Influence of the secondary electrons emitted by a cylindrical metal-dielectric structure on the Frankfurt 14 GHz electron cyclotron resonance ion source performances

L. Schächter
National Institute for Physics and Nuclear Engineering (NIPNE), P.O. Box MG-6, Bucharest, Romania

K. E. Stiebing
Institut für Kernphysik (IKF) der Johann Wolfgang Goethe-Universität, August Euler Strasse 6, D-60486 Frankfurt/Main, Germany

S. Dobrescu and Al. I. Badescu-Singureanu
National Institute for Physics and Nuclear Engineering (NIPNE), P.O. Box MG-6, Bucharest, Romania

S. Runkel, O. Hohn, L. Schmidt, A. Schempp, and H. Schmidt-Böcking
Institut für Kernphysik (IKF) and Institut für Angewandte Physik (IAP) der Johann Wolfgang Goethe-Universität, August Euler Strasse 6, D-60486 Frankfurt/Main, Germany

(Presented on 7 September 1999)

Previous research allowed us to develop highly efficient electron emissive metal-dielectric (MD) structures, which are suitable to be used as sources of secondary electrons in electron cyclotron resonance ion sources (ECRIS). First tests have been performed replacing the stainless steel disk of the Frankfurt 14 GHz ECRIS by a MD structure. This method was recently extended by inserting a MD cylinder (150 mm long and 58 mm in diameter) into this source. The experiments were performed with pure argon as source gas and with gas mixing (argon+oxygen). In this contribution, the performance with MD cylinder is compared to that of the standard source (stainless steel plasma chamber) and to the case, where a cylinder of technical aluminum was installed. With the MD cylinder the yield of highly charged ions from the ECRIS are significantly enhanced. For Ar^{16+} ion current enhancement factors of up to 50 were obtained. [S0034-6748(00)53002-0]

I. INTRODUCTION

In order to enhance the output of highly charged ions from an electron cyclotron resonance ion source (ECRIS), several techniques like wall coating, biased disks, and electron guns have been proposed and are meanwhile employed as standard tools at most of the existing installations.[1] Although the detailed mechanisms are not clear, it has become evident that the additional injection of electrons into the plasma chamber of an ECRIS generally improves its performance considerably. Depending on the special conditions of the source these additional electrons can either compensate for losses of plasma electrons or their sufficiently high currents may change global plasma parameters (e.g., plasma potential) and hence positively influence the extraction of currents of highly charged ions.

At NIPNE, Bucharest, Romania special metal-dielectric (MD) structures of $Al-Al_2O_3$ have been developed. They are characterized by their very high secondary electron emission coefficients[2,3] and therefore seem to be ideal to be used in an ECRIS. First tests have been performed at the 14 GHz Frankfurt ECRIS by replacing the standard stainless steel disk of this source (∅26 mm) by a MD structure of the same diameter.[4,5] In these experiments the disk was not biased. Enhancement factors of 40 were measured for the production of Ar^{11+} ions compared to the ECRIS output with a stainless steel disk under the same conditions (without bias).

Based on these results we manufactured a MD cylinder that was inserted into the plasma chamber of the Frankfurt ECRIS. We studied its effect on the ECRIS output and compared it to the output in the case of the standard (stainless steel) chamber and to the case where the chamber inner wall was lined with a similar cylinder made of technical aluminum.

II. EXPERIMENTAL DETAILS

The Frankfurt 14 GHz ECRIS was described previously.[6–8] A biased stainless steel electrode is located in the stainless steel plasma chamber. The voltage and axial position of this electrode can be adjusted. They are used to maximize the intensity of the extracted ion currents, which are measured in a Faraday cup behind the 90°-analyzing magnet.

The MD cylinder was produced out of a 1-mm-thick sheet of pure aluminum rolled in the form of a tube 150 mm long and 58 mm in diameter. An emissive MD ($Al-Al_2O_3$) layer, obtained by a special electrochemical technology, covered the inner surface of this cylinder. The outer surface of the cylinder remained metallic in order to provide a good electric and thermal contact with the plasma chamber wall.

