FINE FREQUENCY TUNING OF THE PHOENIX CHARGE BREEDER USED AS A PROBE FOR ECRIS PLASMAS

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Abstract

Fine frequency tuning of ECR ion sources is a main issue to optimize the production of multiply charged ion beams. The PHOENIX charge breeder operation has been tested in the range 13.75 – 14.5 GHz with an HF power of about 400 W. The effect of this tuning is analyzed by measuring the multi-ionization efficiency obtained for various characterized injected 1+ ion beams (produced by the 2.45 GHz COMIC source). The 1+/n+ method includes the capture and the multi ionization processes of the 1+ beam and may be considered as a plasma probe. The n+ spectra obtained could be considered, in first approach, as an image of the plasma of the charge breeder. However, in certain conditions it has been observed that the injection of a few hundreds of nA of 1+ ions (i.e.: Xe^{+}) in the plasma of the charge breeder, is able to destroy the charge state distribution of the support gas (i.e.: up to 40 % of O^{6+} and O^{7+} disappears). The study of this phenomenon will be presented along with plasma potential measurements for various charge states. This study may help to understand the creation (or destruction) of highly charged ions inside an ECRIS.

INTRODUCTION

When we inject a characterized 1+ ion beam into a plasma, then extract and analyse all the ion species from it, one may expect some information about the characteristics of this plasma : its ability to capture 1+ ions and its ability to multi ionize the 1+ ions injected (i.e. plasma temperature and density). The 1+/n+ method developed for radioactive ion beams could be considered as a kind of non perturbative probe because the number of ions injected is exactly known (1+ beam intensity measurement), and extremely low with respect to the initial number of ions present in the plasma. In this paper, we propose to check the validity of these assumptions, by using fine frequency tuning of the microwaves injected to modify the characteristics of the ECR plasma, and by measuring the plasma potential to quantify the plasma characteristics variations.

THE 1+ COMIC SOURCE

The availability of a reliable ion source to produce cw 1+ ion beams in the range of 100 nA up to 1 µA with good stability is crucial for the 1+/n+ method in order to have a rather confident experimental simulation of low intensity radioactive ion beams and enough signal to have a precise measurement of the n+ efficiency yield. The microwave coupling of the ultra compact 2.45 GHz COMIC ion source developed at LPSC [1] has been particularly optimized, so the necessary HF power for the ignition and the maintaining of the plasma is extremely low (from 100 mW to 5 W depending on the pressure) and can be delivered by a solid state amplifier (see Fig. 1) leading to an extremely stable operation.

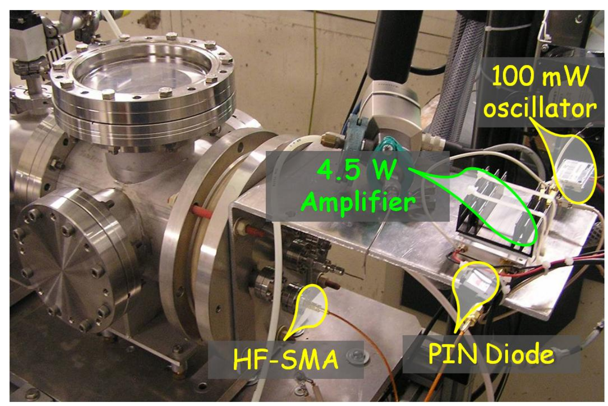

Figure 1: HF circuit of the COMIC Source on the 1+/n+ test stand.

LOW INTENSITY 1+ BEAM INJECTION INTO A PLASMA

Experiment

Oxygen gas is injected to produce the plasma in the PHOENIX charge breeder. The ions extracted from this plasma are analysed in a magnetic spectrometer and the intensities are plotted on Fig. 2 (blue spectrum). In this spectrum, 267 µAe (i.e. 110 µAp) are extracted from the source. Then, a 500 nA $^{132}Xe^{+}$ beam produced by the COMIC source is injected into the charge breeder. The capture is optimized and a second spectrum is performed (red spectrum on Fig. 2). In this second spectrum, the multicharged oxygen ion intensities are lower: the sum of the peaks is 234 µAe, equivalent to 103 µAp. Considering that about 50 % of the $^{132}Xe^{+}$ has been captured by the plasma, we can deduce that the 0.25 µA of $^{132}Xe^{+}$ has destroyed 7 µAp of multicharged oxygen ions, in other words one Xe ion destroys about thirty oxygen ones.

