Time resolved experiments at the Frankfurt 14 GHz electron cyclotron resonance ion source

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Time resolved measurements of the extracted ion currents at the Frankfurt 14 GHz electron cyclotron resonance ion source (ECRIS) are reported. These measurements were performed to provide more detailed information on the ''biased disk effect'' in an ECRIS. From a first series of measurements with pulsed biased disk voltage it was concluded that the ''biased disk effect'' is mainly due to improvements of the extraction conditions and the enhanced transport of highly charged ions into the extraction area. In this article we present new measurements with an improved setup allowing for a faster pulsing of the biased disk voltage. We also present data for the injection of neutral particles from laser ablated plasmas and Bremsstrahlung spectra for different dc biased disk voltages. All results from these measurements support our previous conclusion. © *2000 American Institute of Physics.* [S0034-6748(00)62902-7]

INTRODUCTION

The Frankfurt 14 GHz electron cyclotron resonance ion source (ECRIS) in combination with a variable energy radio frequency quadrupole accelerator (ve-RFQ) now supplies beams in the energy range from a few keV–200 keV/amu for atomic physics and materials research at the Institut für Kernphysik (IKF).[1] In addition, the ion source is used to study and improve the production of highly charged ions and to investigate different phenomena of the ECRIS plasma, for example the influence of secondary electrons,[2] plasma instabilities and oscillations.

A commonly used method to increase the ion intensities of highly charged ions is the use of a biased disk, mounted axially close to the plasma. The extracted ion currents can be increased by a factor of up to 20 by varying the disk voltage and the position (''biased disk effect''). This biased disk effect is usually explained by an increase of the electron density in the plasma, however the detailed mechanisms are still being controversially discussed.[3–6] In order to provide more detailed information, we have carried out time resolved measurements of the extracted ion currents with pulsed biased disk voltage.[7,8] Furthermore the influence of the biased disk on plasma instabilities and oscillations has also been investigated by pulsing the biased disk voltage.

In order to enlarge the variety of ion beams available at the Frankfurt facility, experiments with the laser ablation technique[9–12] have been started. First tests demonstrate the production of different metal ion beams with this method at the IKF-ECRIS (e.g. Cd, Zn, W, Mg). The laser ablated plasmas are produced close to the position of the disk. The ionization times of these metal ions and the influence of the injected particle fluxes onto an argon plasma for different biased voltages are investigated by time resolved techniques. This technique represents a tool well suited for plasma diagnosis.

PULSED BIASED DISK

The measurements were performed at the Frankfurt 14 GHz ECRIS. The details of this ion source are described elsewhere.[13,14] For the time resolved measurements of the extracted ion currents, a ''fast'' Faraday-cup (impedance 50 Ω) is installed behind the 90° analyzing magnet. The time dependent ion currents are displayed on an oscilloscope and recorded by a digital camera.

At the ion source a biased disk is used, which is axially installed and which can be moved within several centimeters. The experiments were made with different disk sizes (from 3 to 25 mm in diameter) and different materials (stainless steel and aluminum). Disk voltages ranging from −1000 to +1000 V can be applied in dc mode and from −500 to 0 V in pulsed mode. The pulses have rectangular shapes with variable repetition rates (1–100 kHz) and variable pulse lengths (10 μs–1 ms).

Our previous experiments with lower repetition rate[7] (1 Hz–1 kHz) showed that the extracted ion currents responded much faster to changes of the disk voltage (rise and fall times of the pulses in all cases <150 μs) than expected from the ionization times for highly charged ions (few ms, see also Fig. 3). From these first results it was concluded that the observed biased disk effect is not due to an enhancement of the electron density in the ECRIS plasma. Instead, in our article we proposed that the extracted ion currents are increased due to the formation of a secondary electron beam. Secondary electrons, which are created at the disk, are accelerated by the potential difference between the disk and the

