-MERIT Corporate Internship-

Anomalous Nernst effect in granular and porous thin films

Hosting Organization: Nagoya University - Mizuguchi Laboratory

Period of Internship: 5th June 2023 - 1st August 2023

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Date: August 9, 2023

I conducted my MERIT Corporate Internship at Nagoya University in Mizuguchi Laboratory. My task was to prepare and investigate the possibilty to enhance the anomalous Nernst effect of materials by inducing a porous structure. In the following I want to introduce my research topic as well as a short paragraph about my life on campus.

Contents

1 Introduction

Porous materials have gained the attention of scientists and engineers alike. Defined by their ability to contain pores or voids within their structure, these materials exhibit a distinctive set of properties that make them highly intriguing and versatile. By introducing voids of varying sizes and arrangements, porous materials provide an extensive surface area per unit volume, paving the way for a wide range of applications across diverse fields. A larger surface area allows for more interaction sites with reactants or other substances which makes them desirable for applications such as gas storage, catalysis, and adsorption processes [1].

The anomalous Nernst thermopile, which converts thermal to electric energy, has been proposed for efficient energy harvesting, however, materials are still suffering from a low efficiency [2]. The aim of this internship is to investigate the possibility to enhance the anomalous Nernst effect (ANE) by applying a porous structure.

The ANE can be described by:

$$\boldsymbol{E} = -S_{xy} \cdot (\boldsymbol{m} \times \nabla T) \tag{1}$$

where S_{xy} is the transverse Seebeck coefficient and $\boldsymbol{m}$ is the unit vector of the magnetic moment [3]. Additionally, S_{xy} (or S_{ANE}) consists of two contributions:

$$S_{ANE} = \rho_{xx}\alpha_{xy} - \rho_{yx}\alpha_{xx} = S_I + S_{II} \tag{2}$$

$$\alpha_{xx} = \frac{S_{SE}}{\rho_{xx}}, \tag{3}$$

where ρ_{xx}, ρ_{xy}, α_{xx}, α_{xy} and S_{SE} refer to the longitudinal resistivity, anomalous Hall resistivity, longitudinal thermoelectric conductivity, transverse thermoelectric conductivity and Seebeck coefficient respectively. α_{xy} is connected to the anomalous Hall conductivity σ_{xy} via the Mott relation [4].

For comparison also a granular thin film sample was fabricated which has recently shown a promising anomalous Nernst effect [5].

2 Experimental

The samples are fabricated by utilizing a co-sputtering technique that allows the deposition of two materials at the same time. Afterwards, the thin films are annealed under a vacuum which creates the pores in our sample. This technique is called vapor-phase dealloying (VPD) method that is utilizing the vapor pressure difference between solid elements to selectively evaporate a component from an alloy. Generally, speaking the longer the annealing time and the higher the temperature the bigger the pore sizes will be. However, the growth rate of nanoporous materials in high-vacuum condition is lower than in low-vacuum due to the lower dealloying temperature [1]. It has to be noted that the nanoporous growth size strongly depends on the materials and annealing conditions, therefore there is no universal 'receipt' for a specific pore size.

The conducted measurements are: anomalous Hall effect, Seebeck effect and anomalous Nernst effect. All are conducted in a physical property measurement system. Depending on which measurement is performed the sample is connected differently. Figure 1 shows the different kind of transport measurements. For the anomalous Hall effect (Figure 1 (Left)) a dc current is applied longitudinal through the sample ($I_1 \rightarrow I_2$) and the transverse voltage is measured between V_1 and V_2 under a varying magnetic field (out-of-plane). For the Seebeck and the anomalous Nernst effect measurements a heater placed on top of the sample generates an in-plane temperature gradient through the sample. However, the position of the voltage measurement differs. Whereas for the Seebeck effect the potential difference is measured longitudinal to the temperature gradient the ANE is measured transverse to the temperature gradient and external magnetic field.

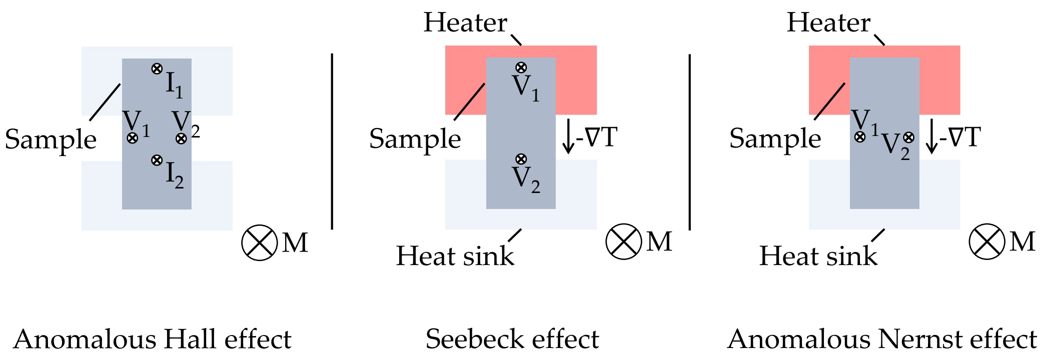

Figure 1: **Setup for the applied transport measurements.** (Left) Anomalous Hall effect measurement. Current is applied through the sample ($I_1 \rightarrow I_2$) and the voltage is measured between V_1 and V_2 under a varying magnetic field (out-of-plane). (Middle) Seebeck effect measurement. A heater on top of the sample creates an in-plane temperature gradient. The longitudinal voltage is measured between V_1 and V_2 under a varying magnetic field (out-of-plane).(Right) Anomalous Nernst effect measurement. Same setup as Seebeck effect but measurement of transverse voltage between V_1 and V_2.

3 Research Outcome

Porous films with different porousities were successfully fabricated by changing the synthesis conditions. The ANE could be revealed for all the films however it could not be enhanced compared to that of pristine films. The main reason for this could be that the ρ_{xx} decreased for every sample from thin film to porous. Using Equation (2) it can be seen that to enhance the ANE the longitudinal resistivity needs to be increased. Therefore, the found trend is contraproductive for improving the transverse Seebeck effect as previously intended. It is still expected that ANE can be enhanced by controlling the resistivity of the porous films.

The mentioned granular thin film sample did no show an ANE which could have been due to a bad signal-to-noise ratio.

4 Life on the Campus & Acknowledgments

I really enjoyed my time in Nagoya. It is a great city with diversity of attractions and great food. I was able to travel a bit and make nice memories during this time. Also, the campus has many things to offer. Especially the green surroundings of the campus are giving a nice environment.

First of all, I would like to express my gratitude to Professor Masaki Mizuguchi for his willingness to have me as an intern for two months in his laboratory and for his kind supervision throughout this time. Additionally, I want to express my thanks to Associate Professor Toshio Miyamachi for fruitful discussions and his support. Also, I want to thank Takuya Tsujimoto, who conducted all the experiments with me. His explanations and support made the research journey all the more fulfilling.

Finally, I would like to express my gratitude to my supervsior Professor Yoshichika Otani and to the MERIT program for providing me with the opportunity to do an internship.

References

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