Calcium Atom Trap for Atom Trap Mass Spectrometer

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1. Introduction

Trace isotope analysis has been an important role in science, archaeological dating, geology, biology and nuclear industry. Artificially produced fission products such as Sr-90, Cs-135 and Kr-85 can be released to the environment when nuclear accident occurs and the reprocessing factory operates. Thus, the analysis of them has been of interest in nuclear industry. But it is difficult to detect them due to low natural abundance less then 10^{-10}.

The ultra-trace radio isotopes have been analyzed by the radio-chemical method, accelerator mass spectrometer, and laser based method. The radio-chemical method has been used in the nuclear industry [1]. But this method has disadvantages of long measurement time for long lived radioisotopes and toxic chemical process for the purification [2]. The accelerator mass spectrometer has high isotope selectivity, but the system is huge and it has the isobar effects. The laser based method, such as RIMS (Resonance Ionization Mass Spectrometry) is a basically isobar-effect free method. Recently, ATTA (Atom Trap Trace Analysis), one of the laser based method, has been successfully demonstrated sufficient isotope selectivity with small system size. It has been applied for the detection of Kr-81 and Kr-85 [1]. However, it is not suitable for real sample detection, because it requires steady atomic beam generation during detection and is not allowed simultaneous detection of other isotopes. Therefore, we proposed the coupled method of Atom Trap and Mass Spectrometer. It consists of three parts, neutral atom trap, ionization and mass spectrometer. In this paper, we present the demonstration of the magneto-optical trap of neutral calcium. We discuss the isotope selective characteristics of the MOT (Magneto Optical Trap) of calcium by the fluorescence measurement. In addition, the frequency stabilization of the trap beam will be presented.

2. Basic Concept of Atom Trap Mass Spectrometer

The ATMS (Atom Trap and Mass Spectrometer) is the coupled method of atom trap and the mass spectrometer. MOT (Magneto Optical Trap) is one of methods to confine the neutral atoms in optical and magnetic fields. In the method, the freely flight neutral atoms are slowed down by the counter propagating light in the absorption and emission processes. In the same manner, the 6-directed laser beams under the quadrupole magnetic field produces the three dimensional restoring and damping forces for trapping the atoms at the center of the fields.

Every absorption and emission processes has the isotope selective and thus repetitive processes of absorption and emission during the trap produce very high isotope selectivity. Therefore, the target isotope is enriched during the trap process while other isotopes are escaped. The trap size, in general, is less than 1 mm.

In addition, the mass spectrometer measures mass to charge ratio of the charged particle. In particular, time-of-flight mass spectrometry analyzes ions by measuring ion signals depending on flight times.

The enriched atoms by trapping technique are ionized by the pulsed laser. The ionization process is in general non-isotope selective, but isotope selective ionization improves the isotope selectivity of whole system. The ions are used as the ion source for the mass spectrometer. The mass spectrometry produces additional isotope selectivity and enables to detect multiple isotopes, simultaneously. The overall isotope selectivity is expected to be the multiplication of isotope selectivities of the atom trap and mass spectrometer. Therefore, we expect that ATMS improves the isotope selectivity and enable to detect the isotope ratio at the time-varying sample. Up to now, 20-elements in the periodic table are available for ATMS.

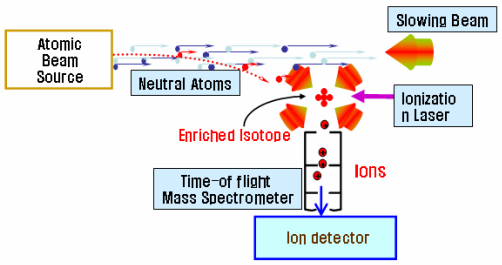

Fig. 1. The schematic diagram of Atom Trap Mass Spectrometer.

3. Magneto-Optical Trap of Calcium

Calcium has 5 stable isotopes with various isotope abundances, Ca-40(96.94%), Ca-44(0.65%), Ca-43(0.14%), Ca-44(2.09%), Ca-46(0.004%), and Ca-48(0.19%). Thus, we used calcium to demonstrate and characterize ATMS. In previous presentation, we reported the continuous wave beam at 423 nm for the atom trap. It was split into four beams for the frequency marker, the saturated absorption spectroscopy, the

Zeeman slowing beam, and the trap beam. The signals from the frequency marker and the saturated absorption spectroscopy were used as the frequency references. The laser wavelength was also stabilized to the red side of the resonances of the saturated absorption signal to generate the red detuned light. The trap beam was split into two beams and provided to the MOT chamber. The polarization and the intensity were controlled by the half-wave plates and the polarizer.

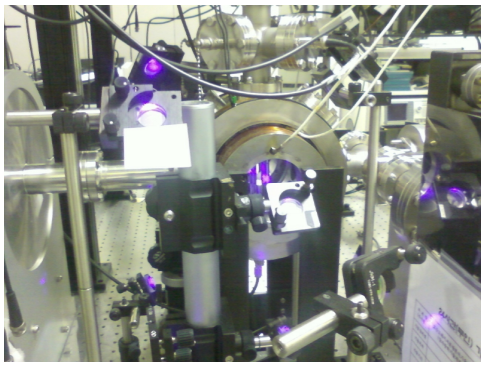

Fig. 2. The experimental setup for the calcium trap.

The neutral calcium atoms were generated by the resistive heated oven and collimated less than 5 mrad. The neutral calcium was slowed down by the slowing beam under the magnetic field. Next, the slow atoms were trapped by six-directed circularly polarized beams under the quadrupole magnetic field. Figure 2 shows the experimental setup for the calcium trap.

After trapping calcium, we characterized the isotope selective characteristics. For this, the wavelength was scanned over the resonance of calcium while the fluorescence from the trapped atoms was measured by a CCD and a PMT (Photo Multiplier Tube) [Fig. 3]. In results, we observed completely separated isotopes and the measured isotope ratio was in good agreement of the natural abundance. We are going to optimize the trap condition and improve the signal to noise ratio.

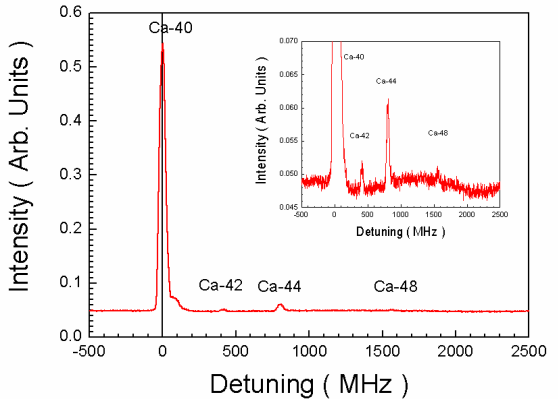

Fig. 3. The fluorescence spectrum of the trapped atoms.

4. Conclusions

The atom trap was performed by the previously reported light source as a first step. The isotope selective property was measured by the fluorescence detection technique. In results, the isotopes were completely separated in the fluorescence detection. The signal ratios are in good agreement of the isotope abundance in reference. We will provide the ion acceleration plate to the MOT chamber and couple it to a time-of-mass spectrometer, in the near future.

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