I. 10. Development of an Optical Dipole Trap System for the Electron Electric Dipole Moment Search

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Ultracold atoms captured by laser cooling and trapping techniques are used for optimizing the measurement precision for a permanent electric dipole moment (EDM) in an elementary particle[1,2)]. In the case of alkali atoms, the EDM signal from the valence electron is enhanced by the large effective electric field from the nucleus in an atom[3,4)]. Francium (Fr, Z = 87), which is the heaviest alkali atom, exhibits a large enhancement factor of 895 for an electron EDM[5)], but all isotopes are unstable.

At Cyclotron and Radioisotope Center (CYRIC) at Tohoku University, Fr atoms will be captured in an optical dipole trap (ODT)[6)] by laser-cooling and trapping techniques in order to reduce statistical and systematic errors in the EDM measurement. Fr is produced via the nuclear fusion reaction of ^{197}Au(^{18}O, xn)$^{215-x}$Fr with an oxygen beam (E_{18O} = 100 MeV) accelerated from an AVF cyclotron into a gold target. The produced Fr is transported as an ion beam and converted to a neutral atom by a neutralizer. The atom is captured in a magneto-optical trap (MOT)[7)], which consists of a 3-dimensional laser cooling and a quadrupole magnetic field, as a cold atomic cloud with a temperature of a few hundred μK. The captured atoms in the MOT are situated in the ODT and moved into a magnetically-shielded area via optical tweezers. The EDM search will be performed by applying electric and magnetic fields to the atomic cloud captured in the ODT. Each apparatus for the EDM measurement has been developed using Fr or rubidium (Rb) atoms.

An ODT is a technique involving a high-intensity, strong-focusing laser light detuned largely from the resonant frequency of the atom. A trap potential depth, as shaped at the focal point, is proportional to the intensity of the trapping laser light. The ODT does not exert a cooling effect for trapped atoms. The MOT and polarization gradient cooling (PGC)[8] are often used as pre-cooling methods before loading into the ODT. The ODT will be used to hold and transport ultracold atoms into the magnetically-shielded area, and also to keep them during the EDM measurement in the experiment at CYRIC.

We reported a red-detuned ODT experiment with a 1083 nm fiber laser (Keopsys KPSBT2-YFL-1083-50-COL)[9], and the development of an offline double MOT system using ^{87}Rb atoms[10]. The experimental setup for the ODT experiment is shown in Fig. 1. First, Rb atoms were stored in the second MOT chamber. We then applied the PGC technique for pre-cooling by turning off the MOT coil current and detuning the trapping light frequency. After the loading into the ODT for 1 s was performed by overlapping the ODT light in the region of the second MOT, the MOT light was turned off. The ODT laser with a diameter of 1 cm and a wavelength of 1083 nm was focused through an f = 250 mm achromatic spherical focal lens. The trapped atoms in the ODT were finally isolated for 5 ms. The trapped atoms in the ODT were observed as an absorption image by using a CCD camera after the ODT trapping light was turned off.

As a result, the absorption image of the atoms trapped in the ODT was confirmed. The shape of the trapped atoms in the ODT is shown in Fig. 2. The number of atoms was estimated from a transmittance distribution of the imaging light through the atomic cloud. The trapped number was 3×10^3 [9]. The improvement in both the pre-cooling process and the ODT light alignment process are required to increase the number of atoms.

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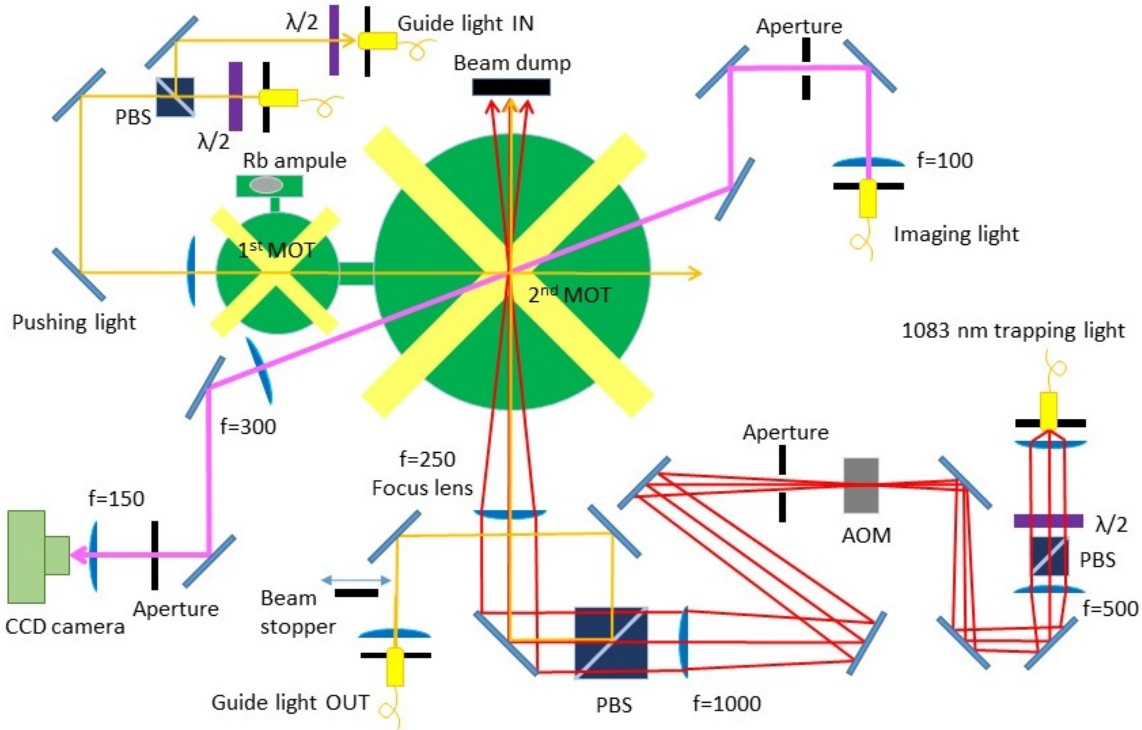

Figure 1. Overview of setup for the ODT experiment around the double-MOT system.

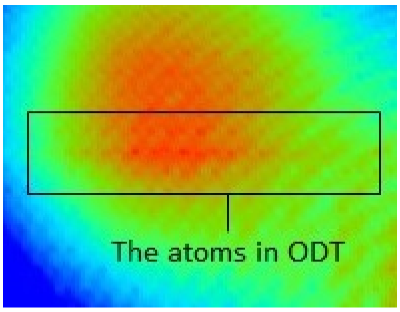

Figure 2. A picture showing an ODT existent. This picture was obtained by comparing two pictures which were taken at the same timing of the differential sequences. One was taken when the ODT trapping light was turned on, and the other was taken when the light was turned off. A different degree of absorption between the two pictures is described as a color distribution. A horizontally long and thin red shape in a black cage is an existence of the trapped atoms in the ODT.