Emittance Measurement at HyperECR

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Abstract

An emittance scanner has been installed in the beam line of the HyperECR ion source. It takes about 4 min to measure the emittance for the horizontal and vertical directions. Typical 90 % emittance was measured to be about 160 π mm·mrad in the horizontal direction and 200 π mm·mrad in the vertical direction in the case of 100 eμA of Ar^{8+} at 20 kV extraction voltage. Dependence of the emittance on the extraction voltage, the charge state of the ions, the beam current and the diameter of the extraction hole was measured.

1 Introduction

An ECR ion source named HyperECR was designed [1, 2] and constructed to study the mechanism how multiply-charged ions are produced. Performance of this source is under testing for gaseous ions by using such techniques as ion cooling and electron injection. Until now, beam intensities of 480 eμA for Ar^{8+}, 480 eμA for O^{6+} and 60 eμA for O^{7+}, for example, have been obtained.

In optimizing procedures of various parameters for higher intensity, it has been found that the hole diameters of the anode and extraction electrodes were found to be 18 mm and 14 mm, respectively, for the best performance. These diameters are larger than those which are usually used in other sources. This fact raises a question that the emittance would be larger compared with that of the similar type of sources. A scanner has been made to measure the emittance of the beams from the HyperECR source and to find out its dependence on the parameters, such as the charge state, the energy, the beam current, the RF power etc..

In these days, it begins to be believed that the higher the charge state of a beam from an ECR source is, the smaller its emittance is. This is explained by introducing a dip of *negative potential* in the center of the plasma [3] produced by excess amount of thermal electrons. The highly charged ions are trapped mainly in this region. Thus the highly charged ions are produced in a narrower space than the lowly charged ions. In addition, this dip is shallower than the plasma potential itself, resulting in smaller spread of the transverse kinetic energy of the highly charged ions. These two effects lead to smaller emittance for highly charged ions, if the space charge effects after extraction are neglected. Actually, some experimental results [4] show agreement with this model.

2 Emittance Scanner

The cross section of the emittance scanner is shown in Fig.1. This kind of device was described in ref. [5].

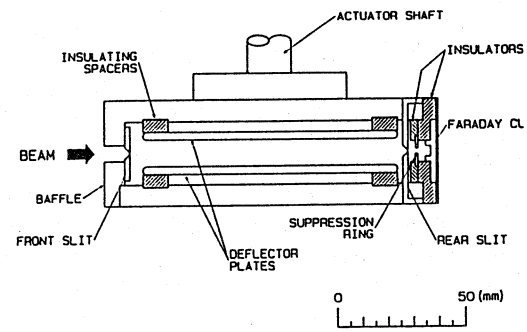

Fig.1. Cross section of the emittance scanner.

The principle of operation of this scanner is that the angle θ which an ion makes with the axis of the transport line can be determined by the voltage V on a pair of parallel plate electrodes required to deflect it to pass through a set of the two collimating slits. The angle is related to the dimensions and voltages as

$$\theta = \frac{V}{4V_i}\frac{L}{D},$$

where

- θ : inclination angle of the ion trajectory to the optical axis,
- V : voltage between the two deflecting plates,
- V_i : extraction voltage of the ions,
- L : length of the two deflecting plates and
- D : distance between the two deflecting plates.

Two scanner probes are set up in a vacuum chamber for the horizontal and vertical directions. The gap between the two deflecting plates is 10 mm and their length is 100 mm. From this geometry, the maximum angle for the beam to pass through the two slits is about 200 mrad.

The widths of the collimating slits are 0.5 mm. A ramp voltage is applied on one of the deflecting plates and the same voltage with opposite polarity is applied to the

other. One cycle time of these ramp voltages is about 2.0 sec. In the case of the scanning width of 50 mm with 1 mm interval, it takes about 4 min to measure the contour plot of the beam intensity in the phase space for both directions. During one cycle, one hundred data points can be sampled. An example of contour plot of the phase space is shown in Fig.2, from which emittance of the beam can be deduced.