The MD cylinder was installed symmetrically with respect to the 190-mm-long hexapole in the stainless steel plasma chamber. The source geometry and the main electrical parameters were kept unchanged during all measurements. The extraction voltage was 25 kV, all measurements

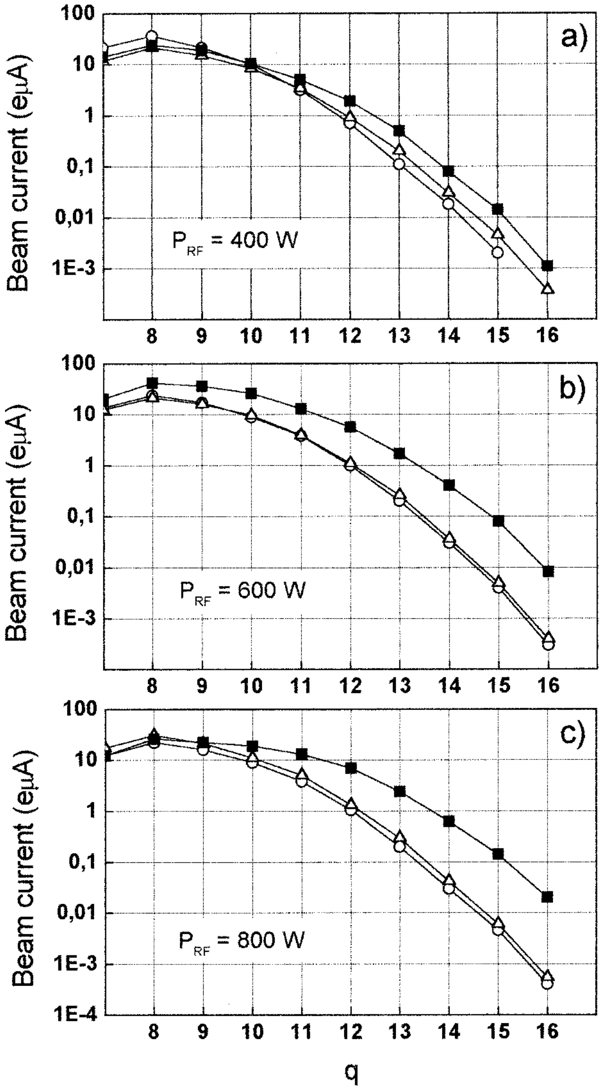

FIG. 1. CSDs of argon ions for the stainless steel plasma chamber (open circles), aluminum cylinder (open triangles), and MD cylinder (solid squares) for: (a) P_{rf}=400; (b) 600; (c) 800 W. Source gas: pure argon.

