Time Resolved Experiments at the Frankfurt 14 GHz ECR Ion Source

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Abstract

Basic production processes of highly charged ions are investigated by time resolved measurements of the extracted ion currents by pulsing the voltage of the biased disk at the Frankfurt 14 GHz ECRIS. The experiments show that the extracted ion currents respond too fast to changes of the disk voltage to explain the “biased disk effect” by enhanced ion breeding. We also report on investigations of the influence of the pulsed biased disk on plasma instabilities/oscillations and on the extraction of pulsed ion beams from an ECRIS by using the technique of pulsing the biased disk voltage.

(See also the contributions to this workshop by O. Hohn et al. and V. Mironov et al.).

Introduction

The performance of Electron Cyclotron Resonance Ion Sources (ECRIS) [1] can be improved by using external and internal electron donors like a first stage, an electron gun, coating of the plasma chamber walls or a negatively biased disk. All these methods mainly serve to compensate the electron losses from the plasma.

The negatively biased disk is a very convenient and therefore especially often used method [2, 3, 4]. It is mounted on axis close to the ECRIS-plasma. The extracted ion currents can be optimized by a factor of up to 20 by varying disk voltage and position (“biased disk effect”).

We have measured the time structure of the extracted ion currents as responding to the pulsed biased disk voltage. First measurements with a pulsed biased disk voltage (range 1 Hz - 1 kHz) are presented in [5]. In this contribution we present new measurements with a faster pulsing unit (range 1 kHz - 100 kHz).

Experimental setup

The measurements were performed at the Frankfurt 14 GHz ECRIS. The details of this ion source are described in [6, 7].

An iron plug of 40 mm in diameter was installed in the chamber to increase the mirror ratio of the magnetic field. This iron plug was positioned about 50 mm away from the plasma (defined by the end of the hexapole). The biased disk is installed in the front of this iron plug and can be moved by 70 mm on axis. Disk voltages ranging from -1000 V to +1000 V can be applied in DC-mode and from -500 V to 0 V in pulsed mode. The low level in pulsed mode can additionally be shifted between -500 V and +500 V. Disk voltage and disk currents were measured by separate volt- and ammeter.

The new pulsing unit delivers periodic pulses with rectangular shape, variable repetition rate (1 kHz - 100 kHz) and variable pulse length (10 µs - 1 ms). With these properties it is distinctly faster in comparison to the pulsing unit used in the first measurements [5].

The ion currents were measured after the 90°-analyzing magnet in a “fast” Faraday-cup (impedance 50 Ω). The time resolved ion currents were displayed on an oscilloscope and recorded by a digital camera, triggered by the pulsing unit.

Results

Prior to experiments with the pulsed disk, we have measured disk currents and extracted ion currents as a function of the DC-disk voltage for four different situations:

1. Stainless steel disk (∅ 25 mm) with argon- and argon/oxygen-plasma (figure 1 and 2)
2. Aluminum disk (∅ 15 mm) with argon- and argon/oxygen-plasma (figure 3 and 4).

Here, argon-plasma denotes measurements at a rest gas level of less than < 1%.

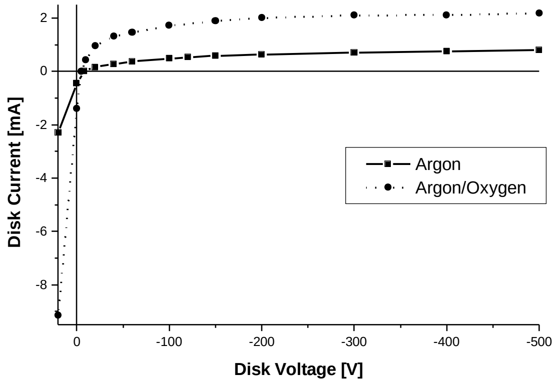

Figure 1.: Disk currents in dependence of the disk voltage for a stainless steel disk.

