（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

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I visited Prof. Yvonne Gao's group in Centre for Quantum Technologies (CQT) in Singapore. I studied continuous-variable (CV) quantum system in circuit-QED there.

Circuit-QED is a quantum system composed of microwave cavities and superconducting qubits. As physics of microwave can be described in the similar way as in quantum optics, recently circuit-QED has attracted attentions as a platform for studying light-matter interaction, and a promising candidate for quantum computing.

My research theme in PhD is CV quantum error correction in optical quantum computing. A special type of quantum state called non-Gaussian state plays an important role there. The reason I decided to visit Prof. Gao's group is that circuit-QED system can easily manipulate non-Gaussian states compared to optical systems, thus there are many experimental studies related to non-Gaussian quantum states.

1. Theoretical research estimation of displacement error
   Although mathematical descriptions of circuit-QED system and optical system are similar, actually they have a lot of differences in experiments. For example, type of possible measurement is quite different. In quantum optics, available measurements are usually homodyne measurement, which is a measurement of quadrature operators, and photon number measurement. On the other hand, in circuit-QED, measurements are usually performed via qubit, so measurement outcome is usually binary. There are many physical quantities that can be mapped onto qubit state, which enable more different kinds of measurement compared to quantum optics. For example, direct measurement of quasi probability distributions is possible, such as Wigner function and Q function. It's also possible to directly measure characteristic function.
   Before I studied about how to estimate amount of displacement accurately using feasible quantum states and measurements in quantum optics. I discussed with people in the group about how to extend the theory to circuit-QED system. From that point of view, we extended the theory of displacement estimation.
2. Experiment of generation of squeezed cat state
   I participated in an experiment to generate squeezed Schrodinger's cat state. In quantum optics experiment, generally non-Gaussian states such as cat state are more difficult to generate than Gaussian states such as squeezed states, so people mainly focus on how to generate non-Gaussian state. For this reason, it was quite interesting for me to observe that cat states are more fundamental and easier to generate in their circuit-QED system, and generation of squeezed states requires more steps thus more challenging. Knowing this kind of difference between different scheme and different physical systems was quite meaningful experience for me and it widened my view.

Another thing I realized while working with people in the group is the diversity they have. Singapore itself has quite high level of diversity compared to Japan, because their culture is mixtures of many different cultures. I confirmed that working with people with different background is not only fun but also quite useful for scientific research, because in order to solve complicated problem, it's important to have many different points of views.