New Method for Trace element analysis using the Electron Cyclotron Resonance Ion Source and Heavy Ion Linac

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Abstract

We have measured of the contamination in the Al_2O_3 rod and composite elements in the cinnabar (Tenjinyama ancient tomb) by using the electron cyclotron resonance ion source (ECRIS) and the RIKEN linac accelerator (RILAC) complex. The elements of mass smaller than 100, such as ^{50}V, ^{55}Mn and ^{75}As, were mainly searched by using system. The ionization chamber and the Si detector were used for atomic number assignment. The production of the positive ions in the ECRIS is not under the influence of ionization tendency. In measurement of the elements, the spectroscopic interference with molecules do not exist due to completely ionize in resonance zone of high temperature by the ECR plasma. The development and the establishment of those systems will play an important role for various fields of elementary analysis. We established this system for the practical method and made consideration possibility for this devices.

1 Introduction

Since 1960's, the technique of accelerator mass spectrometry are developed in cooperation with a electrostatic tandem type accelerator. The negative ion source are usually used for a tandem accelerator, and the development for ion source is one of the important theme. The negative ionization of the element strongly depended on ionization tendency. For elements of low ionization tendency, great effort is made to the sample preparation. In many cases, the result of the measurement have large error by the effect of the various treatment for the element. And the preparation is necessarily need for measurement of rare gases. These problems are week points, though tandem accelerator is used for AMS.

ECRIS for production of highly charged ions was proposed by R. Geller in the early 1970's [1], and the utilization and the more development of ECRIS were done during the past twenty-five years. Many ECRISs are used in heavy ion accelerator in the world and the stably beam of the heavy ion are supplied for various accelerator and users. Low RF power, high beam intensity and plasma stability of ECRIS were made during the past ten years.

The 18-GHz ECRIS at RIKEN is used as the injector of RIKEN linac accelerator(RELAC). The specification and present performance of RIKEN 18-GHz ECRIS are shown in reference [3]. Various heavy ions of such as C, N, O, and Ar are produced by the ion source, and are supplied for various experiments. For producing the metallic ions, ex. ^{40}Ca, ^{48}Ti, ^{56}Fe, ^{58}Ni, ^{181}Ta and ^{192}Os, insertion method, MIVOC(Metal Ion by VOlatile Compounds) method and micro oven method are established by user's group of ECRIS in the world). In RIKEN 18-GHz ECRIS, ^{192}Os, ^{58}Ni, ^{48}Ti and ^{56}Fe beams are supplied by using insertion method and MIVOC for users. The productions of the positive ions not depend on an ionization tendency and the high-charge ionization in the ECR plasma effect for all elements for high temperature.

We tried to measure of the contamination in Al_2O_3 rod and the composite elements in the cinnabar, and established how to heat according to the condition of the samples for use in the ECRIS. The selected several elements were measured by the establishments of A/q values for the accelerator and the analyzing magnets each of samples.

2 System and experimental conditions

The cross-sectional view of ionization chamber is shown in Fig. 1. The ionization chamber was set on the turn table in the scattering chamber. The Si detector for the energy measurement was set on the beam line in the ionization chamber. A thickness of the Si detector is 300 μm, which is thick enough to stop a all elements with the energy of 2.0MeV/u. The iso-butane gas for the ionization chamber was used at the gas pressure of 15~20 torr.

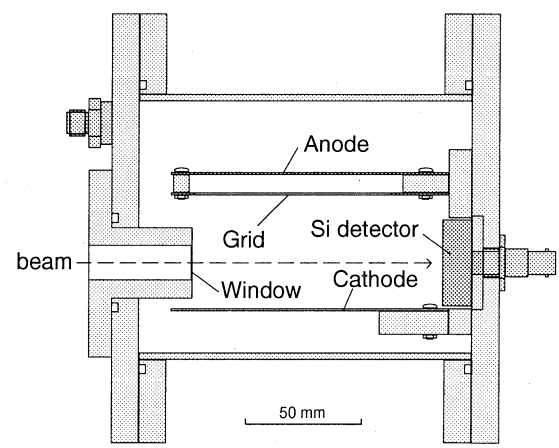

Fig. 1 Cross-sectional view of ionization chamber.

The charged particles were accelerated, a beam spot was made on ZnS in same position with the window of the ionization chamber. The pilot-beams on beam

tuning were mainly used rare gas and air; ^{20}Ne, ^{40}Ar and ^{80}Kr. During measurements of the elements, the pilot-beams were not used because of limits for counting rate of the ionization chamber. The rare gas, nitrogen and oxygen were measured by adsorbed residual-gas in the sample, therefore the sample was baked by low-temperature region near the ECR plasma until a problem of counting rate by the out gas become to be tolerated for the measurements. And the beam currents were reduced by the attenuators on the beam line upon occasion.

