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Development of New Apparatus of Ion Trap with ICP-MS For Trace Isotope Analysis

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Introduction

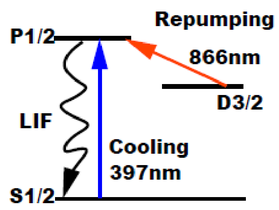
^{41}Ca (lifetime 1.04×10^5 years, γ decay 3.3keV) [1]

- Geochronometry: date determination
- Biomedicine: tracer, bone metabolism
- Geoscience: tracer
- Planetary science: meteorite

Ca II isotope shift

Mass number (abundance)	Isotope shifts [MHz] S-P: 397 nm	D-P: 866 nm	Neclear spin
40 (96.9%)	0	0	0
41 (~ 10^{-14})	unknown	unknown	7/2
42 (0.647%)	425(6)	-2350(4)	0
43 (0.135%)	c.g.:688(17)	c.g.:-3465(5)	7/2
44 (2.09%)	842(3)	-4495(4)	0
46 (0.004%)	1287(4)	-6478(8)	0
48 (0.187%)	1696(6)	-8288(7)	0

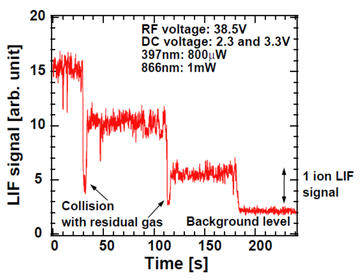
Accelerator Mass Spectrometry [2] requires a large facility and laser based methods[3] such as Resonance Ionization Mass Spectrometry[4], Atom Trap Trace Analysis[5] have been developed.



The Ion trap - Laser cooling technique has the advantages to easily manipulate atomic and molecular ions and detect single isotope ions kept in a trap.

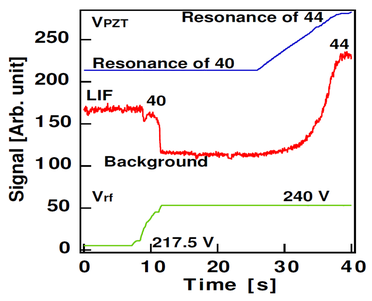
Direct injection of a liquid sample to the apparatus is preferable in analytical chemistry, which can be realized by ICP-MS.
We have combined two techniques and developed a new apparatus for trace isotope analysis.

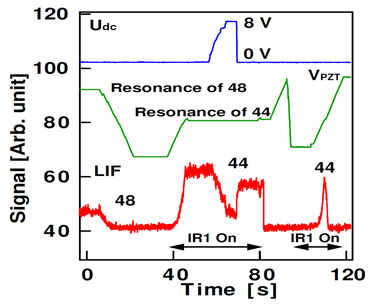
Laser cooling and manipulation realized by our group[6]



