# High-field Study of Superconducting Thallium Doped Lead Telluride ($Pb_{1-x}Tl_xTe$)

Giraldo-Gallo, P. (Stanford University, GLAM and Physics); Riggs, S. (NHMFL); McDonald, R. (LANL); Fisher, I.R. (Stanford University, GLAM and Applied Physics)

## Introduction

PbTe is a narrow-band gap semiconductor. Pb vacancies and/or Tl or Na doping place the Fermi level in the valence band, yielding a degenerate semiconductor with low carrier densities. For Tl concentrations above a critical value $x_c$~0.3%, the material superconducts, with a maximum transition temperature of 1.5K, unusually high given the low carrier density. The Na-doped compound does not superconduct for any concentration. This critical Tl concentration coincides with the appearance of anomalous normal state transport properties that were previously interpreted as evidence for a novel charge Kondo effect associated with charge fluctuations of the Tl impurities. Our Magnet Lab proposal was aimed at obtaining a better understanding of the evolution of the Fermi surface of $Pb_{1-x}Tl_xTe$ through the threshold Tl concentration, in order to provide a much better basis for interpreting the doping effect of Tl-impurities in PbTe, and perhaps the anomalous normal state properties, too.

## Experimental

In this proposal, we have used different techniques to perform measurements in $Pb_{1-x}Tl_xTe$ and $Pb_{1-x}Na_xTe$, in order to fully map the Fermi surface of these compounds: Frequency shift in a proximity detector oscillator (PDO) for samples with Tl concentrations ranging from x=0 to x=1% (Pulsed Facility, 65T magnet); transport measurements (Hall effect and magnetoresistance) for samples with Tl concentration from x=0 to x=1%, and a similar range of Na concentrations (DC facility, 35T magnet). We performed full angle dependence measurement for selected Tl and Na doped samples with compositions above and below the critical concentration of $x_c$=0.3% (for Tl). Through these measurements, we have obtained a complete study of the Fermi surface for a wide range of Tl and Na compositions.

## Results and Discussion

For all the compositions studied we were able to observe Shubnikov-de Haas (SdH) oscillations, and for the low and intermediate doping regime, we were able to determine the area of the Fermi surface and the effective mass of carriers along the [100] direction. For both, Na and Tl doping, we observe a clear evolution of the L-pockets cross-sectional area as we rotate along two different planes (Fig. 1(a) and 1(b)), and the total size of these pockets as we increase doping (Fig. 1(c)). Additional features are observed in the Fermi surface for high Tl and Na compositions. For $Pb_{1-x}Tl_xTe$ the size of the L-pockets, increases rapidly with Tl concentration, and then saturates for compositions above the critical concentration of $x_c$=0.3%, whereas for Na, it keeps increasing for all the concentrations studied (Fig. 1(c)).

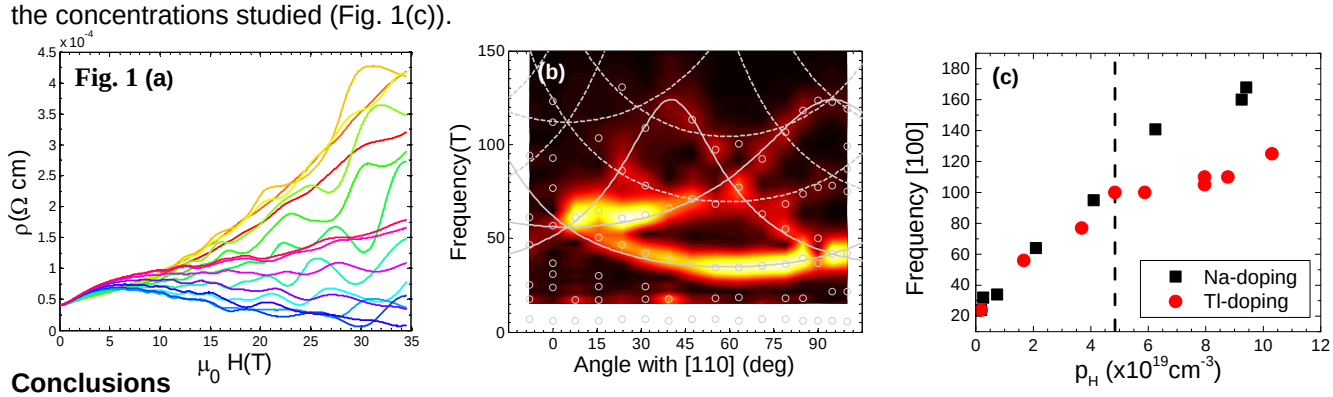


**Fig.1 (a)** SdH Oscillations in magnetoresistance of a sample with Tl concentration of x=0.2%, for different field orientations in a [110] plane. **(b)** Evolution of the frequencies of oscillation along a [110] plane, for the sample shown in (a). **(c)** Frequency of oscillation along the [100] orientation, as a function of hall number, for Na and Tl-doped PbTe.

## Conclusions

SdH measurements reveal the details of Fermi surface of both, Tl-doped and Na-doped PbTe. The size of the L-pockets with dopant concentration is qualitatively different for both compounds above the carrier concentration for which the Tl-compound superconducts.

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