3 Measurement of Al_2O_3 rod

The Al_2O_3 rod was heated by the insertion method. The particles with A/q = 4 analyzed by the first analyzing magnet were accelerated to 2.0 MeV/u with RILAC and the variable-frequency RFQ pre-accelerator [2]. The parameters of each of magnets were fixed to A/q = 4 for an beam transportation after the acceleration. After a C-foil for the electron stripper was set between the last acceleration tank and the switching magnet, the elements in the Al_2O_3 were measured for conditions of A/q = 2.5, 3, 4 and 5 of the analyzing magnets. Then E-ΔE plots are shown in Fig. 2.

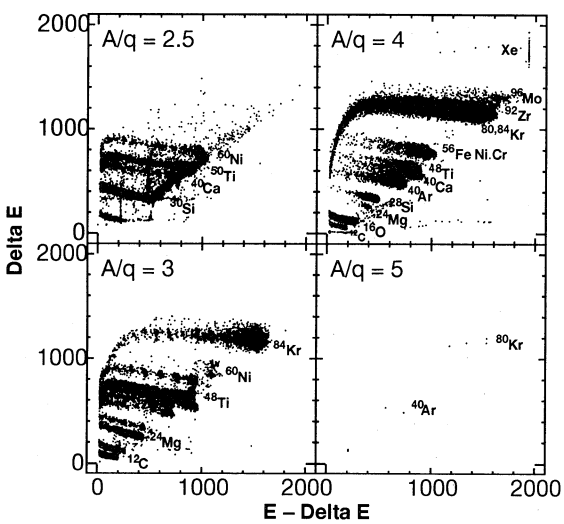

Fig. 2 E-ΔE spectra for measurement of Al_2O_3 rod.

By the acceleration parameter fixed to A/q = 4, main mass number of detected elements were a common multiple of A/q = 4 and the conditions of analyzing magnets; A/q = 10, 12, 16 and 20 or multiple of 4. However the ambiguity of mass resolution in the accelerator is large by an influence such as the fluctuation of RF phase, therefore the elements of near the conditions as above were detected. Calculation of E-ΔE on gas pressure of 15 torr is shown in fig 3. The assign of atomic number in Fig. 2 were determined from the calculated results.

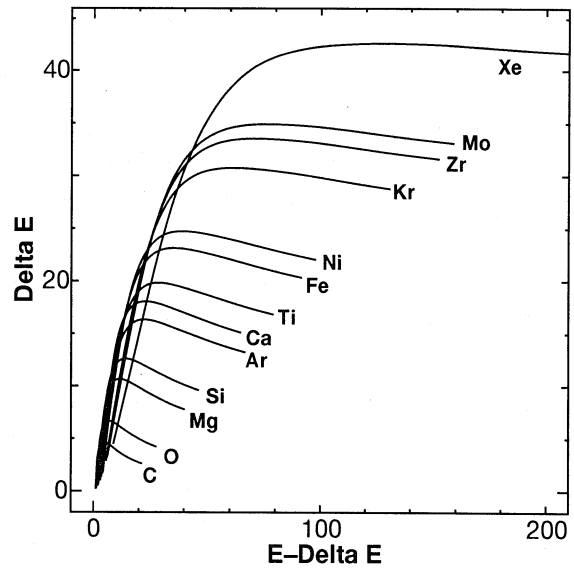

Fig. 3 E-ΔE calculation spectrum on gas pressure of 15 torr.

4 Measurement of cinnabar

The composite elements of cinnabar in Tenjinyama ancient tomb was measured by using the same system. The powdered sample about 100 mg was putted into Ta tube of the outer diameter 4 mmϕ and thickness 0.2 mm, and was heated to insert into the ECR plasma. The tip of the Ta tube was shut by a pliers, and the two holes of the diameter 1mmϕ were drilled to upper side of Ta tube.

