OPTIMIZED EXTRACTION CONDITIONS FROM HIGH POWER-ECRIS BY DEDICATED DIELECTRIC STRUCTURES

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Abstract

The MD-method of enhancing the ion output from ECR ion sources is well established and basically works via two mechanisms, the regenerative injection of cold electrons from an emissive dielectric layer on the plasma chamber walls and via the cutting of compensating wall currents, which results in an improved ion extraction from the plasma. As this extraction from the plasma becomes a more and more challenging issue for modern ECRIS installations with high microwave power input, a series of experiments was carried out at the 14 GHz ECRIS of the Institut für Kernphysik in Frankfurt/Main, Germany (IKF). In contrast to our earlier work, in these experiments emphasis was put on the second of the above mechanisms namely to influence the sheath potential at the extraction by structures with special dielectric properties. Two different types of dielectric structures, Tantalum-oxide and Aluminium oxide (the latter also being used for the MD-method) with contrastingly different electrical properties were mounted on the extraction electrode of the IKF-ECRIS, facing the plasma. For both structures an increase of the extracted ion beam currents for middle and high charge states by 60-80 % was observed. The method is able to be applied also to other ECR ion sources for increasing the extracted ion beam performances.

INTRODUCTION

The MD-method, using special insolating structures with high secondary electron emission coefficients, to enhance the ion output from ECR ion sources is well established and has been extremely successful. In second generation ECRIS sources (e.g. typically sources with 14GHz microwave systems at maximum powers of 2kW), enhancement factors for the highest charge states (e.g. Ar 16+) of up to 100 have been measured and were clearly attributed to the enrichment of the plasma by cold electrons form the secondary emission effect [1,2]. In a dedicated experiment an increase of the plasma density and electron temperature was observed for the Frankfurt 14GHz source equipped with a MD-liner as compared to the standard stainless steel source.

In a series of experiments it also could be shown that the secondary emission is only part of the mechanism that leads to the particularly good results for the highest charge states. A second effect clearly is the isolating properties of such a layer, which blocks all fast recombination currents and hence restores the ambipolarity at those parts of the surface of the plasma chamber where the structure is installed. This enhanced ambipolarity leads to considerably longer ion dwell times and hence serves to augment especially the high charge states by a better ion breeding.

It also has been demonstrated that, also with a MD-structure best results are obtained when the extraction from the source is optimized by carefully shaping the extraction conditions by a biased disk and that this can still be improved by using a MD-structure at the extraction electrode. This additional improvement was ascribed rather to the isolating properties of the MD-structure at the extraction electrode than to its secondary electron emission [3].

This allows for “tailoring” a MD structure to the needs of a respective installation. While a deficit in electron density may best be compensated by the secondary electron effect, for new generation sources with much better plasma densities and temperatures the improvement of the ion extraction by a MD extraction electrode my more appropriate.

In order to support this argumentation we have carried out a new series of experiments, where we have investigated the role of the dielectric character of the MD-structure by inserting two types of structure into the Frankfurt 14 GHz ECRIS, the very successful Al-MD structure with high secondary electron emission coefficient but only moderate dielectric constant and a Ta-MD structure which has a poor secondary electron emission but a distinctly higher dielectric constant as compared to the Al-MD.

EXPERIMENTAL SET-UP

The experiments reported in this article have been carried out at the 14GHz ECRIS installation at the Institute für Kernphysik, Frankfurt, Germany (IKF-ECRIS). Dielectric structures of Tantalum oxide and Aluminium oxide (denoted here as Ta/Al-MD electrode) were successively installed on the plasma electrode facing the plasma. The structures were made of 1 mm of pure Tantalum or Aluminium plates. The MD liner in this experiment was similar to those used in our previous experiments. It covers the radial walls of the plasma chamber on a length of 150 mm centred at the hexapole magnet.

All measurements were performed at the same operating parameters of the source: 15 kV extraction voltage, 1000 W operating RF power and with pure argon as working gas. The beam was optimized for the 12+ and 14+ charge states respectively. Typical values of the vacuum during operation were (3-5) x 10^{-7} mbar in the plasma chamber, measured at the injection flange and (7-8) x 10^{-8} mbar in the extraction area. A biased stainless steel electrode (biased disk) was located at the injection side of the plasma chamber. It's axial position and the voltage was adjusted in order to maximize the intensity of the extracted ion currents measured in a Faraday cup behind the 90 ° analysing magnet.

