

MICROWAVE POWER SAVING AND REDUCED BREEMSTRAHLUNG EMISSION FOR A HIGH CHARGE STATE ION PRODUCTION IN AN ECRIS EQUIPPED WITH MD STRUCTURES*

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Abstract

Metal dielectric structures (MD), installed in the plasma chamber of the Frankfurt 14GHz electron cyclotron resonance ion source (ECRIS), have been used to significantly reduce the level of microwave power, necessary to create comparable ion intensities as for the standard operation of the Frankfurt ECRIS. The measurements indicate that the RF-power may be reduced by a factor of 2-3 to obtain the same output of high argon charge states as in the standard source with stainless steel plasma chamber. This reduced level of microwave power also leads to a much lower level of X-ray emission from the source.

INTRODUCTION

The performance of an electron cyclotron resonance ion source (ECRIS) may be expressed in terms of the „quality factor” $QF = n_e \cdot \tau_i$, where n_e is the density of the plasma electrons and τ_i , the ion dwell time in the plasma. Basically all methods and scaling prescriptions for the optimization of an ECRIS act on one or both of the above factors. One consequent approach is the continuous increase of the microwave power and frequency to enhance the density and energy of the plasma electrons. In modern constructions (e.g. 4th generation ECRIS) this usually goes along with a continuous increase of the plasma volumes, which now have several times the volumes used e.g. in the 14GHz sources of the second generation. Special effects like gas mixing, isotope effect or wall coating also base on the optimization of the above two factors. Approaching the 4th generation of ECRIS's now with microwave powers of tens of kW at frequencies as high as 28-30GHz, reveals unexpected technical problems which set serious constraints to the continually scaling of e.g. the frequency as suggested by the above formula. Only one of these limits is the massive heat load transferred by the Bremsstrahlung radiation into the plasma chamber walls and into the superconducting structure of the magnetic trap. Superconducting technology has become necessary to fulfill both, the resonance condition but also the need for very high mirror ratios for the effective electron confinement.

In this article we report on a method to significantly reduce this production of Bremsstrahlung radiation or alternatively to substantially improve the performance of existing sources of the 2nd and 3rd generation. This method is based on a development made at the Institute of Physics and Nuclear Engineering, Bucharest, Romania, ECRIS Plasma Physics and Techniques

and consists in the production of metal- dielectric (MD) structures (Al-Al₂O₃ transitions) by a special electrochemical treatment of pure aluminum plates. The structures are characterized by high yields of secondary electron emission under bombardment by charged particles (electrons and ions from the plasma), which serves to significantly enhance n_e by sending cold electrons to the plasma, when MD-layers are introduced as wall coating into the plasma chamber⁽²⁾. Additionally, facing the plasma as insulators, the MD structures substantially increase the ion dwell times (ion confinement) by blocking compensating wall currents, hence restoring the plasma ambipolarity. The degree of this restoration depends on the actual configuration of MD-coverage of the plasma chamber walls and can be almost complete even if only part of the chamber is covered by the MD structure⁽¹⁾.

In this way, MD structures allow operation of the source at lower working pressure and RF powers. The reduction of the working pressure is very important to minimize charge exchange and electron recombination in the plasma and in the extraction region. The MD-ECRIS gives much better results than using gas mixing⁽⁴⁾. It is an additional advantage of the use of MD structures that the extraction of distinctly different charge states (e.g. Ar⁵⁺, Ar¹⁰⁺, and Ar¹⁵⁺) from one source tuning is not excluded like in the case of gas mixing.

In the present experiment we focus on the possibility to utilize MD structures to extract essentially the same ion-beam intensities like in the standard ECRIS, however, at a strongly reduced level of RF power. This, of course, means also a significantly reduced level of emission of X-rays with important consequences for the lifetime of ECRIS components, for safety considerations and, quite generally, for the feasibility of improvements.

EXPERIMENTAL PROCEDURE

The experiment was performed at the 14 GHz IKF ECRIS of the Institut für Kernphysik, Frankfurt/Main, Germany (IKF). The plasma chamber of the source was equipped with two MD-structures of 1mm thickness. One structure (MD-liner) was installed in the stainless steel plasma chamber symmetrically with respect to the hexapole magnet for the radial plasma confinement. It covered the radial walls at a length of 150 mm (i.e. roughly 3/4 of the whole radial plasma chamber walls). The other structure (MD-electrode) covered the entire

stainless steel extraction electrode of the source. The emissive layers of both structures faced towards plasma.

