

SECONDARY-ELECTRON-ENHANCED PLASMA AS AN ALTERNATIVE TO DOUBLE/VARIABLE-FREQUENCY HEATING IN ECRIS

K. E. Stiebing, L. Schachter[#], and S. Dobrescu[#],

Institut für Kernphysik der Goethe-Universität, Frankfurt/Main, Germany

[#] National Institute for Physics and Nuclear Engineering, Bucharest, Romania

Abstract

“Double Frequency Heating” (DFH) now has become the method of choice to optimize the output from the newest generation ECRIS installations. It was a challenge to compare this method with the comparatively cheap method of “metal dielectric” (MD) structure introduced into the plasma chamber, which has also proven to strongly enrich the plasma with electrons that are effectively trapped and heated. At the 14GHz ECRIS installation at Frankfurt, we have carried out a series of experiments using the two available RF-transmitters to launch two different frequencies into the IKF ECRIS. Due to restriction in the available frequency difference, the source could not be operated in real DFH-mode but was operated in “Frequency Tuning Mode” (FTM), for which also positive results are reported in literature. It turned out that the double RF-injection does not change the source performance substantially. The measured effects are in the order of 20% to 30% as reported elsewhere. In contrast to this, the enhancement gained by the MD method is much higher. The measured enhancement ratios even surpass those, reported for real double frequency heating.

INTRODUCTION

In order to increase the output, in particular of highly charged ions, from an ECRIS a number of techniques have been developed. One of these methods, DFH, is particularly suited for modern high power ECRIS installations with their ability to vary both the magnetic solenoid and multipole field of the source in a range appropriate to allow for resonance zones for both frequencies. First experiments with DFH were realized with second generation sources and were successful [1,2]. In order to apply DFH e.g. in a 14GHz source the RF-difference should be as large as 2 GHz. If the frequency difference is less than this value, one refers to this mode as “Frequency Tuning” (FT). Pioneering work on FT has been done by L. Celona, who developed FT as a powerful method to optimize the performance of electron cyclotron resonance ion source.[3]

At the 14GHz ECRIS of the Institut fuer Kernphysik Frankfurt (IKF), we have introduced the MD method to increase the output of highly charge ions from an ECRIS substantially [4,5]. The MD method is based on a development made at the Institute of Physics and Nuclear Engineering (INFIN), Bucharest, Romania. It consists in the production of metal-dielectric (MD) structures (Al-Al₂O₃ transitions) by a special electrochemical treatment

of pure aluminium plates. The structures are characterised by high yields of secondary-electron emission under bombardment by charged particles (electrons/ions) from the plasma. The installation of MD-structures as wall coating into the plasma chamber therefore significantly enhances the density of plasma electrons n_e by injecting cold electrons to the plasma. At the same time the ion dwell times (ion confinement) are increased by blocking compensating wall currents, hence restoring the plasma ambipolarity. Due to this reduction in wall currents the method has also been shown to drastically reduce Bremsstrahlung radiation from the source, a limit that becomes more and more a problem in modern high power ECRIS devices.

In IKF we have two RF-transmitters available allowing to run the source in FT-mode. It therefore was a challenge to compare these two methods and in particular the possible benefit of FT-mode in an ECRIS with MD-configuration.

EXPERIMENT

The 14 GHz IKF ECRIS was operated in two different configurations, the standard (all stainless steel) mode of configuration, and the MD-mode, where the plasma chamber of the source was equipped with two MD-structures of 1 mm thickness. In MD-mode 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.

Wave-guides for both available RF-transmitters have been launched to the injection plug of the source. The transmitters are a wider bandwidth TWT-amplifier and the narrow bandwidth Klystron-amplifier. In this configuration the minimum RF-difference of ~2 GHz, required for full DFH, could not be reached. Therefore the source was operated in FT-mode. 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 W to 1000 W. Tests were also performed up to 1500 W. Pure Argon was used as working gas. For the experiments reported here, the ion optical elements of the

LEBT were optimized for the transport of Ar^{14+} ions to clearly focus on highly charged ions.

Charge state distributions, taken at the Faraday cup after the 90° analyzing magnet are reported and discussed. The frequency difference for FT-mode was tuned to optimize the output of Ar^{14+} ions. Typical values of the vacuum during operation of the source were at the injection $(1. - 5.) \times 10^{-7}$ mbar and $(7. - 8.) \times 10^{-8}$ 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 current.

