STUDY OF POTENTIAL APPLICATION OF COMPACT ECRIS TO ANALYTICAL SYSTEM *

M. Kidera#, K. Takahashi, RIKEN, Wako, Saitama 351-0198, Japan
Y. Seto, S. Kishi, NRIPS, Kashiwa, Chiba 227-0882, Japan
S. Enomoto, Okayama University, Kita-ku, Okayama 700-8530, Japan
T. Nagamatsu, T. Tanaka, Tokyo University of Science, Shinjyuku-ku, Tokyo 162-8601, Japan

Abstract

The objective of this study is to develop a desktop-sized system of element mass analysis (element analysis system) with a compact electron cyclotron resonance (ECR) ion source in the ionization section. This system is different from other element analysis systems in terms of the effective use of ionization by ECR plasma. A compact ECR ion source is required to fit in the desktop-sized element analysis system. This paper reports the development of the compact ECR ion source.

INTRODUCTION

An ECR ion source has been developed to meet the demands of users for accelerated heavy-ion beams with high intensity, highly charged ions, high stability, a small consumption rate of rare sample, and new ionic species production. The development of large ECR ion sources is underway at large-scale heavy-ion accelerator facilities. The application of ECR ion sources or ECR plasma to various areas, for example, the use of multicharged ions in the field of atomic physics, the ionization of fullerene [1] and charge state breeding [2], has yielded positive results. The basic mass analysis and ion detection technologies for general mass analysis systems have already been established. The ionization section in mass analysis devices, however, continues to undergo intense development because of the development of new ionization techniques.

In 2007, we developed an ECR ion source for an element analysis system (ECRIS-MS) used for isotope ratio measurement [3]. This ECR ion source is, however, very large as compared to the ionization section of ICP-MS systems typically used for element analysis. In the case of an element analysis system, its size, the ease of handling, etc., are important factors determining its applicability. Thermal ionization mass spectrometers (TI-MSs) and surface ionization mass spectrometers (SIMSs) having both merits and demerits, the improvement is still given to ionize of a difficult sample now. We developed a small-sized ECR ion source for realizing a desktop-sized element mass analysis system.

*This work was supported by a Grant-in-Aid for Scientific Research (KAKENHI: 20310100) from the Japan Society for the Promotion of Science (JSPS) and "R&D Program for Implementation of Anti-Crime and Anti-Terrorism Technologies for a Safe and Secure Society", Special Coordination Fund for Promoting Science and Technology of the Ministry of Education, Culture, Sports, Science and Technology, the Japanese Government

#kidera@kindex.riken.jp

FUNDAMENTAL CONSIDERATIONS IN FABRICATION OF COMPACT ECRIS

ECR plasma is nonequilibrium plasma; its ion temperature is low, although the electron temperature is high. It is advantageous to use ECR plasma sources in element analysis because the mass resolution is high when the ion temperature is low. No molecular ions are generated by the collision of radical ions, because ionization takes place in high vacuum, as compared to ionization by inductively coupled plasma. Further, numerous techniques have been developed to stably ionize gas and solid samples. In these techniques, it is necessary to maintain high vacuum in the plasma chamber. Therefore, the direct introduction of liquid samples is difficult. The directionality of development of the ECR ion source developed for the desktop-sized system differs significantly from the sources used in accelerators. A highly charged intense ion beam is not required, because the high-sensitivity channeltron detectors cannot receive intense ion beams. The charge number of the ions generated in the ECR plasma is optimized to 1+ and 2+. The stability of plasma is closely related to the accuracy of the measurement results. A confinement magnetic field has to be generated using permanent magnets if compact size and low-power consumption are the criteria for the source. A large magnetic field, however, cannot be generated with small permanent magnets. Therefore, the too high microwave frequency cannot be used significantly. In contrast, when an extremely low frequency is used, the miniaturization of the ECR ion source becomes difficult. Because the inside diameter of the magnet (i.e., plasma chamber diameter) cannot be small by the problem of the cutoff frequency. Fig. 1 shows plots of the diameter of circular waveguides (i.e., diameter of the plasma chamber) calculated from the lower cutoff frequency in the TE11 mode and the resonance magnetic field strength for microwave frequencies from 1 GHz to 32 GHz. It is necessary to miniaturize the mass analysis and detection sections.

