Observation of sublimation effect of Mg and Ti ions at the Hyper-Electron Cyclotron Resonance ion source

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INTRODUCTION

A grating monochromator with a photomultiplier has been used for beam tuning at the Center for Nuclear Study Hyper-ECR ion source [1,2]. Hyper-ECR ion source has been successfully used as an injector of the multi-charged ion beams of high intensity for RIKEN Azimuthal Varying Field (AVF) cyclotron [3]. Light intensity observation is an especially useful technique for an identification of the ions of the same charge to mass ratio in the plasma [4]. These ions are difficult to separate by an analyzer magnet. Before the operation of multi-charged metal ion beams chamber baking (degassing from the plasma wall) must be done to obtain a required vacuum condition. At the beginning low RF power (~100W) is fed to the residual gas in the plasma chamber, and a degassing process is conducted with increasing RF power gradually until the vacuum gauge reading is settled (1~5 x 10^{-5} Pa order) to start a metal rod insertion into the plasma chamber. In this paper we describe the sublimation pump effect of Mg and Ti ions of ECR ion source during chamber baking and beam tuning.

EXPERIMENTAL

$^{24}Mg^{8+}$ and $^{48}Ti^{13+}$ ions have been produced in the 14.2 GHz Hyper-ECR ion source. The structure and present operation condition of the ion source are described in Ref. 3. At the beginning of the chamber baking RF power of ~100 W was fed to the residual gas of the plasma chamber. Extraction voltage was set to 10 kV. Then a vacuum gauge reading rapidly dropped down to less than 10^{-4} Pa from 10^{-5} Pa order, and a brake-down of the high voltage power supply happened because of a huge extraction current. Several hours later the extraction voltage was recovered, and vacuum gauge reading also reached 10^{-5} Pa order. RF power gradually increased to ~ 600 W until obtaining a required vacuum condition (1~5 x 10^{-5} Pa), and a row extraction current of less than 2 mA. After baking of the plasma chamber, a pure metal or an oxidized metal rod was gradually inserted into the chamber without an excessive heat. An excessive heat causes a brake-down of the power supply because of a huge extraction current. The RF power was ranging between 500 and 600W for a highly multi-charged ion production. Argon, Neon, Oxygen and Helium gases were used as supporting gases to keep the plasma condition stable. A grating monochromator (JASCO CT-25C) and a photomultiplier (Photosensor module H11462-031, Hamamatsu Photonics) were used for a light intensity observation during chamber baking and beam operation. Beam resolution of the grating is 0.1 nm (FWHM). L-37 and R-64 filters are used for preventing both second and third order light signals. Wavelengths of the observed lines were determined in accordance with the NIST Atomic Spectra Database [5].

RESULTS and DISCUSSIONS

$^{24}Mg^{8+}$ ion beam tuning

Figure 1 shows the optical line spectrum of the Hyper-ECR ion source under plasma chamber baking after three hours from the start. A vacuum gauge reading was 5.7 x 10^{-5} Pa. A drain current (an extraction current) was 12 mA. RF power was 100 W. In this figure most of all peaks were Fe I and Fe II. There were some C, N and O optical lines in the spectrum. However, those lines were all disturbed by Fe I and Fe II strong lights, and therefore it was difficult to separate those. Relative intensities of those Fe I and Fe II are quite strong. Figure 2 shows the optical line spectrum of the ECR plasma during $^{24}Mg^{8+}$ ion beam tuning. A vacuum gauge reading was 1.7 x 10^{-5} Pa. A drain current was 1. 8 mA. RF power was 611 W. Line intensities of Fe I and Fe II almost disappeared, and Mg light intensities appeared. Especially, Mg VIII line spectrum (λ=279.64 nm) was clearly obtained to identify the existence of $^{24}Mg^{8+}$ ions in the ECR plasma. In this figure new Fe I (λ=559.2 nm) and Fe II (λ=570.3 nm) light intensities were observed. A non-magnetic stainless steel cover was used for a smooth heat transfer to the tip of the MgO rod from the plasma. The edge of the cover was melted by plasma as shown in fig.3. Therefore, these two strong Fe lines are thought to be present because of the melted stainless cover.

