

SECONDARY ELECTRON EMISSION INDUCED BY α -PARTICLES FROM Mg-MgO LAYERS

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The paper presents the results of experimental study of forward and backward electron emission induced by α -particles from the deposited film of magnesium. It was shown that during the deposition of magnesium in residual gas atmosphere the deposited film contained a large amount of MgO component, which makes it possible to consider the resulting structure as Mg-MgO. The presence of magnesium oxide on the surface of the target and the collector leads to the fact that the previously obtained dependence of the ratio of forward and backward electron yields on specific energy loss of the ion for various metals is not applicable in the case of deposited magnesium. The differences are explained by the specificity of the emission from magnesium in the presence of a significant amount of MgO. The results obtained can be used to detect MgO on the surface of a magnesium substrate. It was shown the differences in the experimental data for the bulk magnesium collector and the collector with deposited magnesium layer.

PACS: 79.20.Rf78

INTRODUCTION

Secondary ion-induced electron emission is a fundamental effect of ion interaction with matter. The differences between so-called forward (the direction of the projectile movement) and backward (the opposite direction) electron emissions have been intensively studied for the last 25 years (see e. g. [1 - 4]). The parameter characterizing the differences between these types of emissions is the Mekbach factor R , defining the relation between forward and backward electron yields [5]. Physical differences are associated with production of fast emission electrons through direct collisions of bombarding ions with atoms of a substance: convoy and δ -electrons, those momenta are oriented mainly in the direction of projectiles (see e. g. [6, 7]). Most of the researches devoted to R study were carried out using ultra-thin films. The cycle of forward-backward investigations was carried out by Rothard's group with fast accelerated multiply charged ions and a thin carbon film [8 - 9]. It should be noted that in these experiments the projectile energy at the entrance and exit of the foil was somewhat different (part of the energy was lost by the projectile in the foil), and therefore specific energy losses of ion were differed too. But as we know, electron yield is proportional to the mentioned above losses [10], so there was additional disadvantage of thin foil forward-backward emission experimental study. Therefore, we performed the cycle of R factor measurements at the same ion energy earlier [11 - 13]. It was shown that R factor measured by us for a number of metals and founded from Rothard's experiments [8] for carbon foils depended on the specific energy loss of fast ions in a substance.

Great interest are attracted to secondary electron emission application of MgO in efficient emitter development (see e. g. [14 - 17]). MgO is used as additional component to the base material of emitters. Magnesium is chemically active element, so its oxides are often formed during a number of technological operations, such as sputtering, spraying, implantation.

In this work, we studied the effect of magnesium oxide layers, obtained naturally by thermal deposition on

thin magnesium foil, on forward and backward electron yields of secondary electron emission induced by α -particles of the same energy.

1. EXPERIMENTAL SETUP

Emission experiments were performed on the experimental setup, which described in detail in [11]. A source of α -particles, a thin foil target and a bulk collector were placed in the vacuum chamber (Fig. 1). The projectiles were emitted by a radioisotope source with isotope Pu²³⁹ (initial flow intensity 4.64×10^6 particles per second). α -particles with energy of 5.15 MeV were isotropically radiated into the solid angle 2π .

The target was an aluminum thin foil of $5.6 \mu\text{m}$ thickness with Mg deposited layer on one side of the surface. The foil was selected in such a way that its thickness was less than the mean free path of the α -particles emitted by this radioisotope in the target material. The radioisotope source and the metal holder of the target were in the electrical contact.

The flux of α -particles, passing through the target, caused secondary electron emission from its outer surface (forward emission).

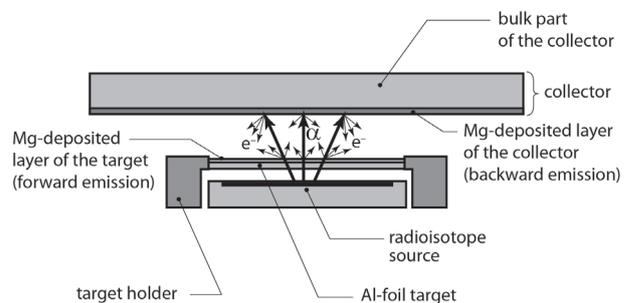


Fig. 1. Scheme of forward-backward electron emission experiments

Then α -particles hit the collector and induced electron emission from its surface (backward emission). To provide collection of all emitted electrons both in the case of forward emission from the target and backward emission from the collector, we applied an electric field in the space between target and collector. We applied a potential of amplitude from -300 to +300 V to the target

using a constant-current source of the Keithley-6487 type. We measured the current of α -particles and emission electrons in the collector electrical circuit. We used a Keithley-6487 picoammeter with a sensitivity of 10^{-14} A for precise current measurements.

