Report of MERIT internship (domestic)

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【Date】

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【Host organization】

Extreme Quantum Matter Physics RIKEN ECL Research Unit, Cross-Divisional Materials Research Program, Center for Emergent Matter of Science (CEMS), RIKEN

（RIKEN ECL Unit Leader：Dr. Yukako Fujishiro）

【Research theme】

Exploration and measurement of chiral spin liquid state under high pressure

【Contents of research】

Frustrated systems with competing interactions sometimes exhibit nontrivial ground states, and their quantum critical behavior has been intensely studied. The application of pressure is one of the few methods to change the interaction without contaminating the material with impurities. However, the pressure required to change sufficient physical parameters often exceeds 3 GPa, the limit of piston-cylinder pressure cells, making it difficult to study detailed behavior near the quantum critical point.

The host of this internship, Dr. Yukako Fujishiro, has established a method for measuring resistivity under ultrahigh pressure (> 30 GPa), low temperature, and magnetic fields using a diamond anvil cell. I worked on ultrahigh pressure measurements using a diamond anvil cell under the supervise of Dr. Yukako Fujishiro in this internship.

The target material is pyrochlore-type $Eu_2Mo_2O_7$. This system is a minimal model of frustrated magnetism and conduction electron in which electrons move under the influence of localized S=1/2 quantum spin. This system shows non Fermi liquid like behavior at above 7 GPa. All the above previous studies were performed under zero magnetic field, but if a magnetic field can be applied by using a small diamond anvil cell, there is a possibility that novel quantum transport phenomena originating from quantum critical points can be observed.

In this internship, I worked on acquiring the technique of diamond anvil cells and measuring the Hall effect with it. I also report on some technical improvements that I made. Unlike metallic samples, the oxide samples cannot be finely terminated by using a spot welder. Therefore, it is necessary to create a good quality electrode. I found that contact resistance of about 100 kΩ could be reduced to about 100 Ω by depositing gold on the sample surface. I also found that it is important to polish the sample surface roughly (about 30 μm) to make it difficult for the deposition film to peel off.

The electrodes were made by removing unwanted portions after deposition. I found that patterning electrodes could be done without damaging the sample by using a femtosecond laser.

Samples with electrodes prepared by the above method were put in a diamond anvil cell, and the electrical resistance and Hall effect were measured (Fig. 1 (a)). At the low-pressure region, the results of the piston-cylinder measurement were well reproduced (Fig. 1 (b), (c)). As shown in Fig. 2, the temperature-pressure phase diagram of the Hall effect shows positive and negative maxima near the ferromagnetic transition point (FM-PM boundary, $P < 2$ GPa) and quantum critical point ($P \sim 7$ GPa). This result suggests the emergence of topological Hall effect due to thermal and quantum fluctuations. We discussed the possibility of such a new type of topological Hall effect and how to verify it.

In the future, I will use the ultrahigh-pressure measurement technique for oxide samples acquired through this internship to explore various quantum critical phenomena and materials.

【Acknowledgements】

I would like to thank to Dr. Yukako Fujishiro, the members of the Strong Correlation Physics Research Group at RIKEN and my Ph. D research supervisor Prof. Yoshinori Tokura, who kindly agreed this internship. Finally, I would also like to thank the MERIT program for providing me such valuable internship opportunity.

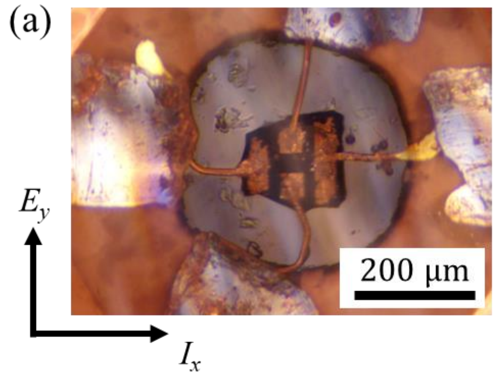
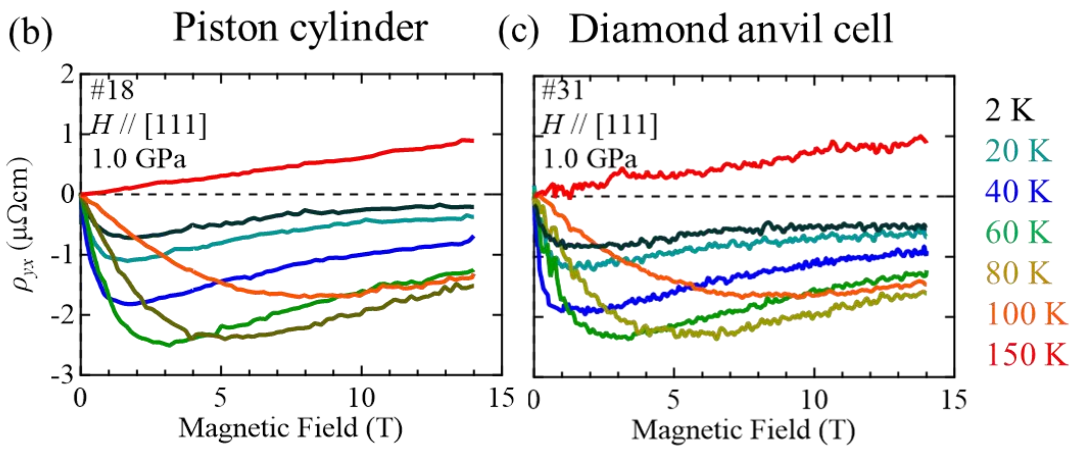


Fig. 1 (a) Measurement setup. Hall effect data of (b) piston cylinder and (c) diamond anvil cell.



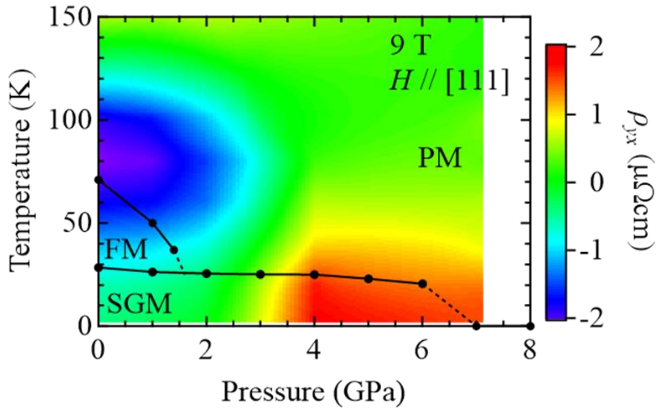


Fig. 2 Temperature-pressure phase diagram of Hall effect. FM, SGM and PM mean ferromagnetic metal, spin glass metal and paramagnetic metal.