Semester Write Up Spring 2023

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Introduction

This project aims to analyze amorphous Platinum Germanium (α-Pt_xGe_{1-x}) thin films and their transport properties, in an effort to understand the effect of Platinum in multilayer thin films. Amorphous materials in general are interesting because of the magnetic properties they exhibit despite having no long range structural ordering. Platinum specifically is used in many magnetic thin film multilayers, despite not being magnetic, since it can result in these structuras exhibiting interesting properties such as large spin orbit coupling, which can be harnessed to host exotic spin textures [1]. Five different compositions of α-Pt_xGe_{1-x} were grown using magnetron co-sputtering and characterized by resistivity using the Van der Pauw technique. Results are compared with previous characterizations of α-Pt_xSi_{1-x}. Understanding Platinum's transport properties will help us understand the effects Platinum has on magnetic materials. These materials also have experimental applications in computing such as magnetic storage and racetrack memory [2].

Experimental Procedures

Sputtering

α-Pt_xGe_{1-x} samples were grown using magnetron sputtering were grown on Si substrates, where $0.6 < x < 0.9$. A reference sample of pure Pt was also grown. The goal thickness of each sample was 50 nm, with an average thickness across all samples of around 52 nm and a median of 49 nm.

The x = 0.9 and pure Pt samples were grown twice due to thickness and resistivity irregularities. Using a stylus profilometer, we observed that the pure Pt sample was significantly thicker than the other compositions. The exact reason for this is not entirely clear, though it could be due to a shadowing effect caused by the clamps to hold the sample in place using sputtering, or due to the surface roughness of Pt causing the profilometer to overestimate the thickness of the film. X-ray reflectometry (XRR) measurements could be used to measure surface roughness to confirm these hypotheses, as well as simply re-growing the sample while playing close attention to the sample holder during preparation.

x	Thickness (nm)	ρ_0 ($\mu\Omega$-cm)
1	69.81	5.0
0.9	49.42	13.8
0.8	49.48	50.5
0.7	49.89	115.2
0.6	49.48	199.1

Structure

The specific structural properties of α-Pt_xGe_{1-x} were examined using XRD measurements. As described in [3], α-Pt_xSi_{1-x} is nanocrystalline up to roughly 30% Silicon, with grain sizes between 10 and 20 nm. Previous work on amorphouse Iron-Germanium and Cobalt-Germanium in [3] has also shown that these alloys are amorphous up to about 70% Fe and Co respectively. XRD scans were performed on all samples to measure thickness and crystal size.

Characterization

Four point resistivity measurements were taken at temperatures from roughly 290K to 4K for each of the composition. Following [3], measurements were done using the Van der Pauw technique, where four Indium contacts are applied to the same sample and a current is run through the sample in two separate configurations. For a thin lamella of an arbitrary shape, the resistivity can be found using the equation

$$e^{(-\pi R_{AB,CD}\cdot\frac{d}{\rho})} + e^{(-\pi R_{BC,CD}\cdot\frac{d}{\rho})} = 1, \qquad (1)$$

where ρ is the resistivity, d is the sample thickness, and $R_{AB,CD} \equiv (V_D - V_C)/I_{A\to B}$, with the same convention applying for $R_{BC,CD}$. The fsolve function in the scipy library was used to solve for the ρ, with the initial case assumed to be the ideal case $R_{AB,CD} = R_{BC,CD}$.

[h!]

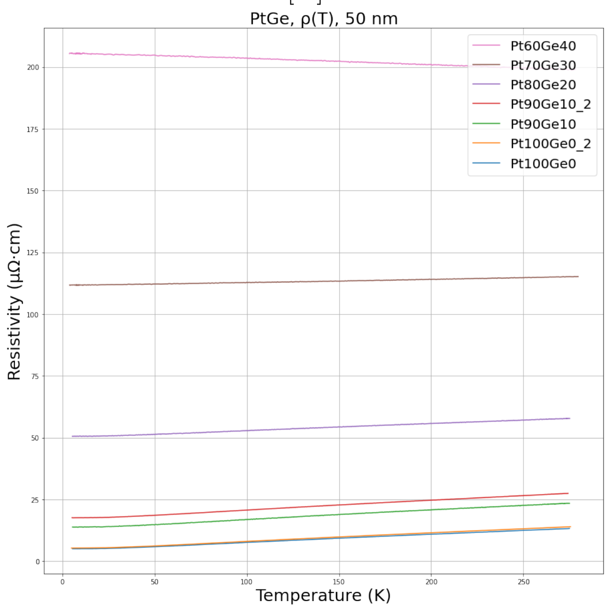

Figure 1: Resistivity as a function of temperature for each α-Pt_xGe_{1-x} sample.