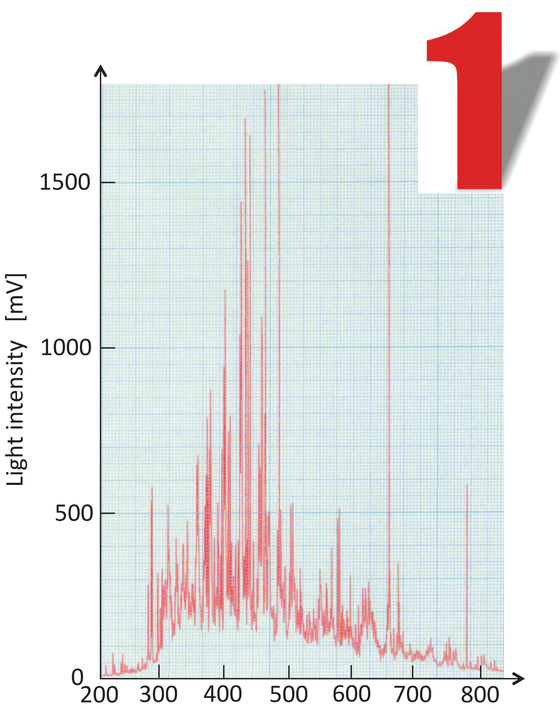


Figure 1: Light intensity spectrum of the residual gas ions after baking for three hours. The peaks of the spectrum are mostly Fe I and Fe II. The pressure and microwave power were 5.7 x 10^{-5} Pa and 100 W, respectively.

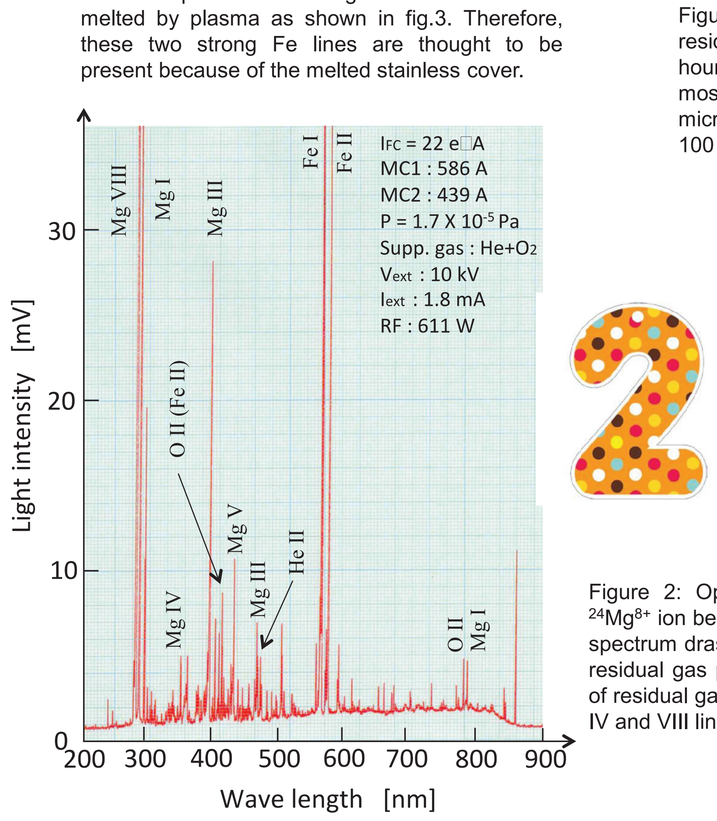


Figure 2: Optical line spectrum during $^{24}Mg^{8+}$ ion beam tuning. The shape of the spectrum drastically changed from that of residual gas plasmas. Fe light intensities of residual gas disappeared, and Mg I, III, IV and VIII lines were clearly observed.

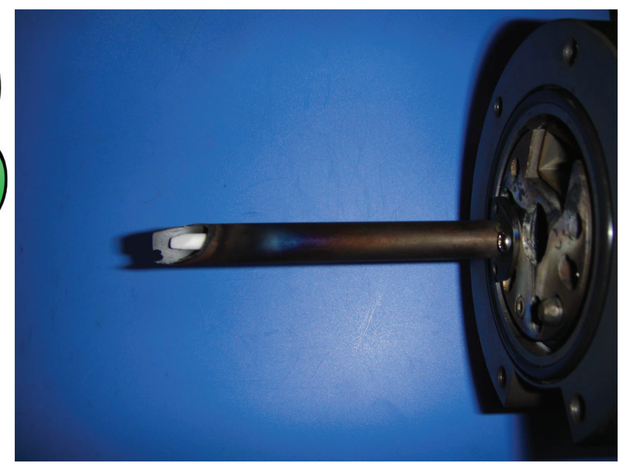


Figure 3: MgO rod with a stainless steel cover.

Oxygen and Helium lines also appeared in the spectrum because Helium and Oxygen gases were fed during the beam tuning as supporting gases to keep a required plasma condition. Figure 4 shows the charge distribution of ion beams extracted from the Hyper-ECR ion source. The ion source was tuned for the production of the $^{24}Mg^{8+}$ ions. Beam intensity of the $^{24}Mg^{8+}$ ions was set at 22 eμA.