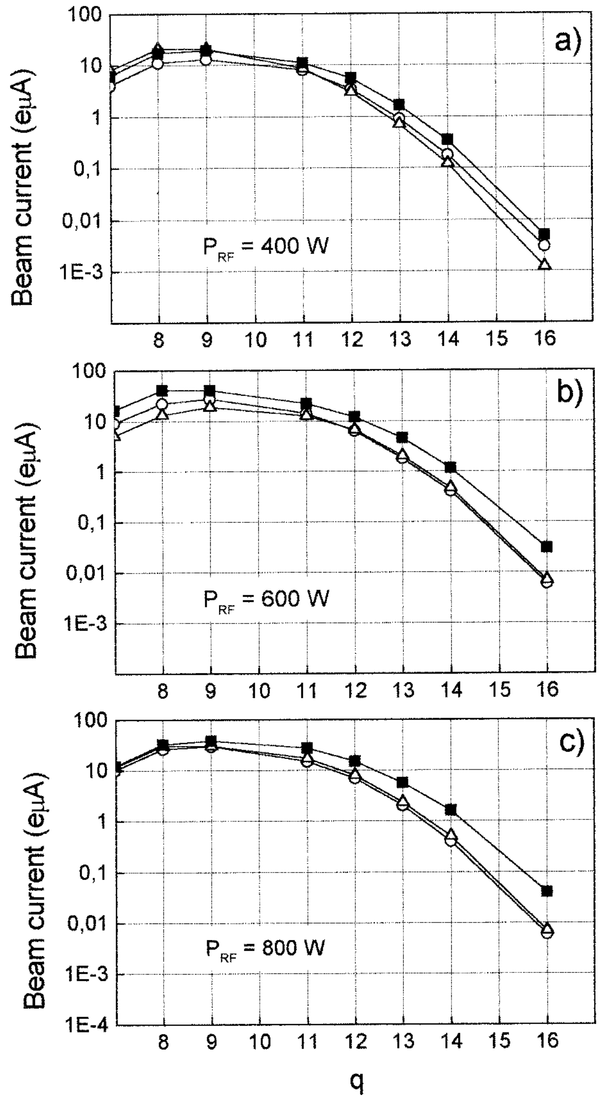

FIG. 2. CSDs of argon ions for the stainless steel plasma chamber (open circles), aluminum cylinder (open triangles), and MD cylinder (solid squares) for: (a) P_{rf}=400; (b) 600; (c) 800 W. Source gas: mixing gas ($Ar+O_2$).

were performed for three levels of radio-frequency power: 400, 600, and 800 W and for two types of source gas: pure argon and mixing gas ($Ar+O_2$). For all experiments presented here, the beam optical elements were optimized for the transport of Ar^{12+} ions. Additionally, a series of measurements with a similar cylinder of technical aluminum inserted in the plasma chamber was performed under the same conditions.

III. RESULTS AND COMMENTS

In Fig. 1 charge state distributions (CSDs) of argon ion beams for charge states $q \geqslant 8$ are presented, for the three different configurations (stainless steel, Al, MD) at the three levels of injected rf power for the case of pure argon as working gas. The CSDs clearly demonstrate that, at least for $P_{rf} \geqslant 600$ W, the output of the source, equipped with the MD cylinder is much higher for charge states $q > 10$ than that of both the standard source and the source equipped with a cylinder of technical aluminum. It is also evident that the MD-structure effect increases with increasing charge state. The effect of the aluminum cylinder is much lower. Enhancements of the source output of only 30%–50% have been observed in this case for charge states $q > 8$.

In Fig. 2 the same plots are given as in Fig. 1 but for mixing gas ($Ar+O_2$). An enhancement of the ECRIS output by the MD structure can be observed in this case too. However, compared to the stainless steel chamber with gas mixing, here a maximum enhancement factor of only 6 for the Ar^{16+}-charge state at the highest rf power (800 W) was obtained. It has to be compared to the enhancement factor 50 that was obtained for pure argon as working gas.

The enhancement factors of the argon ion currents for charge states $q=2-16$ due to the MD cylinder are given in Fig. 3 for both pure argon and mixing gas, at P_{rf}=800 W. In Table I the enhancement factors at P_{rf}=800 W, relative to the case of the standard setup (stainless steel chamber and pure argon as working gas), are given for argon charge states $q=12$ to $q=16$ for the different configurations discussed here. The very strong effect of the MD structure on the EC-

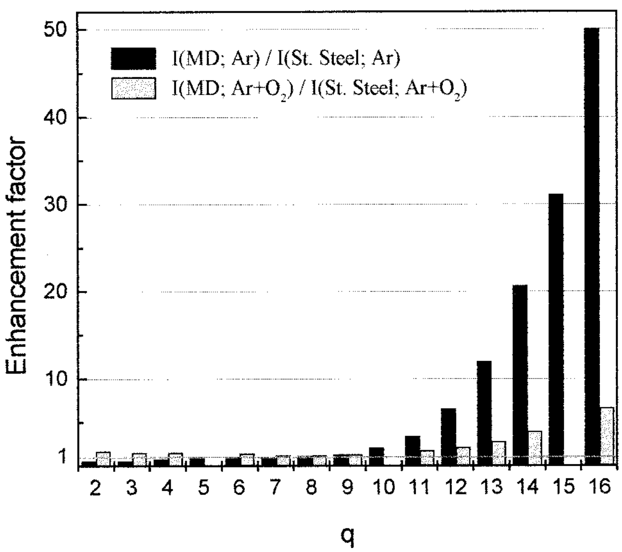

FIG. 3. Enhancement factor of the argon ion current due to the MD cylinder at P_{rf}=800 W.

