18PB-036

Confinement of xenon ion by a linear quadrupole ion trap
イオントラップ装置を用いたキセノンイオンの閉じ込め実験

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The purpose of this research is to understand the behavior of the xenon ion trapped in a linear quadrupole ion trap device. Ion trap is the experimental system to store charged particles, which applied to the mass spectrometry, the frequency standard and so on. In near future, the quantum computer will be realized by this concept of an ion trap. In this experiment, xenon ions are trapped by a combination of using the high-frequency electric field and the static field. The number of stored ions is measured by using a RF resonance absorption method. Two resonant circuits with the frequency of the match to the characteristic vibration of xenon ion are used for this measurement. In this poster, experimental results of RF resonance absorption method are presented.

1. Introduction

Ion trap is one of the techniques for a trap of charged particles. It is known that charged particle cannot be trapped by only magnetic fields or only electric field (Earnshaw's theorem). It is necessary two or more electromagnetic field for trap of a charged particle. In general ion trap, charged particles are trapped by a combination of a magnetic field and an electric field. Penning and RF traps are typical experimental systems for trap of charged particle. The penning trap can trap a few charged particles by using an electrostatic field and a magnetic field. On the other hands the RF trap are used an electrostatic field and a high-frequency electric field for trap of a number of charged particle. In this research, xenon ions are trapped by using RF trap. There are two type of trap method in the RF traps. One is a rotational dipole RF trap and other is a linear RF trap. The rotational dipole RF trap can trap ions near the center point of electrode. On the other hands, a linear RF trap can trap ions on the axis of electrode rods.

One of the purposes of an ion trap is to understand the characteristics of strongly coupled plasma. In strongly coupled plasma, interaction between particles is very strong. The degree of the strongly coupled plasma is determined by the ratio of average coulomb potential energy to thermal kinetic energy. It is given by the following expression.

$$\Gamma = \frac{\text{average coulomb potential energy}}{\text{thermal kinetic energy}} = \frac{q^2}{4\pi\varepsilon_0 a k_B T}$$

Here Γ is called coulomb combined parameter. If this value is larger than 1 or equal, it is state of strongly coupled plasma. If Γ is smaller than 1, it is state of weakly coupled plasma. Weakly coupled plasma shows gaseous physical property. Strongly coupled plasma shows liquid physical property. If more strong coulomb interaction occurs, it shows the state of a solid [1] .

2. A linear quadrupole RF ion trap

The schematic drawing of a linear quadrupole RF ion trap is shown in Fig.1. In this experiment, four electrode rods and two ring electrode are used for trap a xenon ions. The advantage of the RF ion trap is that it is possible to confine side by side a large number of charged particles. The realization of the cooled ions for a quantum computer will also be possible by using a laser cooling. The disadvantage is that the high frequency electric field heats the charged particle.

In our experiment, the rod electrode made of stainless steel and its length is 300mm. The radius R of rod electrode is 5mm. The distance r between

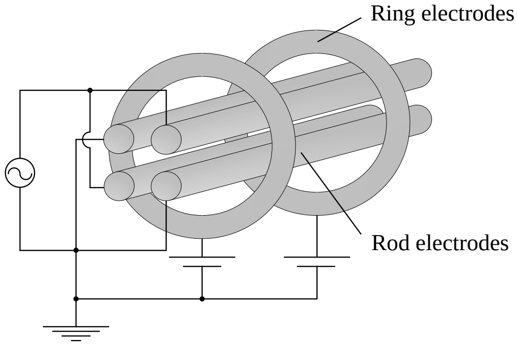

Fig.1.The linear quadrupole RF ion Trap.

the face of a rod and the central axis can be changed an interval of 1mm from 3mm to 6mm. The value of R/r is an important parameter for a linear quadrupole RF trap of a charged particle. Figure 2 shows the schematic drawing of an electrode part of our linear quadrupole ion trap. The distance between two ring electrodes are 47mm and 147mm in this experiment. The insulators between a rod electrode and device are used a Teflon and polyimide.

