Development of cryogenic linear combined ion trap for cold Highly Charged Ion generation

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Introduction

Back Ground

Modern physical theory such as Ground Unification Theory indicates a possible presence of time dependence of fundamental physical constants [1]. In particular, the ratio of the time derivative of space-time (fine structure constant) to βf: proton-electron mass ratio is expected to play an important role for a development of Ground Unification Theory [2]. Over recent decades, time variation detections of fundamental physical constants have been tried by both of astrophysical research and precision spectroscopy. In 2001, J. K. Webb et al., reported that fine structure constant α has a variation as \( \Delta \alpha = 0.72 \pm 0.16 \times 10^{-13} \) from comparison with quasar spectra [3]. On the other hands, experimental measurements on the earth have not been able to detect n-time dependence [4,5]. Recently, V. V. Flambaum Group suggested high sensitivity measurements for the detection of \( n \) time variation using a spectroscopic study of Highly Charged Ions (HCIs) [6,7,8]. Especially, Ho\(^{16+} \) is proposed a detection transition and a clock transition by theoretical calculation [7].

We plan to measure frequency difference between Sr optical lattice clock and a clock transition of Highly Charged Ion using optical frequency comb [9] toward detection of \( n \) time variation during human life time.

For this purpose, we are developing instruments for precision spectroscopy of Highly Charged Ion. In this presentation, we describe a setup of cryogenic linear combined ion trap for cold Highly Charged Ion generation with a progress of this development.

Development of Ion Trap

Concept

Compact constructing ion source and ion trap in one cryogenic chamber

Trap System

This instrument based on linear Paul trap is divided into 3 areas and is combined with Penning ion trap

① Production Area
   • Ion generation using laser ablation & electron beam
   • Cold cathode is located at off-axis position
   • Superconductive wire (Nb:Ti) is looped on quadrupole ion trap rod

② Selection Area
   • Ion selection by secular motion perturbation

③ Spectroscopy Area
   • Flexible Print circuit is straffled on the quadrupole rods
   • Magnetic field is canceled by anti solenoid coil

Procedure for cold HCI generation

1. \( \text{Be}^+ \) generation using laser ablation and electron beam
2. \( \text{Be}^+ \) is transported and mixed at spectroscopy area under laser cooling
3. \( \text{HCI} \) generation using laser ablation and electron beam with Magnetic field
4. \( \text{HCI} \) is transported and mixed with stored \( \text{Be}^+ \) at spectroscopy area (Sympathetic cooling using cold \( \text{Be}^+ \))

Progress of Design & Manufacturing

Chamber System

• Ion trap is placed in 4K cryogenic chamber
• Ultrahigh vacuum
• Superconductive driving

Vacuum Chamber

① Shield (40K)
② Multilayer (300K)
③ Head (Room temp)
④ Nb wire will be rolled up

Vacuum Chamber System

High thermal conductivity materials are selected for vacuum condition and superconductive driving (i.e. Cu, AlN)
• For charge up cleaning, insulation materials are coated with Cr2O3 layer by Ion Plating method

Simulation Study

Electron Trajectory Simulation from Off-Axis Cold Cathode

Magnetic Field from Custom Superconductive Coil

Next Step

• Test of \( \text{Be}^+ \) ion generation and laser cooling
  • Measurement of trap life time using CEM or MCP
  • Setting up cooling laser (313nm)
• Highly Charged Ion generation
• High intensity electron beam design
• Sympathetic cooling experiment for HCI
• Laser spectroscopy of cold HCI

Summary

• We determined a detail design based on simulation studies for ion-electron trajectories and magnetic field.
• We made components of this ion trap.
• Test of \( \text{Be}^+ \) ion generation and laser cooling
  • Measurement of trap life time using CEM or MCP
  • Setting up cooling laser (313nm)
• Highly Charged Ion generation
• High intensity electron beam design
• Sympathetic cooling experiment for HCI
• Laser spectroscopy of cold HCI

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Reference