Metal-dielectric structures for high charge state ion production in ECR plasma

L. Schächter(1), S. Dobrescu(1), Al.I. Badescu-Singureanu(1), K. Stiebing(2), S. Runkel(2), O. Hohn(2) and N. Baltateanu(3)

(1) – National Institute for Physics and Nuclear Engineering, Bucharest, Romania
(2) – Institut fuer Kernphysik der J. W. Goethe Universitat, Frankfurt/Main, Germany
(3) – National Institute for Laser, Plasma and Radiation Physics, Bucharest, Romania

Metal-dielectric (MD) structures of pure (99.999%) aluminum foils were previously studied in the National Institute for Physics and Nuclear Engineering (NIPNE), Bucharest, Romania showing high secondary electron emission properties. Consequently, 26 mm diameter disks of such structures (Al-Al₂O₃) were tested in the ECR ion source of the Institut fuer Kernphysik (IKF) der J. W. Goethe Universitat, Frankfurt/Main, Germany, allowing to demonstrate their ability to significantly increase the ECRIS performances in what concerns the production of high charge state ions.

New experiments carried on in Bucharest on a special facility stressed out the possibility to develop high emissive MD structures starting from lower purity (99%) aluminum foils. This result allowed us to make a special cylinder of 1 mm wall thickness electrolytically treated so that only the inner face had a MD structure layer while the external surface remained metallic. Such a cylinder introduced in the plasma chamber of an ECR ion source provides a high rate of secondary electrons that enhance the ECR plasma electron density while its metallic external surface provides a good electric and thermal contact with the plasma chamber.

The tests performed with such a MD aluminum cylinder in the IKF 14 GHz ECR ion source, successfully demonstrated the possibility to shift the ECRIS output toward very high charge states (Ar¹⁶⁺) due to the strong secondary electron emission of the MD inner surface of the cylinder.

The performances of the electron cyclotron resonance ion sources (ECRIS) may be improved by increasing the free electron density of the ECR plasma [1]. The increase of the ECR plasma electron density leads to an enhanced production of highly charged ion beams, has positive effects on the plasma stability and reduces the necessary rf power for a given beam output. Different authors tested the possibility to increase the ECR plasma electron density by an intensified secondary electron emission from emissive structures introduced in the ECRIS plasma chamber [2-4]. Structures containing oxides, such as Al₂O₃, MgO or SiO₂, are known to have relative high secondary electron emission coefficients under electron or ion impact [5].

Metal-dielectric (MD) structures of the type Al-Al₂O₃ with high secondary electron emission properties have been obtained in the National Institute for Physics and Nuclear Engineering (NIPNE) in Bucharest, Romania and their emissive properties under 0.6 ÷ 5 keV electron beam impact have been measured [6, 7]. Subsequently a 26 mm diameter disk of such a MD structure was axially introduced in the plasma chamber of the 14 GHz ECRIS of the Institute for Nuclear Physics (IKF) of the Johann Wolfgang Goethe University in Frankfurt am Main, Germany. The argon beam intensities and the charge state distributions obtained when the MD disk was inserted were compared to those obtained when similar disks made of iron and pure aluminum were inserted in the same position in the plasma chamber. All the measurements were performed with the disks at the plasma chamber potential. The results, previously reported [8], show a net shift toward the higher charge states in the case of the MD disk. Enhancement factors of the beam current of up to 10 (for Ar¹²⁺) when using an MD disk compared to the output when using an aluminum disk and up to 40 (for Ar¹¹⁺) when using an iron disk have been measured.

The MD structures of the type Al-Al₂O₃ that showed high emissive performances [6] have been prepared by a special developed technology based on electrolytical treatment of Al foils of high purity (99.999%). In these conditions, their application in the ECR ion sources for the realization of an aluminum
chamber provided on the inside wall with a high emissive MD structure would be, if not impossible, very prohibitive due to the huge price of high purity aluminum. Even the lining up of a stainless steel plasma chamber with an internal thin cylinder of high purity aluminum provided on the inner face with a MD structure involves high costs. In order to overpass this difficulty, we extended our research in the direction of a modified treatment technology that would allow to obtain MD structures with comparable secondary electron emission properties using lower purity aluminum (99%). The price of aluminum foils or bars of this lower purity is much lower, by orders of magnitude, as compared with the price of high purity aluminum.