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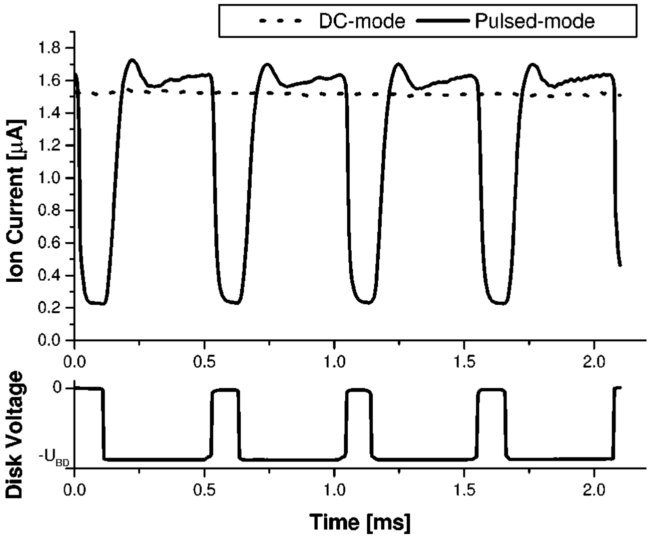

FIG. 1. Time dependent Ar^{11+} ion beams for pure argon plasma. The dashed line shows the optimized dc level (upper). (Lower) The shape of the disk voltage pulse.

plasma boundary. These energetic electrons are radially confined by the magnetic field, they pass through the plasma and are reflected by the potential in the extraction area, and oscillate between the disk and the extraction many times. The space charge of this oscillating electron beam decreases the potential on axis of the ECRIS and consequently influences the conditions in the extraction. Also the ion transport from the central dense part of the ECR plasma to the extraction is positively influenced. Our new measurements with faster pulses confirm the previous results. Figure 1 shows the time structure of an Ar^{11+} ion beam extracted from a pure argon plasma. The amplitude of the pulse is of the same order as the optimized dc level. This behavior changes in the case of an argon/oxygen plasma (gas mixing) which is displayed in Fig. 2. The fast response of the extracted ion currents remains the same, but the amplitude of the pulse is two times higher in comparison to the optimized dc level. This improvement may be due to the fact that in pulsed mode for sufficiently high frequencies no plasma oscillations are excited, which normally limits the performance in dc mode. In our experiments we observe such oscillations in the frequency range of 4–12 kHz.[8]

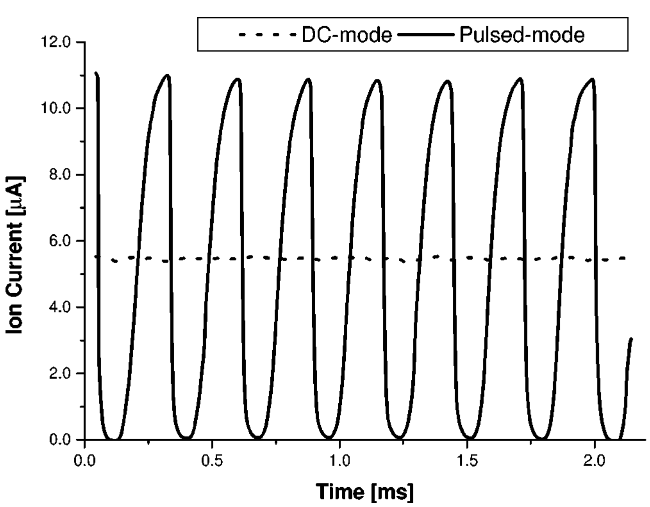

FIG. 2. Time dependent Ar^{11+} ion beams in the case of argon/oxygen plasma. The dashed line shows the optimized dc level.

