MICROWAVE FREQUENCY DEPENDENCE OF THE PROPERTIES OF THE ION BEAM EXTRACTED FROM A CAPRICE TYPE ECRIS

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Abstract

In order to improve the quality of ion beams extracted from ECR ion sources it is mandatory to better understand the relations between the plasma conditions and the beam properties. The present investigations concentrate on the analysis of different beam properties under the influence of various applications of frequency tuning and of multiple frequency heating. The changes in the microwave frequency feeding the plasma affect the electromagnetic field distribution and the dimension and position of the ECR surface inside the plasma chamber. This in turn has an influence on the generation of the extracted ion beam in terms of intensity, shape and emittance. In order to analyze the corresponding effects, measurements have been performed with the CAPRICE-Type ECRIS installed at the ECR Injector Setup (EIS) of GSI. The experimental setup uses a microwave sweep generator which feed a TWTA (Traveling Wave Tube Amplifier) covering a wide frequency range from 12.5 to 16.5 GHz. This arrangement provides a precise determination of the frequencies and of the reflection coefficient along with the beam properties. A sequence of viewing targets positioned inside the beam line monitors the beam shape evolution.

INTRODUCTION

The increasing request of higher energies for higher charge states pushes towards the development of more performing ECR ion sources or to the research of methods to enhance the performances of the existing ones. The tuning of the microwave frequency feeding the plasma can be a promising technique even if a better understanding of this effect is mandatory. In 1998 the ORNL CAPRICE-Type ECRIS was used to demonstrate how the frequency domain technique was useful to enhance the ECRIS performances [1]. In 2008 several measurements were carried out with the CAPRICE ion source at GSI in order to investigate the frequency tuning effect on the extracted Helium beam intensity and shape [2]. In 2009 an experiment was carried out at JYFL in order to measure the effect of the frequency tuning on the intensity, quality and emittance of a mass separated Argon beam [3]. In both of these last tests the frequency was swept over a narrow range of ±40 MHz around the Klystron center frequency of 14.5 GHz and in the 14.04-14.13 GHz range, respectively. In the present experiment the frequency tuning effect has been analyzed in the 12.5-16.5 GHz frequency range. The availability of a TWTA driven by a signal generator gave the possibility to change the source operating frequency with steps of a few hundred kHz. This experiment allows to analyze the beam properties when the ECRIS operative frequency sweeps over a wide range of 4 GHz, and hence for increasing ECR surfaces. The influence on lower and higher charge states has been analyzed for different source conditions concerning the magnetic field configuration, the gas pressure and the power setting.

EXPERIMENTAL SET-UP DESCRIPTION

The CAPRICE-Type [4] ECR ion source used for this experiment is equipped with a 1.2 T maximum radial magnetic field. The plasma chamber dimension was 179 mm of length and 64 mm of diameter. The RF power was provided by a TWTA working in the 8÷18 GHz frequency range and able to provide an output power higher than 650 W in the frequency range of 12÷18 GHz. The input of the amplifier was driven by a signal generator able to sweep from 1 to 20 GHz. According to the maximum manageable power reflected to the amplifier, it has been restricted to work at a power of 100 W and in the frequency range of 12.5÷16.5 GHz. The use of a waveguide microwave isolator covering this frequency range and handling up to 650 W could allow to work with higher powers. The frequency steps were set to 200 kHz with a dwell time of 20 ms for each step. Then the duration of one measurement was around 400 seconds. Two directional couplers of high directivity were inserted in the waveguide line in order to measure the forward power and the reflected power with two microwave power probes. The experiment has been carried out with Argon and Helium as a support gas at gas pressures of 3.9÷5 $*10^{-6}$ mbar. The ion currents of the charge states Ar^{7+}, Ar^{8+} and Ar^{9+} have been measured with a faraday cup; the drain current of the high voltage power supply of the extraction has been recorded as well. The extraction voltage was set to 15 kV; a -2 kV voltage was applied to the screening electrode. Viewing targets could be remotely inserted at three positions along the beam line in order to monitor the beam shape evolution right after the extraction, the focused beam and analyzed beam [5]. KBr was used as target coating material for this experiment.