The current-voltage characteristics measured in this way allowed to calculate electron yield γ from the saturation current, i.e., from the maximum current corresponding to the total collection of emission electrons. Taking into account that we performed current measurement in the experiment, it is possible to calculate γ by the expression:

$$\gamma = 2 (I_e - I_\alpha) / I_\alpha,$$

where I_e is the corresponding saturation emission current, I_α is the current of α -particles that passed through the target and caused the emission; the coefficient 2 characterizes the fact that the charge of the α -particle is twice the electron charge.

All emission experiments were carried out in a vacuum chamber at a residual gas pressure approximately 2×10^{-4} Pa.

We performed 2 series of experiments with different target-collector combination: 1) target № 1 is aluminum foil substrate ($5.6 \mu\text{m}$) with deposited Mg-layer with thickness of $0.4 \mu\text{m}$ and bulk Mg-collector № 1; 2) the target № 2 is aluminum foil substrate ($5.6 \mu\text{m}$) with deposited Mg-layer with thickness of $1.8 \mu\text{m}$ and bulk duraluminum collector № 2 with the same deposited Mg-layer ($1.8 \mu\text{m}$). Mg layers on the surfaces of thin foil targets and collector were produced by thermal vacuum deposition of pure Mg (99.99%) in vacuum universal station «VUP-5M». The residual gas pressure was approximately 1.7×10^{-3} Pa. Thin Mg layers were deposited on the outer surface of aluminum foil and face surface of the bulk duraluminum collector (the side of α -particle incidence).

2. RESULTS AND DISCUSSION

To simulate the passage of α -particles through our target, we used the SRIM-TRIM software (Fig. 2) [18]. As can be clearly seen from Fig. 2, straggling of α -particles is insignificant in the case of normal incidence. In the absence of the target, the particles emitted by the α -source emitted isotropically into the solid angle 2π . The solid angle into which the α -particles moved passing through the target is determined by the thickness of the foil. Indeed, at large exit angles with respect to the normal to the surface, the projectile path in a target foil becomes comparable to the range.

As a result, if a certain angle is exceeded, the α -particles cannot leave the target. Thus, initially the monochromatic flow of α -particles, passing through the target, would be distributed by energy from 0 to E_{max} . The maximum energy would correspond to the particles with incidence angle of 0° . In our case, E_{max} was approximately 4.15 and 3.97 MeV for target № 1 and 2, respectively.

The collector current as a function of voltage applied between the target and collector is shown on Fig. 3.

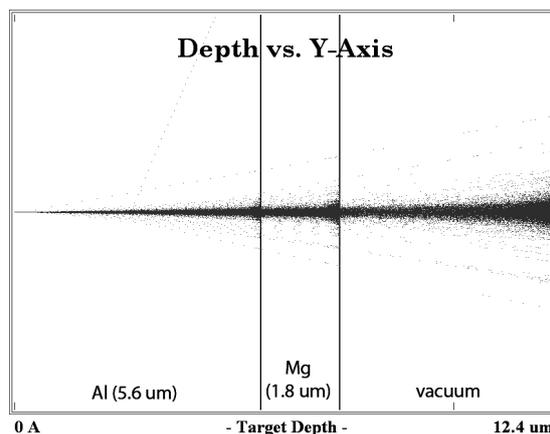


Fig. 2. Ion trajectories in Al-Mg target № 2 for incidence angle of 0°

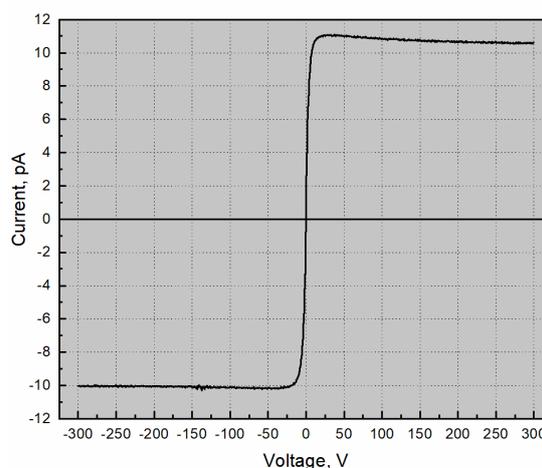


Fig. 3. The experimental current-voltage characteristics for Mg target and Mg massive collector (case 2)

On the basis of measured current-voltage characteristics we calculated the electron yields of forward (γ_F) and backward (γ_B) emissions for different cases of target-collector pairs (Table).