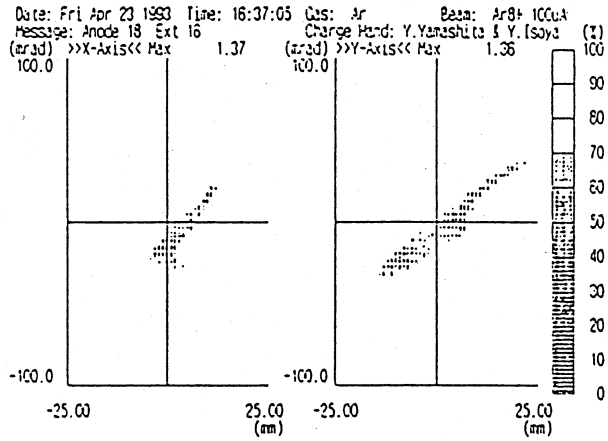

Fig.2. An example of graphic output.

The charge states of the ions are analyzed with a 90° bending magnet which is approximately double focusing. The aperture of the analyzing system is enough for a beam with emittance less than $250\,\pi$ mm·mrad. Details about this transport system is described in ref. [6].

3 Emittance Measurement

Interdependence between working parameters of the source is important for good performance of an ECR ion source: pressure in the plasma chamber, RF power, magnetic mirror field and extractor configuration. Especially, the shape of the plasma surface, the size and position of the anode and extraction electrodes and the extraction voltage will affect the electric field to extract the ions from the plasma source. One can expect that the emittance of the extracted beams has some dependence on the anode and extraction electrode hole diameters.

Emittance of the argon and oxygen beams was measured as typical examples under various conditions in order to clarify the relations between the emittance and those parameters.

During these experiments except the last, the coil current, the RF power, the gas flow rate and the voltage on einzel lens in addition to the field of the analyzer magnet were varied to get the maximum beam current in each measurement. When the beam current is to be adjusted to keep it at a specified amount, only the gas flow rate was varied.

Fig.3 shows the emittance of the Ar^{8+} beam extracted at different voltages, the current being kept at 100 eμA except for the case of 5 kV extraction voltage where it was kept at 50 eμA. It can been seen from this figure that the emittance does not change from 10 kV to 25 kV of the extraction voltage. Consequently the normalized emittance increases as the extraction voltage. Generally, emittance should become smaller for beams with higher kinetic energy, if other conditions are same. Since each data point was measured after varying the parameters, it is possible that the measured emittance is affected not only by the extraction voltage but by other parameters. It seems that the tuning at higher extraction voltage makes the normalized emittance larger.

In the measurements whose data are shown in Fig.4 to Fig.7, the extraction voltage was kept at 20 kV, and the source was tuned as described above in each measurement. The beam intensity of the Ar^{8+} was kept to be 100 eμA.

Fig.4 shows the emittance multiplied by square root of charge state q for each charge state. This means that the emittance shown in this figure is normalized with the ion velocity. No clear relationship has been found between the emittance and the charge state.

Fig.5 shows the emittance at various beam currents. The beam currents were controlled only by the gas flow rate. In this case, emittance does not show dependence on the beam current within the present range of variation.

Fig.6 shows the emittance measured when anodes with different hole diameters were used while their shapes being same. The hole diameter of the extraction electrode was 14 mm. Four diameters were tried: 10 mm, 14 mm, 18 mm and 22 mm.

Fig.7 shows emittance for each charge state of the oxygen beam extracted from the same plasma, i.e., the source was not tuned during this series of measurements. It is also normalized with the ion velocity. From charge state 5 to 7, emittance decreases as mentioned in the introduction, but it is not the case for the charge state 3. The measured emittance and its general tendency of variation in the case of oxygen are similar to those for argon gas.

4 Discussions

It has been shown in the present measurements that the emittance of the beams produced by HyperECR is not much different from that of the similar type of sources, even if this source employs large hole diameters for the anode and extraction electrodes. In addition, the present measurements show no systematic increase of emittance when the hole diameter of the anode becomes larger. It seems that the emittance is determined not only by the hole diameter of the anode and extraction electrodes. However, the data did not show clearly the effects of the space charge and dependence of the emittance on the charge states.

Since the beam current is more than a few mA just after extraction, the space charge should affect the emittance measured with the emittance scanner.

Depending on the spatial distribution of the ions in each charge state at extraction, the space charge effects on the ions in each charge state are different. Thus, this space charge effect may smear out the spatial distribution of the ions in the plasma. Consequently, the present re-

sults do not necessarily contradict the current model on the confinement mechanism of the ECR plasma.

