Anisotropic Magnetoresistance of Cobalt Thin Film

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The anisotropic magnetoresistance (AMR) of a 400 Åpolycrystalline thin-film of Cobalt deposited of Silicon was measured in magnetic fields of -10 kOe to 10 kOe. The magnetic fields were oriented in a longitudinal (parallel), transverse (in-plane of sample), and polar (out of plane) to the current in the sample. At the same time the sample is subjected to temperatures of 100 K, 200 K, and 300 K. A Physical Property Measurement System (PPMS) measured the Co-films transport properties. The longitudinal resistance was up to 7353.49% larger than the transverse resistance and 7320.29 % larger than the polar resistance due to the greater electron-scattering in the conduction band of the crystal. Increasing temperatures provided greater electron-scattering and greater resistance. The resistance became field intensity independent only after a few hundred Oe and the longitudinal sample reached its constant resistance value due to magnetization saturation quicker than the polar sample, which reached it quicker than the transverse resistance.

I. INTRODUCTION

In 1879, E. H. Hall stated if the current of electricity in a fixed conductor is itself attracted by a magnet, the current should be drawn to one side of the wire, and therefore the resistance experienced should be increased leading to the idea of magnetoresistance. Applications of thin-film Anisotropic magnetoresistance (AMR) range from electronic cellphone compasses to automotive magnetic sensors that detect quantities like angular speed of wheels for driver safety to man-made planetary satellites. Thin-films are accurate magnetic sensors, allow a contactless method for measuring mechanical quantities such as angular speed of steering wheels, and are inexpensive to manufacture in bulk. The myriad of applications force thin films to be utilized in environments with varying temperatures, different magnetic field intensities, contrasting distances, and wavering degrees of angular precision. These necessities require specific transport properties of a thin-film such as AMR properties and temperature-dependent resistance.

II. THEORY

A. Resistance Due to Magnetic Field

AMR is a form of electrical resistance dependent on the angle between the current in the body and the orientation of the magnetic field the body is subjected to. In the presence of a magnetic field, electrons excited in the conduction band experience a smaller mean free time between collisions or electrical resistance. This scattering frequency is higher for electrons moving parallel with the applied magnetic field. The relationship between AMR and the relative angle of Magnetization to the current is given by

$$R = R_0 - \Delta R_i sin^2\theta_i \tag{1}$$

R is the total resistance of the body of metal. R_0 is its longitudinal resistance. ΔR_i is the change in resistance due to the presence of the magnetic field. θ_i is the angle between the current of the system and magnetization. A longitudinal magnetic field leaves only the R_0 component and gives the sample the greatest resistance, while the transverse and-or polar magnetic field (90 $^\circ$) drops the total resistance by the total magnetic field resistance. The percent change in resistance between different magnetic field orientations

$$\begin{aligned} \% &= (R_i - R_j)/R_j \\ i,j &= polar, transverse, longitudinal \end{aligned} \tag{2}$$

B. Temperature Effects on Resistivity

Rising temperature increases the thermal vibrations in the lattice. This increase interferes with conduction electrons causing greater electron-scatter frequency. Electron drift velocity slows from the electrical energy transfer to the atoms and resistance rises. For temperatures above 15 K, the resistivity is limited by atomic thermal vibrations. The overall relationship is expressed as

$$\rho = \rho_0(1 + a_0(T - T_0)) \tag{3}$$

, where P_0 is the resistivity at the reference temperature, a_0 is the temperature coefficient of resistance, and T is the temperature. The resistivity is linearly proportional to the temperature for metals.

C. Magnetic Hysteresis Effect on Resistance

Ferromagnetic elements, such as Cobalt, develop permanent magnetization when exposed to magnetic fields. Applying a magnetic field forces the atomic dipoles in the crystal to align themselves to the field. The magnetization increases until it reaches saturation. After the metal has reached magnetic saturation there is no longer an increase due to the increasing applied magnetic field. This explains the spikes in the Resistance-Magnetic Field curves and their asymptotes.

III. EXPERIMENT

The Cobalt film was deposited onto a silicon substrate using DC-magnetron sputtering at room temperature. The base pressure of the deposition chamber was about $2.0x10^{-7}$ Torr. Before the deposition, the substrate was chemically cleaned using acetone and methanol. Argon (Ar) pressure during the sputtering was 1.5 mTorr. The sample was mounted onto the resistance sample bridge holder board (part number 3084-371) with wires using indium and an N-grease. Then the sample bridge was incorporated into the horizontal rotator option of the PPMS. The sample was rotated manually to achieve polar (out of plane), longitudinal (parallel), and transverse (in-plane of sample) magnetization to the current. The PPMS MultiVu software was utilized to run a resistance sequence under a range of temperatures, magnetic field intensities and orientations. There was a 100 μA current run through the sample during this sequence.