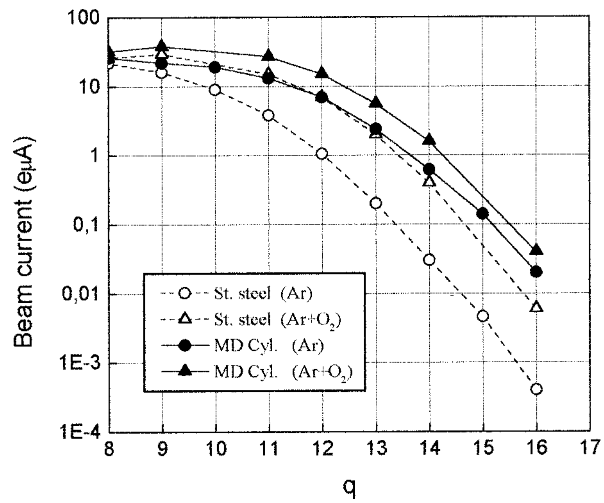

FIG. 4. Effect of the MD cylinder and mixing gas methods on the ECRIS argon ion beam output.

RIS high charge state productivity is evident.

The relative effect of the MD cylinder and of the mixing gas method on the source output is best illustrated in Fig. 4 where the CSDs at P_{rf}=800 W are given for the standard source and the source with MD cylinder both for pure argon and mixing gas. It can be seen that for $q>11$ the output of the source with MD cylinder and pure argon is higher than that of the source with stainless steel or aluminum walls and with mixing gas. It should be noted that even carefully degassing the ion source after insertion of the MD structure, still a more or less constant contribution of oxygen was observed in the charge state spectra. This contribution depends on the method of production of the cylinder. It was much smaller (1%–10%) compared to the relative pressures necessary for gas mixing, not excluding eventually the use of Ar^{5+}, Ar^{10+}, and Ar^{15+} beams. If one considers that the tuning of the source with mixing gas generally is more difficult, it is a supplementary advantage to use the MD structures. In order to obtain maximum currents, the combination of both MD structures and gas mixing methods can yield another factor of 2.

IV. CONCLUSIONS

The experiments presented here, clearly demonstrate the very good capability of the MD structures to enhance the output of the highest charge states of an ECRIS. The MD structures proved to be more efficient than the use of an aluminum plasma chamber or gas mixing, are low cost devices, and may be used in any ECRIS. Offering highest rates of secondary electron emission, the MD structures are also well suitable for detailed investigations of the role of electron injection into an ECRIS[9–10] and of the physical processes involved in the mixing gas method.[11]

TABLE I. Enhancement factors $I_1(q)/I_0(q)$ of the source argon ion beam at P_{rf}=800 W, where $I_0(q)$ denotes the q charge state beam current of the standard source: stainless steel chamber and pure argon.

q	Al Cyl. (Ar)	MD Cyl. (Ar)	St. steel ($Ar+O_2$)	Al Cyl. ($Ar+O_2$)	MD cyl. ($Ar+O_2$)
12	1.3	6.5	6.7	7.6	14.3
13	1.5	12	10	11.5	28
14	1.4	21	13.3	16.7	53
16	1.3	50	15	17.5	100

ACKNOWLEDGMENTS

This work was performed in the frame of a collaboration supported by wissenschaftlich-technische Zusammenarbeit (WTZ), Bundesministerium für Bildung und Forschung (BMBF), and the Romanian National Agency for Science, Technology and Innovation, Grant No. RUM-029-97. Valuable discussions with V. Mironov and C. Besliu are gratefully acknowledged.

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