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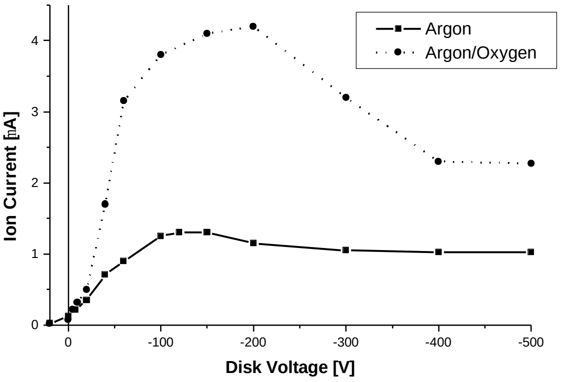

Figure 2.: Extracted ion currents Ar^{11+} in dependence of the disk voltage for a stainless steel disk.

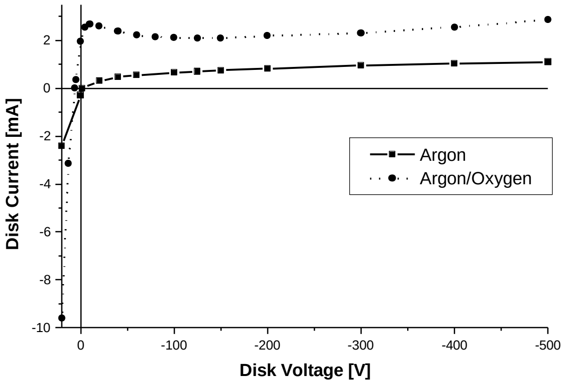

Figure 3.: Disk currents in dependence of the disk voltage for an aluminum disk.

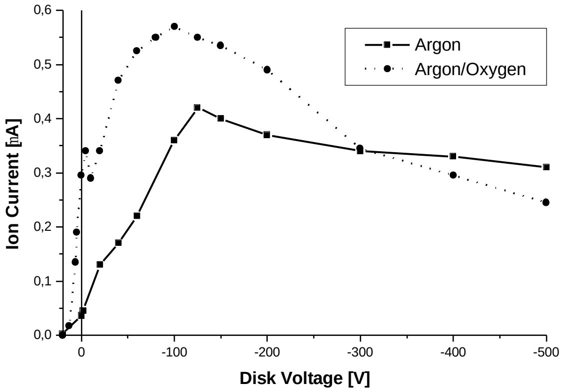

Figure 4.: Extracted ion currents Ar^{11+} in dependence of the disk voltage for an aluminum disk.

In all cases the disk currents and the extracted ion currents (displayed here for the Ar^{11+}-charge state) are higher with argon/oxygen-plasma (gas mixing [8]). For a positively biased disk the disk currents are negative. In the given configuration this means that less ions from the plasma are hitting the disk and/or more electrons from the plasma are going to the disk. In this case the extracted ion currents are very low, except from the case of an aluminum disk with argon/oxygen-plasma.

Putting zero voltage to the disk (the disk is not floating) the disk currents are negative, also except from the case of an aluminum disk with argon/oxygen-plasma, here the disk currents are positive.

Zero disk currents correspond to the case of a floating disk. Here the floating potentials for the stainless steel disk is -8 V for argon-plasma and -5 V for argon/oxygen-plasma. For the aluminum disk the floating potentials are -2 V and +6 V.

By setting the disk voltage to negative values the extracted ion currents increase rapidly, reach a maximum and then saturate for the case of the pure argon-plasma, but decrease clearly in the case of argon/oxygen mixture. In contrast to this and with the exception of the argon/oxygen-plasma with an aluminum disk, the disk currents increase monotonically with increasing negative disk voltage. For the aluminum disk with argon/oxygen-plasma the disk currents reach a local maximum close to zero bias voltage, then decreasing between -10 V and -150 V disk voltage and then increasing again.

The special behavior of the aluminum disk (positive disk currents at positive disk voltage) with argon/oxygen gas mixing points out, that in this case substantially more secondary electrons are created at the disk and attracted by the plasma potential. This could be due to reactions between the oxygen and the aluminum on the surface of the disk (e. g. formation of a thin Al_2O_3-layer with enhanced secondary electron emission coefficient).

From the first series of measurement [5] with pulsed bias disk voltage it was concluded, that the plasma corresponds too fast to changes of the disk voltage to explain the "biased disk effect" by enhanced ion breeding. The new measurements with faster pulses confirm these results. Figure 5 and 6 present time resolved measurements of the extracted ion currents with continuously (DC-mode) and pulsed disk voltage (pulsed-mode) for pure argon-plasmas.