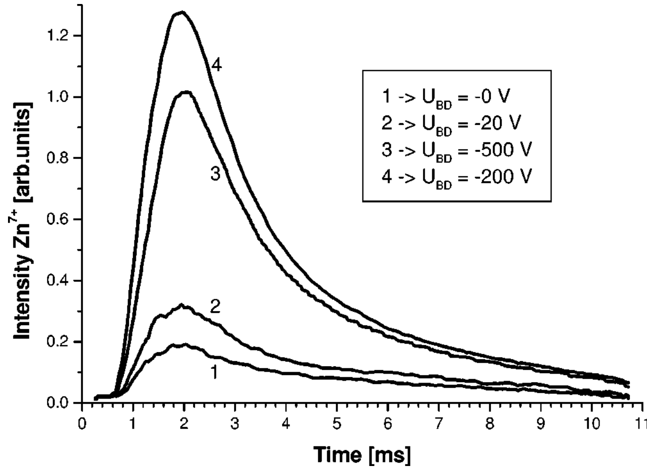

FIG. 3. Time structures of laser ablated Zn^{7+} ions with different biased disk voltages in dc mode (U_{BD}).

LASER ABLATION

Laser ablation is a technique to produce ions from solid state materials. The advantages of this method are that ions from any kind of solid state material can be produced. Varying the laser energy and repetition rate the ablation rate can be adjusted to the low material consumption of an ECRIS and hence the pollution of the source can be minimized. In our first experiments, we have mainly used the laser ablation technique as a diagnosis tool for the ECR plasma. For this reason single shots of the laser light were used.

A YAG:Nd^{+3} laser (30 mJ, $\lambda = 1.064\,\mu$m, 15 ns pulse duration) is used. The laser beam is introduced into the plasma chamber from the injection side with an inclination of 17° with respect to the source axis. The laser target is installed close to the position of the disk (off-axis), tilted by about 30°–60° relative to the laser beam, so that the particle fluxes from the target are reflected at the plasma chamber wall before crossing the ECR plasma.

Figure 3 shows the time structure of extracted Zn^{7+} ions for different dc disk voltages, after the laser ablated zinc atoms are injected into an argon plasma. The ionization time of the ions is absolutely independent of the voltage applied to the disk, but the extracted ion currents have their maximum at -200 V disk voltage (optimized value). This again clearly shows that the secondary electrons, which are created from the disk, do not increase the electron density in the plasma and therefore do not improve the ionization rate of the ions in the plasma, but rather influence the extracted ion intensities.

X-RAY MEASUREMENTS

The measurements of x-ray spectra from ECRIS are a standard tool to investigate the electron energy distributions either in the plasma or in the electron loss cones to the walls. We use a 1 in. × 1 in. NaI(Tl) detector at 4 m distance from

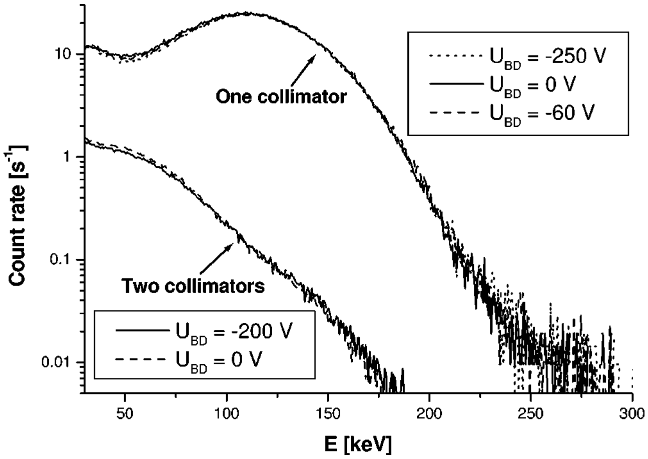

FIG. 4. X-ray spectra with different biased disk voltages in dc-mode (U_{BD}) for the two cases of collimation. (Note) The spectra are not corrected for photon absorption in the vacuum window (quartz window) and in the plasma electrode (only for the case that one collimator is used).

the plasma positioned behind the analyzing magnet. Two collimators are used. The first, directly in front of the detector selects the solid angle of observation. The second, at about half the distance between the detector and the plasma, defines the source volume. In order to achieve a careful collimation of the photon emission cone along the axis of the plasma, the second collimator serves to eliminate the Bremsstrahlung from the plasma chamber walls. The second collimator can be removed to detect the combined spectrum of the Bremsstrahlung from the plasma chamber walls.

