Development of ^{3}He comagnetometer for ^{129}Xe EDM measurement

Y. Ichikawa,[*1,*2] M. Chikamori,[*2] Y. Ohtomo,[*2] E. Hikota,[*2] Y. Sakamoto,[*2] T. Suzuki,[*2] T. Sato,[*2] S. Kojima,[*2] H. Shirai,[*2] H. Miyatake,[*2] T. Nanao,[*2] K. Suzuki,[*2] T. Inoue,[*3] T. Furukawa,[*1,*4] A. Yoshimi,[*1,*5] C. P. Bidinosti,[*6] T. Ino,[*7] H. Ueno,[*1] Y. Matsuo,[*1,*8] T. Fukuyama,[*9] and K. Asahi[*1,*2]

A permanent electric dipole moment (EDM) that directly violates time reversal symmetry attracts much attention, because an unknown CP-violating phase which is necessary for understanding the present matter-dominated Universe, is expected to be probed by EDM. The present study aimed to measure the EDM in a ^{129}Xe atom to the order of 10^{-28} $e$cm, which is beyond the present upper limit[1]. We employed an active nuclear spin maser[2,3] to sustain the spin precession of ^{129}Xe over a long duration. The active spin maser operates in the following manner. The ^{129}Xe spin is longitudinally polarized through spin exchange with optically pumped Rb atoms. Precession of the ^{129}Xe spin in an applied static field is detected optically by transversely repolarized Rb atoms. By referring to the precession signal thus obtained, a feedback magnetic field is generated such that its direction is kept orthogonal to the transverse component of the spin. The feedback field thus prevents decay of the transverse magnetization.

In an EDM measurement, magnetometry is essential because a large systematic uncertainty in frequency arises from long-term drifts in the external magnetic field. A comagnetometer using ^{3}He was incorporated into the nuclear spin maser system in order to cancel out the drifts[4]. Because a ^{3}He comagnetometer can measure the field exerted on the ^{129}Xe precession, it is an *in situ* magnetometer.

The main difficulty in realizing the ^{3}He comagnetometer stems from the fact that the spin-exchange rate between ^{3}He and Rb is lower than that between ^{129}Xe and Rb by several orders of magnitude. Because there is little source of polarization, spin relaxation at the surface of the cell and impurity in the gas critically degrade the polarization of ^{3}He. Therefore, a GE180 glass with low magnetic impurity and low gas leakage was employed to fabricate the cell. The cell has a spherical shape with a diameter of 20 mm, containing 1 Torr of ^{129}Xe, 470 Torr of ^{3}He, 100 Torr of buffer N_2 gases, and Rb vapor. We typically achieved 3% of the polarization and over 50 hours of the longitudinal spin relaxation time for ^{3}He at 100 °C.

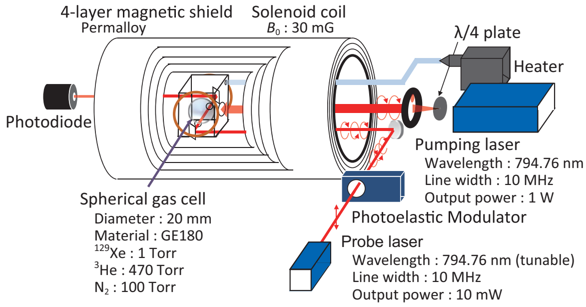

Fig. 1. Experimental setup for active spin maser.

The experimental setup used to test the ^{3}He comagnetometer is shown in Fig. 1. The gas cell is placed in a solenoid coil which generates a static magnetic field B_0 ($\sim$ 30 mG), and is enclosed in a 4-layer magnetic shield. A circularly polarized pumping laser is incident on the cell parallel to B_0. A probe laser passes through the cell in a direction orthogonal to B_0 and is detected by a photodiode. The signal from the photodiode is divided into two, each being lock-in-amplified with ^{129}Xe or ^{3}He precession frequency, and the resulting two beat signals are obtained and processed individually at the same time to generate their feedback magnetic fields through two separate coils.

We succeeded in operating the masers of ^{129}Xe and ^{3}He concurrently[4]. The individual determination precisions of the average frequencies achieved in 10^6 seconds for both ^{129}Xe and ^{3}He are ~100 nHz. However, the frequency shift due to contact interaction with polarized Rb atoms prevents the ^{3}He comagnetometer from realizing its full potential because the strengths of the Rb-^{129}Xe and Rb-^{3}He contacts are different. Therefore, we decided to employ a double-cell geometry in which the gas volume is divided into a section for optical pumping and another for optical spin detection in order to suppress Rb polarization in the optical detection section and thus reduce the frequency shift[5]. Development of the ^{3}He comagnetometer with the double-cell geometry is in progress.

*1 RIKEN Nishina Center
*2 Department of Physics, Tokyo Institute of Technology
*3 Cyclotron and Radioisotope Center, Tohoku University
*4 Department of Physics, Tokyo Metropolitan University
*5 Research Core for Extreme Quantum World, Okayama University
*6 Department of Physics, The University of Winnipeg
*7 Institute of Material Structure Science, KEK
*8 Department of Physics, Hosei University
*9 Research Center for Nuclear Physics, Osaka University

References

1) M. A. Rosenberry et al.: Phys. Rev. Lett. **86**, 22 (2001).
2) A. Yoshimi et al.: Phys. Lett. A **304**, 13 (2002).
3) A. Yoshimi et al.: Phys. Lett. A **376**, 1924 (2012).
4) Y. Ichikawa et al.: Eur. Phys. J. Web of Conf. **66**, 05007 (2014).
5) E. Hikota et al.: Eur. Phys. J. Web of Conf. **66**, 05005 (2014).