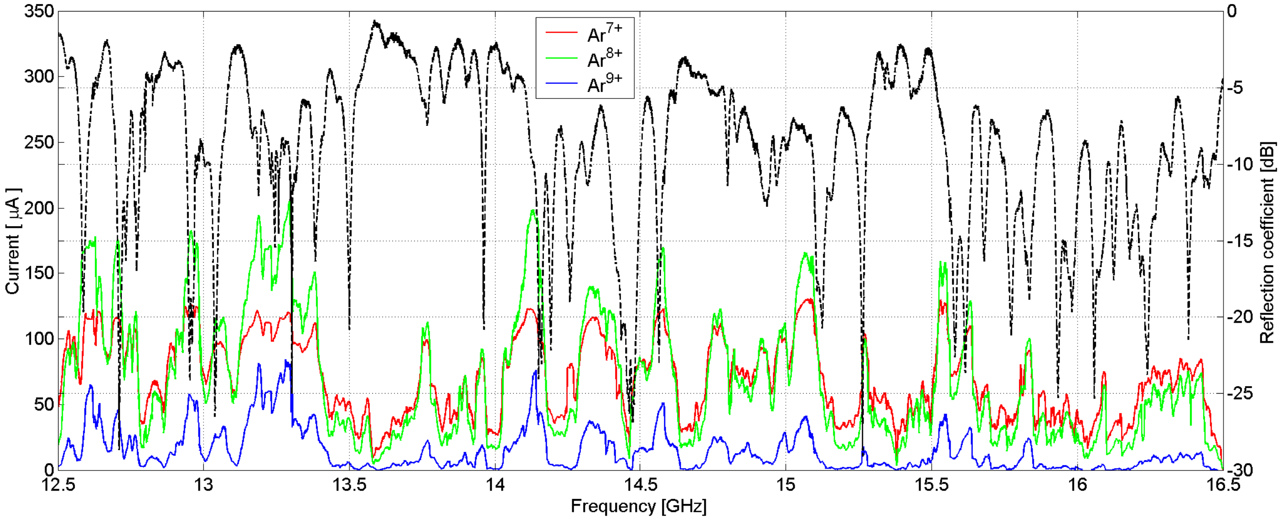

Figure 1: Reflection coefficient and current evolution vs. microwave frequency (the coloured solid lines refer to the left scale while the dashed black line is the reflection coefficient referring to the right scale).

RESULTS AND DISCUSSION

Different measurements have been carried out by sweeping the frequency and setting different ion source parameters, i.e. injection and extraction magnetic field values, gas pressure and microwave power.

The source parameters were set to operate with a charge state distribution with a maximum on the Ar^{8+} (by feeding the plasma with 100 W microwave power at 14.5 GHz). An Ar^{8+} current of 85 μA and a drain current of 2.36 mA were obtained. From these source conditions the frequency sweep was started by ramping the signal generator from 12.5 GHz up to 16.5 GHz, while the reflection coefficient, the Ar^{7+}, Ar^{8+}, Ar^{9+} currents and the drain current were recorded simultaneously.

The evolution of the reflection coefficient with the frequency is shown in figure 1. As expected by the previous experiments the matching impedance between the cavity filled by the plasma and the electromagnetic wave is strongly dependent on the frequency [1-3]. It is remarkable that the plasma properties are also changing considerably with varying frequency. The strong correlation between the peaks of the reflection coefficient and the current amplitude are clearly visible around the frequencies where the reflection coefficient is higher than -9.54 dB (matching condition). The relationship between the resonance frequencies and the heating efficiency has been theoretically analyzed and particle in cell codes has been used to correlate the electromagnetic field patterns and the electron cyclotron resonance surface. [6] However it is not possible with our analysis to determine the electromagnetic field patterns (modes) related to these peaks. The comparison of the current evolution in the frequency range indicated above is presented in figure 1. It is clear how the current amplitude is affected by the choice of the operative frequency. Looking at the Ar^{8+} current it ranges from a few μA up to 200 μA. The experimental results were clearly reproducible in several runs thus confirming the reliability of the measurements. The evolution of the Ar^{7+} and Ar^{8+} currents is similar, but the amplitude is different. In fact at the frequencies where both currents present a peak, the Ar^{8+} is quite higher than the Ar^{7+}(for instance at 14.119 GHz the difference between the two currents is 80 μA). The opposite behaviour is visible for the minima of the current amplitudes where the Ar^{7+} is higher than the Ar^{8+}. In the range 15.64-16.5 GHz the currents of the higher charge states, i.e. Ar^{9+}, tend to lower values even if the reflected power is less than 10%. This seems to be due to the confining magnetic field restricting the source operation to lower frequencies. It has been also observed that the drain current evolution is following the trend of the three charge states presented in figure 1.

In order to have a complete comprehension of the sweep effects on the ionization process, the charge state distribution has been analyzed for different frequencies. It has been decided to restrict the analysis to the frequency range of 14-15 GHz. Several frequencies have been considered where peaks and minimum amplitudes occur. In figure 2 the charge state distribution is presented for four different frequencies. The 14.5 GHz value is the normal operation frequency of the CAPRICE ion source; 14.46 GHz and 14.119 GHz are the frequencies where respectively the minimum and the maximum Ar^{8+} current were measured in the 14-15 GHz frequency range. The charge state distribution related to the 14.0 GHz operation is also reported in order to show how important the electromagnetic field pattern and the choice of the frequency are. In fact the charge state distributions at 14.0 GHz and at 14.46 GHz are quite similar even if the amount of power feeding the plasma was more than doubled. In the first case the reflection coefficient (indicated in the legend of the figure 2) was -2.3 dB, more than one half of the power was reflected, and in the second case it was -25.8 dB , the impedance matching condition was fulfilled and almost no power was reflected. It is also interesting that for the frequencies where the higher charge states are favoured,