RESULTS

Quite generally, the output of highly charged ions from an ECRIS can be optimized by carefully tuning RF-frequency and magnetic field. The installation of the TWT wave-guide provided the possibility to test this in a wider range of RF-frequencies. In Fig. 1 the influence of the “single”-frequency-tuning by changing the RF-frequency of the TWT on the CSD is shown for the reference and the MD configuration of the source. For each CSD, the magnetic field was tuned to optimize the output of highly charged ions (Ar^{14+}). The RF power was 600 W for all frequencies. Two distinct features stand out. One is the well-known shift of the CSD towards higher charge states when a MD-configuration is installed. The output of all high charge states is enhanced by roughly one order of magnitude, the CSD is wider representing a hotter and better confined plasma as already derived in other experiments [6,7,8]. The second distinct feature is that the frequency tuning leads to marked improvement for the standard source while it has very little influence on the CSD taken with MD-configuration. This second behavior becomes clearer in Fig. 2. Here the same data are analyzed as a function of frequency for three selected charge-state groups, low (averaged over $q=2-4$), mediate ($q=6-9$) and high ($q=12-14$) charge states. The data are shown in terms of relative gain factors $g(v) = I(v) / I(v=13,38 \text{ GHz})$, i.e. normalized at the lowest frequency. In addition, also three data points for Ar^{16+} in MD-configuration are shown. As no signal could be analyzed for the lowest frequency in this case, these data points are normalized to the MD-data point at 14,16 GHz. It is evident that, while the intensity of highly charged ions can be increased by a factor of 3 to 4 for the standard configuration, the effect for the MD configuration is strongly reduced to only a factor of 1,5. The data also show that, quite generally, the output of highly charged ions increases with RF-frequency as expected from the general scaling laws formulated by Geller [9]. This increase is limited in this experiment by the magnetic field configuration of the source, which for the last two frequencies was already in saturation.

While this increase is reduced for the MD-configuration, due to its much better confinement and plasma stability the increase for Ar^{16+} indicates that the scaling law is also valid for this configuration. This

general behavior supports earlier conclusions that an MD configuration changes the plasma electron density of any standard 14 GHz - ECRIS into that of an 18 GHz - ECRIS.

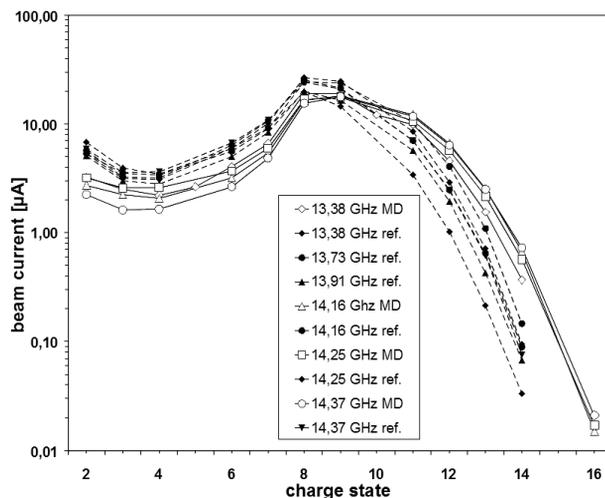


Figure 1: Optimizing single frequency for the standard ECRIS (closed symbols dashed lines) and for the ERCIS with MD configuration (open symbols solid lines).

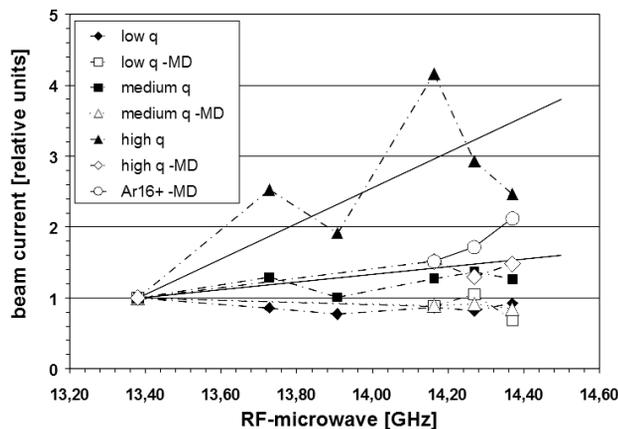


Figure 2: relative intensities as function of RF-frequency for selected charge-state groups (see text).

In Fig. 3 a collection of CSD taken with FT-mode are displayed. All spectra are optimized for the production of Ar^{14+} . Despite of the complexity at first glance, three different groups may readily be identified. First group (dashed dotted lines): CSD taken with reference source at RF-powers between 600 and 800 Watt, second group (dashed lines): CSD taken with reference source at RF-powers at 1 kW to 1,1 kW, third group (solid lines open circles): CSD taken with MD-configuration at a RF Power of 800 Watt.

