MERIT Internship Report

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Overview

2021/6 〜 2021/7

Dr. Hiro Tajiri, Japan Synchrotron Radiation Research Institute(JASRI)

I worked at JASRI as a research student accepted by Dr. Tajiri during the above period. We did the study of the structural analysis of the surface at low temperature using synchrotron radiation X-rays and the device development for that purpose.

Title

Structural analysis of monolayers of helium adsorbed on graphite at ultra-low temperature by X-ray diffraction

Research Summary

Introduction

At extremely low temperatures, various phase transitions and quantum phenomena appear such as superconductivity or superfluidity. Furthermore, in two-dimensional materials, low-dimensionality is involved and interesting physical phenomena such as topological insulators or surface superconductivity occurs. However, since it occurs at extremely low temperatures, there are limited experimental techniques for direct investigation of the structural changes associated with these phase transitions.

Monolayer helium film is an ideal two-dimensional quantum boson (^{4}He) or fermion (^{3}He) system. Because various phase transitions occur, many studies have been done for this system and a large variety of quantum phases or phenomena have been found. The experimental methods have been almost limited to the measurement of macroscopic physical quantities such as heat capacity, nuclear spin magnetic susceptibility, and mechanical response of torsional oscillators. No experimental research has been conducted from the viewpoint of the atomic structure except for a few neutron scattering experiments that confirmed the formation of an incommensurate solid. Thus, there are many unsolved problems because the crystal structures explaining the experimental results have not been confirmed experimentally. Although there are a number of theoretical calculations, it is difficult to completely explain the experimental finding because the measured values cannot be used for the parameters in their theoretical calculations. Observing the structure of the material will elucidate the unexplained physical phenomena expected in the experiments, develop up a new field of condensed or quantum matter physics, and can contribute to research on phase transitions, quantum material physics. In the research in this internship, the following is the aim:

"Make the bases for working on many unsolved problems by developing a new technique for structural analysis using synchrotron radiation at low temperatures, cultivating new fields."

Device Development

The low temperature device for this project can cool down to about 1.5 K by a self-made 1 K-pot refrigerator using evaporative cooling of helium-4, which is attached to a commercial GM refrigerator. A sample cell is attached to the 1 K-pot. The purpose of this period was to observe monolayer helium films adsorbed on the graphite surface at 1 K by synchrotron radiation X-ray diffraction at the beam time at the end of July. We had three tasks as follows.

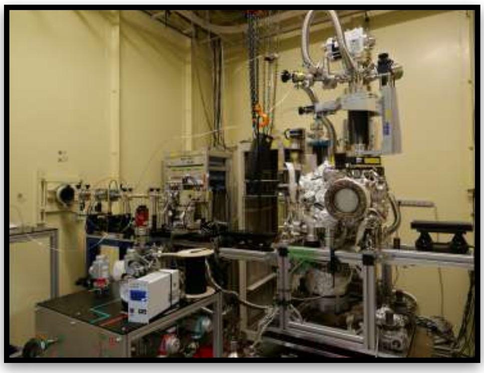
1. Development and improvement of refrigerator to maintain 1 K stably
2. Selection and evaluation of the graphite substrate that is suitable for diffraction experiments (large single crystal size and small mosaic angle)
3. Development of experimental equipment or a setup for the study of monolayer helium

Low temperature instrument for scattering experiment

In regards to 1, a group of Dr. Tajiri and Prof. Yamaguchi at the University of Hyogo had already developed the 1 K-pot, thus I contributed to the improvement from the thermal analysis by making use of the experience of my Ph.D. research.
About task 2, we used a HAPG (Highly annealed pyrolytic graphite), which is a type of HOPG and has a large single crystal size. Dr. Tajiri led in this part. It was found that the HAPG has a smaller mosaic spread than that of commercially available HOPG from locking curve measurements of 002 reflection at room temperature. In attaching the HAPG to a sample cell, it was difficult to achieve two requirements simultaneously of maintaining performance of the sample such as mosaic spread, and cooling the sample enough for measurements at low temperatures. We eventually cut an entire glass substrate on which HAPG was grown because degradation of the sample can be suppressed, while we tried several ways such as transferring a HAPG film to a copper plate. Silver paste was put so as to cover the side surface of the HAPG substrate for increasing the thermal conductance to the cooling medium.
I was responsible for task 3. We designed a system setup according to the size of the cooling equipment. We constructed a surface area cell, low temperature pressure gauge, and sample cell, and installed them in the refrigerator, connecting them to the gas handling system at room temperature via gas capillaries.

Measurement

Crystal truncation rod (CTR) scattering was measured using a two-dimensional detector with the surface X-ray diffractometer on the beam line BL13XU. We succeeded in observing CTR scatterings from HAPG at low temperature $T = 1.5$ K and their intensity changes due to adsorbed monolayer helium at $T = 4$ K although some troubles occurred in the low temperature device and the thermometer during the beam time. For further discussion, detailed analyses are needed with simulations. We got great progress in synchrotron X-ray diffraction experiment at low temperatures since obtained results suggest that helium film actually exists on the HAPG. Future tasks are preparation of large samples in size and improvement of the refrigeration system.

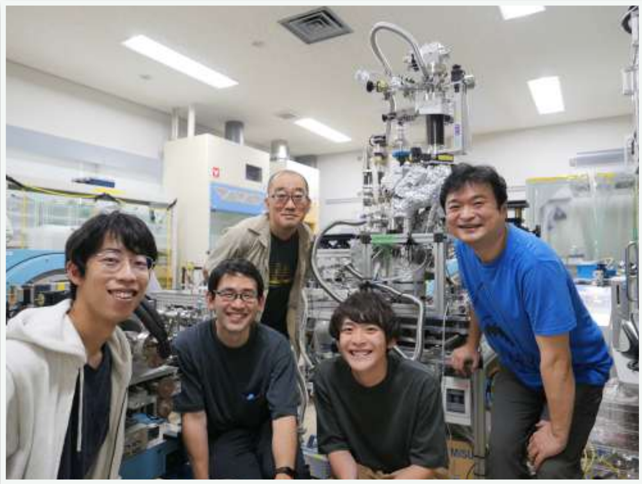


Inside the experimental hatch

Although my internship has finished, it is expected using this device that we can obtain structural information in the surface normal direction i.e., the height of a helium monolayer to the substrate, and furthermore, this research has a possibility to elucidate even in-plane structures of a He absorbed system. That is, our new experimental technique has a potential to provide new physics and a new understanding of quantum physics or material physics. I was very impressed that I was involved in this important first step.

Acknowledgments

I would like to express my gratitude to Dr. Hiroo Tajiri, Senior Researcher at JASRI, Prof. Akira Yamaguchi at the University of Hyogo, and Prof. Hiroshi Fukuyama, my former supervisor, for giving me this wonderful opportunity. I would like to thank Dr. Tajiri for accepting and supporting me during the internship. I am grateful to Prof. Yamaguchi, Prof. Yamane, Mr. Kumashita, Prof. Sumiyama, and their member, for their help and doing the study together. I want to thank JASRI, Dr. Kimura, director of Diffraction and Scattering Division at JASRI, Graduate School of Science, my supervisor Prof. Murakawa, and Prof. Yamada for allowing me to be a research student at JASRI even in the difficult situation. I also thank Ms. Koujibata at JASRI, Ms. Sasaki at Cryogenic Research Center, for their help before and during the internship. I am deeply grateful to MERIT and Mr. Asano for giving me this opportunity and the support.



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