（別紙様式５）

変革を駆動する先端物理・数学プログラム（FoPM）

国外連携機関長期研修　報告書

氏　　名	田中 宏明
所属部局	理学系研究科 物理学専攻
受入先	東京工業大学 フロンティア材料研究所 笹川研究室
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I stayed in Sasagawa Group (Tokyo Institute of Technology) for three weeks with the help of the International Research Experience program of FoPM. I am a graduate student of Kondo Group and specialize in condensed matter physics. I mainly perform angle-resolved photoemission spectroscopy (ARPES) measurements to investigate the electronic structure of crystals. Sasagawa Group specializes in single crystal growth and measurements of their properties. It has been a collaborator of Kondo Group as our sample provider [1-4] for a long time.

In this stay, I developed some devices for my running research. I also experienced the growth of single crystals and the evaluation of them. In our previous collaborative research, we have frequently discussed our results but have hardly shared experimental techniques with each other. However, in my planning ARPES measurements, I need to be more careful in the sample preparation process. That is why I decided to develop some tools with the help of Sasagawa Group.

In device development, I experienced both advantages and disadvantages of collaboration with a different group, even in the same field of condensed matter physics. The main difficulty in my planning measurements is that samples are so small (dozens of micrometers) that I cannot handle them with usual techniques like tweezers. However, since Sasagawa Group has been developing microscopic pick-up systems to fabricate small devices, I just needed to learn how to use them. Also, I borrowed photolithography techniques to indicate the positions of samples on a substrate. These two cases are advantages of collaborative research; in other words, there may be other research groups that already have techniques to solve our problems. In these points, my plan advanced as planned.

On the other hand, a disadvantage is that other groups may not have techniques which we usually use. In my case, ARPES measurements require high vacuum due to their surface sensitivity. However, Sasagawa Group does not have such vacuum systems, so I realized a lack of instruments for vacuum. As a result, I had to start with listing what is necessary for my research. If I do not go out of Kondo Group, I will not experience such difficulty. However, such experience told me that our research techniques are not always standard in other research fields.

As well as the device development, I tried to grow single crystals of a transition metal dichalcogenide (TMD). TMDs are layered materials with composition MX_2, where M is a transition metal (titanium, vanadium, niobium, molybdenum, tantalum, or tungsten), and X is a chalcogen (sulfur, selenium, or tellurium). TMDs show various types of layered structures depending on the selection of elements. In addition, metal atoms can be inserted between the layers. Such intercalated materials exhibit various interesting magnetic and transport properties. For example, I recently studied $CoNb_3S_6$ with Sasagawa Group, which is the TMD NbS_2 with intercalation of cobalt atoms [4]. This time I experienced the process of crystal growth and characterization through the synthesis of a TMD (Figure). After synthesizing single crystals, we checked their quality by x-ray diffraction (XRD) and temperature-dependent resistivity measurements. Clear diffraction spots in the XRD measurements mean that the sample is a good single crystal. The resistivity of the single crystal decreases by lowering the temperature, which also means that the material is a metal with poor impurity. Although I have used many crystals given from Sasagawa Group, for the first time I knew how they are synthesized and how their physical properties are investigated. Also, I remember the impression when shiny single crystals were successfully grown in a quartz tube from powder of elements. I hear that the method

which I performed is relatively easy in crystal growth techniques, which means that we should deeply appreciate our sample providers, who grow complex single crystals using their sophisticated techniques.

Originally this International Research Experience program encourages us to study abroad but staying in a foreign country is difficult due to the spread of COVID-19 now. Considering this situation, I decided to use the program to advance my collaborative research in Japan. I think the main purpose of the program is to feel culture and research environment largely different from ours, and in this viewpoint, I did not achieve the purpose. However, I think promoting collaborative studies is also meaningful in my case. We always need the combination of several research fields to solve problems currently occurring and discover something new. Such deep collaboration cannot be achieved by sending emails or talking online but by direct interaction with researchers. I will continue such collaboration to make progress in my research and to solve problems that I am interested in.

In the end, I thank Prof. Sasagawa for allowing me to stay in his lab. Also, I thank Mr. Okazaki and Mr. Kobayashi (master students of Sasagawa Group) for helping with my experiments despite being about to graduate.