Orientation	$\vec{H}$-Field Range	Temp. Range (K)
Longitudinal	-10 to 10 kOe	10 to 300
Transverse	-10 to 10 kOe	10 to 300
Polar	-10 to 10 kOe	10 to 300

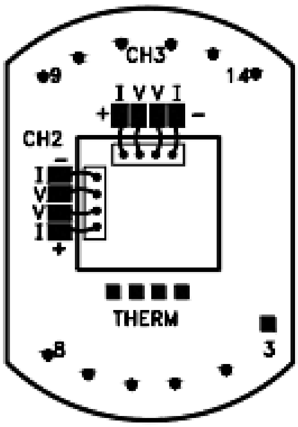

FIG. 1: Resistance Sample Holder Board with wires connected to two samples

IV. RESULTS AND ANALYSIS

A. Temperature

The polar, transverse, and longitudinal resistances of the Co-film rises with an increase in temperature. The largest increase occurs from 100 to 200 °K for the MR_t (transverse resistance), MR_p (polar), and MR_l (longitudinal). All three resistance seem linearly proportional to the temperature, but we must take more data points over a more continuous range of temperatures to confirm the theoretical prediction. This dependence on temperature

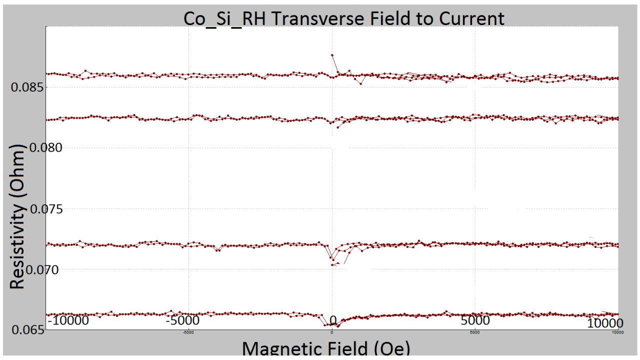

FIG. 2: Low-field transverse resistance of a 400 ÅCo-film at varying temperatures 10, 100, 200, and 300 K. On average the respective resistances are 0.065 Ω, 0.070 Ω, 0.082 Ω, and 0.086 Ω.

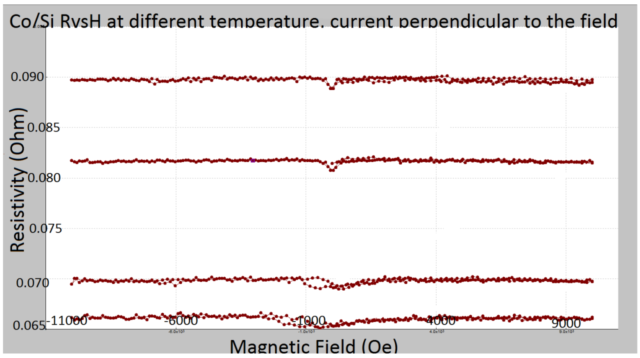

FIG. 3: Low-field polar resistance of a 400 ÅCo-film at varying temperatures 10, 100, 200, and 300 K. On average the respective resistances are 0.065 Ω, 0.069 Ω, 0.081 Ω, and 0.090 Ω. The respective changes to the transverse resistances are 0.0 %, 1.43 % increase, 1.22 % decrease, and a 4.65 % increase.

is similar to that obtained [3] and points to charge-carrier scattering due to a decrease in mean free path between collisions from defects or from an increase in lattice vibrations in the crystal from rising temperature.

B. Magnetic Field

The transverse and longitudinal resistances grows with an increase in Magnetic field for the first few 100 Oersteds. This is due to the magnetization of the sample saturating. The resistance approaches a constant consistent with predictions of low-field AMR from the Semiclassical Model of Electron Dynamics [1]. The model predicts high-field AMR will grow without limit with increasing magnetic field. Data points over a range incorporating both low and high-fields may confirm said prediction. My data does not show a continual increase in resistance with an increase in Magnetic field [3]. Additionally, the longitudinal resistance has significantly greater resistance values and shows greater independence of the field intensity than the transverse and polar resistance. The

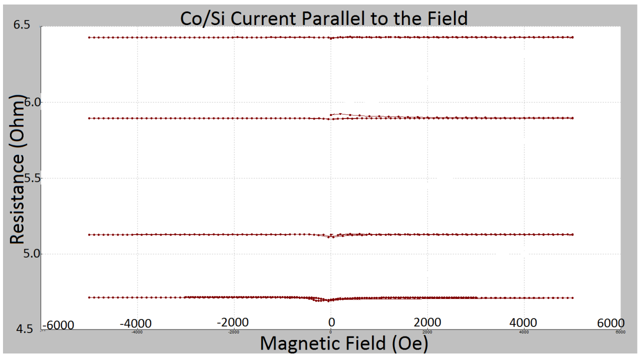

FIG. 4: Low-field longitudinal resistance of a 400 ÅCo-film at varying temperatures 10, 100, 200, and 300 K. On average the respective resistances are 4.17 Ω, 5.12 Ω, 5.91 Ω, and 6.41 Ω. The respective changes to the transverse resistances by temperature are 6315.38 %, 7214.285 %, 7107.32 %, and 7353.49 %. The respective changes to the polar resistances are 6314.38 %, 7320.29 %, 7196.30 %, and 7022.22 %.

polar and transverse resistances do not have enough of a distinction to claim a difference between them. Also, the properties of the Cobalt-Oxide/Cobalt interface may have affect some results due to the relatively small thickness of the thin film. Transport properties of both thicker and thinner Co-film samples may be examined to realize the effects of the interface on the resistances.