RESULTS AND COMMENTS

In order to better unveil the role of dielectric properties, it is meaningful to reduce the influence from the secondary emission effect as far as possible. This is best done by using a "standard" Al-MD liner installed at the radial plasma chamber walls for all experiments discussed here, because it strongly enhances the plasma density and any further contribution to secondary electron enhancement from the MD-electrode can be neglected. At the same time this resembles the best condition of the plasma that can be achieved in the IKF ECRIS because the presence of an Al-MD liner leads to an increase of the plasma electron density by a factor of 2.5 and the electron temperature by a factor of 1.7 [4]. The influence of this is demonstrated by comparing the charge-state-distributions (CSD) for the reference source and for the source equipped with a Al-MD-liner in Fig. 1. It is evident that the intensity of a typical intermediate charge state of argon (e.g. Ar^{12+}) is increased by a factor of 4, whereas Ar^{14+} (representing high charge states) is increased by a factor of 8.

Fig.1 also shows the influence of a Ta-MD-electrode, additionally installed on the plasma electrode. While the MD-liner considerably changes the shape of the CSD in the region of intermediate and high charge states, the additional Ta-MD-structure has only negligible influence on the shape of the CSD but clearly enhances the extracted ion currents in this whole range of charge states. This can be explained by the above described difference between both structures. While the Al-MD-liner enhances plasma density and temperature, leading to the observed considerable increase of high charge states in the CSD, the additional presence of the Ta-MD electrode improves the extraction of the ions from the plasma by suppressing the ion losses by wall currents at the extraction hole. It does not contribute, however, to a change of the plasma parameters. This is also shown by another experiment, where we installed a Ta-MD liner, which represents essentially an insulator, in the source (Fig. 2). The Ta-MD liner had exactly the same size and position as the Al-MD liner. Besides the fact that the Ta-MD liner had no markable emission of secondary electrons and hence did not influence the shape of the CSD very much, this scenario resulted obviously in a strongly reduced output from the source. Part of this reduction could then be restored by improving the extraction from the source again by adding the Ta-MD electrode.

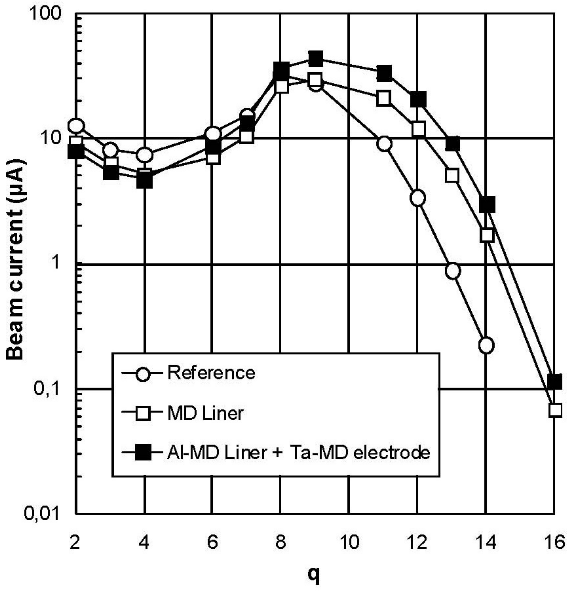

Figure 1: Charge state distributions (CSD) for Ar-ions for three different source configurations as indicated. The ion optics was optimized for the transport of Ar^{14+} ions the extraction voltage was 15kV, the RF power was 1kW.

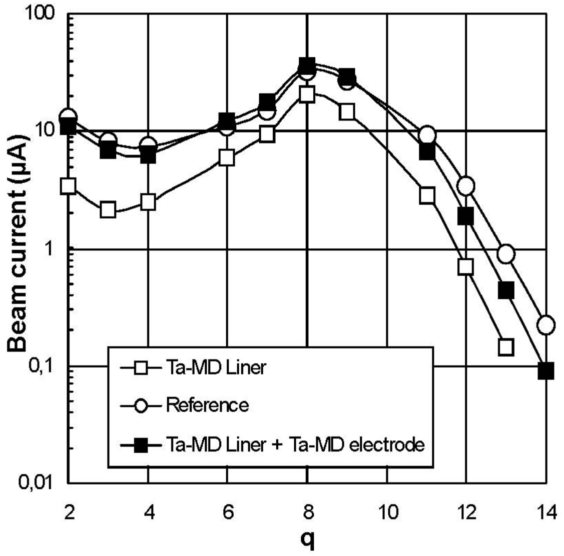

Figure 2: CSD for Ar-ions for different configurations as indicated. Ion optics, extraction voltage and RF power are identical to the ones given in Fig. 1.