It is evident that by changing the frequency and the power ratio $P_{Klystron} / P_{TWT}$ within the groups a moderate modification of the CSD is obtained, however at a level of normal parameter tuning of the source. In particular the

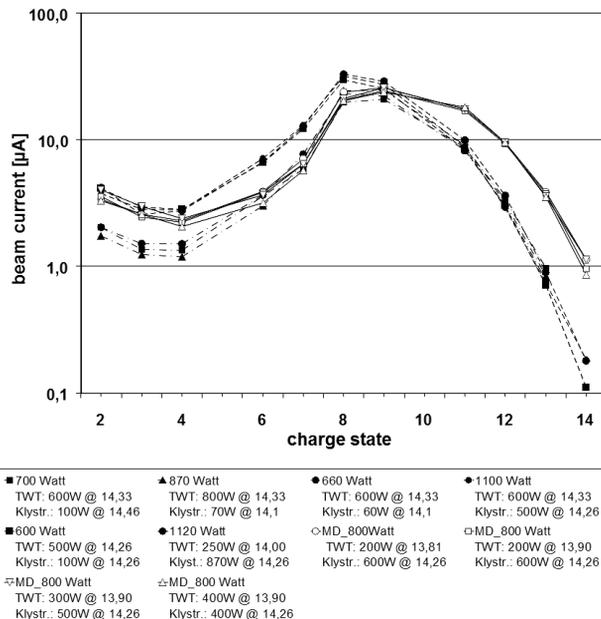


Figure 3: Optimized CSD for FT-mode. Reference-ECRIS (solid symbols), MD-ECRIS (open symbols).

power scaling still is stronger than the FTM-effect and more ions are created at higher input powers, however at low charge states. Most prominent, however, is the MD-effect, which changes the form of the CSD completely, indicating the strong improvement of the plasma parameters by this method.

FT-mode in MD-configuration does not change the CSD significantly. In this configuration the plasma volume, created by the RF-frequency and the magnetic trap of the source is best optimized by the mechanisms, which are due to the MD effect. Injection of a broader RF-Band into the source generally will enhance the resonance volume in the source, however, for optimized performance, this effect has to be accompanied by a better confinement and supply of cold electrons. MD exactly affects these changes, demonstrating that heating is not the limiting factor for the source performance here. This may be due to the restricted volume of this second

Table 1: Comparison to other Experiments

METHOD	INTENSITY GAIN				REFERENCES
	Ar ¹²⁺	Ar ¹³⁺	Ar ¹⁴⁺	Ar ¹⁶⁺	
DFH / SFH	-	1.13	1.38	1.6	[1] (10+14.5) GHz/ 14.5 GHz
DFH / SFH	1.74	2.02	1.07	-	[2] (10+14.5) GHz/ 14.6 GHz
FT(MD) / SFH(MD)	1.038	1.055	1.0	-	IKF this experiment
SFH(MD) / standard	5	10	20	-	IKF best results, good MD perform.
DFH / SFH	Xe ³⁰⁺	Xe ³¹⁺	Xe ³⁵⁺	Xe ³⁸⁺	[10] (24+18) GHz/ 24 GHz
	1.55	2.44	1.42	1.33	

generation ECRIS and does not allow to draw conclusions about the effect of DFH in large-volume superconducting sources, which provide the capability to adjust the magnetic field in a much wider range than in the case given here.

CONCLUSION

Frequency tuning is a method applied to enhance the output of highly charged ions from modern high-performance ECRIS installations. Some of the values reported in literature are compared in Table 1 to results using the ECRIS in MD-mode to enhance the highly charged ion production. It is obvious that the gain factors for the MD configuration with only single frequency injection, are by far higher than the gain factors reached by the quite involved injection of two frequencies, which for optimized conditions also demands for the ability to adjust the fields of the magnetic structures to the injection conditions. Like all methods that really improve the production of highly charged ions, DFH and MD lead to more stable plasma. However, taking into account that only the MD drastically reduces the x-ray emission from the source (by more than an order of magnitude), the MD method could be a real alternative to the double frequency plasma heating, taking also in account the much lower costs.

ACKNOWLEDGEMENT

We acknowledge financial support of the European Union 7th Framework Program FP7/2007-2013-Grant Agreement No. 262010-ENSAR. The EC is not liable for any use made on the information contained herein.

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