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# The effect of plasma instabilities on the background impurities in charge breeder ECRIS

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**Abstract.** Experimental observations of plasma instabilities in the 14.5 GHz PHOENIX charge breeder ECRIS are summarized. It has been found that the injection of $^{133}$Cs$^+$ or $^{85}$Rb$^+$ into oxygen discharge of the CB-ECRIS can trigger electron cyclotron instabilities, which results to sputtering of the surfaces exposed to the plasma, followed by up to an order of magnitude increase of impurity currents in the extracted *n*+ charge state distribution. The transition from stable to unstable plasma regime is caused by gradual accumulation and ionization of Cs/Rb altering the discharge parameters in 10 - 100 ms time scale, not by a prompt interaction between the incident ion beam and the ECRIS plasma. This time scale is similar to the reported breeding times of the high charge state Cs and Rb ions. Since the commonly applied method of measuring the breeding time, i.e. pulsing the 1+ injection, clearly affects the buffer gas discharge, it is argued that the actual breeding times in continuous operation can differ from those obtained by studying the injection transient.

## INTRODUCTION

Plasmas of minimum-B Electron Cyclotron Resonance Ion Sources (ECRIS) have been shown to be plagued by kinetic instabilities arising from the anisotropy of the electron velocity distribution [1]. The appearance of the instabilities limits the parameter space available for the optimization of the high charge state ion beam currents extracted from ECRIS [2]. A recent study with the 14.5 GHz PHOENIX ECRIS charge breeder has revealed that the injection of $^{133}$Cs$^+$ or $^{85}$Rb$^+$ beam can perturb the charge breeder oxygen plasma sufficiently to trigger (or sometimes suppress) kinetic instabilities [3]. Here we elaborate on two aspects of the previous study, namely the up to an order-of-magnitude increase of the background impurities of the extracted *n*+ beams induced by the instabilities and the temporal delay between switching on the 1+ injection and the appearance of the instabilities, both of which have far-reaching consequences on the operation of charge breeder ECRISs and on the measurement of charge breeding times in ECRIS plasmas.

## EXPERIMENTAL SETUP AND PROCEDURE

The experimental data discussed hereafter were taken with the 14.5 GHz PHOENIX ECR charge breeder [4] at Laboratoire de Physique Subatomique et de Cosmologie (LPSC). The appearance of the instabilities was detected with three diagnostics methods each of them measuring characteristic features of the periodic onsets of electron cyclotron instability: (i) the plasma microwave emission was detected with a low-barrier Schottky diode detector connected to the secondary waveguide port of the CB-ECRIS (ii) bursts of bremsstrahlung indicating abrupt losses of high-energy electrons were detected with a bismuth germanate scintillator coupled to a photomultiplier and placed in the proximity of the CB-ECRIS and (iii) the temporal fluctuations of the $m/q$-analyzed beam currents were measured with a Faraday

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cup. In addition, an Allison-type emittance scanner equipped with a pair of 0.2 mm entrance and exit slits was used for recording high resolution charge state distributions (CSDs), which allowed monitoring the level of impurities within the extracted *n*+ beam.

The transition threshold from stable to unstable operation regime of the CB-ECRIS is affected by the magnetic field strength, microwave power and capture rate of the injected 1+ ions. The capture rate itself is determined by the incident 1+ beam current, energy of the 1+ ions controlled by the potential difference between the surface ionization source producing the 1+ ions and the charge breeder ($\Delta V$) as well as ECRIS discharge parameters. In the experiments described in the following section the instabilities were induced either by ramping up the magnetic field strength (impurity study) or by adjusting the pulsed 1+ current at constant $\Delta V$ and ECRIS discharge parameters (temporal study).