For a compact and high-performance system, a small-sized quadrupole mass spectrometer or an ion-trap-type mass spectrometer is a promising candidate for the mass analysis and detection sections. In the case of time-of-flight spectrometers, miniaturization is difficult. Because the size of system is increased with the use of pulsed power supplies for time-of-flight method.

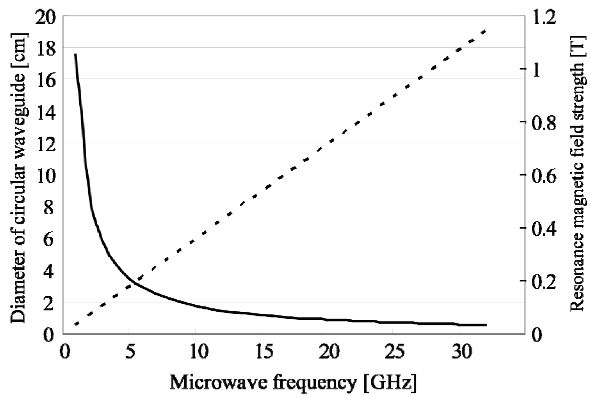

Figure 1: Microwave frequency vs. lower diameter of circular waveguide in TE11 mode and resonance magnetic field strength. The solid line indicates the diameter and the dashed line indicates the magnetic field strength.

FABRICATION OF PERMANENT MAGNET

The permanent magnet for the compact ECR ion source was manufactured by Hitachi Metals, Ltd. Fig. 2 shows a photograph of this magnet. The main specifications of the permanent magnet are listed in Table 1. For a microwave frequency of 5.76 GHz, the lower limit diameter of the chamber calculated from the cutoff frequency is 30.5 mm.

Table 1: Main Specifications of Magnet

Mirror magnet	
Maximum field strength	
Injection side	0.38 T
Extraction side	0.33 T
Minimum field strength	0.16 T
Hexapole magnet	
Maximum field strength	0.58 T
Size	
Outer diameter	100 mm
Inner diameter	45 mm
Length	150 mm
Weight	7 kg

Even if the cooling mechanism is installed outside the chamber because the inner diameter of the magnet is 45 mm, the inner diameter is an enough size. Distributions of magnetic field strength in the axial and radial directions are shown in Fig. 3 and 4, respectively. A commercially available quadrupole mass spectrometer is selected for the mass analysis and ion detection sections. When this spectrometer is installed in the ECR ion source equipped with a magnet, it is necessary to consider the leakage magnetic field from the magnet. The distribution of magnetic field strength from the edge of the magnet to a distance of 150 mm in the axial direction is shown in Fig. 3.

Figure 2: Photograph of permanent magnet for compact ECR ion source.

The spectrometer is not significantly affected by the leakage magnetic field if it is about 200 mm from the edge of the magnet. A solid-state-type microwave amplifier operating at a frequency of 5.76 GHz with an output power of about 100 W was used.

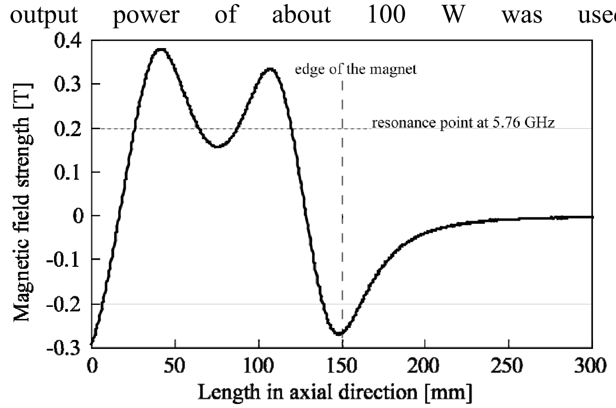

Figure 3: Distribution of mirror magnetic field strength. The region from 0 mm to 150 mm is inside the magnet.