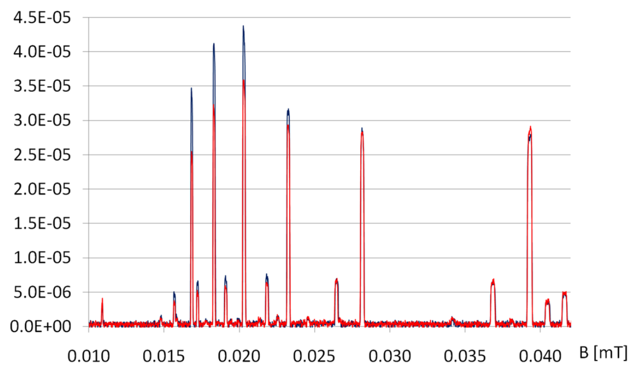

Figure 2: Evolution of the multicharged oxygen ion intensities when injecting a $^{132}Xe^{+}$ beam.

Discussion

One may think that the decrease of the measured intensities of the multicharged ions could be due to an emittance variation of the beams, showing a transmission problem of the beam line. We have measured, with an Allison type emittancemeter, the emittance of O^{6+} without and with 1+ injection. Fig. 3 shows that the emittance in the two cases has almost the same shape and the same value (10 π.mm.mrad at 1σ).

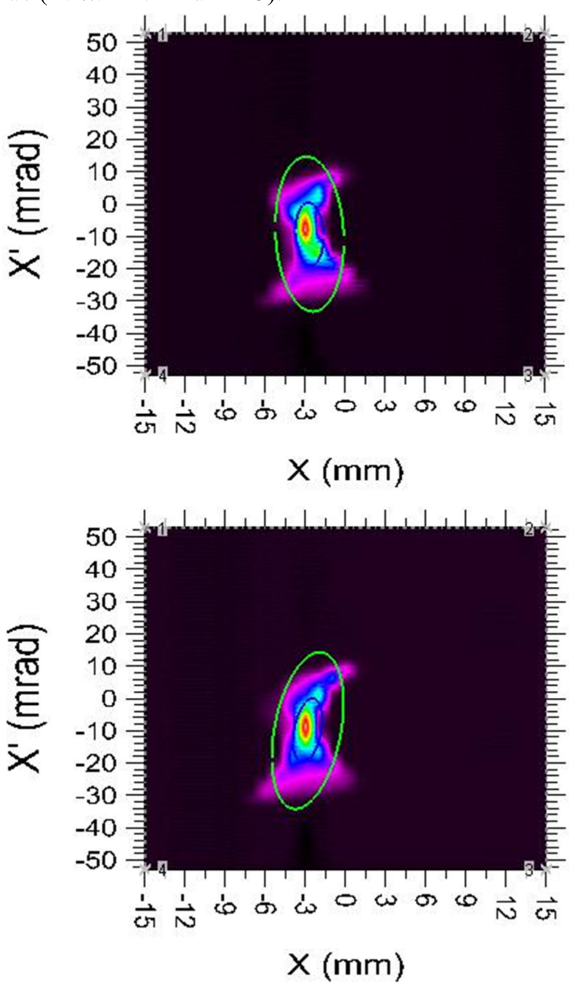

Figure 3: O^{6+} emittance, top – without Xe^{+} injection, bottom – with Xe^{+} injection

The other possibility investigated is a change in the plasma characteristics. For this, the plasma potential has been measured using a retarding potential in front of a Faraday cup [2]. Fig. 4 shows the currents measured in the Faraday cup while varying the retarding potential with (black curve) or without (red curve) injecting Xe^{+} into the charge breeder. The plasma potential is almost the same for the two experiments (about 16 V) and so plasma characteristics may not change sufficiently to explain the destruction of multicharged ions. Finally, let us note that this phenomenon cannot be explained by charge exchange, the low charge states remaining constant when the multicharged ones disappear.

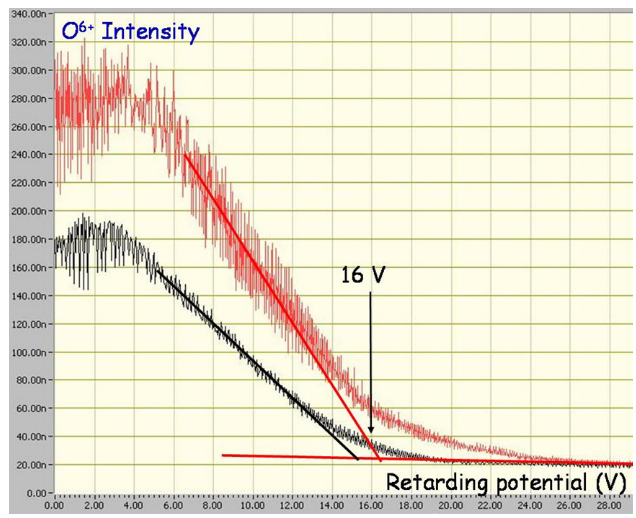

Figure 4: Plasma potential measurements on O6+

FINE FREQUENCY TUNING OF THE ECR CHARGE BREEDER

Context

Fine frequency tuning (in the range of a few MHz around the well known 14 GHz frequency, for example) of ECR ion sources, is known to have a great influence on the extracted ion current intensities and a significant effect on the optical characteristics of the beams [3]. One may take advantage of this effect to increase the efficiency yield of a charge breeder or to optimize it on a specific charge state.