In figure 7 the measured ion pulse shapes are displayed for different charge states, again for the case of pure argon-plasma. As in the previous measurements, they all exhibit the same shapes.

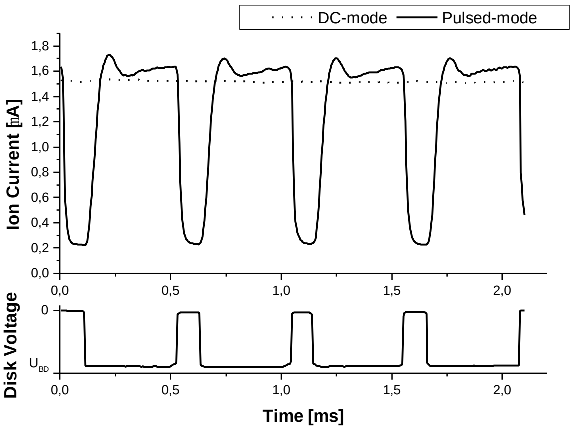

Figure 5: Shape of the pulsed ion beam Ar^{11+} in comparison to the DC-level for pure argon-Plasma (upper picture) and shape of the disk voltage (picture below).

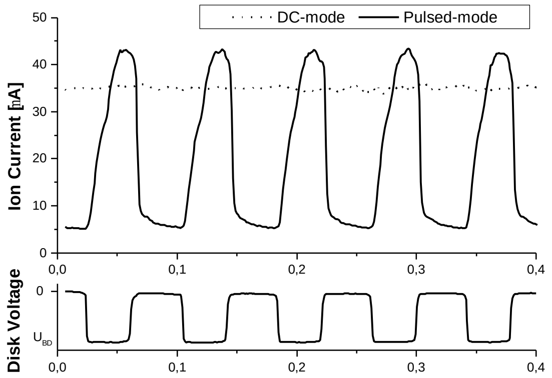

Figure 6: Shape of the pulsed ion beam Ar^{8+} in comparison to the DC-level for pure argon-plasma (upper picture) and shape of the disk voltage (picture below).

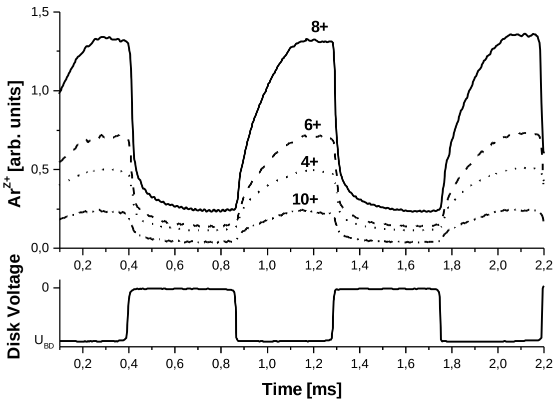

Figure 7: Extracted ion currents for different charge states (argon-plasma).

For a pure argon-plasma the pulsed increase of the ion current is very small compared to the DC case (about 25%, see figure 6). This situation changes if argon/oxygen gas mixing is used. Here, by carefully tuning the gas pressure, frequency, width and voltage of the biased disk pulse, the pulsed currents increase by a factor of 2 compared to the DC case. In figure 8 extracted Ar^{11+}-ion beams with DC and pulsed disk voltage are displayed.

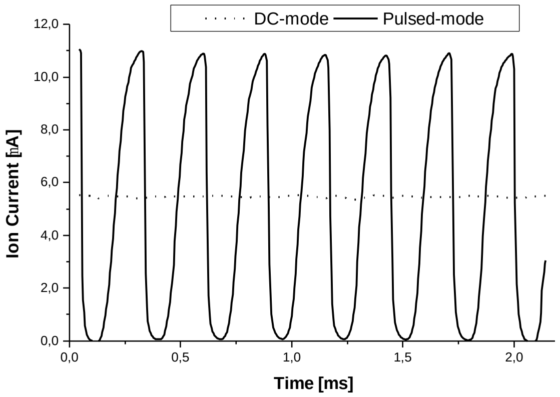

Figure 8: Extracted ion beams Ar^{11+} in DC- and pulsed-mode (argon/oxygen-plasma).