C. Magnetic Hysteresis

Magnetic saturation occurs more rapidly at 200 K than 10 K. Additionally, when the sample reaches saturation magnetization for either temperature the increase in resistance begins to slow down.

V. CONCLUSION

The transverse, polar, and longitudinal resistances at10 K, 100 K, 200 K, and 300 K for a 400 ÅCo thin-film are respectively 0.065 Ω, 0.070 Ω, 0.082 Ω, and 0.086 Ω; 0.065 Ω, 0.069 Ω , 0.081 Ω , and 0.090 Ω; and 4.17 Ω, 5.12 Ω, 5.91 Ω, and 6.41 Ω. The resistances are proportional to the temperature of the Cobalt. The respective difference between the longitudinal resistance to both the transverse and the polar resistances are 6315.38 %, 7214.285 %, 7107.32 %, and 7353.49 %; and 6314.38 %, 7320.29 %, 7196.30 %, and 7022.22 %. A magnetic field parallel to the sample current produces a substantially greater resistance compared to any other principal direction. The resistance is dependent on the magnetic saturation of the sample.

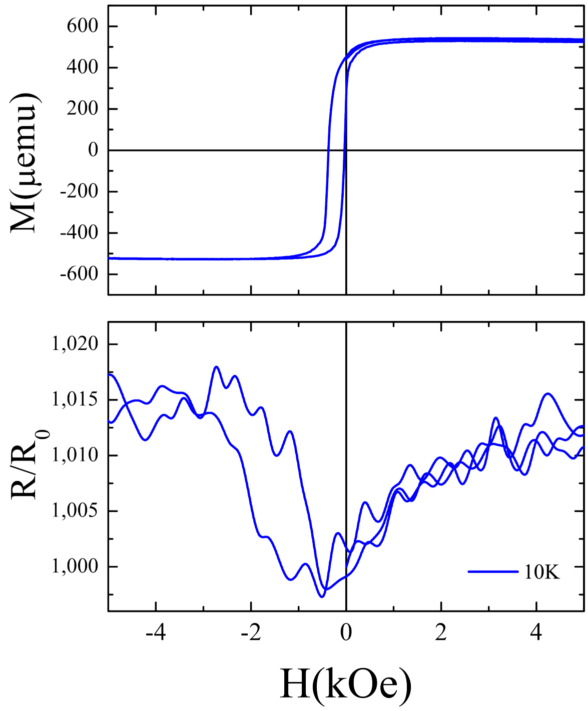

FIG. 5: Comparison between the magnetic moments and magnetoresistance of a 400 ÅCo-thin film both due to a magnetic field at 10 K. Saturation of the magnetization occurs quickly at 0.46 kOe.

VI. ACKNOWLEDGMENTS

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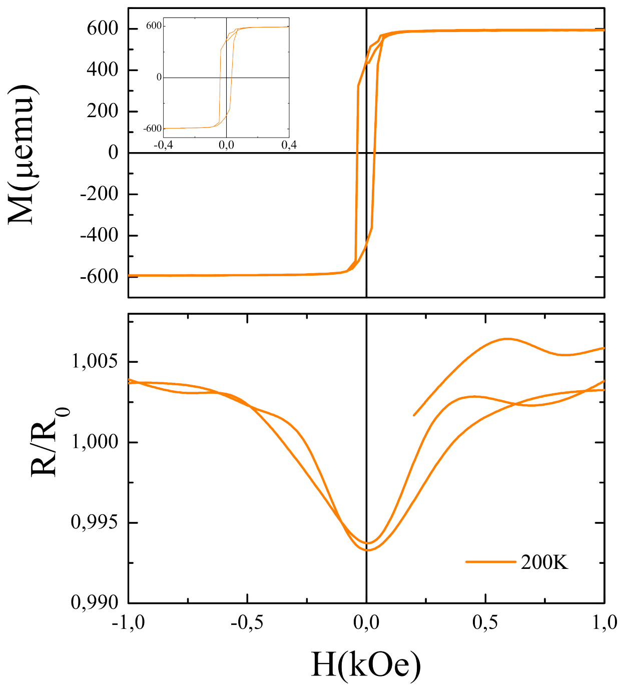

FIG. 6: Comparison between the magnetic moments and resistance of a 400 ÅCo-thin film both due to a transverse magnetic field at 200 K. Saturation of the magnetization occurs quickly at 0.23 kOe.