We have performed measurements of x-ray spectra for different biased disk voltages in dc mode. All measurements show no dependence between the applied voltage to the disk and the detected electron energy distribution. This is demonstrated in Fig. 4 for the two cases of collimation. It is evident that the absolute intensities as well as the spectral shapes of the Bremsstrahlung radiation spectra are coincident. This also demonstrates that the secondary electrons from the disk do not influence the electron density in the plasma.

CONCLUSION

The presented measurements with three different methods clearly show that the ''biased disk effect'' is not due to an improvement of the electron density in the ECRIS plasma, resulting in better ionization conditions for the ions. Instead we propose that the secondary electrons from the disk create an oscillating electron beam, which decreases the plasma potential on axis of the ECRIS and therefore improves the conditions in the extraction and the transport of highly charged ions into the extraction area.

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[1] H. Schmidt-Böcking, A. Schempp, and K. E. Stiebing, in *Materials Research with Ion Beams*, edited by H. Schmidt-Böcking, A. Schempp and K. E. Stiebing (Springer, Berlin, 1992).
[2] L. Schächter, S. Dobrescu, Al. I. Badescu-Singureanu, S. Runkel, O. Hohn, L. Schmidt, A. Schempp, and H. Schmidt-Böcking, Rev. Sci. Instrum. (these proceedings).
[3] R. Geller, *Electron Cyclotron Resonance Ion Sources and ECR Plasmas* (IOP, Bristol, 1996).
[4] D. Meyer, D. O. Bolshukhin, I. P. Vinogradov, and K. Wiesemann, *Proceedings of the 12th International Workshop on ECR Ion Sources* (Riken, Japan, 1995), p. 34.
[5] T. Nakagawa *et al.*, *Proceedings of the 14th International Workshop on ECR Sources* (CERN, Switzerland, 1999), p. 1.
[6] S. Biri, T. Nakagawa, M. Kidera, L. Kenéz, A. Valek, and Y. Yano, *Proceedings of the 14th International Workshop on ECR Sources* (CERN, Switzerland, 1999), p. 81.
[7] K. E. Stiebing, O. Hohn, S. Runkel, L. Schmidt, H. Schmidt-Böcking, V. Mironov, and G. Shirkov, Physi. Re. ST Accel. Beams **2**, 123501 (1999).
[8] S. Runkel, K. E. Stiebing, O. Hohn, V. Mironov, G. Shirkov, A. Schempp, and H. Schmidt-Böcking, *Proceedings of the 14th International Workshop on ECR Sources* (CERN, Switzerland, 1999), p. 183.
[9] R. Harkewicz, P. J. Billquist, and R. C. Pardo, *Proceedings of the 12th International Workshop on ECR Ion Sources* (Riken, Japan, 1995), p. 19.
[10] P. Yuan, Z. W. Liu, X. Z. Zhang, and X. H. Guo, *Proceedings of the 12th International Workshop on ECR Ion Sources* (Riken, Japan, 1995), p. 232.
[11] L. Bex, P. Lehérissier, and J. F. Hamet, Nucl. Instrum. Methods Phys. Res. A **365**, 674 (1995).
[12] V. Mironov, O. Hohn, S. Runkel, L. Schmidt, G. Shirkov, K. E. Stiebing, H. Schmidt-Böcking and A. Schempp, *Proceedings of the 14th International Workshop on ECR Sources* (CERN, Switzerland, 1999), p. 212.
[13] Homepage of the ECR-RFQ-Group at IKF (http://hsbpc1.ikf.physik.uni-frankfurt.de/ezr/).
[14] O. Hohn *et al.*, *Proceedings of the 14th International Workshop on ECR Sources* (CERN, Switzerland 1999), p. 180.