The Magnetic Susceptibility Bifurcation in the Ni-Doped Sb_2Te_3 Topological Insulator with Antiferromagnetic Order Accompanied by Weak Ferromagnetic Alignment

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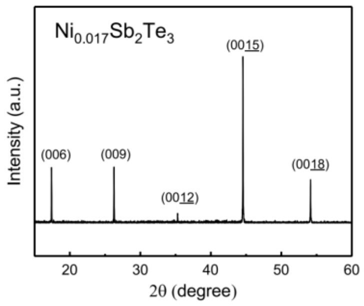
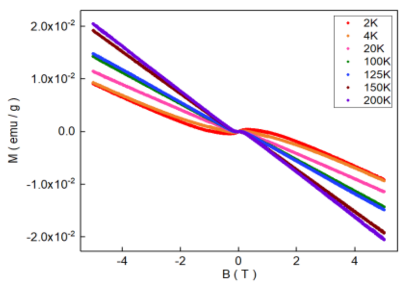
Background

- Introducing magnetism in topological insulator can break time-reversal symmetry and opens a gap of Dirac surface state. The Dirac fermion in the surface state becomes massive and leads to many interesting properties, such as quantum anomalous Hall effect, topological magneto-electric effect , tunability of chiral edge mode and Majorana braiding.
- Many experimental works were performed in Mn, Cr, and V-doped $(Bi, Sb)_2Te_3$ thin films to realize the theoretical prediction, and rare work study in the magnetic element-doped topological insulator.
- The magnetic properties of $Ni_{0.017}Sb_2Te_3$ was studied, and it reveals the antiferromagnetic order accompanied by weak ferromagnetic alignment.

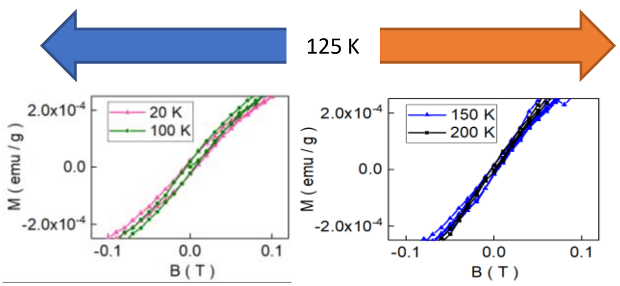
Results and Discussions



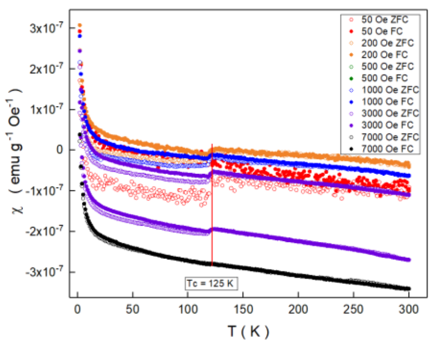
- The XRD spectrum of the $Ni_{0.017}Sb_2Te_3$ single crystal. It reveals sharp peaks and that supports the highly single-crystallized structure



- The susceptibility as a function of magnetic fields from 2 to 200 K. It reveals the diamagnetism at high magnetic fields.



- The hysteresis loops were observed at temperature below 125 K while no hysteresis loops were observed at temperature above 125 K.
- The coercivity is about 50 Oe, the remanent and saturated magnetization is 10^{-5} emu/g and 10^{-4} emu/g at 100 K. These value are related small to a ordinary ferromagnetism materials.

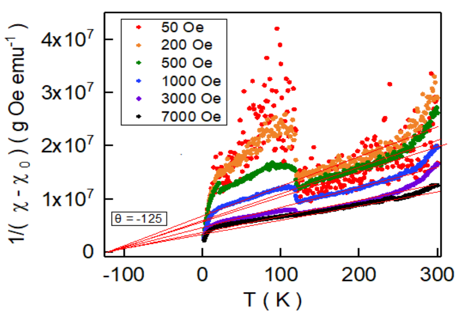


- The magnetic susceptibility of field cooled and zero-field cooled processes at different external magnetic fields coincides above 125 K and bifurcates below 125 K.
- A large magnetic susceptibility splitting was observed 50-7000 Oe external magnetic fields undern temperatures of 0-125 K and temperatures. No more magnetic susceptibility splitting is observed at magnetic field above 7000 Oe.

