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DEVELOPMENT OF ZEOLITE ION SOURCE FOR BEAM PROBE MEASUREMENTS OF HIGH TEMPERATURE PLASMA

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Abstract

A zeolite ion source has been developed for plasma diagnostics. Extracted beam current is increased by a factor of ~10 after redesigning the ion source structure and improving the method to make emitter material (zeolite). The paper introduces an experiment on making desirable ion emitter, together with properties of the newly developed ion source.

Key words: ion source, zeolite, heavy ion beam probe, beam probe diagnostics

I. Introduction

Development of advanced diagnostics techniques is necessary to access a high temperature plasma core and to clarify physics of magnetically confined plasma. Beam probes are one of such diagnostics that can measure several physics quantities and their fluctuations without giving any disturbance to the target plasmas. A key issue to improve the signal-to-noise ratio in beam probe measurements is enhancement of beam current. Recently, we have succeeded to measure the plasma fluctuation in the high temperature core (~ 1 keV) by increasing the probing beam current of a beam diagnostics, named heavy ion beam probe (HIBP) [1,2]. In this paper, we describe our modification of zeolite ion source to increase the beam current for plasma diagnostics, and report several properties of the ion sources.

II. Development of Ion Source

II-1. Revised Source Structure

In our laboratory, heavy ion beam probe (HIBP) is applied to study the plasma turbulence and structure, since the HIBP is a powerful tool to measure density, potential and magnetic field, and their fluctuations simultaneously. The ion gun for our HIBP is composed of Pierce-type electrodes, Einzel lenses and an ion source. In this system, the beam ions are simply extracted by heating up the zeolite emitter filled in a small ceramic case [3,4,5,6]. In order to improve the performance, we have carried out (i) refinement of the source structure, and (ii) improvement of zeolite quality to contain larger fraction of favorable ion species.

In the previous system, the zeolite is indirectly heated up with a ceramic covered filament, and the temperature of emitter could not be raised to obtain maximum beam current from the zeolite. Hence, the ion source is redesigned to allow directly heating up the zeolite. The schematic view and photograph of the new structure of the source are shown in Figure 1. The external and internal diameters of the case are 6mm and 5mm. Zeolite is tamped into the cylindrical ceramic case. The 8-turn filament (3% rhenium tungsten) of 0.3mm diameter is placed in the case to heat emitter material (zeolite) directly. The case is held with a stainless cylinder having 3 legs to adjust the ion source position in the gun.

II-2. Process of Making Zeolite Ion Source

In our HIBP diagnostics, the emitter material is manufactured by substituting Na in sodium-zeolite ($Na_{12}((AlO_2)_{12}(SiO_2)_{12})\cdot(27H_2O)$) with the desired alkali ions (usually cesium is used). The process is as follows. By stirring the Na-zeolite and the cesium-chloride(CsCl) in purified water(ion-exchanged water) of ~70℃ for about a day, ion exchange reaction occurs between the alkali (cesium and sodium) ions. After the percolation and washing the material by purified water for impurity removal, the obtained zeolite is solved into the cesium-chloride solution and ion exchange reaction takes place again. The same process is repeated several times. Then, the self-made zeolite emitter containing the needed alkali ions is obtained, although a certain amount of sodium ions remains as impurity.

In order to obtain zeolite with higher fraction of cesium, we have studied the relationship between the replacement ratio of cesium in the zeolite $\alpha=N_{Cs}/(N_{Cs} + N_{Ns})$ and the ratio of Cs to the total alkali ions of the purified water in a substitution process; the ratio is here denoted as Δ. The progress of the replacement is plotted in Figure 2a as a function of the number of the ion exchange processes, n, for four cases of the ratio Δ=1, 4, 15 and 50 in the ion exchange reactions. Here, the fractions α are determined with use of Scanning Electron Microscope – Energy Dispersive X-ray Spectroscopy (SEM-EDS). Obviously, the cesium fraction, $\alpha=N_{Cs}/(N_{Cs} + N_{Ns})$), increases as the number of the substitution process increases, and finally is saturated at a value. The saturation value becomes higher as increasing of the ratio of Δ. However, the complete replacement is not achieved, even in the case of $\Delta=50$. Note that the resultant cesium fraction is found to be unsusceptible to the water temperature and concentration of a solute. Previously, the substitution was usually done with $\Delta\sim1$; it corresponds to 5g Na zeolite and 3.5g cesium chloride.

