Observation of Three-dimensional Behavior in Surface States of Bismuth Nanowires and the Evidence for Bulk Bi Surface-quasiparticles

T.E. Huber (Howard U.); A. Nikolaeva and L. Konopko (IIETI, Moldova); M.J. Graf (Boston College)

Introduction
The spin-orbit coupling on the crystal surfaces of bismuth (Bi) is strong enough to give rise to surface-state conduction bands that are spin split because of the lack of inversion symmetry. The effort aims at characterizing the surface conduction and the surface spin orbit coupling. Our proposed research is a collaborative effort to study the electronic transport under a magnetic field and the magnetic properties of nanowires of Bi and some of its alloys with Sb. In fine nanowires (diameter < 50 nm), these properties are related to the surface species because the quantum size effects are strong enough to depopulate the nanowires from the bulk-like carriers, electrons, and holes that are native to bulk (semimetallic) Bi.

Experimental
We fabricated the samples by employing a high-pressure, high-temperature injection technique that uses nanochannel dielectrics as a template structure to construct dense, massive composites consisting of arrays of nanowires with controllable diameters. The crystalline orientation is trigonal along the wirelength.

Results and Discussion
We studied Bi nanowires (30 nm < diameter < 200 nm) via low-temperature magnetotransport and investigated the Landau levels using the Shubnikov-de Haas method. We found a three-dimensional behavior, with a rich spectrum of Landau levels, in a nearly spherical Fermi surface of heavy carriers. The results for magnetic fields up to 14 T are shown in the Fig.1. Recent experimental studies of the Nernst thermopower effect, the Hall effect, and the magnetic susceptibility of bulk (large samples) Bi in the quantum limit (magnetic fields > 9 T), show peaks that have been interpreted in terms of charge fractionalization. However, the peaks magnetic energy (~1/B) that are observed, and the periods, match those observed in the Bi nanowires.

Conclusions
Based on the similarity of the periods, the peaks in the bulk Bi magnetotransport near the 9 T quantum limit, which had been attributed to charge fractionalization, can be more plausibly interpreted in terms of surface states. A quantum limit of about 70 T is predicted for the heavy mass carriers.

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References