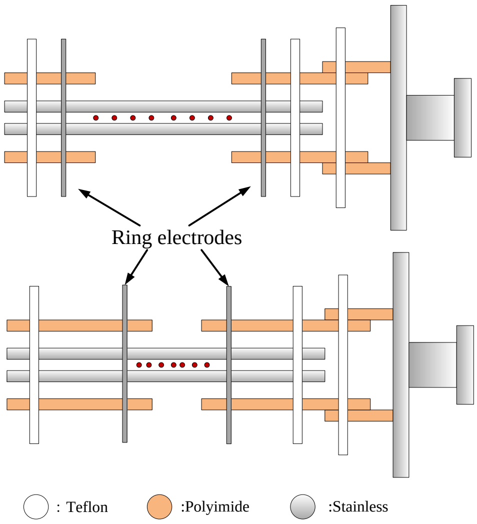

Fig.2.Trapping part of the charged particles

3. Measurement of stored ions

In this research, the RF resonance absorption method is used for measurement of a number of trapped charged particles. The RF resonance absorption is a detection method using the resonance phenomena of the electric circuit. This measurement method is used characteristics of the ion absorbing high frequency electric field that matches the motion frequency of the trapped charged particles. The circuit diagram of the RF resonance absorption method is shown in Fig.3. The series resonant circuit is constructed by a coil L_1 and a capacitor C_1. Because the high AC voltage is applied to the quadrupole rod electrode, the voltage oscillation affects the RF resonance absorption measurement. To reduce such an influence, the L_1 and C_1 is selected to match the frequency ω of the AC voltage $v_r(t)$. The parallel resonant circuit is constructed by a coil L_0 and a capacitor C_0. This is a circuit for measurement of the number of charged particles. The resonance frequency f_0 has to adjust to match the resonance frequency f_{ion} of the ion and the frequency f_p of the RF resonance absorption circuit. The frequency of a RF resonance is very narrow and the signal from charged particles is minute. Thereby, the output of a circuit needs to match harmonic oscillation of a charged particle. In this measurement, the Q value will become important parameter. The Q value indicates the sharp of a peak at the frequency of the circuit. The figure 4 shows the results of the simulation of the RF resonance absorption method. The eigen-frequency of the motion frequency of the charged particles is approximately 156.7 kHz. The dashed lines are shown the results when the charged particles are not present in the ion trap and solid lines are that of when the charged particles exist. The rapid decrease of the output voltage at the eigen frequency is the result of confinement of charged particles. Since the drop of the output voltage is due to the harmonic oscillation of the trapped charged particles in the electrode of the ion trap device, the number of the trapped charged particles can be estimated by this voltage. In the poster, experimental setup, results and conclusive summary are presented.

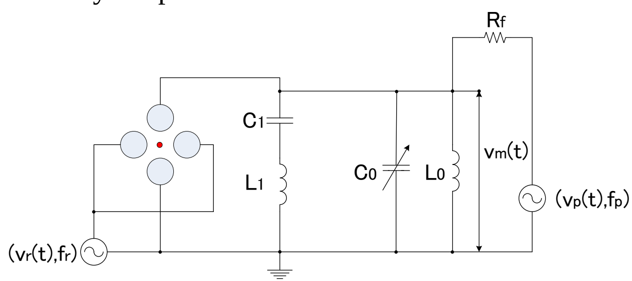

Fig.3.Circuit system for RF resonance absorption method

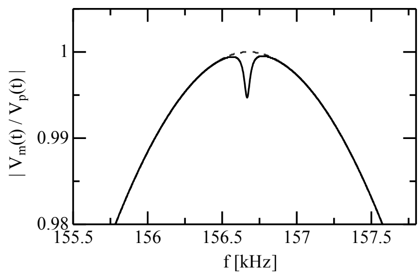

Fig.4.Simulation of the RF resonance absorption method.

Reference

[1]Yasuaki Hayashi, Kunihide Tachibana, Coulomb Crystal and strongly Coupled Plasma, Plasma and Fusion Research (PER), 72(1), (1996)

[2]W.L. Slattery, G. D. Doolen and H. E. DeWitt, Phy. Rev.A21, 2087 (1980)

[3]Tomoyuki Watahiki, The basic research on the charged particle confinement in a linear RF trap (2011)

[4]Koichiro Kiho, A basic research on production methods and confinement property of charged particles for a quadupole linear RF ion trap (2013)

[5]Yasushi Nagata, Measurement of stored ion by the RF resonance absorption method in a linear quadrupole trap (2014)

[6]Shinji Urabe, Jun Umezu, Mitsuo Ishizu, Radio Research Laboratories,Ministry of post and Telecommunications, applied physics, 54(9) (1985)