The source geometries and the main electrical parameters were kept unchanged during all measurements. The extraction voltage was 15 kV and measurements were performed at RF power levels of 200-1000 W. Tests were also performed up to 1500 W. Two types of working gas were used, pure argon and argon-oxygen mixing gas (20% Ar + 80%O₂). The beam optical elements were optimized for the transport of Ar⁸⁺, Ar¹²⁺ and Ar¹⁴⁺ ions.

During the experiment the CSD for different levels of the microwave power at different optimizations were registered and studied for the source operated in "reference" mode (i.e. standard stainless steel source) and for the "MD-ECRIS" (i.e. with the above described insertions).

The X-ray emission from the source was measured using a Ge(Li) detector positioned ~4 m downstream from the source. Its solid angle was limited to the size of the extraction electrode by means of a special multilayer-collimator (Pb-Cu-Al) with a bore of 50mm in length and 1mm in diameter. Typical values of the vacuum during operation of the source were at the injection (1.0 - 5.0) × 10⁻⁷ mbar and (7.0 - 8.0) × 10⁻⁸ mbar at the extraction. A biased stainless steel electrode was located at the injection side of the plasma chamber. Axial position and voltage of this electrode were adjusted by optimizing the extracted ion currents measured in a Faraday cup after the 90° analyzing magnet.

RESULTS AND COMMENTS

In a previous publication we have demonstrated the gain of performance of an ECRIS equipped with MD structures (MD-electrode and MD-liner) ⁽¹⁾. In figure 1 this is shown again for the new series of experiments. The spectra shown in figure 1 are for a source tuning for the production of intermediate charge states of argon.

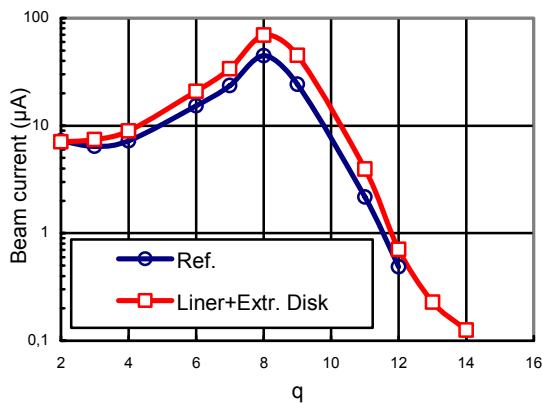


Figure 1

The beam transport system was tuned for the transport of Ar⁸⁺. Indeed, as expected from a partial restoration of the plasma ambipolarity ⁽³⁾, all currents of the extracted ECRIS Plasma Physics and Techniques

charge states are enhanced compared to those, obtained from the reference mode (denoted as Ref. in the figure). Up to q ≤ 11+ this enhancement varies from 30% to 90%. The apparent decrease for the charge states higher than q = 11 is readily understood from the source tuning at intermediate charge states, where the comparatively high source pressure leads to increased charge transfer. Hence recombination rates are higher as compared to a typical tuning for highest charge states. The measurements were performed at 800 W RF power.

As demonstrated in a large number of experiments ^(4,5), MD structures (in particular MD liners covering the radial plasma chamber walls) are capable of enhancing the high-charge -state ion production from an ECRIS by orders of magnitude. Therefore, the most interesting situation is represented by the gain for the production of high charge states. It was the purpose of this experiment to take advantage of this performance and to introduce a facile possibility to strongly reduce the level of microwave power and still obtain the same high beam intensities for highly charged ions as in the reference mode at high microwave powers.

The results from this series of measurements are summed up in the nomograph in figure 2. It is evident that the necessary RF power is reduced by a factor 2-3 for obtaining the same intensity of Ar 12+ / Ar 14+ if MD-structures are installed. For example, to obtain 100nA of Ar 14+ a RF-output level of 800 W was needed in reference mode, whereas only 380 W were necessary with the MD-structures installed at otherwise very similar conditions of tuning of the source and the beam optics.