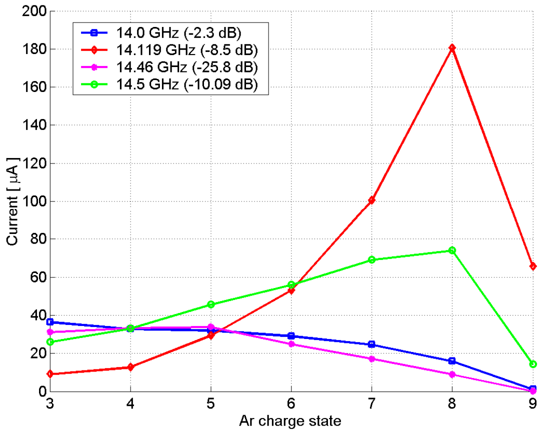

Figure 2: Ar charge states distribution for four significant operating frequencies.

The current of lower charge state is decreasing and vice versa. The analyzed charge state distributions confirm that the frequency tuning is more affecting the higher charge states (at 14.119 GHZ the current enhancement respect to the 14.5 operation frequency is 244% for the Ar^{8+} and 456% for the Ar^{9+}).

The enhancement of the current is not the only effect of the frequency sweeping, in fact also the quality, the shape and the emittance of the ion beam are varying. The use of beam viewing targets has proven to be a favourable technique to monitor the beam shape and a promising beam diagnostic tool. The images recorded after the extracted beam focusing solenoid (VT2 position) and in the diagnostic box after the mass/charge selection dipole (VT3 position) are shown in figure 3. Here the same frequencies are chosen as in figure 2. The Ar^{8+} beam is shown on the right column and the focused beam images also refer to the Ar^{8+} magnetic field setting. At 14.0 GHz and 14.46 GHz, which are the frequencies where the Ar^{8+} presents a minimum point, the focused beam shape seems to remain unchanged in the orientation of the arms (at 14.0 it is a little bit brighter, also according to the higher intensity measured at the faraday cup). At 14.119 GHz the focused beam is a little bit bigger and brighter than the one at 14.5 GHz and in both cases the orientation of the arms is turned by more then 40° clockwise with respect to the 14-14.6 GHz beam shapes. An emittance variation is clearly expected and in the next measurement session a pepper pot device will be used to analyze the emittance.

CONCLUSIONS

The experiment reported here has confirmed again how the frequency and the corresponding electromagnetic field feeding the plasma affects the ECRIS performances. The complete results of the measurements for the several source parameters settings together with the results of the multiple frequency heating experiment will be published soon.

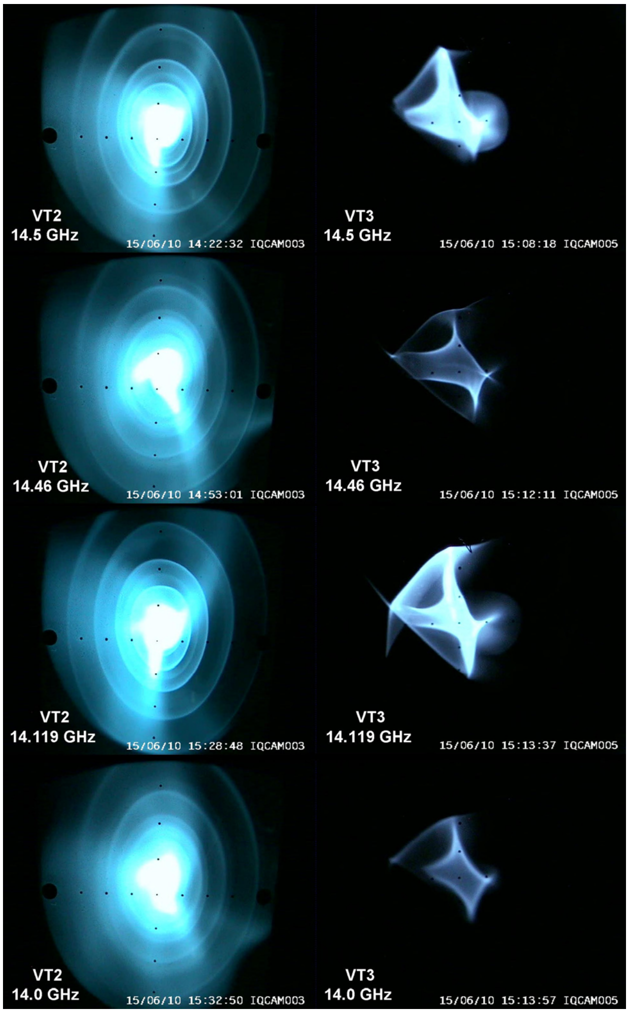

Figure 3: Ar^{8+} beam viewed at the targets located after the focusing solenoid (left column) and after the dipole (right column).

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