It seems to be necessary to measure the charge state dependence of emittance at low beam current where the space charge effects can be neglected, in order to see directly the spatial distribution of the ions in the plasma by means of the emittance of the extracted beam. On the other hand, in order to study the effects of space charge at extraction on the emittance of the beams, it will be better to use a H_2 or a He beam, which do not have many charge states and is available with higher beam current.

References

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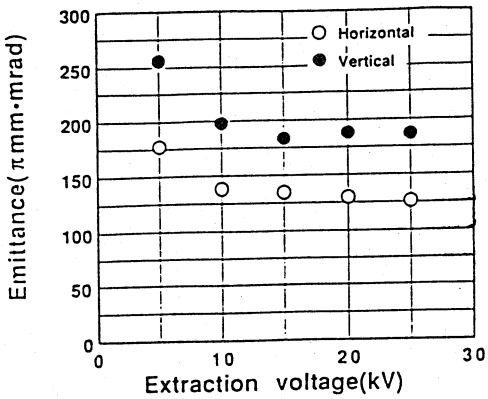

Fig.3. Dependence of emittance on the extraction voltage in the case of Ar^{8+}, 100 eμA (50 eμA for 5 kV).

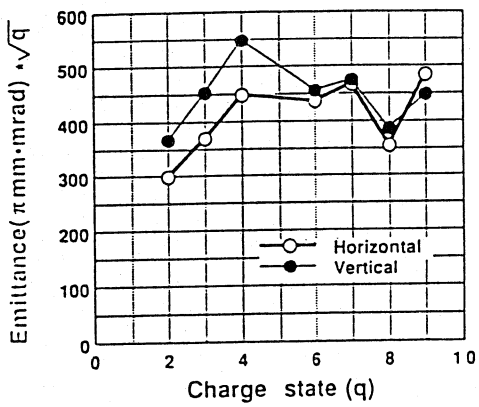

Fig.4. Charge state dependence of emittance in the case of Ar ions. The measured values are multiplied by $\sqrt{q}$ to compare the normalized emittance.

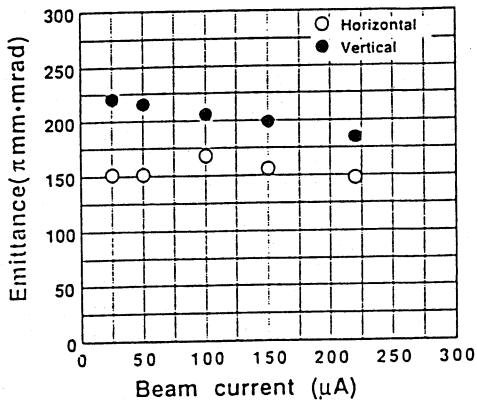

Fig.5. Dependence of emittance on the beam current for Ar^{8+}. The beam intensity was adjusted only by the gas flow rate.

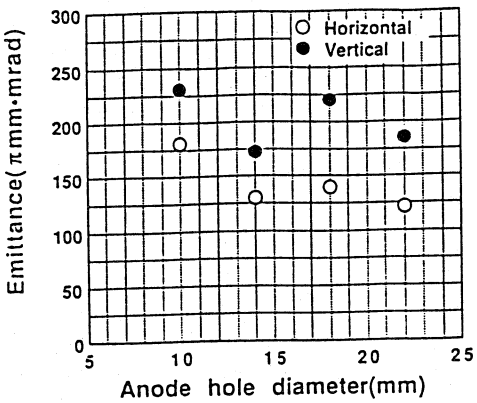

Fig.6. Dependence of the emittance on the diameter of the anode hole in the case of Ar^{8+}, 100 eμA (50 eμA for 5 kV).

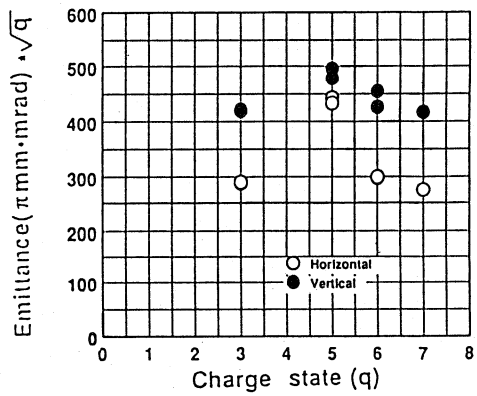

Fig.7. Charge state dependence of the emittance for oxygen ions. The source was not adjusted during this measurement.