## RESULTS AND DISCUSSION

The effect of the instabilities on the level of impurities released from the plasma-facing surfaces in the extracted *n*+ charge state distribution (CSD) is demonstrated in Fig. 1. The figure shows examples of high-resolution *n*+ ion beam spectra (max. 2 nA scale) in the $A/Q$ range of 4.5–9.5 at different $B_{min}/B_{ECR}$-ratios. The instabilities of the oxygen discharge were induced without 1+ injection by adjusting the current of the charge breeder central coil, which affects the magnetic field strength and gradient on the resonance surface. $B_{min}/B_{ECR}$=0.80 corresponds to stable regime while at $B_{min}/B_{ECR}$=0.83 and $B_{min}/B_{ECR}$=0.85 periodic instability events were detected; the magnitude of the diagnostics signals, i.e. microwave and x-ray bursts, being larger in the latter case. In the unstable regime the extracted currents of impurities, visible e.g. at $A/Q$=5.5–5.8, $A/Q$=6.1–6.9 and $A/Q$ >8, are significantly higher in comparison to stable operation. Detailed analysis of the *n*+ spectra reveals that the notable increase of the impurity level in unstable mode can be explained by sputtering of the plasma chamber made of 316L stainless steel (Fe, C, Cr, Ni, Mo) and plasma electrode / RF blocker electrode made of AU4G aluminum (Al, Cu, Mn, Zn, Si, Mg).

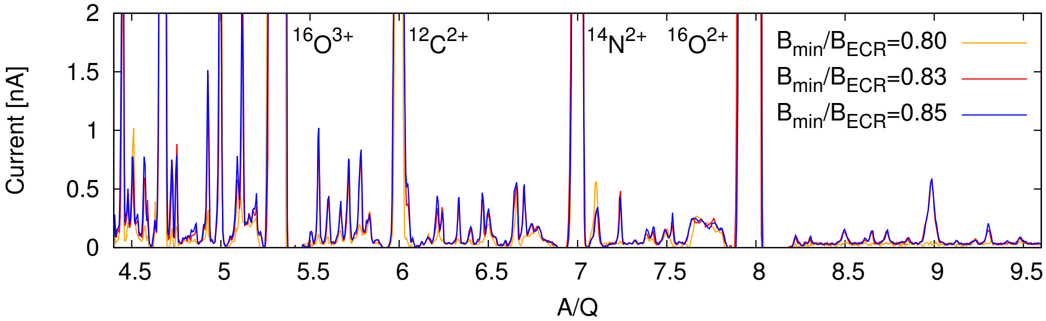

**FIGURE 1.** Examples of high-resolution *n*+ ion beam spectra in the $A/Q$ range of 4.5–9.5 at different $B_{min}/B_{ECR}$-ratios.

The observed increase of impurity currents can be explained as follows: The instabilities expel a significant fraction of the electrons [5] causing the plasma potential to exhibit a transient lasting some tens of microseconds and reaching values of ≥ 1 kV as confirmed in an experimental campaign with the conventional JYFL 14 GHz ECRIS. The ions repelled by the plasma potential ($V_p$) are accelerated across the plasma sheath towards the plasma-facing surfaces with a final energy of $E = QeV_p$, thereby causing significant sputtering of the plasma chamber wall material. The sputtered atoms then undergo stepwise ionization in the ECRIS plasma and appear as impurities within the extracted *n*+ beam. It is worth noting that the two spectra (see Fig. 1) obtained in unstable mode are almost identical, which implies that the level of impurities in the temporally averaged CSD does not correlate directly with the severity of the individual instability events. This is presumably due to vastly different time scales of the instability events (1–10 $\mu$s) and high charge state ion production (10-100 ms) as well as the averaging feature of the CSD scan. The described results underline the importance of avoiding ECRIS operation near the instability threshold as the presence of impurities in the extracted ion beam is often considered as the major drawback of ECRIS charge breeders in comparison to their EBIS counterparts [6].

Figure 2a shows an example of the $^{133}Cs^{26+}$ current and x-ray scintillator signal as a function of $\Delta V$ (with continuous 1+ injection) and demonstrates that the capture of the injected 1+ ions can trigger kinetic instabilities in the oxygen discharge of the charge breeder. The instabilities, represented by the random fluctuation of the diagnostics signals, occur when the capture efficiency of the incident 1+ beam is sufficiently high i.e. $-11\ \text{V} \leq \Delta V \leq -5$ V. Since the x-ray power flux, represented by the scintillator signal, depends on $\Delta V$, it is concluded that the capture of the 1+ ions through ion-ion collisions affects the electron energy distribution or electron density of the charge breeder. This is further highlighted by the fact that the temporal delay ($t_d$) between the leading edge of the 1+ pulse and the first appearance of the instabilities was observed to depend on the injected $\text{Cs}^+$ current as $t_d \propto I_{Cs}^{-0.97\pm0.04}$. Figure 2b shows an example of the diagnostics signals depicting a delay of approximately 90 ms measured with 915 nA of injected $\text{Cs}^+$ current at $\Delta V$=-5 V. The delay being inversely proportional to the injected current implies that the instability appears after the Cs concentration of the charge breeder plasma exceeds a certain threshold i.e. the transition from stable to unstable plasma regime is caused by gradual accumulation and ionization of Cs altering the discharge parameters, in particular the electron energy distribution, in 10 - 100 ms time scale, not by a prompt interaction between the incident ion beam and the ECRIS plasma.

