**Multiple Fermi Surfaces in Superconducting Nb-doped Bi2Se3**

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**Introduction**

Topological insulator Bi2Se3 has shown a number of interesting physical properties. Doping Bi2Se3 with copper (Cu) or strontium (Sr) has been demonstrated to make the material superconducting and potentially even a topological superconductor [1]. However, direct experimental confirmation has not been realized and is controversial. The recent discovery of superconducting niobium (Nb) doped Bi2Se3 reveals an exciting new physical phenomenon, the coexistence of superconductivity and magnetic ordering. To understand this new phenomenon, a detailed knowledge of the electronic structure is needed. To date, the quantum oscillations needed to reveal this structure have not been reported in Nb-doped Bi2Se3. In this letter, we present the first observation of quantum oscillations in the magnetization (the de Haas-van Alphen effect) of Nb-doped Bi2Se3. In the fully superconducting crystal, two distinct orbits are observed, in sharp contrast to Bi2Se3, Cu-doped

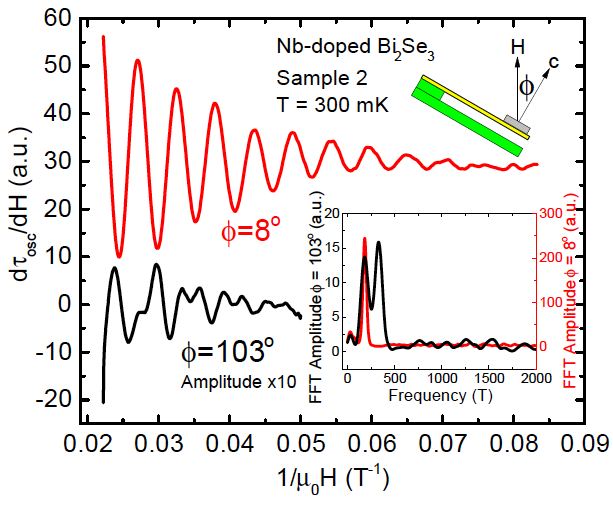
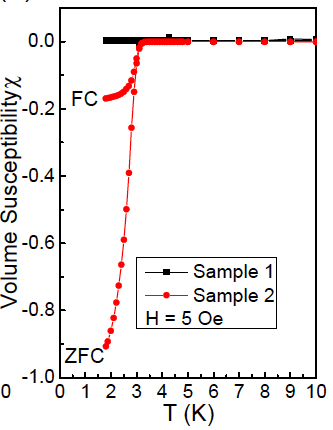
Bi2Se3, and Sr-doped Bi2Se3. [2].

**Experimental**

High-resolution torque magnetometry was used to measure the magnetic moment of the samples [3-8]. Torque is measured as the change of the capacitance between the metal cantilever and a nearby metal plate.

**Results and Discussion**

Our quantum oscillation results provide the map of the Fermi surfaces in Nb-doped Bi2Se3. In the superconducting sample, we observe at least two oscillation frequencies as field is in the Bi2Se3 plane.

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**Fig.1** (Left) Volume magnetic susceptibility of Nb-doped Bi2Se3crystals, measured in Zero-Field-Cool (ZFC) and Field-Cool (FC) conditions. Sample 1 is non-superconducting. For Sample 2, the Meissner effect in the ZFC condition reaches close to -1, indicating a nearly 100% superconducting volume. (Right) Derivative of oscillatory magnetic torque of superconducting Nb-doped Bi2Se3. The top curve in red is taken at tilt angle of magnetic field around 8o and shows one oscillation frequency. The lower curve in black is taken at tilt angle of magnetic field around 103o and shows 2 oscillation frequencies. The inset shows the Fast Fourier Transformation (FFT) traces.

**Conclusions**

The multiple frequencies observed in our quantum oscillations, combined with our electrical transport studies, indicate the multi-orbit nature of the electronic state of Nb-doped Bi2Se3. [2].

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