In Figure 9 two situations are shown: a pulsed Ar^{11+} ion beam with a frequency of 4.4 kHz, but different pulse width of 150 μs (pulsed-mode I) and 180 μs (pulsed-mode II). It is remarkable, how drastically such a small change in the pulse width influences the amplitude of the extracted Ar^{11+}-ion currents.

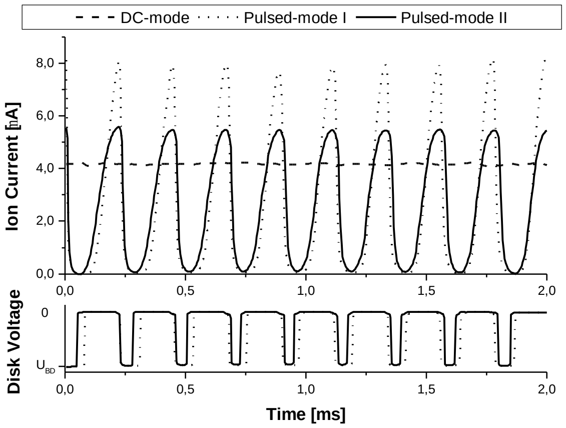

Figure 9: Pulsed Ar^{11+} ion beams with a frequency of 4.4 kHz and a pulse width of 150 ms (pulsed-mode I) and 180 ms (pulsed-mode II).

It is also possible to produce oscillations in an argon/oxygen-plasma with DC biased disk voltage by increasing the oxygen gas pressure only by a small amount compared to the optimized condition. In this case, the average ion current remains the same as for the case of the optimized DC ion current for a tuning where no oscillations are observed. Note, that it therefore is not possible to detect the transition from quiet to the oscillatory behavior in a conventional Faraday-cup measurement viewing the ion current on an ammeter. In figure 10 some examples for different biased disk voltages are given. A clear dependence of the frequency of oscillations on the biased disk voltage can be observed. In figure 11 the frequency of oscillations as a function of the disk voltage and the maximum and mean ion currents (averaged over a large number of oscillations) for Ar^{11+}-ions are given. A comparison with figure 2 shows, that the DC ion currents indeed are identical to the currents for the optimized production of Ar^{11+}-ions from an argon/oxygen-plasma.

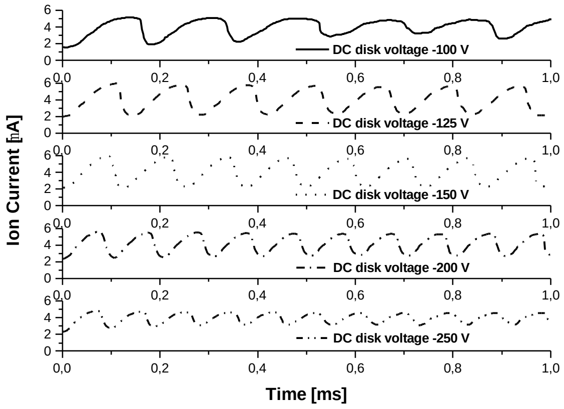

Figure 10: Oscillations of the extracted ion beams Ar^{11+} in the case of argon/oxygen-plasma for different disk voltages.

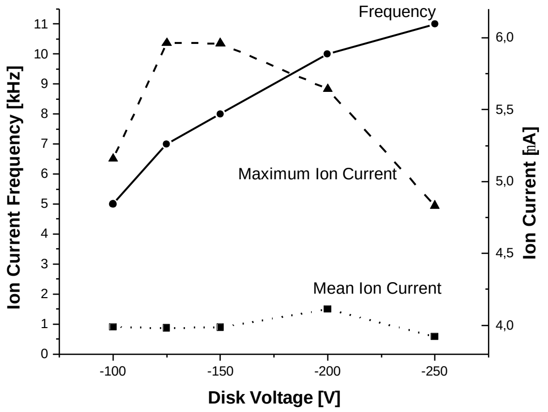

Figure 11: Frequencies of the plasma oscillations in dependence of the DC disk voltage.

Acknowledgments

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