Stepwise LIF change

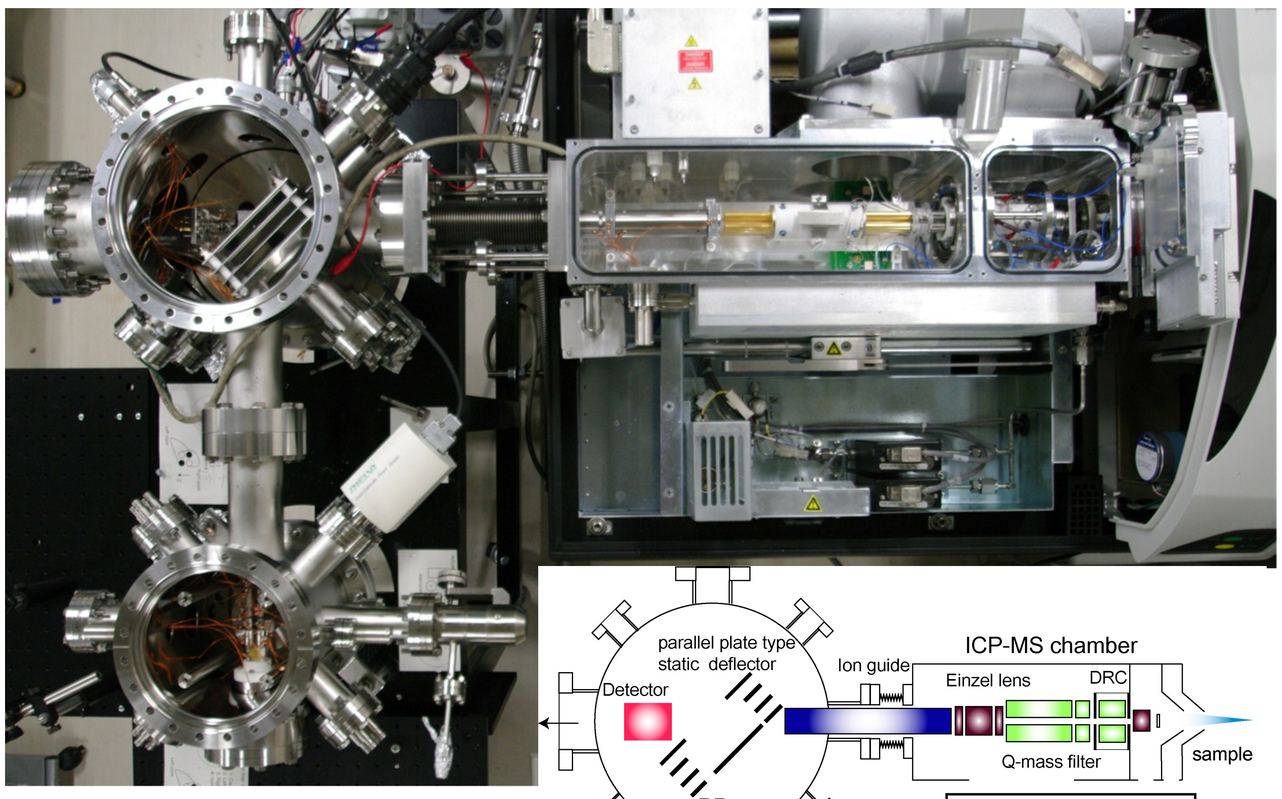
Single ions detection: stepwise difference of LIF signal corresponds to individual single ions.

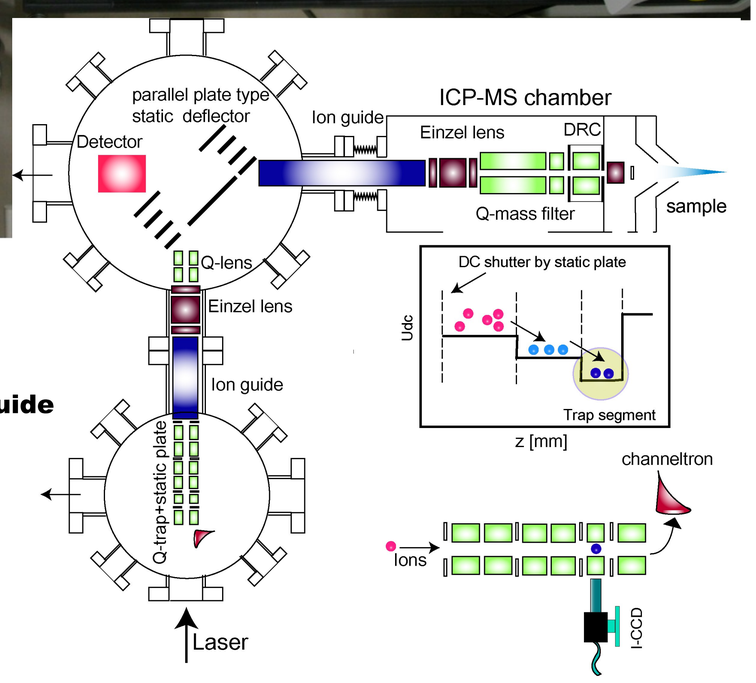




Manipulation of each isotope: low and high pass filters by nonlinear resonance of Mathieu parameters