$^{48}Ti^{13+}$ ion beam tuning

Figure 5 shows light intensity spectrum of residual gas plasma just after inserting TiO_2 rod. Vacuum condition became stable after insertion of TiO_2 rod. However, a sublimation effect is too strong, and a production of highly multi-charged Ti ions was complex. Then, a pure Ti rod instead of TiO_2 rod was used to make $^{48}Ti^{13+}$ beam. Figure 6 shows the optical line spectrum during $^{48}Ti^{13+}$ beam tuning with Ne supporting gas. Natural Neon gas has 9.22 % of ^{22}Ne and $^{22}Ne^{6+}$ is the same charge to mass ratio of $^{48}Ti^{13+}$ (q/m=0.27). Beam intensity of these beams was 3.0 eμA. Ti XIII light intensity was observed clearly. However, it was difficult to separate these ions by a magnetic analyzer. Then, Ar was selected as a supporting gas instead of Ne to separate $^{48}Ti^{13+}$ ions. However, the plasma condition became unstable, and the desired $^{48}Ti^{13+}$ ions were not obtained. As a result, He gas was selected as a supporting gas in order to produce $^{48}Ti^{13+}$ ion beam. Figure 7 shows light intensity spectrum during $^{48}Ti^{13+}$ ion beam tuning with He supporting gas. Ti XIII line was clearly observed and $^{48}Ti^{13+}$ beam intensity was 1.0 eμA. Beam intensity of $^{48}Ti^{11+}$ was also set at 9.6 eμA. Figure 8 shows the charge distribution of these multi-charged Ti beams.

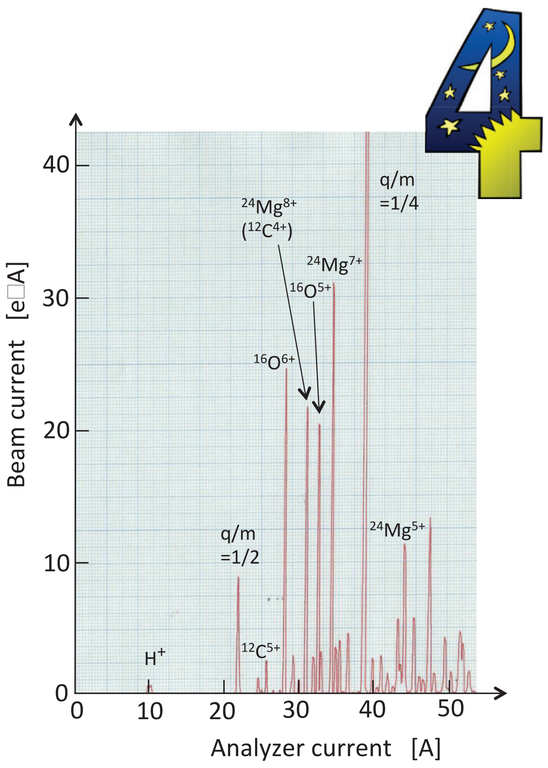


Figure 4: Charge state distribution of Mg, Helium, Oxygen and residual gas ions. The ion source was tuned for production of $^{24}Mg^{8+}$ ions. The beam intensity of $^{24}Mg^{8+}$ was 22 eμA. Small peaks of near multi-charged ^{24}Mg ions were those of ^{25}Mg and ^{26}Mg.

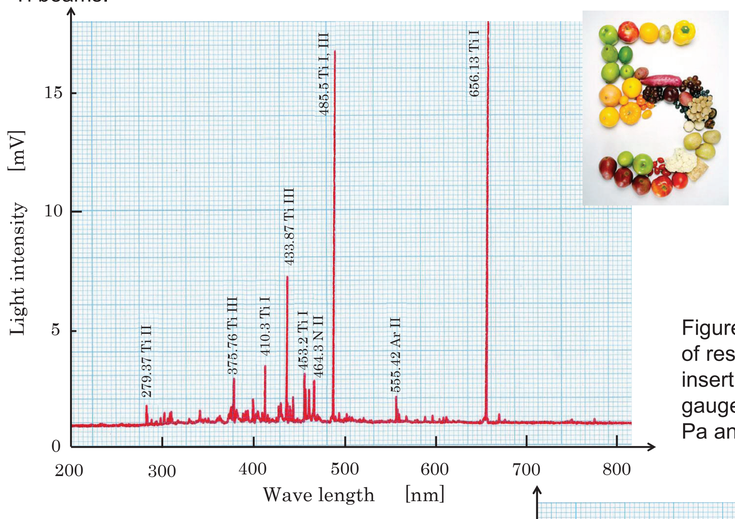
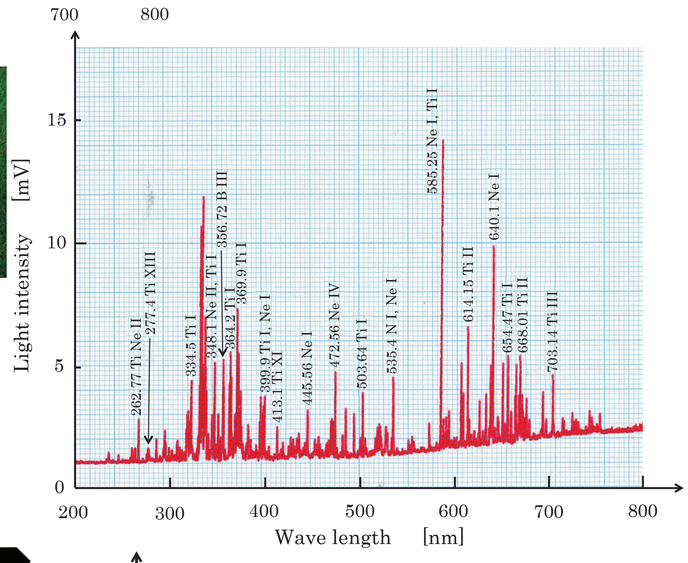


