（別紙様式２）

フォトンサイエンス国際卓越大学院プログラム（XPS）
光科学特別実習　報告書

氏　　名	小澤直也
所属部局	理学系　研究科　　　物理学　専攻
研究機関・企業名	理化学研究所・量子多体ダイナミクス研究ユニット
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As part of this program, I worked on a collaborative project with the Quantum Many-Body Dynamics research unit (QMBD) at RIKEN. The group, led by Dr. Takeshi Fukuhara, aims for the realization of quantum simulations of frustrated magnetism using ultracold atoms in a triangular optical lattice. The group is currently working on the realization of single-site-resolved imaging of Rb atoms in a triangular lattice. During my stay in the lab, I worked together with the lab members to efficiently trap the atoms in the lattice, and to achieve a high-quality fluorescence imaging system. In particular, the fiber laser for the optical lattice had been sent for repair for a few months, so my project was to restore the optical lattice to the same condition as prior to the repairment.

This project is closely related to the project I work on in my lab. We are aiming for the high-precision measurement of the permanent electric dipole moment (EDM) of electrons using laser-cooled Francium atoms. Up to now, we have been successful in the production of Fr using nuclear reactions. However, the laser cooling has not been implemented yet, and requires knowledge on cold-atom experimental techniques. EDM measurements require extreme precision, and the laser cooling of sample atoms is crucial to achieve a high statistical sensitivity. This collaboration was an opportunity for me to gain experience on the basic techniques for cold-atom experiments, especially on trapping atoms in optical lattices.

The potential depth of an optical dipole trap or an optical lattice can be indirectly measured by observing the parametric modulation spectrum. A red-detuned optical dipole trap creates a restorative force towards the intensity maximum of the beam which can be approximated by a harmonic potential when the atoms are deeply trapped. Through this approximation, the trap depth can be parametrized by the “trap frequency”, which is the angular frequency of the equivalent harmonic oscillator. When the intensity of the beam is modulated at twice the frequency of the trap frequency, the quantum mechanical equivalent of a parametric oscillation occurs, and the trapped atoms are heated until they escape the trap. Using this technique, the potential depth of the triangular lattice at the start of the collaboration was observed to be shallow than previously observed.

Based on this observation, we started troubleshooting the possible defects. The main parameters that determine the potential depth of a lattice are the beam intensity, the alignment of polarization, and the beam pointing. The beam intensity, or the power density, is proportional to the trap depth, so by measuring them, the trap depth could be directly determined. Unfortunately, the geometry of the apparatus limited access to the trap region, thus the direct measurement was not possible. If the polarizations of the overlapped beams are not aligned, the interference becomes smaller, which leads to a shallow lattice potential. Also, the QMBD group uses a triangular lattice, where three beams are crossed at 120-degree angles. This requires that the three beams intersect at a single position, otherwise only 1D lattices would be formed. These were checked by adjusting the polarization or pointing and remeasuring the trap frequency.

There are other factors which may lead to an effectively shallow potential, which include the power noise and phase noise of the laser beams. The former is the instability of the beam power, and especially when it includes an oscillation at twice the trap frequency, it is equivalent to the parametric modulation. The latter is the instability of the phase, and when the contributions are different for each overlapped beam, the lattice starts to move according to the phase difference.

During the collaboration, each possibility was checked by adjusting the parameter and taking the parametric modulation, except for the phase noise. In the end, everything we checked seemed to be already sufficiently optimized, and the reason for the shallow potential could not be determined.

Another project that I worked on simultaneously was the construction of a numerical simulation code for the Raman sideband cooling of ^{87}Rb in the triangular optical lattice. This was meant to be a cross check of the same calculation done by a former master course student. Unfortunately, the code was not finished by the end of the collaboration, but as it was written in Python, it is expected to give more accessibility, compared to the previous calculation code which was written in MATLAB and required the software license.

Unfortunately, due to the time limit for the program, the projects were not completed. However, the trial-and-error experiments in the lattice potential optimization was a perfect opportunity for me to gain experience in the style of cold-atom experiments. Also, as I wrote the calculation code, reading various related references served me as an introduction to optical lattices and Raman spectroscopy. Making use of the experimental techniques and knowledge learned through this program, I am closer to my goal of observing laser-cooled Fr atoms.