A model was proposed[7] to describe the cesium fraction α,. as a function of the number of the ion exchange processes n for a fixed value of Δ. According to the model, the fraction is expressed as

$$\alpha(n)=\frac{\Xi^n-1}{\Xi^n-\xi},$$

Where $\Xi=(1+\Delta)/(1+\varepsilon)$, $\xi=\varepsilon/\Delta$ and ε is a parameter indicating difference in coupling strengths to zeolite lattice between sodium and desired alkali ions. More negative value means that target ions are easier to be replaced with the sodium.

The comparison between the actual results and the analytical solutions for the substitution process for cesium were exhibited in Figure 2a (see broken lines). The broken lines are fitting curves to the real data using the above function form with assuming ε being a fitting parameter (see Table 1). The curves are well fitted with the experimental data for each case. However, the parameter ε has different value for each value of Δ. In the model, the parameter ε is expected to be the same for each case. Hence, this discrepancy may suggest that there exists another factor to associate with the substitution process.

Similarly, substitutions for other alkali and alkali-earth ions, Ca, Mg, Sr and Rb, are examined, as shown in Figure 2b. The ratio Δ is kept 1 for all species presented here (Mg, Ca, Sr or Rb). Substitution for Mg and Rb tends to saturate as similar to Cs, however, almost complete replacement is possible for Ca and Sr in this condition.

II-3. Temperature Dependence of New Ion Source

Revised ion source allows the zeolite emitter to attain higher temperature up to ~1100ºC, and gives higher beam current. Figure 3 shows temperature dependence of beam current, and change in the beam components for zeolite emitter with cesium fraction $\alpha\sim80\%$. These experiments were performed in a test stand. A Wien filter (velocity filter) was used for separation of the beam components. The average temperature of the emitter's surface was measured with radiation thermometer. The beam current is detected in a simple metal plate located at the end of the test stand. Here, the beam ions are accelerated at 10 keV. The extractor voltage is optimized at each temperature to obtain the maximum current at the Faraday cup position that is placed at the front of Wien filter.

In this case, the sodium fraction to the total current is dominant below ~950ºC (Figure 3a); the sodium fraction to the total current is maximum. However, the total and sodium currents start to decrease above this temperature, while the continuous increase of cesium current results in an increase in the ratio of cesium current to sodium one. Finally at ~1100ºC, the components of the extracted beam are almost accounted for by cesium ions. Note that above ~950ºC the extractor voltage of Pierce gun (composed of extractor and accelerator electrodes) becomes difficult to control. The reduction of total current can be caused by the difficulty. However, the almost complete reduction of sodium current implies that the sodium current takes a maximum at a temperature from ~900ºC to 1100ºC. By taking into account the practical current tolerance of the ion gun, less impurity current fraction is desirable to optimize the target beam current (cesium in our case). Therefore, the new temperature regime of ~1100ºC will give a favorable condition for our purpose of the diagnostics.

In a case of cesium zeolite with $\alpha\sim30\%$, the total current exceeded the operational tolerance below ~1000ºC where the sodium current is dominant, accordingly the cesium beam could not be extracted efficiently. Thus, cesium zeolite with large α is favorable for our beam probe operation.

Another important issue to be mention is that properties of the zeolite emitter are that the temperature dependence is changed with aging of the ion source. In other words, aging is a factor to influence the source property of beam extraction. Figures 4bc show difference in temperature dependence between a zeolite emitter (with α~50%), and the same zeolite emitter after about 12 hours beam extraction as an example of aging effect. Clear difference is found between the temperature dependencies before and after the aging. Apparently, a peak of cesium beam current is recognized at low temperature of ~850ºC in the case before aging, while the peak is not found after aging. As for sodium beam current, the peak at ~1000ºC before aging is lost in the case after aging. The temperature dependence in Figure 3 is for the case of about 6 hours aging. It is reported that the structural change occurs at 1050ºC for the case of Cesium-Mordenite emitter[6].