Experimental setup





Design Requirements of the system

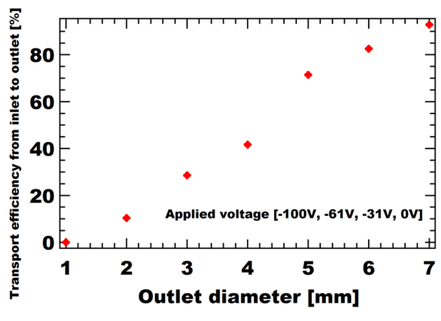
1. Differential pumping
   => long focus ion lens + static ion guide
2. Deflection of ion's trajectory
   => laser and direct detection
3. Ion trap
   => laser cooling

Parallel deflector

A simple deflector which consists of four parallel plates is used for the deflection region. The advantages of the deflector are;

- Simple configuration
- Suitable for beams with low kinetic energy
- Beam focusing at outlet plane

The inlet diameter of the deflector is 5.6 (4 sqrt{2}) mm.
According to the simulation, larger outlet diameter gives higher efficiency as expected.
The outlet diameter of the deflector is determined as 6 mm because the diameter of the following lens is 6 mm.

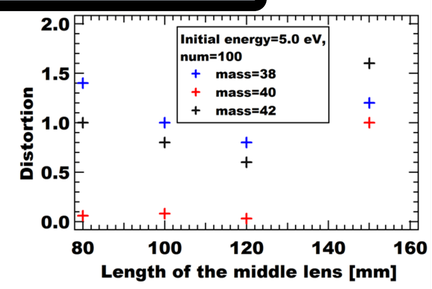


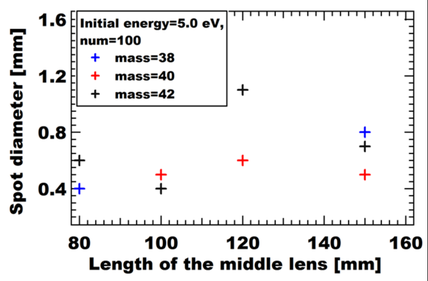
Long focus ion lens system

To obtain high vacuum environment at ion trap region, low conductance ion guide system from ICP-MS to Ion trap is required. A long focus ion lens system is suitable to this requirement. Simulation of the mass dependency at long focus lens system was performed with SIMION;

- Three ring electrodes : Inner diameter 10mm,
- Length of the first and last lens 10mm
- Spot diameter : 0.2~1.2 mm

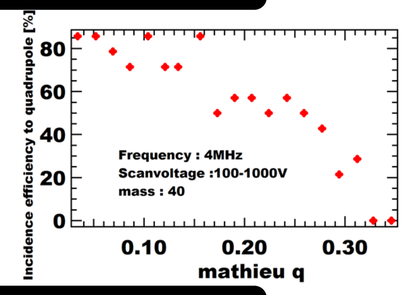
The distortion of the ion beam is calculated as a function of the length of the middle lens.
The dependence of the spot size (at 300mm behind the lens) on the mass is also simulated.
Based on these calculations, the length of the middle lens is determined as 100 mm. A following ion guide with static electric field limits the conductance, the diameter of which is 4 mm. (Length = 300mm and 150 mm)



