The Global COE Program

"The Next Generation of Physics, Spun from Universality and Emergence"

Bilateral International Exchange Program (BIEP, invite) report

Send report to: Your responsible Professor in Kyoto University

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(Year/Month/Day)___2009/10/05_____

Invited Student

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Responsible Researcher in Kyoto University

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Research Project

Title	**Josephson tunneling study of Sr_2RuO_4-Ru**
Duration	**2009/08/03 – 2009/10/08**

Please summarize your activities and results during your stay in Kyoto University.
Also please describe how your stay has been beneficial to the graduate students in the host institute. You can add a sheet, if you need more space.
You can also write any comments and requests to the GCOE program.

First, I would like to thank Prof. Maeno and the GCOE program for inviting me to Kyoto, a beautiful city with many traditional Japanese cultural places. I would like to also thank the group members of the quantum materials laboratory and Prof. Terashima in the research center of low temperature and materials sciences, for their kindness and willing to help during various research activities.

My stay in Japan can be divided into three parts. First one from Aug. 2 to Sep. 6, I have been working on Josephson tunneling experiments between single crystals of p-wave spin-triplet superconductor Sr_2RuO_4 with micro-Ru islands (so called eutectic crystals) and s-wave superconductor Pb. The purpose of the experiments is to understand pairing symmetry of Sr_2RuO_4, the mechanism of the enhanced superconductivity (so called the 3K-phase) in the eutectic crystals, and the possible existence of chiral domains and domain walls in Sr_2RuO_4. With the help of graduate students, Nakamura san and Nakagawa san, I have successfully made a junction between a single Pb electrode and the eutectic crystal, as well as performed low temperature Josephson tunneling measurements in a ^{3}He fridge with a base temperature of 0.3 K. My results clarified the experimental origin of the previously observed multiple critical current features on the proximity junctions of two

Pb electrodes separated by an FIB cut thin channel. The anomalous temperature dependence of critical current has been reproduced. Meanwhile, I was trying to prepare a conference preceding and a poster for the M2S conference on superconducting materials and theories.

During this period, my major contribution in terms of helping the Japanese graduate students was to help them figure out how to greatly improve the noise level of the DC electric measurements. As a result, we have been successful in performing both low noise AC and DC measurements in finding the critical current of the Josephson junction, making the results much more reliable. I also helped them fix a mechanical pump and measure one of their own samples.

The second part was from Sep. 7 to Sep. 16. In this period, I attended two conferences, the M2S 2009 in Tokyo and the NSP 2009 in Kyoto with most of the lab members. I helped the Japanese students preparing their posters by giving them some suggestions in terms of proper English, figure appearances, and contents. Meanwhile, we discussed what we had heard from various interesting presentations, sharing ideas so as to improve our understanding of some physical problems.

The third period was from Sep. 17 to Oct. 8. I tried to focus on improving the surface quality of Sr_2RuO_4 single crystals in order to prepare better Josephson junctions. The way of doing this, is to use Ar ion mill after a fine mechanical polish following by annealing the surface. Since none of us had experience on ion milling, I tried to work with Nakagawa san, learning how to use the facility from Prof. Terashima. During the training, I had inspiring discussions with Nakagawa san about the experiments and preliminary results, while planning for new experiments. We discovered that ion milling at proper conditions may improve the surface roughness of the polished Sr_2RuO_4 surface, while doing a little to the Ru islands when the eutectic crystals were used. Consequently, it may help emphasize the Ru islands for the junction experiments. We also made a manual regarding how to use the ion mill machine for the lab members. At the same time, I helped Nakagawa san prepare a sample using focused ion beam, which are currently being measured. I also measured a control junction sample consisting of an Au electrode and a eutectic crystal made by a graduate student, Yamagishi san. Some new features owing to superconductivity of Ru, Sr_2RuO_4, and the 3K-phase, were observed. The result was found to be interesting as it implies detailed features of the sample geometry. However, after some long discussions, we were still not able to fully understand the data, and therefore more control experiments are still needed. During this experiment, I shared some of my own unpublished data from Pennstate with the Japanese students, showing them data of different types of junctions and thus helping them gain more experience in the junction experiments. I also taught them how to get good data from quasiparticle tunneling measurements and how to properly analyze the data. Finally, I am now trying to make more samples for the Japanese students as planned before.

As mentioned above, in general, I have finished what was planned originally. Also, I have done more on surface characterizations and modifications of Sr_2RuO_4, and eutectic crystals. These results will benefit both Maeno san's group and my own group in Pennstate, demonstrating a very good collaboration.

During my stay, I always tried to help improve the English skill of the Japanese students, not only on research aspect, but also in daily life. I talked to each lab member on a wide variety of topics, ranging from Japanese cultures, histories, and economics. I encouraged them to express their ideas on such topics, using understandable English. I asked them for help on lunch and dinner menu, while they had to do proper translation. As a result, the

Japanese students' English skills have been improved, particularly for Nakagawa san, who worked closely with me. Meanwhile, my own Japanese skill also got improved in the sense that I can now understand some Japanese conversations and use some simple expressions in daily life. I really enjoyed this communication procedure, with prominent mutual benefit. My only suggestion for the GCOE program in terms of helping the Japanese students is that sending them to US may be much more efficient for practicing English. I would be very happy to help in case you send Japanese students to my lab.

In my spare time during the obon festival and the national vacations, I have visited many interesting temples, shrines, museums, and castles in Kyoto, tried delicious Japanese food, and enjoyed traditional Japanese performances. I was really impressed by the Japanese culture, the politeness and elegance of Japanese people and will never forget such precious experiences in Kyoto.

Finally, I would like to again thank all people who have been involved in this project, especially Fukahara san, Nishigawa san, Nishimura san, Nakamura san, Nakagawa san, and Maeno san. I hope that I will meet some of the lab members in future international conferences.