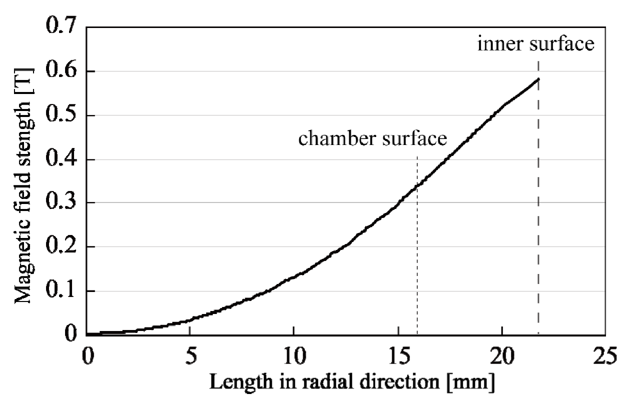

Figure 4: Distribution of magnetic field strength of hexapole magnet. The region from the center of the magnet to its inner surface is shown.

The amplifier does not contain a signal generator, and its dimensions, including a cooling mechanism with a heat sink and a fan, are 300 × 200 × 200 mm. The transportation line for the ion beam from the extraction electrode to the quadrupole mass spectrometer consists of an einzel lens and an XY deflector electrode. Fig. 5 shows photographs of the einzel lens and XY deflector electrode. The ions accelerated by an extraction voltage of about 150 V are transported to the 1-mm-diameter injection hole of the quadrupole mass spectrometer. The entire system, including the abovementioned components, a vacuum pumping system, a control system, and the cooling system, is enclosed in a 100-L box.

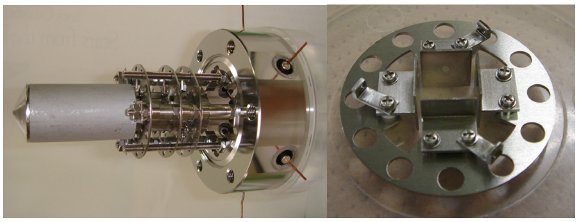

Figure 5: Photographs of extraction electrode and einzel lens (left) and XY deflector electrode (right).

SUMMARY AND FUTURE STUDIES

A desktop-sized element mass analysis system with a compact ECR ion source in the ionization section has been developed. The conditions for the compact ECR ion source to be installed in the desktop-sized element mass analysis system were determined, and the permanent magnet for the compact ECR ion source was fabricated considering these conditions.

We plan to use this system for the high-sensitivity detection of contaminants (especially, metallic floating particles) in the atmosphere. Most mass analysis techniques involve sample preparation processes, the use of expendable supplies, and setting up of a sample holder etc. for the introduction of the sample. In contrast, the use of the ECR ion source simplifies the analysis by facilitating the direct sampling of air, generation of ECR plasma in air, and ionization of the elements in air. Therefore, this system is effective for the automatic long-term monitoring of environmental conditions. The use of the ECR ion source is expected to expand the application range of desktop-sized element mass analysis system.

REFERENCES

[1] T. Uchida, H. Minezaki, K. Tanaka, M. Muramatsu, T. Asaji, Y. Kato, A. Kitagawa, S. Biri, and Y. Yoshida, Rev. Sci. Instrum. 81 (2010) 02A306.

[2] T. Lamy, J.L. Bouly, J.C. Curdy, R. Geller, A. Lacoste, P. Sole, P. Sortais, T. Thuillier, J.L. Vieux-Rochaz, K. Jayamanna, M. Olivo, P. Schmor, and D. Yuan, Rev. Sci. Instrum. 73 (2002) 717, DOI: 10.1063/1.1429778.

[3] M. Kidera, K. Takahashi, S. Enomoto, Y. Mitsubori, A. Goto, and Y. Yano, Eur. J. Mass Spectrom. 13 (2007) 239, DOI: 10.1255/ejms.883.