Experimental report

08/06/2016

Proposal: **5-42-388** **Council:** 10/2014

Title: Topological superconductivity in Sn-In-Te

Research area: Physics

This proposal is a new proposal

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Samples: Sn0.9In0.1Te0.1

Instrument	Requested days	Allocated days	From	To
D22	4	0		
D33	4	4	14/07/2015	18/07/2015
D11	4	0		

Abstract:

Recently materials with topologically protected states have become an area of intense research. Here we propose to investigate the vortex lattice (VL) in the topological superconductor Sn-In-Te. Based on symmetry arguments, the superconducting in this material may be described by four types of momentum-independent gap functions with different internal spin and orbital structures. We will used SANS studies of the VL provide information about the order parameter in Sn-In-Te.

Experiment Summary for Proposal 5-42-388: Topological Superconductivity in $Sn_{0.9}In_{0.1}Te$

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INTRODUCTION

This experiment was an exploratory SANS study of the vortex lattice (VL) in the theorized topological superconductor $Sn_{0.9}In_{0.1}Te$. The experimental goal was primarily to confirm the presence of a well-ordered VL, as well as identify its symmetry and order parameters as functions of magnetic field and temperature.

EXPERIMENT DETAILS

The experiment was performed on the D33 beam line at the ILL using the standard SANS configuration. The specific instrument settings used for the experiment are listed in Table I.

Sample Mount and Alignment

Crystals of $Sn_{0.9}In_{0.1}Te$ were obtained from Athena Sefat and were characterized by x-ray Laue and neutron scattering at the Paul Scherrer Institute by M. R. Eskildsen and D. Mazzone. Two-fold (110), four-fold (100), and six-fold (111) symmetry axes were obtained through a simple rotation about the (110) direction. These symmetry axes and their relative angular positions can be seen in Fig. 1. The sample was glued with a mixture of Bostick and acetone to an aluminum plate that had been designed with a small bend such that the (110) symmetry axis is parallel to the top portion of the plate, see Fig. 2a. This was then securely clamped to the sample holder at the top, unbent portion of the plate. From this and the $Sn_{0.9}In_{0.1}Te$ symmetry axes, it was easy to move perpendicular to any of the desired faces.

Because it was unknown whether or not $Sn_{0.9}In_{0.1}Te$ would exhibit an observable VL, a well-characterized type-II superconductor was necessary for alignment. The $Sn_{0.9}In_{0.1}Te$ sample, the alignment sample, and the sample plate can be seen in Fig. 2b. By aligning with the known sample, the bent face of the aluminum plate was oriented normal to the beam. This was then attached to the end of a sample stick and inserted into a dilution refrigerator.

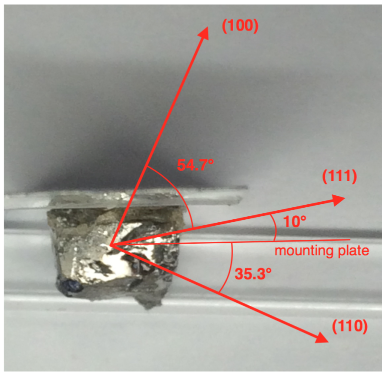


FIG. 1: $Sn_{0.9}In_{0.1}Te$ crystalline symmetry axes, as determined experimentally with x-ray scattering at the Paul Scherrer Institute.

Parameter	Value
Wavelength (λ)	6, 9 $\AA$
Temperature	50 mK
Collimation	12.8 m
Detector 1 Distance	1.2 m
Detector 2 Distance	13 m
Source Aperture	30 mm
Sample Aperture	5, 4 mm

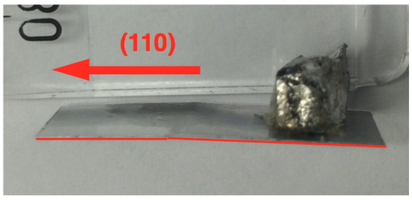
TABLE I: D33 Instrument Settings

Searching for the Elusive Bragg Peak...

Various crystalline symmetry axes, magnetic fields, and wavelengths were explored, which are summarized in Table II. At some of these configurations, potential Bragg peaks were identified. When examined further, the peaks did not behave as expected for a VL Bragg peak, and no convincing rocking curves were obtained. For example, a potential peak was identified at 0.1 T, see Fig. 3. When the field was then increased to 0.2 T, the peak remained at the same $\vec{q}$, indicating the original peak was just a background fluctuation.

SCIENTIFIC AND TECHNICAL DIFFICULTIES

There was a sizable small-angle scattering background consisting of long streaks along the horizontal and ver-



(a)

(b)

FIG. 2: (a) Detail of the bend in the aluminum plate for alignment. (b) The single-crystal $Sn_{0.9}In_{0.1}Te$ sample mounted between two cadmium strips on an aluminum plate. Above the top cadmium strip, an additional type-II superconductor was mounted for alignment purposes. The aluminum plate simply screws into the actual sample holder.

