The Periods of Shubnikov-de Haas Oscillations in an Individual Single-Crystalline Bi Nanowire Grown by On-Film Formation of Nanowires

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1. Introduction

Bismuth (Bi) is a particularly favorable material with which to study the electronic properties of quantum wires due to the small effective mass of carriers, low carrier concentrations and the anisotropic Fermi surface. These characteristics and the resonance of Landau levels lead to prominent Shubnikov-de Haas (SdH) oscillations that are periodic 1/H. The period of SdH oscillations are required to obtain quantitative information such as the charge density and the anisotropy of Fermi surface. However, it is expected that the period of oscillations can be varied by the spatial confinement in one-dimension. The electrostatic-field-effect (EFE) also modulates the charge carrier concentrations and the Fermi surface, resulting in change of period of SdH oscillations.

2. Experiment

The Bi thin film was deposited onto a thermally oxidized Si (100) substrate by a radio frequency (RF) ultra high vacuum (UHV) magnetron sputtering system at a base pressure of 4×10^{-8} Torr. And after annealing at 270℃ for 10 hours, we obtained single-crystalline Bi nanowires which were grown along the trigonal direction [00l]. Four-terminal individual nanowire devices were fabricated using the photolithography process. To obtain ohmic contact, the Bi oxide layer on outer surface of the Bi nanowire was removed by plasma etching system and Au electrodes were deposited in-situ by a DC UHV magnetron sputtering system. Fig. 1 (a) shows a scanning electron microscopy (SEM) image of a four-terminal device based on an individual single-crystalline Bi nanowire. To measure electrical properties at low temperature and high external magnetic field, we used physical property measurement system (PPMS) QUANTUM DESIGN. We measured magnetoresistance of the four-probe individual 400 nm diameter single-crystalline Bi nanowire at a range of $2 < T < 300$ K and $0 < H < 9$ T for the transverse (T) and longitudinal (L) geometries. The T geometry (L geometry) means that the magnetic field is applied perpendicular (parallel) to direction of nanowire.

3. Result & Discussion

In the present work, we report the observation of the modulated period of oscillations by the spatial confinement and EFE in an individual single-crystalline Bi nanowire. The SdH oscillations are periodic in 1/H with period of $\Delta(1/H) = 2\pi/\hbar cA$, which is inversely proportional to the extremal cross-sectional area A of the Fermi surface in the plane normal to H. We observed that the period of SdH oscillations in transverse (T) geometry is $\Delta(1/H)T$, h = 0.074 T-1, $\Delta(1/H)T$,e1 = 0.16 T-1, and $\Delta(1/H)T$,e2 = 0.77 T-1, which is in good agreement with those of Bi thin film and bulk Bi [2]. It is due to that there are three different A: AT, h from the holes, and AT, e1, AT, e2 from the electrons. In longitudinal (L) geometry, however all three electron

ellipsoids are equivalent, there are only two extremal cross sections AL, h and AL, e, and these are nearly the same, resulting in only one period similar to that of bulk was expected. However, it was found that the period of SdH oscillation in L geometry is Δ(1/H)L, h = Δ(1/H)L, e = 0.24 T-1, which is larger than the value of 0.16 T-1 and 0.24 T-1 reported for bulk Bi. This deviation may come from a misalignment of angle between the magnetic field and the nanowire axis of the Bi nanowire device.

4. Summary

We observed period of SdH oscillation in an individual Bi nanowire with the transverse and longitudinal magnetic fields along the axis of the nanowire grown by OFF-ON. Our results provide good qualitative description of the cyclotron behavior of the single-crystalline Bi nanowire in the ballistic regime.

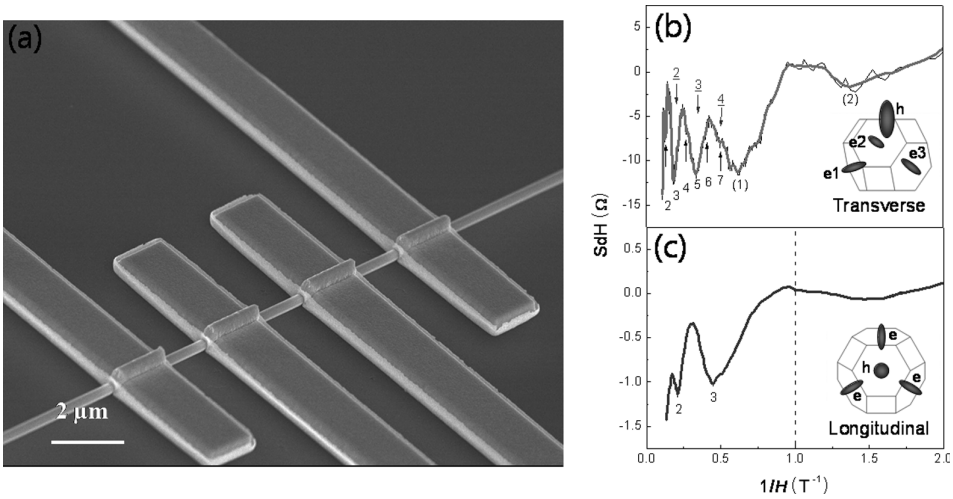

Fig. 1. Scanning electron microscopy (SEM) image of a four-terminal device based on an individual single-crystalline Bi nanowire (a) and Shubnikov-de Haas (SdH) oscillations, displayed as MR(measured)-MR(fitted), versus magnetic field in the (b) tansverse and (c) longitudinal geometries at 2K.

keyword: Bi, bismuth, nanowire, Shubnikov-de Haas