II. 2. Present Status of the Development of an Optical Dipole Force Trap System towards the Electron Electric Dipole Moment Search

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The permanent electric dipole moment (EDM) search experiments for the test of violation of fundamental symmetries using various kinds of atoms and molecules have been vigorously carried out in recent decades. The finite value of an EDM signal provides signature of parity (P) and time reversal (T) violations, which are explicit evidences for a new physics beyond the standard model of particle physics[1)]. The several ingenious experiments for obtaining sufficient sensitivity to detect the EDM are attempted in the world as these signals are extremely small. The signal enhancement calculated in several theories is emphasized by total number of protons (Z) in an atom and the effective internal electric field in a polar molecule and is approximately proportional to Z^3. Hence heavy atoms for EDM search have been widely employed.

The electron EDM measurement using thorium monoxide (ThO) molecule[2)] is well known as the most precise measurement. The upper limit of the electron EDM obtained from the experiment is 8.7×10^{-29} $e$cm. However, in the atomic or molecular beam experiment the significant systematic effects are caused by the motional-magnetic field $v \times E / c^2$ effect that comes from the atoms moving with velocity v through an applied electric field E (c: speed of light) and by the geometric phase shifts generated by complicated field gradients. These systematic errors mimic the true EDM signal and limit the accuracy of measurement of the EDM.

The measurements using laser cooling and trapping techniques for atoms are proposed to achieve more sensitive detection beyond the current upper limit. The velocity of the laser cooled atom is low, and therefore the interaction time between an atom and an electric field is elongated by approximately three orders of magnitude compared to the conventional beam experiments. Moreover, the significant systematic effects caused by the motional-magnetic field and by the geometric phase shifts are strongly suppressed. Thus, there are several advantages of using optically trapped atoms for these measurements. Additionally, Francium (Fr) being the heaviest alkali atom has a large enhancement factor of about 900[3,4]. The EDM experiment using laser cooled Fr atoms promises to reach sensitivities even with their upper bounds, thus better than that of beam experiments.

We report the current status of the development of an optical dipole force trap (ODT) system for trapping Fr and rubidium (Rb) atoms at Cyclotron and Radioisotope Center (CYRIC), Tohoku University. As Rb atom has similar chemical properties to that of Fr, we mainly employed Rb atoms for the development of the ODT system. The ODT is a versatile technique for trapping neutral atoms into regions of high electric field strength and is useful for the EDM measurement. A Magneto-optical trap (MOT) is widely used as a pre-cooling method before the atoms are loaded into the ODT. The details of development of the MOT system for Rb atoms was previously reported[5,6]. The number of atoms trapped in the magneto-optical trap (MOT) chamber was about 10^8. The size of the atomic cloud was approximately 3 mm. The temperature of the atoms estimated by time-of-flight method was 90 μK. We have already achieved optical dipole force trapping of rubidium atoms. However, the loading efficiency from MOT to ODT was about 0.01%. To overcome this issue, we use polarization gradient cooling method to lower the temperature and a compressed MOT technique to increase the density of atomic cloud, and employ a high-power fiber laser of 50 W for ODT.

We introduced a new light source for optical dipole force trapping of atoms. The light source consists of a seed light and a fiber amplifier. The wavelength of the light was 1064 nm. The experimental setup is shown in Fig.1. Figure 2 shows the output power from seed light source as a function of input current. The maximum power was 550 mW at a current of 1.35 A. The power was measured by a power meter which was set in front of an isolator as shown in Fig 1. After passing through a half waveplate (λ/2) and a polarizing beam splitter (PBS) to optimize the intensity and polarization of the seed light, the light was input into the fiber amplifier. The amplifier is a continuous wave, narrow-linewidth, polarization maintaining fiber amplifier and amplifies a single-frequency light more than 50 W. The power of the seed light required as an input to the fiber amplifier is minimum 50 mW and a maximum of 200 mW, respectively. The output power of about 56 W from the amplifier measured by a power meter was confirmed when the seed light power was 120 mW.

This research was supported by a Grant-in-Aid for Scientific Research (JP21104005, JP26220705), the Murata Science Foundation and SEI Group CSR Foundation.

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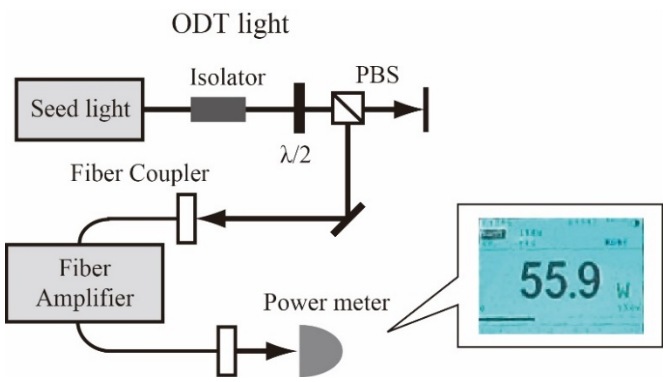

Figure 1. Experimental setup for ODT light. The picture in figure is a display of the output power of 55.9 W obtained from the fiber amplifier.

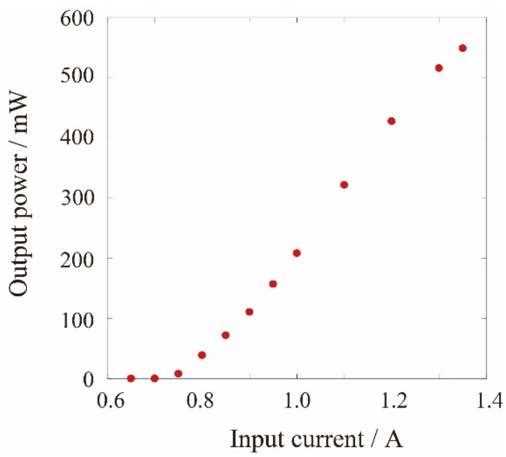

Figure 2. The output power of the seed light as a function of an input current. The threshold current was approximately 0.7 A.