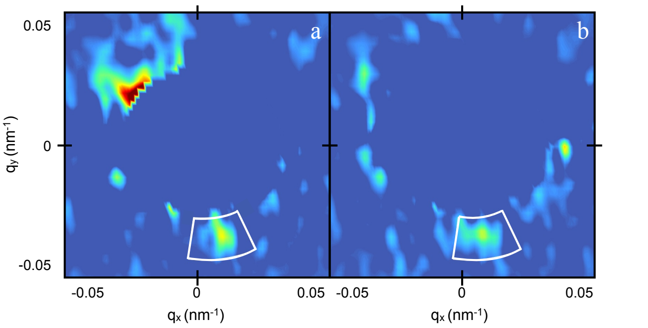


FIG. 3: Comparison of the "Bragg Peak" location with a field of 0.1 T (a) and 0.2 T (b) along the (111) symmetry axis. The peak location did not change with increasing field, indicating this was not an actual Bragg peak. The integrated intensity from the 0.1 T background fluctuation was used to put a lower limit on the penetration depth.

Sym. Axis	Magnetic Field (H)	Wavelength (λ)	VL Ordering Method	Sample Aperture
(100)	0.3 T	6 $\AA$	FW	5 mm
	0.1 T	9 $\AA$	FW	5 mm
(111)	0.1 T	9 $\AA$	FW	4 mm
	0.1 T	9 $\AA$	FW & FC	4 mm
	0.2 T	9 $\AA$	FW	4 mm
(110)	–	–	–	–

TABLE II: The experimental parameter space. For the VL Ordering Method, FW indicates a field wiggle and FC indicates a field cool.

tical axes of the detector. This complicated the background subtraction and made it difficult to distinguish potential Bragg peaks from background fluctuations. Things were further complicated by the strong neutron absorption cross-section of Indium. At operating wavelengths, it was estimated that only (62 to 49)% of the neutron beam was transmitted.

Additionally, there was an unexpected power surge on 7/14 which caused the reactor to shut-down briefly. As the reactor restarted, the power was not consistent. Normally this is not an issue, but as there was no monitor on D33, finding a suitable normalization for both the foreground and background was rather difficult. Fortunately, the reactor returned to full power later that evening.

CONCLUSIONS

In conclusion, no definitive indications of a vortex lattice were observed in the topological superconductor $Sn_{0.9}In_{0.1}Te$. While we are unable to conclusively eliminate the possibility of a vortex lattice, we can certainly say the scattering intensity from such a lattice must be well below the background.

A lower limit on the penetration depth (λ) based on this experimental data (or lack thereof!) can be found using the London theory form factor corrected for the non-zero extent of the vortex cores [1]:

$$|h| = \frac{B}{1+\lambda^2 q^2}\; e^{-c*\zeta^2 q^2} \tag{1}$$

where h is the form factor, B the magnetic field, q is the scattering vector, c is a constant typically taken to be $\frac{1}{2}$, and ζ is the coherence length. The form factor can be calculated from the reflectivity (R) [1]:

$$R = \frac{2\pi\ \gamma_n^2}{16\ \phi_0^2}\ \frac{t\ \lambda^2}{q}|h|^2 \tag{2}$$

where γ_n is the gyromagnetic ratio of the neutron, ϕ_0 is the magnetic flux quantum, and t is the sample thickness. From these equations and the background fluctuation shown in Fig. 3, $h = 1.30 \times 10^{-4}$ T and $\lambda(0) = 550$ nm for $Sn_{0.9}In_{0.1}Te$. For a more conservative estimation of the penetration depth, the core cutoff term in Eq. 2 should be ignored, giving $\lambda(0) = 630$ nm. The penetration depth for a slightly different doping level, $Sn_{0.6}In_{0.4}Te$, was estimated to be $\lambda(0) = 860$ nm from the upper critical field temperature dependence [2].

There are many possible reasons for why this experiment failed to see a VL. The VL may not have been ordered enough to see strong Bragg peaks, the peaks could have been obscured by the considerable background, or $Sn_{0.9}In_{0.1}Te$ may not be a bulk superconductor. Regardless, $Sn_{0.9}In_{0.1}Te$ is not a suitable sample for SANS.

[1] Gannon, W. J. et al. Nodal Gap Structure and Order Parameter Symmetry of the Unconventional Superconductor UPt_3. New J. Phys. 17 (2015) 023041.

[2] Balakrishnan, G. et al. Superconducting Properties of the In-substituted topological crystalline insulator SnTe. Phys. Rev. B 87, 140507(R) (2013).