (B) longitudinal to the wire axis.

References

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