Evidence of Two-Dimensional Metallic Surface States in Bismuth Nanoribbons

W. Ning, F. Kong, C. Xi (HMFL, CAS), D. Graf (NHFML), H. Du, Y. Han, J. Yang, M. Tian, Y. Zhang (HMFL, CAS)

Introduction

Semimetallic bismuth is a fascinating material with low carrier density, small effective mass and long mean free path, which distinguishes it from other metals as particularly suitable for studying quantum phenomena. Recently, the surface states (SS) of Bi attracted a renewed interest due to its strong spin-orbital interaction and in relation to the Bi-based topological insulators. It was found that the surface of an ultrathin Bi film is quite distinct from the bulk semimetal but can be viewed as a quasi-two-dimensional (2D) metal with unique spin properties. Such metallic SS have been confirmed by angle-resolved photoemission spectroscopy (ARPES) and showed great interest on potential application in spintronics and the related fields. Unfortunately, the nature of the SS in bulk Bi remains unsolved, and there were no direct evidence of such 2D SS identified by electrical transport measurements although some previous transport data have been reported in Bi films or quasi-1D nanowires.

Experimental

Bi nanoribbons were synthesized by solvothermal method. The contact electrodes of four-probe devices were deposited by FEI NanoLab 600i SEM/FIB dual beam system. The angular-dependent magnetoresistance measurement at high magnetic field (~31 T) was performed using standard a.c. lock-in techniques in a He-3 cryostat inside of a DC-resistive magnet at the National High Magnetic Field Laboratory (NHMFL) at Tallahassee.

Results and Discussion

Figure 1 shows the MR versus magnetic aligned at different angles (θ) measured at 0.4 K for a nanoribbon with thickness of 50 nm. Periodic oscillations in 1/B and appearance of the maxima of the spectra marked by vertical dashed lines appear at the same $B_{\perp}$ for all angles provide direct evidence of a 2D character of the electronic states. Further analysis indicated that the obtained surface carries density and the effective mass in nanoribbons are much higher than the bulk semimetal but consistent with those in ultrathin Bi films estimated by the ARPES results.

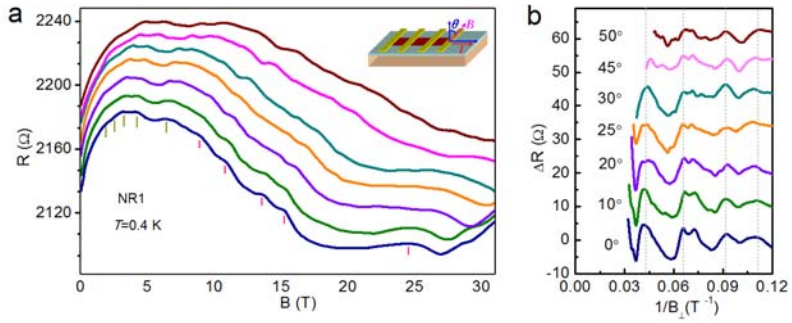

Figure 1(a) shows the resistance as a function of magnetic field at different tilt angle (θ) at 0.4 K. The inset is the schematic arrangement of four-probe technique for transport measurements of nanoribbon. (b) Amplitude of the SdH oscillations, ΔR, versus perpendicular component, $B_{\perp}=B\cos\theta$, of the applied magnetic field.

Conclusions

Through the angular dependent MR study, we have identified two sets of the SdH oscillations in thin nanoribbons due to the exact 2D metallic surface states. Our observations provide a promising pathway to understand the quantum phenomena arising from the surface states and develop the nanoscale electronic and thermoelectrics devices based on surface bands.

Acknowledgements

This work was supported by the National Key Basic Research of China, the National Nature Science Foundation of China and the Hundred Talents Program of the Chinese Academy of Science. Work at NHMFL was supported by NSF under Grant No. DMR-0654118, the State of Florida, and the U.S. Department of Energy.

References

[1] Behnia, K., *et al*., Science 317, 1729 (2007).
[2] Seradjeh, B., *et al*., Phys. Rev. Lett. 103, 136803 (2009).