Development of co-existing ^{129}Xe and ^{131}Xe nuclear spin masers with active feedback scheme for the Xe atomic EDM search

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Astronomical observations reveal that the matter to photon ratio in the Universe is many orders of magnitude larger than the prediction based on broadly accepted cosmological scenarios. The extra CP-violation, which may come from physics beyond the Standard Model (SM), will contribute to understanding of the origin of matter. The electric dipole moment (EDM) of a particle is one of the cleanest probes for new physics, because the SM contribution to the EDM is undetectably small while most of proposed candidates for new physics predict detectable sizes of EDM. There are only three CP-violating effective operators at the hadron level that can enter EDMs of diamagnetic atoms.[1)] Therefore, a combination of measurements for at least three different atoms is essential to distinguish the new physics beyond the SM. The improvement of the upper limits of the EDMs of diamagnetic atoms has a significant impact on the study of new physics in the nucleon-nucleon and nucleon-electron interactions. Thus, we aim to improve the current upper limit on the Xe atomic EDM, $|d(\mathrm{Xe})| < 4.1 \times 10^{-27} e\mathrm{cm}$,[2)] by more than one order of magnitude.

To detect the EDM of a Xe atom, the frequency of spin precession in a static magnetic field and an electric field is measured. The presence of an EDM of a size 10^{-28} $e$cm, for instance, in a 10 kV/cm electric field would change the frequency of the Xe spin precession on the level of nanohertz. In order to detect such an extremely small frequency change, an experimental scheme, a nuclear spin maser with an active feedback was developed.[3–5)] The spin maser enables the elongation of the spin coherence time to an infinitely long duration, and thus, the statistical sensitivity can be improved rapidly with time compared to repeated short measurements. In addition, in order to eliminate the effect of the drift in the magnetic field, the ^{131}Xe spin maser was introduced as a reference system (co-magnetometer). For this purpose, ^{3}He is often used[2)] as its small EDM compared to that of Xe due to the small atomic number is suitable for the reference atom. However, there remains a difficulty due to the difference in the magnitudes of the frequency shifts caused by the contact interaction with polarized Rb atoms. This limitation can be eased by using ^{131}Xe. Since the magnitude of the polarized Rb interaction is almost the same between ^{129}Xe and ^{131}Xe,[6)] the systematic errors arising from the polarized Rb interaction will be reduced dramatically.

The operation of the co-existing ^{129}Xe and ^{131}Xe masers with the active feedback scheme was realized for the first time, as shown in Fig. 1. By taking the frequency difference between the ^{129}Xe and ^{131}Xe masers, the dependence of the frequency on the cell temperature, which virtually limits the measurement sensitivity in our ^{129}Xe/^{3}He masers, was mitigated significantly in the ^{129}Xe/^{131}Xe case. The study on the optimization of the maser operation is ongoing. We expect that further improvement in the maser stability can be achieved by increasing the magnitude of the polarization and elongating the spin coherence times for ^{129}Xe and ^{131}Xe.

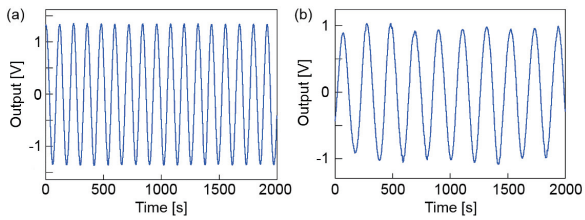

Fig. 1. Maser signals obtained for (a) ^{129}Xe and (b) ^{131}Xe. Beat signals from the lock-in amplifiers which were employed to improve the signal-to-noise ratio were observed at the reference frequency of 33.036 Hz for ^{129}Xe and 9.797 Hz for ^{131}Xe.

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