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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

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We are developing a millimeter/submillimeter-wave multichroic camera to observe the structure formation process of the universe, such as the population of dusty star-forming galaxies and the plasma motion in galaxy clusters. One of the essential technologies of our camera is the microfabrication of superconducting millimeter-wave circuits. From my research interest, I focused on two components in the circuit; on-chip bandpass filters and Microwave Kinetic Inductance Detectors (MKIDs). The on-chip filters define observing bands (or frequencies in order from 100 GHz to 1 THz). By integrating multiple filters of different bands in a single circuit, we can detect these bands simultaneously. MKID is a kind of superconducting photon detector and has been rapidly developed worldwide over a couple of decades. Both of the two enable us to make a large-format array of multi-band photon detectors on a silicon chip. Therefore, I decided to develop multi-band photon-detecting circuits with a combination of on-chip filters and MKIDs.

My overseas training program was accepted and I initially set the goal to design and demonstrate the on-chip filters. The prototype chip with designed on-chip filters was planned to be fabricated in the Netherlands. In advance of my departure, I started a discussion with my collaborators. Through the discussion, we noticed there were certain critical problems in our previous design and then we came up with a new form of filter. As a result, the main work in my overseas training was focused to establish this new filter design. Filter design was carried out mainly using Python coding (for circuit calculations) and electromagnetic simulations.

In my work, I faced several challenges to overcome. Firstly, I had to learn the basics of superconducting circuits. I became aware that a circuit with superconductivity behaves differently from that with a perfect electric conductor. Secondly, it was hard to find a new solution for filters compatible with MKIDs. Fortunately, I had learned the filter theory in other study before so it was somewhat easy to construct a theoretical circuit model. The most difficult was to rebuild the theoretical model into a series of real structures. Furthermore, even if any design solution was found, I had to pay attention to the possible radiation loss of transmitted power by the filter structures. It needed additional simulations with much computational power to estimate the impact of this radiation loss. I tackled these challenges until the end of my stay.

I worked for nearly three months in the Terahertz Sensing Group at the Delft University of Technology. This group has outstanding achievements in the development of MKIDs and implementation for astronomical observation. That is why I believed it was the best place to learn the know-how on designing MKIDs. In addition, this group has a high ability to fabricate superconducting devices. I have learned a lot from their design technique including their experience of fabrication behind it. During my stay in Delft, I was able to closely discuss not only with my collaborators but also with other professionals, and I got much technical support and advice. Thanks to them, my circuit design has become better and better.

Other than my own work, I attended a weekly Lunch Meeting held in this group. At each meeting, one of the group members or a guest gives a presentation about their research, and the audience listens to it having lunch. In the first month, I presented the overview of my filter design. Every presentation at this Lunch Meeting is related to microelectronics but there were many kinds of exciting topics with different backgrounds such as quantum computers, the Casimir effect (a quantum phenomenon), and a future space mission.

What is more, I also enjoyed the time in Delft outside the working hours; regular group lunch, casual talk with a couple of coffee, and the Christmas party!