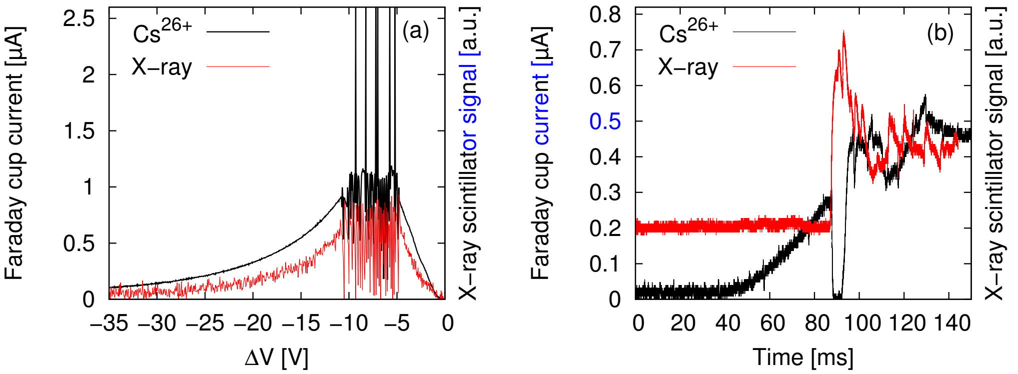

**FIGURE 2.** (a) The extracted beam current of $\text{Cs}^{26+}$ and the x-ray (bremsstrahlung) power flux as a function of $\Delta V$ with 915 nA of injected $\text{Cs}^+$ current and (b) the extracted beam current of $\text{Cs}^{26+}$ and the x-ray (bremsstrahlung) power flux as a function of time measured from the leading edge of the 915 nA $\text{Cs}^+$ pulse at $\Delta V$=-5 V.

As the (delayed) appearance of instabilities with the 1+ injection is caused by the variation of the discharge parameters in a time-scale similar to the 90% rise times of the high charge state ion currents [7], it can be argued that the commonly applied method of measuring the charge breeding time, namely pulsing the 1+ injection, could distort the result. It is therefore proposed that the breeding times should instead be measured by modulating the current of the 1+ ions by a fast (1–10 ms) transient, e.g. a square pulse superimposed on the continuous current representing only a small perturbation to the charge breeder discharge, and estimating the average breeding times from the temporal characteristics of the resulting *n*+ transient currents of different charge states.

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## REFERENCES

[1] O. Tarvainen, I. Izotov, D. Mansfeld, V. Skalyga, S. Golubev, T. Kalvas, H. Koivisto, J. Komppula, R. Kronholm and J. Laulainen, *Plasma Sources Sci. Technol.* ***23**, 2*, (2014).
[2] O. Tarvainen, T. Kalvas, H. Koivisto, J. Komppula, R. Kronholm, J. Laulainen, I. Izotov, D. Mansfeld, V. Skalyga, V. Toivanen and G. Machicoane, *Rev. Sci. Instrum.* ***87**, 02A703*, (2016).
[3] O. Tarvainen, J. Angot, I. Izotov, V. Skalyga, H. Koivisto, T. Thuillier, T. Kalvas and T. Lamy, *Plasma Sources Sci. Technol.* ***23**, 105002*, (2017).
[4] T. Lamy *et al.*, *Rev. Sci. Instrum.* ***73**, 717*, (2002).
[5] S.A. Hokin, R.S. Post, and D.L. Smatlak, *Phys. Fluids B: Plasma Physics* ***1**, 862*, (1989).
[6] R. Vondrasek, *Nucl. Instr. Meth. Phys. Res. B* ***376**, pp. 16–23*, (2016).
[7] P. Delahaye *et al.* *Rev. Sci. Instrum.* ***87**, 02B510*, (2016).