Concept design for cold highly charged ion generation toward time variation detection of fine structure constant α

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A ground unification theory approves that fundamental physical constants have a time dependence.[1)] Over recent decades, time-variation detections of fundamental physical constants have been attempted through several approaches. In astrophysical research, J. K. Webb et al. reported that a variation of fine-structure constant α was observed as $\delta\ \alpha/\alpha = 0.72(\pm 0.18) \times 10^{-5}$ by comparison with quasar spectra.[2)] Recently, V. V. Flambaum et al. have focused on achieving a high enhancement factor K of highly charged ion(HCI) atomic transitions and suggested high-sensitivity measurements for the detection of α-time variation by Ho^{14+} precision spectroscopy.[3)] Additionally, they proposed special enhanced measurements using highly charged Actinide ions Cf^{15+} and Es^{16+}.[4)]

As mentioned above, HCI precision spectroscopy is expected to be a candidate for the next-generation atomic clock for conducting the constancy test of fundamental physical constants. We plan to measure the frequency difference between a Sr optical lattice clock and a clock transition of HCI using an optical-frequency comb[3,5)] in the detection of α-time variation during a realistic experimental period. In this experiment, we have to prepare an HCI Coulomb crystal for Doppler-shift reduction. However, there are few studies on HCI Coulomb crystals awing to experimental difficulties. In 2015, Ar^{13+} Coulomb crystallization in laser-cooled Be^{+} ions was demonstrated by an external HCI injection system from an electron beam ion trap via a deceleration tube.[6)] For the demonstration of HCI Coulomb crystallization and clock transition detection, we also set a plan to generate an HCI Coulomb crystal using a sympathetic cooling method via laser cooled Be^{+} in a compact instrument as explained below.

Figure 1 shows a temporary assembled ion trap without a solenoid coil and a flexible printed circuit. It will be mounted on the 4K cryogenic chamber as shown in Figure 2,under an ultra-high-vacuum condition with superconductive driving. This ion trap based on the linear Paul trap is divided into three areas and is combined with the Penning ion trap. In the 1st area, HCI and Be^{+} are generated by laser ablation and an electron beam. The off-axis cold cathode injects an electron beam into a trap region while maintaining the cryogenic thermal condition and cooling laser path. A superconductive Nb:Ti wire will be looped on quadrupole rods directly. This wire will become a solenoid coil and generate a strong magnetic field for Penning trap driving and the concentration of the electron beam. Generated HCI ions are transported to the 3rd area by electrical manipulation and cooled by the prepared Be^{+} Coulomb crystal.

A function test of this instrument will be performed by observations of Be^{+} trapping and cooling. After this test, we will try to perform HCI generation and sympathetic crystallization.

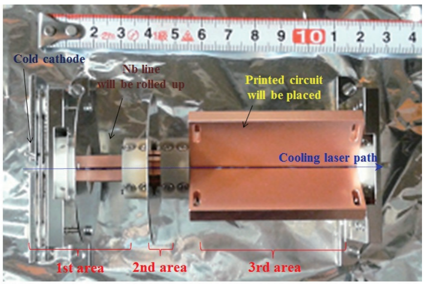

Fig. 1. HCI trap (without coils and print circuits).

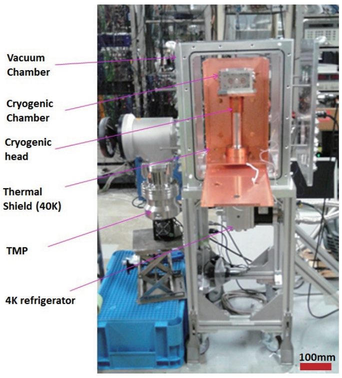

Fig. 2. Cryogenic chamber system.

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