For this equation to hold, the sample must be homogeneous in thickness and composition, not have any holes or scratches, and contacts must be less than a tenth of the sample size and positioned at its edge. As can be seen in Figure 2, the resistivity measurements for x = 0.9 produced unphysical results, where the resistivy of pure Pt is shown to be less than the resistivity of 90 % Pt. Upon examination of our samples, we noticed that the contacts used to measure resistivity of the x = 0.9 sample were too large as well as not correctly applied, resulting in this inconsistency.

Results

Resistivity measurements were plotted as a function of temperature for each sample in Figure 1. We see resistivity increases as the percentage of Ge increases. The two measurements of the x = 0.9 and x = 1 samples are very close, indicating that the issues with resistivity discussed earlier are not due to random errors. Whereas resistivity increases with temperature for the pure Platinum and and 0.1 < x < 0.7 samples, the x = 0.6 sample shows the opposite trend. This indicates that for this composition the 'semiconductor threshold' has been crossed, and the film is behaving like a semiconductor, rather than a metal. For samples with a higher Ge percentage, this trend would continue before transitioning to a pure insulator.

[h!]

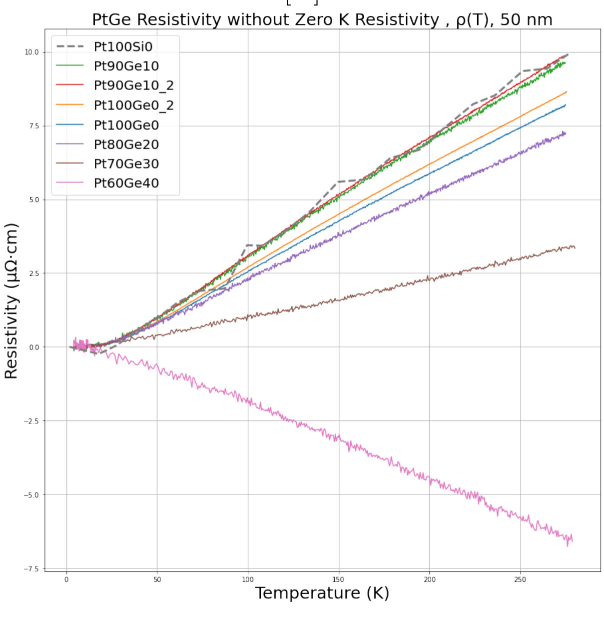

Figure 2: Intrinsic resistivity for each α-Pt$_x$Ge$_{1-x}$ sample, including each sample that was measured twice. The dotted line shows the (approximation of) the pure Pt sample from [4].

This trend can be seen more clearly when the intrinsic resistivity is plotted as a function of temperature in Figure 2. Intrinsic resistivity refers to the resistivity with the resistivity at 0 K, ρ_0, subtracted from each value. Matthiesen's rule tells us that the total resistivity of a sample is the sum of the effect of thermal fluctuations in the crystal lattice, as well as imperfections in the material, so by subtracting out ρ_0 we are left only with 'intrinsic' effect. The ρ_0 value for each sample is also shown in Table 1.

Comparison to Platinum Silicon

[4] analyzed the effect of amorphization of α-Pt$_x$Si$_{1-x}$ films on the spin-Hall effect, and also plotted the resistivity of a number of compositions as a function of temperature. We use the pure Pt sample from [4] as a reference for our samples, as well as selecting similar Pt % percentage samples to compare with α-Pt$_x$Ge$_{1-x}$. Data from the report was not directly available, so the α-Pt$_x$Si$_{1-x}$ data points plotted in Figure 3 (shown with dashed lines) are estimations for qualitative comparison. Intrinsic resistivity of the Pt sample from [4] is also shown in Figure 2. Other samples are not shown due to messiness of the approximated data making the figure more difficult to read.