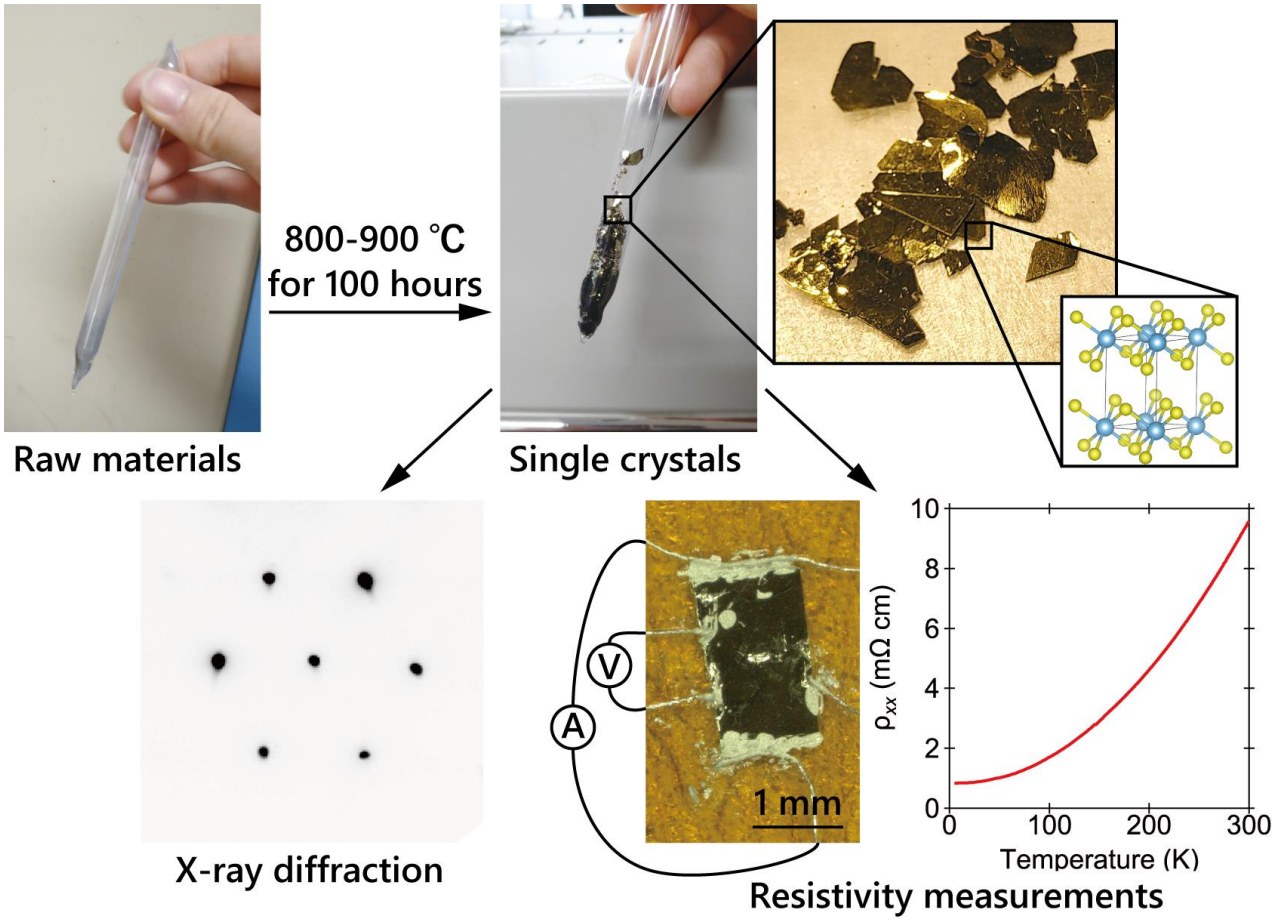

Figure: Synthesis of single crystals and their characterization by x-ray diffraction and transport measurements.

References:

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[2] M. Sakano *et al.*, Phys. Rev. Lett. **124**, 136404 (2020).
[3] R. Noguchi *et al.*, Nat. Mater. **20**, 473 (2021).
[4] H. Tanaka, S. Okazaki *et al.*, Phys. Rev. B **105**, L121102 (2022).