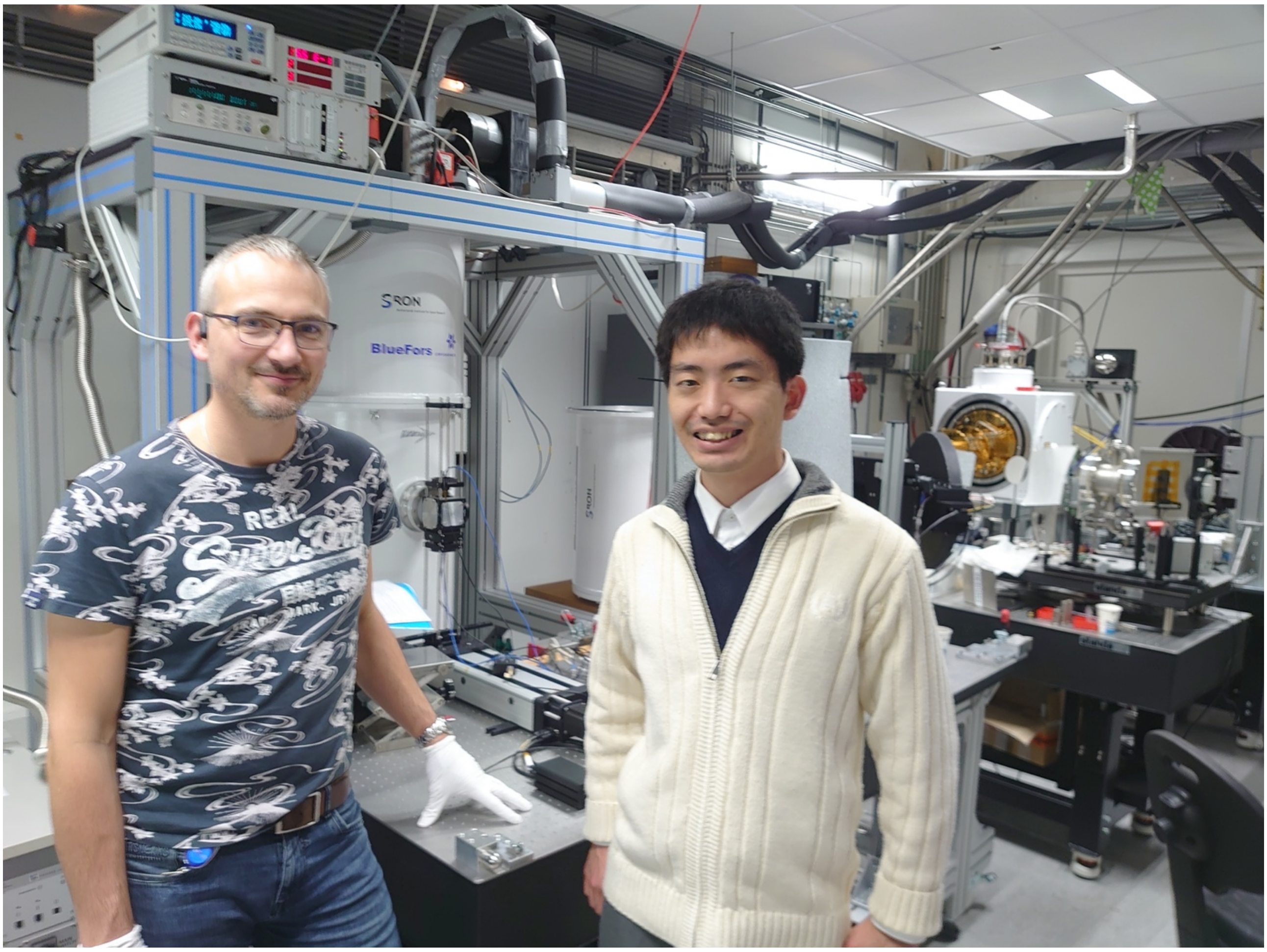
I have finally achieved the following things.

1. MKID-compatible filter design using a coplanar waveguide. This form of filter is relatively easy to be fabricated because it can be realized by a single superconductor layer, and thus it is suitable for a large-format detector array. The concept originated from our preliminary discussion. I have already found optimal solutions for three observing bands.
2. Alternative filter design using microstrip line. This type of filter is also compatible with MKIDs and has better transmission performance with less radiation loss than the former type, while it needs additional superconductor and dielectric layers. The idea of this alternative design arose in the mid of my stay.
3. Design method of photon-sensitive MKIDs. It covers a technique to gain sensitivity. I think what I learned is a very basic but important skill for further development.
4. Usage of an electromagnetic simulator. It is relevant to the design of almost all circuitries. I also learned a convenient way to simulate radiation loss.

After the oversea training, I am working on the design of prototype chips to be fabricated. The details of our filters will be published together with the results of upcoming measurements.

The research would not have grown so far without this program. Moreover, it was also the best opportunity to simulate my possible postdoc life overseas. I would like to do research overseas again.

I want to thank Dr. Akira Endo and Dr. Kenichi Karatsu for a lot of support on this project, and all members in Terahertz Sensing Group for kindly accepting me to the group.



Photograph of Technician David J. Thoen and me in the laboratory at the Delft University of Technology