Activity report for MERIT Overseas Dispatch Program

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With the financial support by MERIT Overseas Dispatch program, I stayed in Basel, Switzerland for 2 months from December, 2015, and engaged in research in Basel University. Basel University is the oldest university in the country, and today known for its state-of-art research in various fields. Especially the physics department is very well known for its latest work, both experimental and theoretical, on novel quantum effects in nanostructures fabricated on semiconducting substrates. Professor Christian Schönenberger's group, which kindly hosted me for the stay, has reported many interesting results in the devices with InAs nanowires, carbon nanotubes, and graphenes.

Fig.1 Physics department
@ Basel Univ.

The group consists of approx. 10 Ph.D students, and most of them come from the outside of the country. So when I joined, it was already filled with the atmosphere of internationality. The fact that all of them spoke fluent English also made it quite easy for me to blend in.

All group members work on each project in a quite liberal atmosphere, but at the same time there was always an active discussion among them. I was impressed with how they are self-dependent but willing to ask for others' opinion. Most colleagues come in around 8:30 in the morning and work till 18:30. After the work we often went out for dinner, jogging, bouldering, etc. All these off-school activities helped me get along with many of the students.

In the respect of research, I mainly worked with Andreas Baumgartner, a postdoc researcher, and Christian Juenger, a Ph.D student. They kindly understood that my time there was limited to 2 months, and still I was desperate to get some real result, and on the first day of my arrival we had a meeting to plan something that can be achieved within my stay. Without their understanding I couldn't have done any of the things that follow.

Because these people helped me a lot, and also because the machines necessary to fabricate our samples were somewhat familiar to me, we were able to complete the first batch of measurable devices after 2 weeks. Also at the stage of measurements, I was assigned to the same He3-He4 fridge that I was using in Japan right before my departure, which made the entire process extremely smooth. Although there were many familiar things, the differences in the details of know-hows were quite inspiring to me. .On the other hand some fabrication/measurement steps were speeded up by the knowledge I brought from Tarucha group, which gave us the feeling that this collaboration was really successful.

An example of the samples we fabricated and measured is shown in Fig.2. A single InAs nanowire was contacted by 3 superconducting Pb leads, with each junction distance ranging from 30-250nm. When DC anti-symmetric voltage biases are applied to left and right contact, such that V_{left}=-V_{right} , where V_{left} and V_{righ} represent each contact's bias voltage, two Cooper-pairs that split in the middle contact can be transported to each side, and there again form Cooper pairs. In such a transport process, each electron recombines with another electron which originally belonged to the other Cooper pair. Therefore this tunneling event can be regarded as a process where the superconducting coherence is maintained over 2 nonlocal junctions.

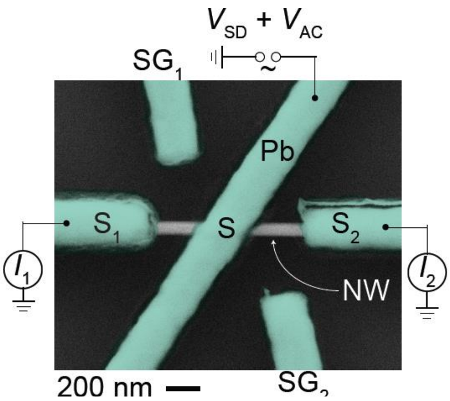

Fig.2. SEM micrograph of a sample

As for the fabrication process, several improvements were made. In the beginning we utilized Ar sputtering to remove the native oxide layer on nanowire surface. However, samples fabricated in such a way showed superconducting energy gaps which are almost 10 times as small as the expected value, which we attributed to the damage to the electron layer given by the Ar plasma. The nonlocal transport process described above can only take place within the energy scale of the gap, so a large gap was preferable. Therefore we changed the surface treatment to sulfur passivation (wet etching with $(NH_4)_2S$, which is expected to remove only the oxidized layer, but not the electron layer. The samples fabricated with sulfur passivation showed the energy gap which is comparable to the reported value for bulk Pb. The etching recipe was developed in Tarucha group, so here also we realized the success of our collaboration.

The samples were measured at the temperature around ~100mK. The conductances of the two junctions were measured separately while each contact was biased individually. On some conditions we observed a positive correlation in the conductances of the two junctions, which disappears with the applied magnetic field of ~100mT. This field is comparable with the critical field of the superconducting Pb, suggesting that this correlation is coming from a transport process which involves Cooper-pair splitting.

Now it's 2 weeks after my departure, we are still measuring and analyzing together, with me connecting to their measurement PC and server remotely. We will keep updating each other as often as possible, and if possible summarize this work into a publication.

Acknowledgement

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