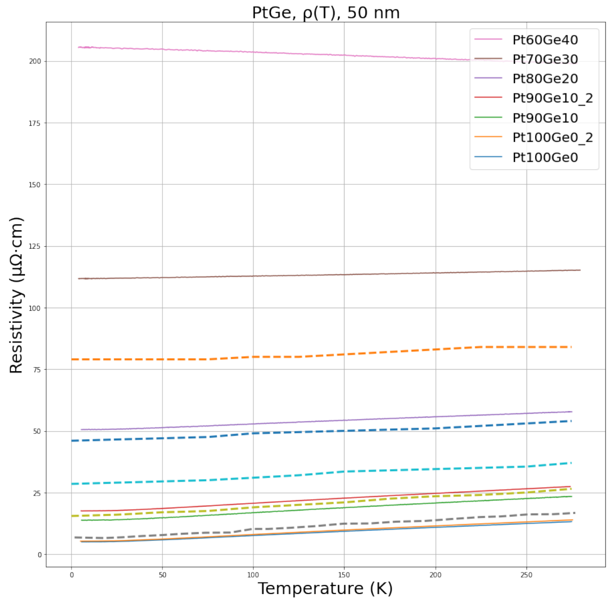

Figure 3: Resistivity as a function of temperature for α-Pt$_x$Ge$_{1-x}$ (solid lines) and α-Pt$_x$Si$_{1-x}$ (dashed lines) from [4]

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In Figure 3, we can see that for each x value, the Si samples generally have a higher resistivity than the Ge samples. Qualitatively speaking, the pure Pt samples all agree well. In Figure 2, we can again see the issues with the resistivity measurements for α-Pt$_{90}$Ge$_{0.1}$ and potentially with α-Pt$_{100}$Ge$_0$, as the intrinsic resistivity of the pure Pt from [4] overlaps with the former, showing that the intrinsic resistivity for the x = 90 sample is higher than physically sensible. Though the pure Pt from [4] also shows a higher resistivity than our pure Pt film, but due to the small number of and approximation of the data, this is not an entirely reliable comparison, especially since they do generally overlap in Figure 3. There were no obvious issues with the growth or resistivity measurement of the pure Pt sample, though as mentioned before, it was noticeably thicker than the other samples, something that could indicate other problems with the sample. More investigation into this problem is needed, as well as a better reference point for pure Pt samples.

Conclusion

α-Pt$_x$Ge$_{1-x}$ exhibits the expected trends in resistivity as a function of temperature and composition, with the semiconductor transition occuring at x = 60. Experimental issues affected the quality of our data for x = 90 and potentially pure Pt, and improved resistivity measurements in the closed cycle as well as potential measurements of surface roughness are needed to clarify the problem. Comparison with [4] showed qualitative agreement between the Pt samples, as well as a higher resistivity of α-Pt$_x$Si$_{1-x}$ for equivalent x values.

References

[1] Durga Khadka, Sabit Karayev, and S. X. Huang. Dzyaloshinskii–moriya interaction in pt/co/ir and pt/co/ru multilayer films. *Journal of Applied Physics*, 123(12):123905, 2018. doi: 10.1063/1.5021090. URL `https://doi.org/10.1063/1.5021090`.

[2] Aroop Kumar Behera, Chandrasekhar Murapaka, Sougata Mallick, Braj Bhusan Singh, and Subhankar Bedanta. Skyrmion racetrack memory with an antidot, 2019. URL `https://arxiv.org/abs/1907.03449`.

[3] Dinah Simone Diller Bouma. *Non-Collinear Magnetism and Magnetotransport in Amorphous Transition Metal-Germanium Thin Films.* PhD thesis, University of California, Berkeley, 2020.

[4] Daisy O'Mahoney, Neal Reynolds, and Frances Hellman. Amorphous ptxsi(1-x) growth and characterization. *Internal Report*, 2020.