The changes in the beam extraction properties can be ascribed to the changes in zeolite structure or/and in fractions of alkali ions contained in zeolite. Actually, SEM (scanning electron microscopy) pictures of the zeolite emitter surface prove structural change of zeolite. Figure 4a shows three SEM pictures; zeolite in powder (initial state), heated up zeolite for about an hour, and that after about 6 hours beam extraction. It is obvious that the grain structure becomes to be completely lost in case as aging period becomes longer. Further research on the aging effect of zeolite should be needed for an efficient use of zeolite emitter.

III. Beam Probe Application of New Source

The HIBP measurement using a new ion source was performed in a toroidal helical plasma named Compact Helical System (CHS). Figure 5 shows an example of the power spectrum of potential fluctuation. The integral of the fluctuation power (from 10kHz to 250kHz) gives us the fluctuation amplitude of ~3V. In HIBP measurements, the beam energy fluctuation corresponds to the potential fluctuation of the plasma. In this case, the initial beam energy is about 70 keV. Therefore, the fluctuation measurements can be performed with quite high energy-resolution of 10^{-5}. This energy resolution cannot be achieved without the development of the new ion source.

In summary, we achieved development of the new zeolite ion sources for advanced beam probe measurements. The performance of developed sources is ten times or higher than that of old sources by operating the source in higher temperature region. At present, the technique can be also applied on other alkali ion sources. For example, we are trying to obtain intense Rb source to measure CHS plasma with higher density. In addition, research and development of alkali-earth zeolite source is now being performed to apply beam probes to plasmas in lower temperature regime less than 10 eV.

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Figure captions

Figure 1. A schematic view and a photograph of developed ion source.

Figure 2. Progress of the ion exchange in the case (a)of Δ= 50, 15, 4 and 1 for Cs and (b)of Δ= 1 for Ca, Mg, Sr and Rb. Points and lines indicate actual results and analytical solutions, respectively.

Figure 3. Temperature dependency of beam intensity and ratio of the beam component for high quality source(α=80%)

Figure 4. (a) SEM pictures of zeolite (Left) powder (before heating), (Center) heated up zeolite for a hour, and (Right) that after about 6 hours beam extraction. (b) Temperature dependency of the beam components before and (c) after aging of the new source.

Figure 5. An example of potential fluctuation spectrum measured with HIBP on CHS plasma.

Table 1. The table indicates the parameter ε for each case.