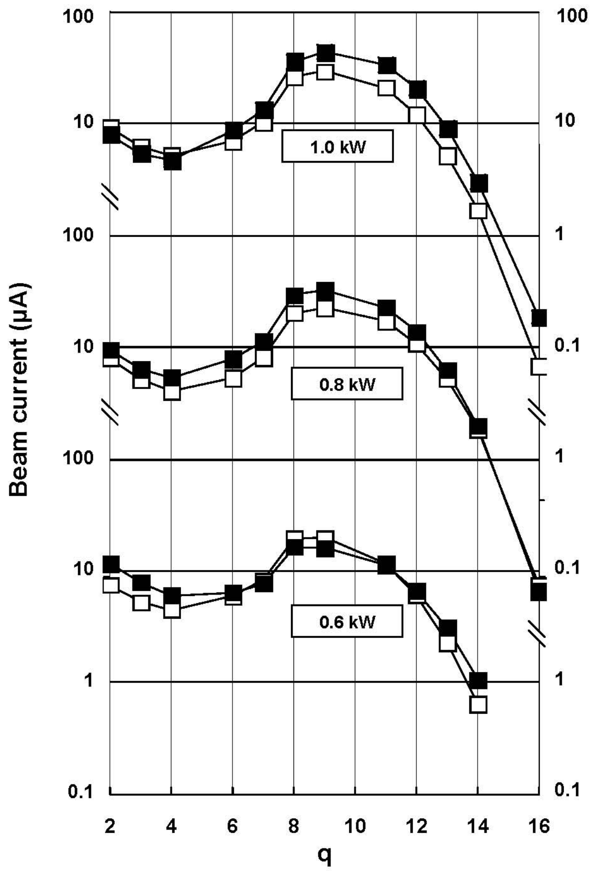

Figure 3: Comparison of CSD with (solid symbols) and without (open symbols) Ta-MD electrode for three different microwave powers as indicated in the figure. The ion optical transport was optimized for the transport of high charge states (Ar^{14+}) the extraction voltage was 15kV. The plasma parameters and extraction conditions were kept identical for the corresponding set of spectra.

All spectra, presented so far, have been measured at 1kW microwave power in order to demonstrate the usefulness of this method for high performance sources. It is well known that a careful shaping of the extraction conditions becomes more and more important the higher the source performance in terms of plasma density and temperature is. In Fig. 3 a series of measurements for different microwave powers is displayed. It is interesting to realize a “shift” of the effect towards higher charge states with increasing microwave power. While at 600 Watt some enhancement at the low-charge state-end of the CSD can be identified, at 1000 Watt clearly the range of intermediate and high charge states is enhanced, demonstrating that this method works the better, the higher the microwave power and hence the plasma parameters are.

The net contributions, given by the Ta dielectric structure are displayed in Fig. 4 as a function of the charge state. A gain of 70-80%, relative to the standard source with Al-MD-liner and stainless steel electrode, can be observed for intermediate and high-charge-state Ar-ions.

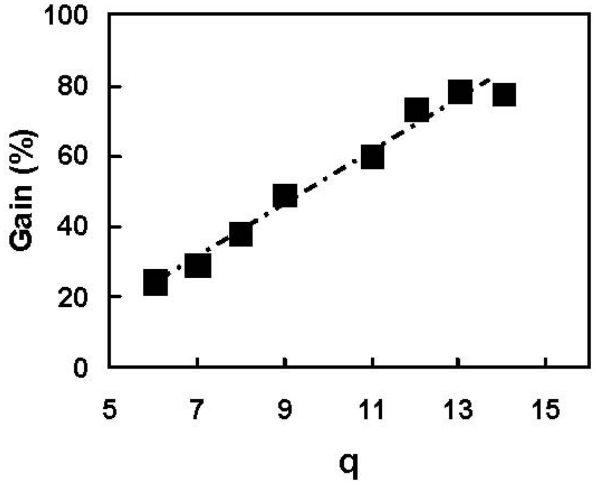

Figure 4: the net contributions from the Ta-structure: $G(q) = [I_{Ta\text{-}str}(q) - I_{std}(q)] / I_{std.}(q)$, $I_{std.}(q)$ is the ion current per charge state q for the source with stainless steel electrode and Al-MD-liner; $I_{Ta\text{-}str.}(q)$ is the configuration with a Ta-MD electrode in addition to the configuration of $I_{std.}(q)$.

The results demonstrate that dielectric structures on the extraction electrode introduce a new feature, which is not present in the standard ECRIS with stainless steel plasma electrode. An isolating structure at this position not only serves to cut the wall currents at the extraction, avoiding ion losses at this point, but also serves to improve the extraction conditions of ions by optimizing the sheath potentials at this point in such a way that a considerably higher amount of ions can be extracted through the extraction hole. The important factor is the positive charging of the plasma facing surface of the structure under electron bombardment. Here the degree of the charging, and hence the improvement factor, depends on the dielectric constant of the layer, which is distinctly higher for Ta-oxide than for Al-oxide, which we used for earlier studies.

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