Samples of Al\{hp\} (high purity Al – 99.999%) and Al\{p\} (pure Al – 99%) were electrolytically treated by the same initial technology developed for Al\{hp\} and used in our first experiments [6 – 8]. The emissive properties of the MD structures were estimated by measuring the effective secondary electron emission coefficient: $\sigma_{\text{eff}} = I_C/I_B$ as a function of the incident electron beam energy. $I_B$ is the current of the incident electron beam hitting the MD target with energies in the range 0.6 – 5.1 keV and $I_C$ is the current of the secondary electrons emitted by the MD structure, collected in a Faraday cup (for details see [7]). The compared results are presented in figure 1, where the ratio $\sigma_{\text{eff}}(p; i)/\sigma_{\text{eff}}(hp; i)$ as a function of the incident electron beam energy is given (empty dots curve). $\sigma_{\text{eff}}(hp; i)$ and $\sigma_{\text{eff}}(p; i)$ are the effective secondary electron emission coefficients of MD structures made by the initial technology \{i\} using highly pure \{hp = 99.999\%\}, respectively pure \{p = 99\%\} aluminum foils. The effective secondary electron emission coefficients were measured at a collecting voltage $U_C = 0$ V and at an incident electron beam $I_B = 5$ µA. It may be seen from this figure that the effective secondary electron emission coefficient is lower in the case of the 99% aluminum by a factor of $1.5 \div 2$ than the same coefficient in the case of 99.999% aluminum.

Slightly modifying the parameters of the electrolytical treatment, the emission coefficients of pure (99%) aluminum could be improved so that $\sigma_{\text{eff}}(p; m)$ became larger by 20% as compared to $\sigma_{\text{eff}}(hp; i)$ (m denotes the modified technology of electrolytical treatment) for incident electron energies in the range $0.3 \div 3$ keV, that is the energy of most electrons in the ECR plasma (figure 1, solid dot curve).

As our final goal was to line up the plasma chamber of an ECRIS by a cylinder provided with a MD structure, we simulated this configuration by constructing a “sandwich” target composed of an Al-Al$_2$O$_3$ structure introduced in a stainless steel case and studying its emissive properties under an electron beam impact. The best results were obtained when the Al$_2$O$_3$ structure was deposited only on one face of the Al foil that is thus in good electrical contact with the metallic case.

This study was extended by preparing a cylinder made of pure (99%) aluminum 1 mm thick foil, electrolytically treated by the “modified” technology so that only the inner face had a MD structure layer while the external surface remained metallic. Such a cylinder introduced in the plasma chamber of an ECR ion source provides a high rate of secondary electrons that enhance the ECR plasma electron density while its metallic external surface provides a good electric and thermal contact with the plasma chamber. In figure 2 are presented the values of the effective secondary electron emission coefficient $\sigma_{\text{eff}}(p; m)$ of this cylinder, measured in the special NIPNE facility, as a function of the incident electron beam energy, at different collector biases.

The cylinder of 61 mm outer diameter and 148 mm long was then tested by inserting it in the stainless steel chamber of the 14 GHz IKF ECRIS in Frankfurt, Germany. The preliminary results were very encouraging, the charge state distribution of the argon beam being significantly shifted toward the high charge states (Ar$^{16+}$) due to the strong secondary electron emission of the MD inner surface of the cylinder. In figure 3 a charge
state spectrum of the argon ion beam obtained from the IKF ECR ion source is presented. A similar significant shift toward higher charge states was observed in a preliminarly tested Xe beam. Charge states above 30+ were observed.

The present paper demonstrated the possibility to significantly increase the performances of ECR ion sources by using pure (99%) aliminum provided with MD structures. Consequently, the construction of a 99% pure aluminum plasma chamber having a highly emissive MD structure on its inner surface is feasible.

References
Fig. 1. Secondary electron emission relative efficiency of Al-Al$_2$O$_3$ structures versus the primary electron beam energy

Empty dots: $\sigma_{\text{eff}} \{p; i\}/\sigma_{\text{eff}} \{hp; i\}$. Solid dots: $\sigma_{\text{eff}} \{p; m\}/\sigma_{\text{eff}} \{hp; i\}$

$\{p\}$ pure 99% aluminum; $\{hp\}$ highly pure 99.999% aluminum; $\{i\}$ initial technology of electrolytical treatment adapted for highly pure aluminum; $\{m\}$ modified technology adapted for pure aluminum
Fig. 2. The secondary electron emission coefficient of the MD cylinder versus the incident electron beam energy, at different collector biases