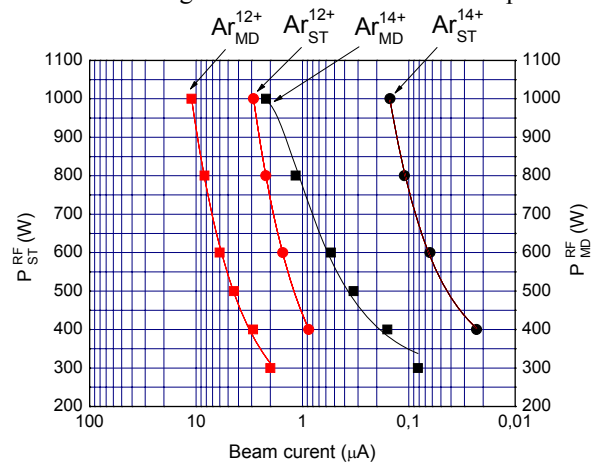


Figure 2

A series of dedicated experiments ⁽⁶⁾ demonstrate that the MD structures in the plasma chamber of an ECRIS generally serve to drastically reduce the level of electron Bremsstrahlung radiation compared to the standard (stainless steel) source. This very important consequence is illustrated in figure 3, where the Bremsstrahlung radiation spectra for Ar¹²⁺ (with MD at 300 Watt) and Ar¹²⁺ (reference at 800 Watt) are compared. The use of MD structures allows a reduction

in X-ray load by a factor of 10 for obtaining the same output of highly charged ions as in reference mode. It is obvious that any reduction of the level of microwave power and hence of X-ray load to the source components is transferred into longer source lifetime, into relaxed safety problems and, last but not least, into considerably reduced energy consumption.

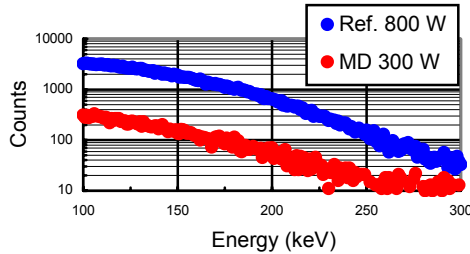


Figure 3

This gain in source performance is entirely due to the intrinsic properties of the specially produced MD layers. It cannot be achieved by any other of the established methods to increase beam intensities extracted from an ECRIS. In particular, despite of contrary experimental evidence ⁽⁵⁾ “gas mixing” is still sometimes misunderstood as the working mechanism of the MD effect. We therefore have carried out one series of measurements with Ar/O₂ mixing gas. An optimized mixture of 20% argon and 80% Oxygen has been used.

The results are displayed in figure 4. It is obvious, that gas mixing in the presence of the MD structures in the plasma chamber changes the shape of CSD. While the high charge states are increased by a factor of less than 2 compared to MD, lower charge states are strongly depleted if compared with the depletion due to the MD for the same plasma. The total amount of extracted ions is not drastically changed. This is in clear contrast to the MD-effect, which increasing the output from the source significantly for all charge states (fig 1) has a much lower effect on the low charge state depletion as the gas mixing.

This relative gain is stronger for very high charge states, as one would expect from a more ambipolar source. This fundamental difference is enhanced by the fact, that for the case of MD, after some period of conditioning, the amount of gas admixtures (representing an unwanted background here) becomes more and more negligible (less than 1% at effective MD-layers) at otherwise unchanged or even still improving

performance. In contrast to this, with mixing gas the dominant content of ions in the plasma consists of supporting gas ions. The result displayed in figure 4 is in perfect agreement with earlier dedicated experiments, where we have shown that the intrinsic MD effect is 3 times stronger than the gas mixing effect.⁽⁴⁾

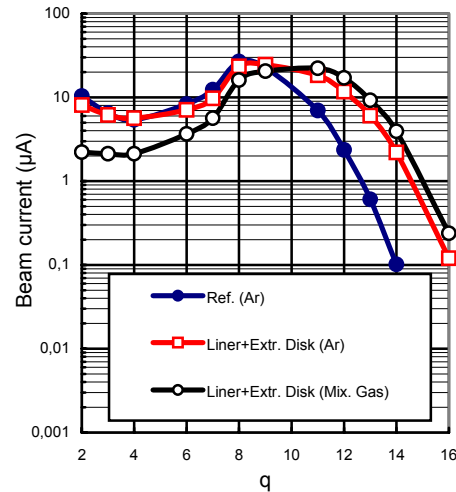


Figure 4

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