The Curie-Weiss law state that

$$\chi = \chi_0 + \frac{C}{(T-\theta)}$$

χ : magnetic susceptibility
χ_0: the magnetic susceptibility at 0 K
C : Curie constant that is corresponding to the Bohr magneton
T : temperature
$\theta > 0$: Curie temperature in ferromagnetism state, T_C.
$\theta < 0$: Néel temperature in anti-ferromagnetism state, T_N.

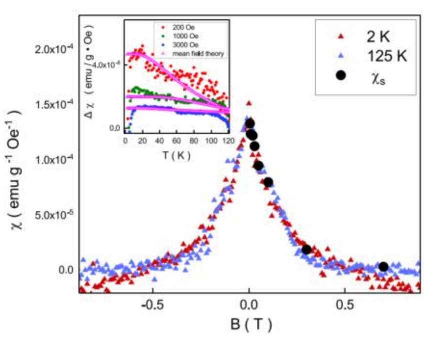


- The fluctuation signal under 50 Oe is more obviously which may correspond to the coercivity fields and the magnetic moment might have meta state under 50 Oe.
- The $\theta = -125$ indicates the antiferromagnetism structure appear below Néel temperature, 125 K.
- It show the paramagnetism at temperature higher than the Curie temperature.
- Following the Langevin paramagnetic function show below.

$$C = \frac{N\mu_0\mu^2}{3k_BT}$$

N: number of magnetic elements per unit gram
μ: effective moment of a magnetic element
μ_0: vacuum permeability
k_B: Boltzmann constant

- The estimated μ at 200 Oe is about 3.5 μ_B that is closed to the theoretical value of 3.32. This confirms that magnetism behavior could be explained by the Curie-Weiss law.



- The extracted saturated magnetic susceptibility, χ_S, fit well with the paramagnetic cusp in low field and the susceptibility splitting changing with temperature.

The bifurcation of FC (field cool) and ZFC (zero field cool) might be origin from the partial polarize weak ferromagnetism and induce the magnetic anisotropy energy, MAE.

Fallow the mean field theory below.

$$T_N = \frac{S(S+1)}{K_bT}J_0$$

T_N: Néel temperature
T : temperature
S : spin moment
J_0 : exchange coupling strength,

- The magnetic moment could be expressed as $M \propto e^{\frac{-J_0S}{K_bT}}$, and the magnetic susceptibility is $\chi = \chi_S(1 - e^{\frac{-J_0S}{K_bT}})$. Thus, the magnetic susceptibility splitting can be expressed as the equation below.

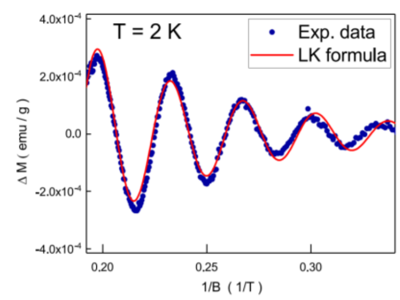
$$\chi_{FC} - \chi_{ZFC} = \chi_S e^{\frac{-J_0S}{K_bT}}$$

The splitting no longer be observed under 7000 Oe. This splitting value of susceptibility is related to the magneto crystalline anisotropy energy, MAE.

$$\Delta E = \frac{M_SH_CV}{2}$$

M_S: saturation magnetization
H_C: coercivity fields
V : sample volume.

- The estimated MAE value can be translated to the magnetic moment energy, $g\mu_B B$. The corresponding magnetic field is 0.61 T. This can explain the merging of susceptibility under 7000 Oe.



- The dHvA oscillations as a function of inverse magnetic fields.
- The experimental result fits well with the Lifshitz-Kosevich formula. The extracting value of berry phase factor, δp=0.43. Also, the fermi wave vector, K_f is consistent with our ARPES result. These results suggest that the dHvA oscillations originate from the topological surface state.

Conclusions:

- The magnetic susceptibility reveals a kick at T_N that is independent of the external magnetic field. The magnetic susceptibility of ZFC and FC processes are coinciding above the T_N, and they are bifurcation below T_N. The magnetic susceptibility splitting is larger at a lower external magnetic field. No more splitting is observed when the MAE is lower than the magnetic moment energy at 0.7 T.
- The extracted χ_S goes well with the tendency of the measured magnetic susceptibility cusp. This indicates that the widely observed susceptibility cusp might originate from the weak ferromagnetism.
- The observed dHvA oscillation comes from the topological surface state.