Experimental setup

The microwaves (MW) injected into the PHOENIX charge breeder are delivered by a 14.5 GHz klystron. The plasma chamber has two WR62 MW ports. It has been decided to explore the fine frequency tuning by injecting on the second port of the plasma chamber MW delivered by a Travelling Wave Tube Amplifier (TWTA) with a power adjustable from 0 up to 400 W, for a 13.75 to 14.5 GHz frequency range. The low level signal injected into the TWTA is generated by a tunable oscillator (20 µW). The MW injection of the experiment is shown on Fig. 5

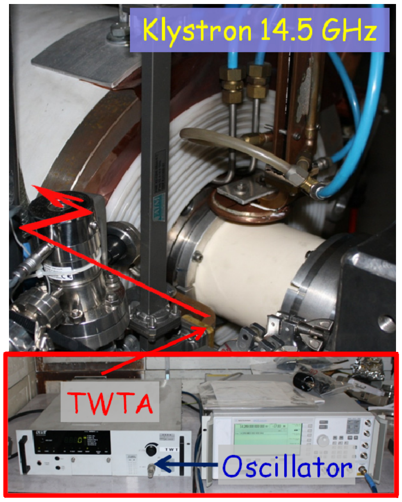

Figure 5: Scheme of the microwaves injections

Experiments and results

The effect of the TWTA frequency tuning on various charge breeding efficiencies and buffer gas ion intensities has been measured in numerous experiments. A few examples of these measurements will be shown below.

It was not possible to initiate and maintain the plasma with the TWTA alone due to its reflected power limitation (10%). Therefore the 14.5 GHz klystron was used first, then its power was decreased (100 W) and the power of the TWTA increased at the highest power (330 W) to allow frequency exploration while maintaining a reflected power of less than 10%. The charge breeding efficiency obtained with the klystron alone was 8.5 % on Ar^{8+}. After the adjustment of the TWTA power, its frequency was decreased from 14.5 down to 14.3 GHz by 10 MHz steps. At each step, Ar^{8+} charge breeding efficiency and O^{5+} intensity were measured (Fig.6). This graph shows:

- An important effect (up to a factor of 2.5) of the fine frequency tuning on the O^{5+} intensity extracted from the charge breeder.
- A moderate effect (up to a factor 1.2) on the charge breeding efficiency for Ar^{8+} (however without improvement).

On Fig. 7, the influence of the fine frequency tuning on the charge breeding of a $^{132}Xe^{+}$ beam is presented.

The initial tuning is performed with the klystron on Xe^{24+} at 14.5 GHz and shown by the blue dot (red and green dots are the efficiencies at 14.5 GHz for charges 20 and 17). Then, the klystron power is decreased and the TWTA power is adjusted to get the same efficiency on the 24+ charge state. The curves are the efficiencies measured when varying the frequency of the TWTA. One can see in these experiments, a slight increase of the charge breeding efficiencies for charges 20 and 24.

Discussion on fine frequency tuning

Reproducibility problems have been noticed during this study. Compared to a standard ECR ion source, the charge breeder MW cavity has an electrical discontinuity

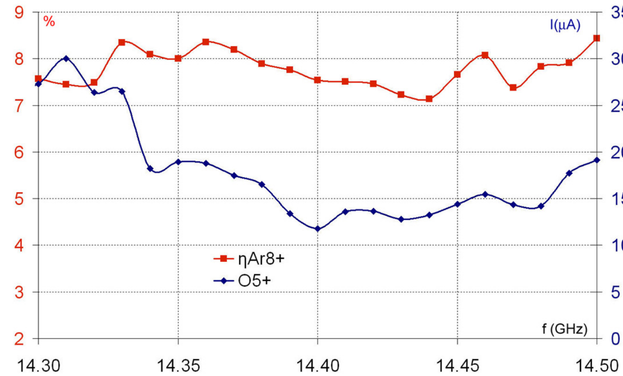

Figure 6: Fine frequency tuning effect on the Ar8+ charge breeding efficiency compared to its influence on O5+ intensity.