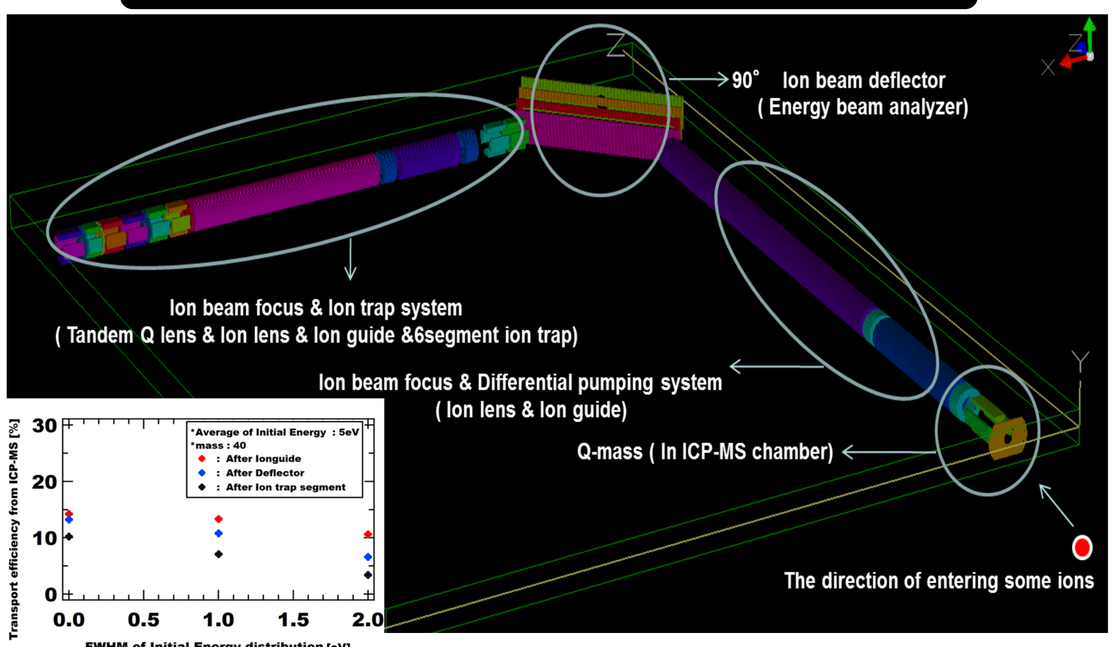


Ion trap

The ions are decelerated from 100 eV to 5 eV at the inlet of the ion trap. The probability to be trapped was calculated as a function of Mathieu q parameter. The injected ions are generated at ICM-MS and transferred through the system.



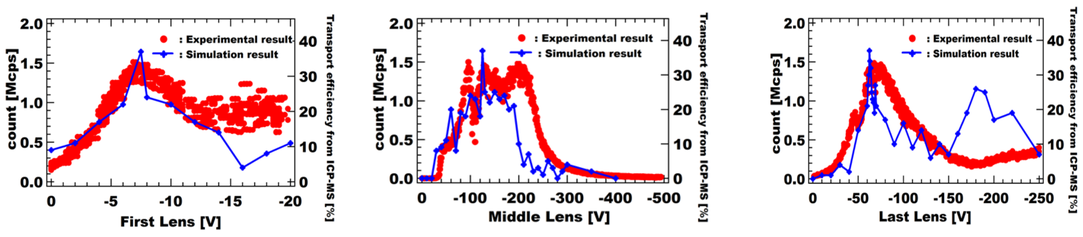
Simulation of the system



Total probability of the ions generated at the ICP section.

The whole system is designed on SIMION and the trajectory of the ions ejected from ICP can be simulated.

Experiment



$^{40}Ar^+$ ions are extracted from ICP-MS to the detector placed behind the deflector to investigate the performance of the ion les system. The experimental results are in good agreement with the numerical ones. The main reason of the discrepancy may derive from the space charge effect.

Summary

- We have designed and constructed a novel apparatus of ICP-MS-TRAP.
- SIMION calculations were performed to obtain the parameters of the ion optics to maximize the transport efficiency of ions.
- The extraction of the ions from ICP-MS was performed and the ion beams were measured at the detector behind the deflector.

Future works

- Guidance of the ion beams to the trap
- Laser cooling of ions with this apparatus
- Realization of trapping ions from ICP-MS
- Optimization of the experimental system for detecting trace isotopes

Acknowledgments

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References

[1] Science 236, 725(1987). Nucl. Instrum. Methods Phys. Res., Sect. B 52, 531(1990). Nucl. Instrum. Methods Phys. Res., Sect. B 52, 572(1990). [2] Nucl. Instrum. Methods Phys. Res., Sect. B 172, 399 (2000). [3] Rev. Sci. Instrum. 74, 1169(2003). [4] Nucl. Instrum. Methods Phys. Res., Sect. B 229, 519 (2005). [5] Phys. Rev. Lett. 92, 153002(2004). [6] J. Nucl. Sci. Technol. 43, 300(2006). Spectrochimica Acta. B 63, 645(2008). Int. J. Mass Spectrom. 279, 163(2009).