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New Isotope Analysis Method: Atom Trap Mass Spectrometry

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1. Introduction

Trace isotope analysis has been an important role in science, archaeological dating, geology, biology and nuclear industry. Some 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 artificially produced radioactive isotopes has been of interest in nuclear industry. But it is difficult to detect them due to low natural abundance less then 10^{-10}.

In general, radio-chemical method has been applied to detect ultra-trace radio isotopes [1]. But this method has disadvantages of long measurement time for long lived radioisotopes and toxic chemical process for the purification. The Accelerator Mass Spectrometer has high isotope selectivity, but the system is huge and its selectivity is affected by isobars. The laser based method, such as RIMS (Resonance Ionization Mass Spectrometry) has the advantage of isobar-effect free characteristics. But the system size is still huge for high isotope selective system. Recently, ATTA (Atom Trap Trace Analysis) has been successfully applied to detect ultra-trace isotope, Kr-81 and Kr-85 [2]. ATTA is the isobar-effect free detection with high isotope selectivity and the system size is small. However, it requires steady atomic beam source during detection, and is not allowed simultaneous detection of several isotopes.

In this presentation, we introduce new isotope detection method which is a coupled method of Atom Trap Mass Spectrometry (ATMS). We expect that it can overcome the disadvantage of ATTA while it has both advantages of ATTA and mass spectrometer. The basic concept and the system design will be presented. In addition, the experimental status of ATMS will also be presented.

2. Atom Trap Mass Spectrometer

MOT (Magneto Optical Trap) is one of the neutral atom trap techniques to confine the neutral atoms in optical and magnetic fields. MOT slows down the velocity of the freely flight neutral atoms by transferring the momentum of photons to the atoms in absorption and emission processes. The 6-directed laser beams under quadrupole magnetic field produces the restoring and damping force on the target isotopes. During the repetitive absorption and emission processes, only target isotopes stay in the center of the quadrupole magnetic field while others escape.

Every absorption process is isotope selective, and the isotope selectivity during the repetitive processes of absorption and emission increases exponentially. Thus the trapped isotope can be enriched. In experiment, non-target isotopes are not completely removed, so real isotope selectivity becomes lower than expected. Up to now, MOT is available to 20 elements in the periodic table.

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. We proposed the coupled method of atom trap and mass spectrometer. In this case, the trapped atoms are used as an atomic source for mass spectrometer.

We choose the time-of-flight mass spectrometer to demonstrate ATMS due to its compactness and ease of use. In this case, the coupled system consists of the atom trap and the time-of-flight mass spectrometer. At the first stage, the target isotope is enriched by the magneto optical trap. At next stage, strong laser ionizes the trapped atoms and the ions are accelerated by the acceleration plate inside the trap chamber. The ions are measured by the ion detector. The overall isotope selectivity is expected to be the multiplication of isotope selectivities of the atom trap and mass spectrometer and the whole isotopes in the traps can be observed simultaneously.

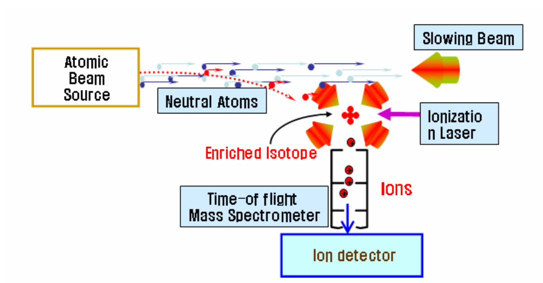

Fig. 1. The schematic diagram of Atom Trap Mass Spectrometer

3. Results and Discussion

We consider calcium to demonstrate ATMS. Calcium has 5 stable isotopes, 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%). Calcium is suitable to demonstrate and characterize ATMS because it consists of many isotopes with various isotope abundances.

Figure 2 shows the general 2-D numerical calculation results in the cases of various inlet velocities. In this calculation we used the classical force induced by the photon-atom interaction. The lines represent the trajectories of the neutral atoms with different inlet velocities. The atoms less than trap depth are trapped and others pass through the trap region. The thermal atomic beam under the trap depth is less than 0.1%, and therefore the atoms should be initially slowed down to improve trap efficiency.

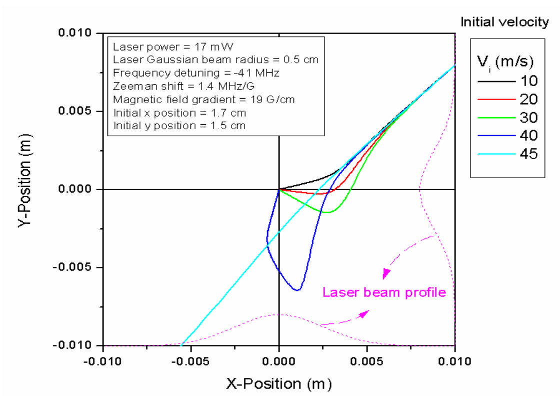

Fig. 2. The numerical calculation results of the trap in 2-D plane.

The atom trap requires a frequency stabilized laser beams resonant on the cycling transition. For this, we consider $4s^2\ {}^1S_0$ -> $4s4p\ {}^1P_1$ transition of calcium. The corresponding wavelength is 423 nm.

The single frequency 423 nm beam was produced by the frequency doubling of a Ti:Sapphire laser. The total power was around 250 mW and it was split into 3 parts for the trap, slowing neutral atoms and frequency stabilization. The saturated absorption spectroscopy was performed in the calcium hollow cathode discharge cell and high-resolution Doppler free signal corresponding transition was obtained. These signals will be used to stabilize the laser frequency to $4s^2\ {}^1S_0$ -> $4s4p\ {}^1P_1$ transition of calcium.

4. Conclusions

ATMS is the isobar-effect free detection method and applicable to long lived radio-isotope detection. We believe that ATMS has the advantages of fast detection time, ultra-trace detection, small system size etc. So we expect it can be applied to the analysis of some fission products.

In addition, we'll try to apply this method to the isotope analysis of calcium which has difficulties due to abundant isobars.

We present the concept of ATMS and the preparation of light source for its demonstration. ATMS will be demonstrated soon.

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