

Classical Linear Magnetoresistance in Polycrystalline InSb

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Abstract

Polycrystalline Indium antimonide exhibits a linear magnetoresistance which is qualitatively similar to the magnetoresistance of lightly doped, single-crystal InSb at low temperatures. Unlike the single-crystal case, magnetoresistance in polycrystalline InSb is a purely classical effect. The irregular current paths found in polycrystalline InSb force current into unfavorable alignments with an applied voltage, resulting in linear magnetoresistance. Recent measurements established this effect in polycrystals up to 350 K. [1] This paper extends the magnetoresistance measurements up to the melting point of InSb at 800 K. The linear magnetoresistance is observed over the whole range from 350 K to 800 K, and in fact increases as the temperature increases.

1 Introduction

The linear magnetoresistance of polycrystalline InSb is due to its inhomogeneous structure. In order to prepare the polycrystals, pure single-crystal InSb is ground into a fine powder, with an average grain size of 10-20 μm . These grains are then formed into a polycrystal with droplets of Sb along the grain boundaries serving as the inhomogeneities. These inhomogeneities cause the current paths in the polycrystal to misalign with an applied voltage. This flow perpendicular to the applied voltage results in a significant contribution to the resistance from the Hall resistance, which is proportional to the magnetic field. Mathematically, this is represented by the introduction of off-diagonal elements dependent on the magnetic field in the resistivity tensor. This misalignment is then at the root of the observed linear magnetoresistance in InSb.[2]

2 Methods

The successful execution of this project required the construction of two devices, one great and one small. In order to attach leads to the polycrystals conducting Ti/Au pads must be deposited in an E-gun evaporation unit. To make this process streamlined and uniform, a simple mask was designed that allows the deposition of 5 top leads on 3 separate crystals. The crystals are recessed into ‘pockets’ in order to keep them stationary during the evaporation. The mask is made out of aluminum 0.041 *in* thick, and the pockets are about 0.030 *in* deep, leaving the Ti/Au about 0.01 *in* of aluminum to pass through. If the holes for the contacts were too small, it is possible that shadow effects around the edges of the holes could be a problem. However, the evaporation source is nearly 30 *cm* from the crystal, and the holes in the mask are 0.5 *mm* across, so shadow effects are minimal.

The final mask was designed to ensure uniform current distribution across the sample. A uniform current distribution makes resistivity calculations more credible, since a better estimate of the effective area and length over which the current is traveling can be obtained.

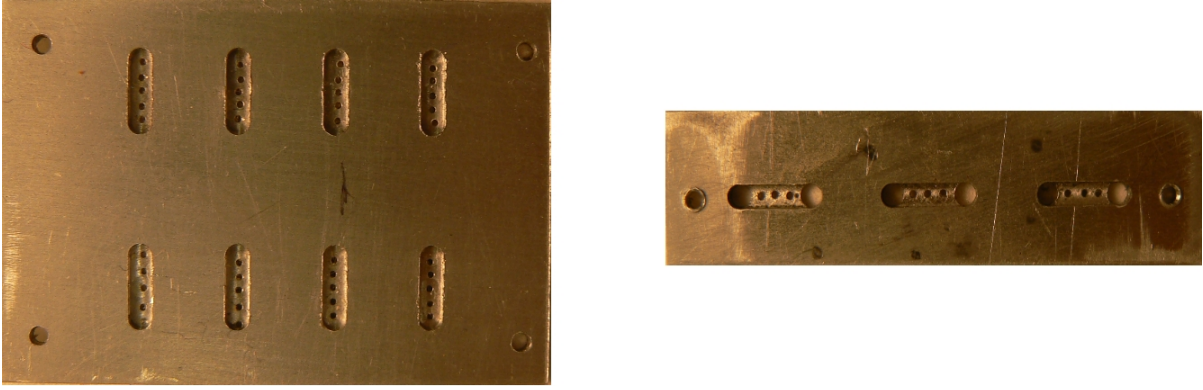


Figure 1: Left: first mask made for evaporating Au/In contact pads. Right: final mask with enlarged current contacts to ensure more uniform current distribution

Crystals were cut from a 1 *mm* thick wafer into rectangles 5 *mm* long and 1 *mm* wide. These cut crystals fit securely into the pockets and are held in place by a backing plate of aluminum which is screwed into the mask. The evaporation takes place in two steps: the first evaporation deposits 40 Å of titanium (which makes good contact with InSb) on the surface, and the second evaporation deposits 250 Å of gold.

A spot-welder is then used to attach gold leads to Ti/Au pads. Care must be taken to correctly adjust the duration and magnitude of the voltage pulse to avoid sparking, which destroys the sample surface.

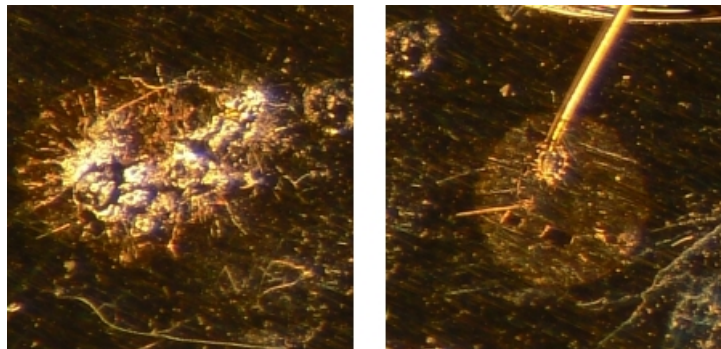


Figure 2: Left: A contact pad damaged by sparks from the spot-welder. Right: An undamaged contact pad with gold wire.

The greater design challenge came in the form of a heated sample stage capable of reaching 800 K. This sample stage had to maintain a temperature stable enough for measurements, yet be immersed in a helium-3 refrigerator in order to access the high magnetic field therein. The temperature of the stage is PID controlled with a resistor supplying heat to the stage and a thermocouple measuring the temperature. The sample stage is mounted inside a double vacuum can to thermally isolate the stage from the surrounding helium.

Upon completion of the heated sample stage magnetoresistance measurements were taken up to 14 Tesla in a Kelvinox helium-3 refrigerator. The resistance of the sample was measured with a standard 4-point lead configuration in a transverse magnetic field.

3 Results

The magnetoresistance of polycrystalline InSb continues to be linear above 350 K up to the melting point at 800 K. Figure 1 shows the percentage deviation from the zero-field resistance as a function of

magnetic field for several temperatures. The magnetoresistance continues to increase with T throughout the temperature range, indicating that the physics behind the magnetoresistance between 350 K and 800 K is likely the same as the physics between 200 K and 350 K.

References

- [1] J. S. Hu and T. F. Rosenbaum. Classical and quantum routes to linear magnetoresistance. *Nature Materials*, 7, 2008.
- [2] M. M. Parish and P. B. Littlewood. Classical magnetotransport of inhomogeneous conductors. *Physical Review B*, 72(094417), 2005.