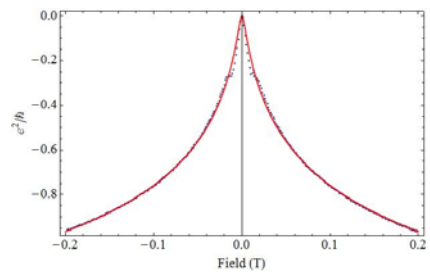
Search for Topological Phases in Ultrathin Sb Films

S.D. Cairns, N. Teasdale, S.Q. Murphy, C.K. Gaspe, T.D. Mishima, J.Keay, M.B. Santos (University of Oklahoma, Physics)

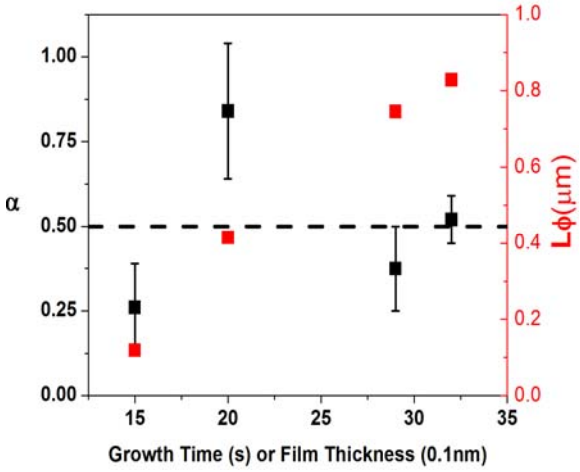
Introduction

Band structure calculations of elemental Sb indicate that the inherently large spin-orbit coupling enables topological insulator (TI) behavior [1]. TIs are a new class of materials that are electrical insulators in their bulk interior, but electrical conductors at their surfaces. These conducting surface states are topologically protected from elastic backscattering[2], unlike those found in ordinary electron systems. While the semimetallic states in bulk Sb preclude TI behavior, recently topo-electronic phase transitions in Sb films as a function of film thickness have been predicted[2]. A semimetal-to-3D TI transition induced by quantum confinement is expected at a critical thickness of ~7.8nm and a 3D TI-to-2D quantum spin Hall state transition at a critical thickness of ~2.7nm with a trivial semiconductor state for films thinner than ~1nm. The search for these topological phases has motivated our recent studies of atomically flat, ultra-thin Sb films.

Results and Discussion



We have developed a molecular beam epitaxy procedure to realize ultra-thin films of Sb with good crystalline quality on semi-insulating GaSb (111)A substrates. Our growth rate of 0.1nm/sec provides excellent control over final film thickness. High field transport taken in the 18T magnet system at the NHMFL (SCM-2) in tilted magnetic fields demonstrate that our Sb films ranging from 1.3 to 3.2nm behave two-dimensionally and that the transport is dominated by the Sb. The high field magneto-resistance evolves from a quadratic to linear behavior as the film thickness is reduced, a trend anticipated for a high density, low mobility system with linear dispersion.[3] in At lower fields, the magneto-transport indicate weak anti-localization (WAL) as evidenced by a strong resistance minimum at zero field (a necessary, but not sufficient condition indicating the presence of a TI.) The WAL behavior of a TI is expected to follow the conventional form predicted Hikami, Larkin and Nagaoka[4] albeit with infinite spin-orbit coupling (i.e. fully suppressed backscattering). This form provides an excellent fit to the Sb data (as shown above) with two fitting parameters (the phase coherence length and a pre-factor indicative of the number of channels contributing to the WAL). The phase coherence length decreases with increasing temperature as $1/T^{1/2}$ as expected for systems limited by electron-electron scattering. Analysis performed as a function of film thickness reveals the trends shown in the left panel. The phase coherence length (red squares) decreases linearly with film thickness, while the prefactor α shows a peak near the value of 1 (expected for two uncoupled TI surface states) at a film thickness of 2nm. The trend is consistent with TI surface states for films>2nm which are coupled by bulk states. Those bulk states are sufficiently quantum confined at 2nm such that the surface states are uncoupled. For films as thin as 1.5nm the surface states interact spatially and a gap opens. Work is ongoing to increase the film mobility and to lithographically fabricate 1D wires to study quantum interference effects.



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References

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