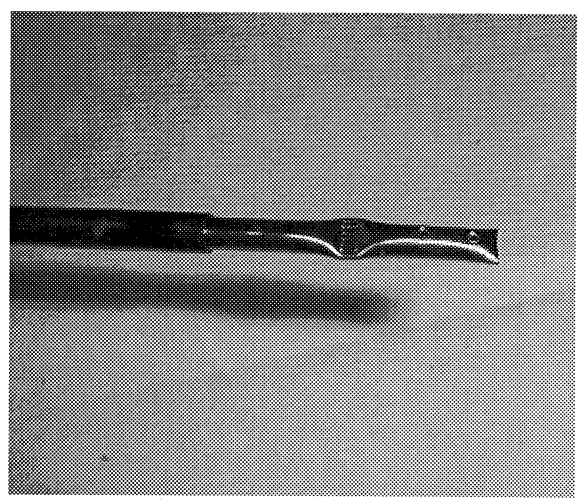

Fig. 4 Photograph of sample holder by using Ta tube.

The photograph of Ta tube is shown in Fig. 4. The particles with A/q = 5 analyzed by the first analyzing magnet were accelerated to 1.0 MeV/u with RILAC and the variable-frequency RFQ pre-accelerator. The parameters each of magnets were fixed to direct A/q = 5 particles for an beam transportation after the accelera-

tion. After a C-foil for the electron stripper, the elements in the cinnabar were measured for conditions of A/q = 5 for the analyzing magnets. Then E-ΔE plots are shown in Fig. 5. By the acceleration parameter was fixed to A/q = 5, mass number of detected elements were multiple of 5. The accelerator have large ambiguity for the mass resolution by an influence such as the fluctuation of RF phase, however the detected elements were almost A/q = 5, because it was selected by the analyzing magnets once more. E-ΔE Calculation of gas pressure of 15 torr is shown in Fig. 6. The assign of atomic number in Fig. 5 were determined from the calculated results.

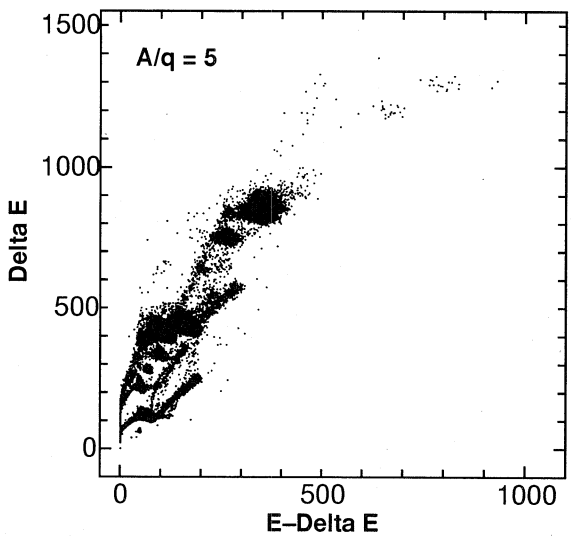

Fig. 5 E-ΔE spectrum for measurement of the cinnabar.

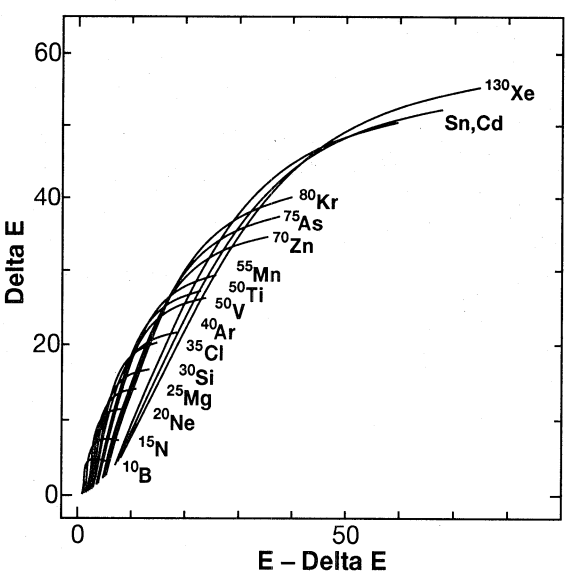

Fig. 6 E-ΔE calculation spectrum on gas pressure of 20 torr.

5 Discussion and Conclusion

We established the measurements of the relative abundance of the elements in a sample positive by using ECRIS. The treatments for the sample were not need for solid and gas. The heating method of sample by using Ta tube is a strong tool for measurement of composite elements in other powdered sample. We can measure many elements at the same time, which that differs from the present AMS in that only the same mass elements were measured basically. And effect of a spectroscopic interference becomes negligible small due to the ionization in high temperature field by the ECR plasma, implying that number of elements were increased and margin of error for measurements is decreased.

References

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[2] O. Kamigaito et al., Rev. Sci. Instrum., in press
[3] T. Nakagawa et al., Nucl. Instrum. Methods Phys. Res. A 396(1997)9