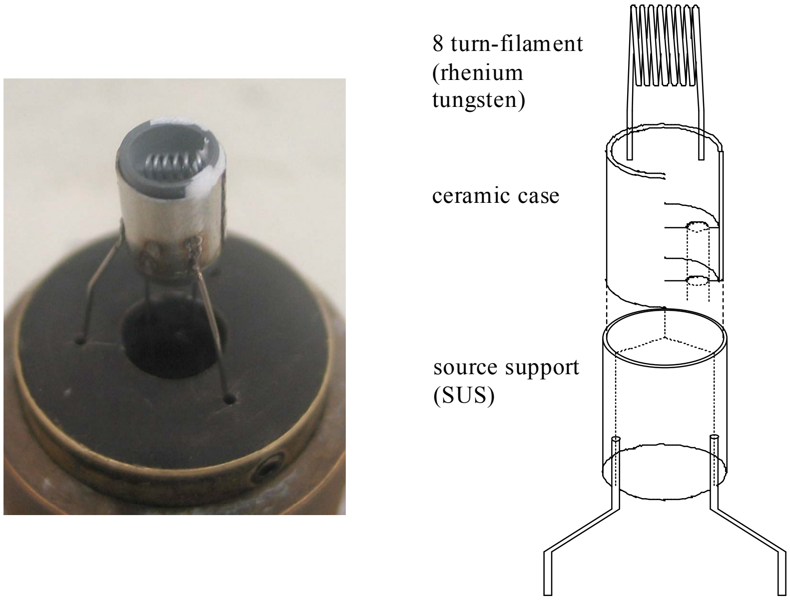


Figure 1. Ohshima et al

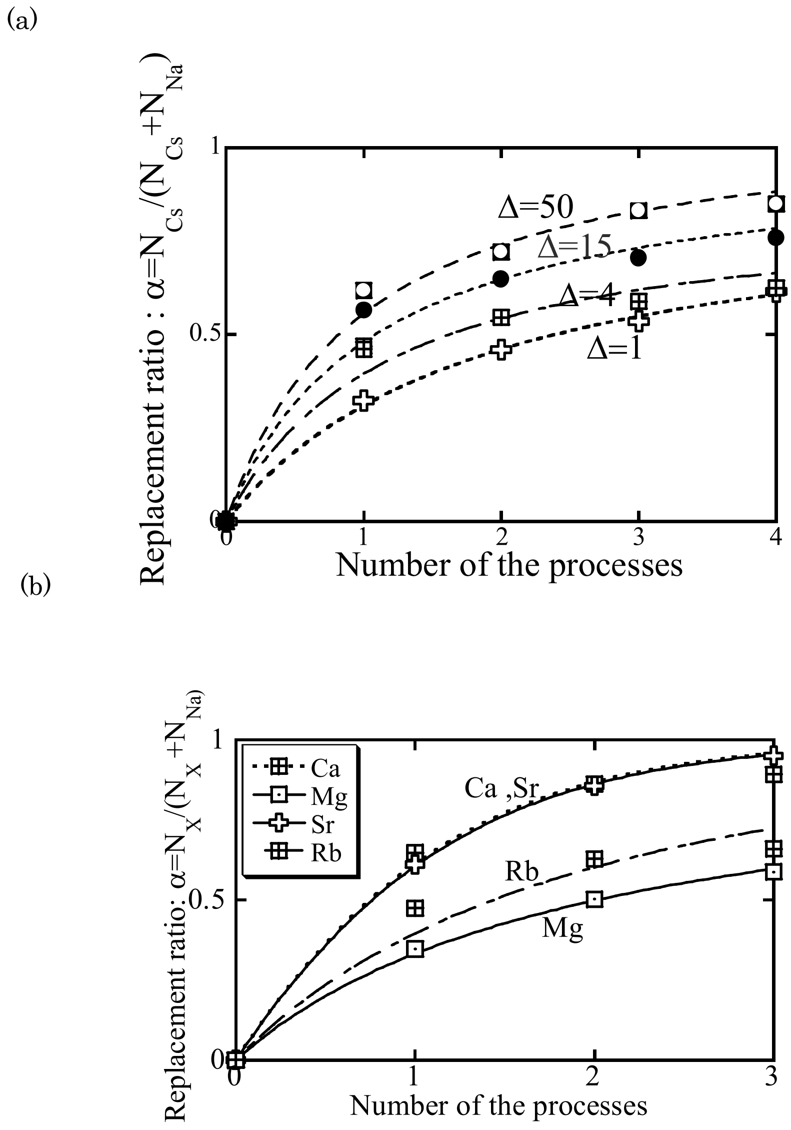


Figure 2. Ohshima et al

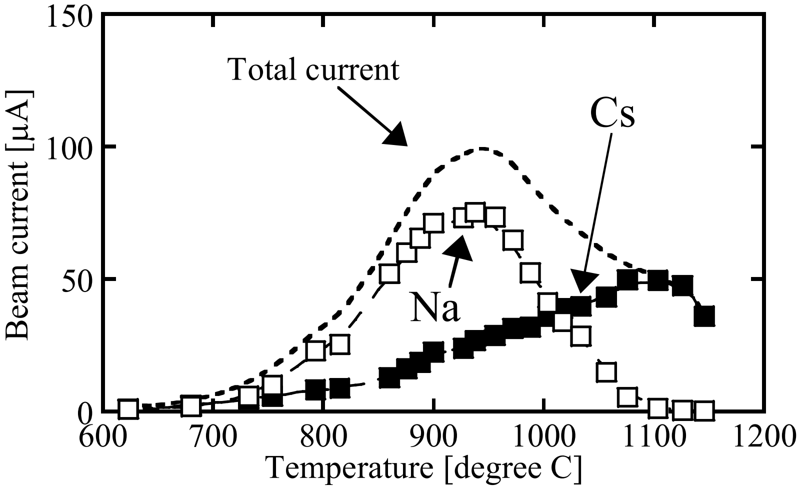
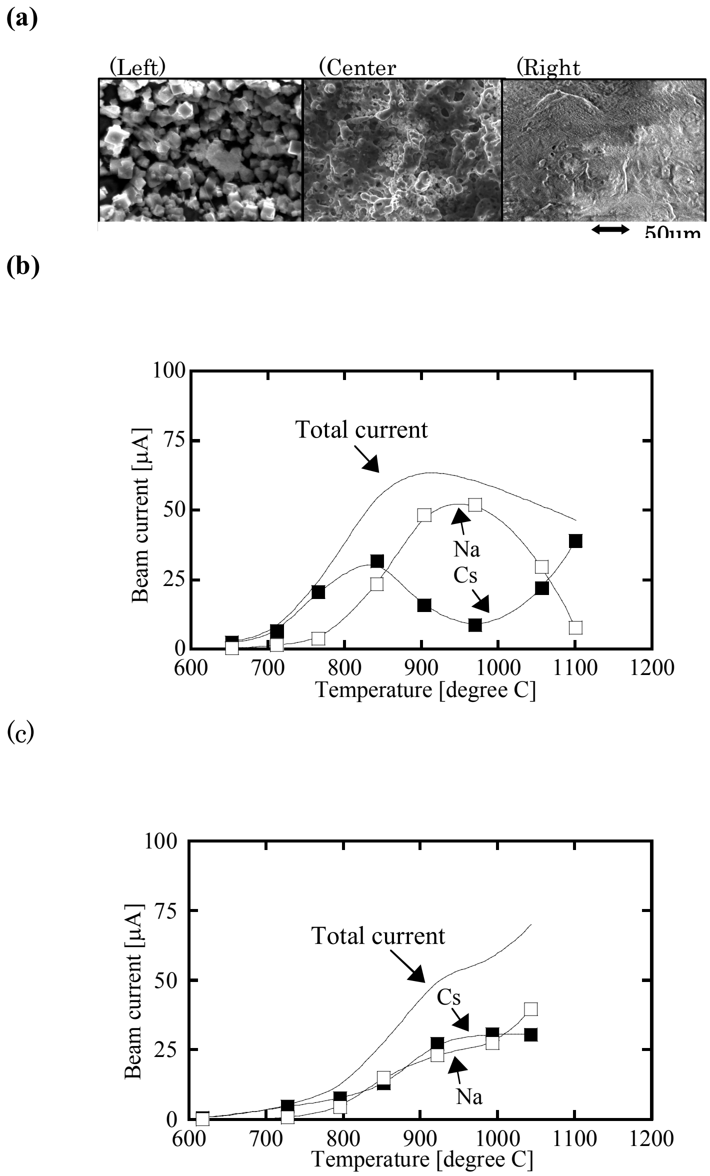


Figure 3. Ohshima et al



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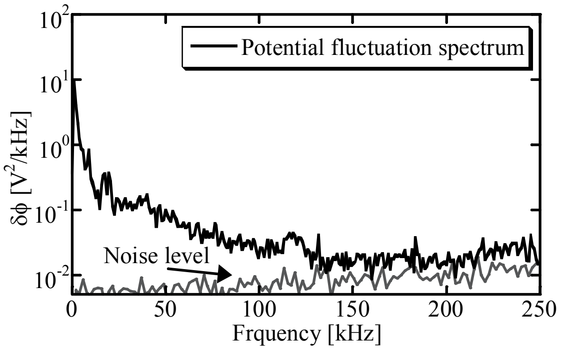

Figure 5. Ohshima et al

Ion species	$\Delta(=N_{Cs}/N_{Na})$	ε
Cs	50	38.91
Cs	15	15.22
Cs	4	5.11
Cs	1	1.22
Ca	1	-0.37
Mg	1	1.01
Sr	1	-0.34
Rb	1	0.53

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Table 1, Ohshima et al