Report of MERIT Long-Term Dispatch (Term:30/06/19~01/08/19)

Graduate school of frontier sciences, Department of advanced materials science, Arima-Tokunaga Lab. D2 Tsuyoshi Omi

Summary

This long-term overseas dispatch involved a series of events that were different from the original schedule and resulted in a number of problems. At the same time, with helps of many people, I could overcome the difficulties and achieve joint research. It was originally scheduled to stay at the Budapest University of Technology and Economics in Hungary to measure THz spectroscopy, but due to equipment failure, I hastily decided to conduct joint research with a team in the University of Augsburg in Germany. In addition, I had an opportunity to visit Vienna during my itinerary and held a seminar at the TU Wien. In this report, I will summarize my experiences, personal connections and experimental techniques I obtained in this long-term dispatch.

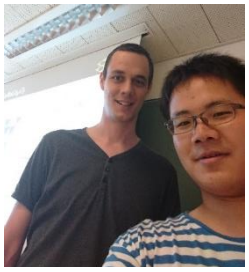
Trouble in Budapest University of Technology and Economics

Budapest, the capital of Hungary, is a famous tourist site, divided into the Buda district on the right bank of the Danube river, where Buda Castle is located, and the Pest district on the left bank. Budapest University of Technology and Economics, on the Danube river, is known as one of the world's oldest university of technology. I was planning to measure the THz absorption of a multiferroic $Co_4Nb_2O_9$ with the help of Dr. Sándor Bordács, who specializes in the THz response of multiferroic. On July 1, as soon as we arrived at the university, we met in moderation to discuss the detailed schedule of the experiment. At that time, I heard that the equipment for measuring the amplitude of the oscillating electric field was not working well. The bad prediction came true, and the device did not get fixed when the measurement started, so it was returned to the production company. At this rate, one month's worth of measurements will be wasted, so I have nothing to do in Budapest but sightseeing. Dr. Sándor has taken various routes and suggested that I could do it in a few months. He told me that THz absorption can be measured in a strong magnetic field in Prof. István Kézsmárki team in the University of Augsburg, Germany. Prof. István also suggested that I hold a seminar at the Vienna University of Technology on the way from Budapest to Augsburg, and I stopped by. Despite the many unplanned consequences of equipment failures, I consider the experience in Budapest as a rare opportunity to go to Austria and Germany for seminars and experiments.

Seminar in TU Wien

Dr. David Szaller of TU Wien introduced me for a seminar on my research. In front of about 10 people who were major in similar research contents, we had a discussion for a

total of 1 hour. It was a good opportunity for me to review my research because there were many crucial questions that I had little understanding or discussion. In addition, I could feel the significance of the announcement in foreign countries for getting the proposal of the cooperative research on THz absorption and other physical property measurement.

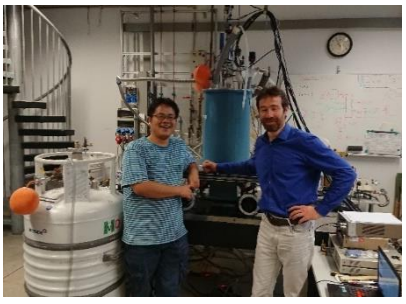


Picture 1. Dr. David and me in TU Wien

THz spectroscopy in Augsburg University

After the seminar in Vienna, I moved to the Augsburg University. Augsburg is a rural city which is away about 30 minutes train ride from Munich. The physics department building, however, at the University of Augsburg is equipped with many experimental devices such as nuclear magnetic resonance measurement, electron spin resonance measurement, and various physical properties measurement equipment in addition to the THz absorption measurement equipment, and is a facility where physical properties measurement can be performed from various viewpoints. In addition, regarding the living room of the students, it was a room in which many discussions on collaboration were made with people from various laboratories in the same room. It is designed so that physical properties can be measured in various ways when a phenomenon that is difficult to clarify by one measurement is encountered. As I felt when I was offered the experiment in Germany in Budapest, I realized the depth of lateral communication and the low hurdles for joint research. I think it is characteristic of Europe countries which are connected by land.

The THz absorption measurement was carried out using the time domain spectroscopy which could measure the time dependence of the oscillating electric field. For the measurement of nonreciprocity in multiferroic materials, it is necessary to be able to reverse magnetization, electric polarization and direction of light propagation. The measurement system in the Augsburg University was able to reverse the direction of the magnetic field, so there was no problem with the magnetization reversal. However, it was not easy to reverse the electric polarization and the direction of light propagation in the measurement system. So I teamed up with István's students, Stephan Reschke, and Sándor's colleagues at the lab, Dániel Gergely Farkas, who came to the University of Augsburg for a collaborative study, to insert wires to reverse the electrical polarization, and to reverse the direction of the light. As a result, nonreciprocal THz light absorption of $Co_4Nb_2O_9$ was observed in three reversal operations: magnetic field reversal, electric polarization



Picture 2. Prof. István and me in Augsburg University.

reversal, and light traveling direction reversal. In the future, the absorption measurement will be carried out in another arrangement in order to search the origin. The experience which succeeded in the experiment by devising the measuring system in foreign countries was a good experience to expand the opportunity of the next cooperative research.

Acknowledgment

I would like to thank the MERIT program for giving me the opportunity of overseas dispatch and Dr. Sándor Bordács in the Budapest University of Technology and Economics and his colleagues, Dr. David Szaller of the TU Wien and Prof. István Kézsmárki of the Augsburg University and his colleagues for their coorperation in the experiment. In addition, I would like to express my gratitude to the mentors, Professor Taka-hisa Arima and Yusuke Tokunaga, as well as to our secretary, Ms. Mieko Uemura, for consulting on experiments and applying for travel expenses while traveling abroad, for which my schedule has often changed.