Figure 5: Optical line spectrum of residual gas plasma just after inserting TiO_2 rod. Vacuum gauge reading was 1.9 x 10^{-5} Pa and RF power was 100 W.

Figure 6: Optical line spectrum during $^{48}Ti^{13+}$ ion beam tuning with Ne supporting gas. Ti XIII line was clearly observed. However, Ne lines also were present.



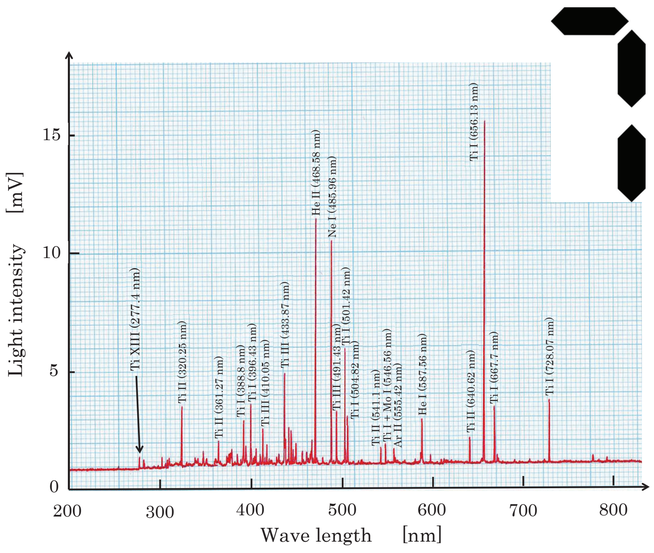


Figure 7: Optical line spectrum during $^{48}Ti^{13+}$ ion beam tuning with He supporting gas. Ti XIII line was clearly observed.

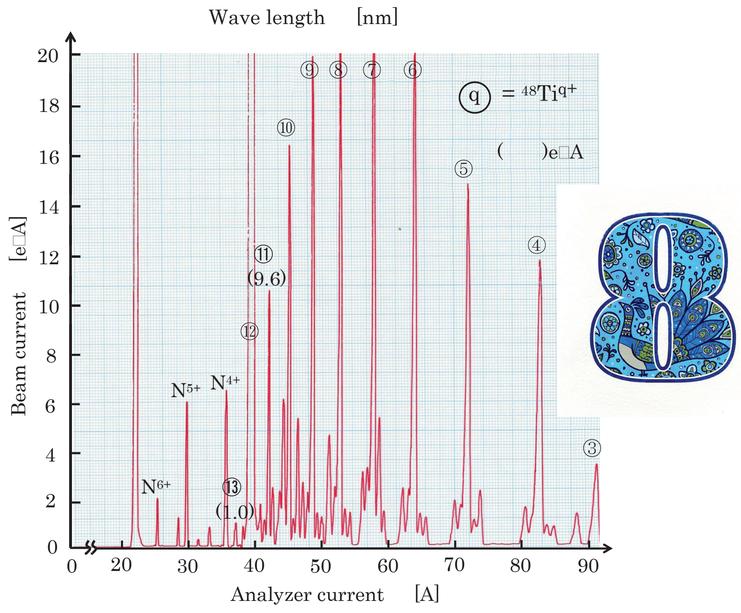


Figure 8: Charge state distribution of multi-charged Ti beams. The beam intensity of $^{48}Ti^{13+}$ was 1.0eμA.

CONCLUSIONS

During plasma chamber baking observed light intensities were mostly Fe I and Fe II. Fe ions were relatively heavy and not easy to extract from the plasma chamber. Those atoms were present for a long time in the vacuum chamber. Therefore, stainless steel is thought to be an unsuitable material for a plasma chamber to extract multi-charged ions. Aluminum or Magnesium based light alloy is better for plasma chamber materials for degassing and extraction.

REFERENCES

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[5] www.nist.gov/pml/data/asd.cfm for NIST Atomic Spectra Data base.