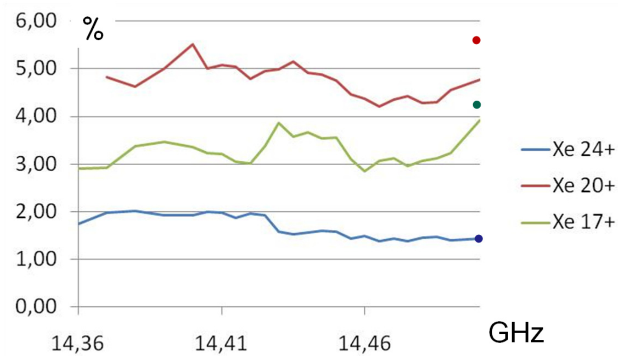

Figure 7: Fine frequency tuning effect on the ^{132}Xe charge breeding efficiency (charge states 17, 20 and 24+).

due to the grounded tube transporting the 1+ beam at high energy towards the plasma. Depending on the tuning of the charge breeder, the coupling of the HF power and so the impedance of the system, may vary substantially, leading to unstable operation. Some studies have been performed in a sweep mode allowing a fast and quasi continuous frequency variation. During such experiments the results were reproducible from sweep to sweep, however due to the variation of the net power coupled to the plasma during a sweep, the influence of the fine frequency tuning could not be properly deduced.

The main conclusion from this study seems to be the difference of behaviour of the buffer gas plasma and the charge bred beams with respect to fine frequency ECR tuning.

GROUNDED TUBE SUPPRESSION

The possibility of removing the grounded tube which permits to transport the high energy 1+ beam towards the plasma, and to fix the position of the deceleration, has been proposed and calculated with SIMION [4]. A cut view of the configuration experimentally tested is shown Fig. 8: on the top, the previous grounded tube configuration (with the last electrode of the double Einzel lens on the left) is represented; on the bottom, the configuration without grounded tube inside the charge breeder is shown.

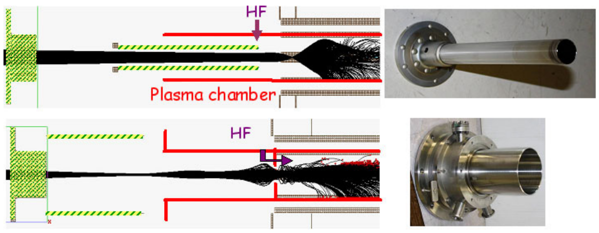

Figure 8: Configuration of the 1+ beam injection in the charge breeder, top – with the grounded tube in the charge breeder, bottom – without grounded tube.

The new electrode has been baked under vacuum and installed one morning. After three hours of pumping, the experiment was performed with a 132Xe+ beam. The n+ signal was found by applying the potential, calculated with SIMION, on the two electrodes of the double Einzel lens. It is interesting to notice that better efficiency than the ones obtained in the last experiments was almost immediately obtained with a power of 85 W (compared to the 400 to the 600 W generally injected to get a reasonable efficiency). The drain current of the high voltage was much lower than in the configuration with the grounded tube (400 µA versus 2 mA), the plasma was much more stable and easier to tune like a standard ECR ion source. The preliminary 132Xe charge breeding spectrum is presented Fig. 9.

This new configuration is promising. Much lower MW power being necessary for operation, the use of a solid state MW generator could be possible. The separation of the injection optics from the ECR charge breeder can simplify the maintenance in the context of radioactive ion production.

Moreover, the HF cavity has no more electrical discontinuity when the grounded tube is removed, thus

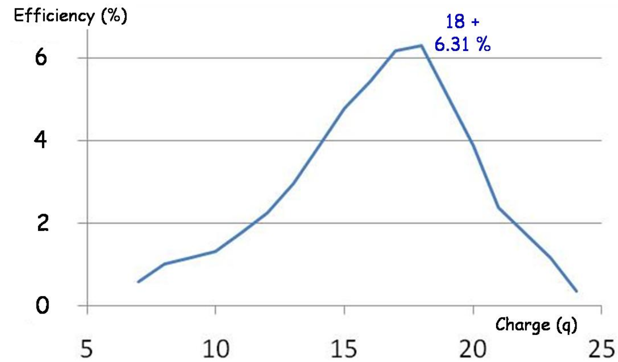

Figure 9: Preliminary charge breeding spectrum obtained without grounded tube

allowing studying properly fine frequency tuning effects. This new configuration has to be tested with alkali and metallic ions in the near future.

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