Target-collector combination	Case 1	Case 2
γ_B	15.8	28.37
γ_F	28.3	30.65
R	1.79	1.08

As can be seen from the table, when Mg bulk sample was used as a collector, the R ratio between the forward and backward electron yields was approximately 1.79, which was close to the values obtained earlier by us [11 - 13] and other authors for different substances [8]. Earlier we also found R ratio dependence on the specific energy loss of an ion [13]. According to this dependence, the predicted R value for magnesium should be approximately 1.50...1.55, which is less than the value measured in this experiment (1.79).

The most significant differences were observed for the second case of Mg layer deposited on the collector. At the same time, the backward electronic yields γ_B differed by about 2 times for the bulk Mg collector (№ 1) and for Mg layer deposited on the duraluminum collector (№ 1). While in the case of forward emission the electron yields γ_F for the targets № 1 and 2 (Mg layers of different thickness), were slightly differed. This slight difference can be explained by the fact that α -

particles that have passed through the target and cause forward emission, have different maximum energy (due to the difference in thickness of Mg deposited layers) and, accordingly, different specific energy losses at the exit from the target. As we mentioned above the electron yield is proportional to specific energy loss of fast ion [10]. Since for the deposited layer of greater thickness (case 2), we have larger specific energy loss of α -particles at the exit from the target, then larger value of γ_F for target № 2 is well understood.

The table also shows that the R ratio for the second case is too low 1.08 and is differed from the predicted value. This slight difference in forward-backward emissions induced by ions of the same energy cannot be explained if we deal with metallic Mg layers. Apparently, in our case, the samples were not in a form of Mg metal film, but the deposited layer were heterogeneous structure of Mg-MgO, and, most likely, MgO predominated on the surface. Magnesium oxide compound was formed as a result of the interaction of evaporated magnesium and oxygen from the residual atmosphere of the chamber.

It is known that deposited thin MgO films, even if it doesn't have an island structure, have a great roughness. As was shown in the work of Yoon [19], regardless of the substrate, the MgO film had a high roughness. In our case the large surface roughness of deposited layers leads to the fact that α -particles, falling on the local area of the surface at different angles, have greater path in the emission layer (the depth of emission layer for electrons is approximately 30 angstroms). Since it is well known that γ has inverse cosine law upon incident angle for light ions [20], the proportion of true secondary electrons with respect to fast δ - and convoy electrons increases significantly. In the case of normal incidence of ion on a surface the fraction of true secondary electrons (with energy less than 50 eV) is approximately 90% [11]. Large roughness of the surface leads to significant increase of the fraction of slow electrons in the emitted continuum and, as a consequence, R ratio is decreased.

MgO is well known as an efficient emitter of secondary electrons. The presence of a dielectric layer on the surface of deposited magnesium leads to the fact that during emission processes the surface is charged, thereby lowering the potential barrier on the surface of magnesium, which leads to a significant increase in electron yield due to emission of slow electrons.

CONCLUSIONS

The forward and backward electron emission induced by isotropic flux of α -particles from Mg deposited layers was studied. It was shown that using the technique of thermal deposition during the oxidation of magnesium in the atmosphere of residual gas the deposited film contains a large amount of MgO component, which allow considering it as Mg-MgO structure. The presence of MgO on the surfaces of the target and the collector leads to the fact that the previously obtained dependence of the ratio of forward and backward electron yields on specific energy loss of the ion for various metals is not applicable in the case of Mg deposited layers. The differences can be explained by the specificity of the emission from magnesium layer in the presence of a significant amount of MgO. The results ob-

tained can be used to detect MgO on the surface of a magnesium substrate.

ACKNOWLEDGMENT

We would like thank to prof. V. I. Karas' for continuous interest to our work.

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Article received 25.06.2019

ВТОРИЧНА ЕЛЕКТРОННА ЕМІСІЯ, ІНДУЦІЙОВАНА α -ЧАСТИЦАМИ ІЗ СЛОЕВ Mg-MgO

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Приведены результаты экспериментов по исследованию эмиссии электронов, индуцированной α -частицами на прострел и на отражение из напыленной пленки магния. Было показано, что при напылении магния в атмосфере остаточного газа пленка содержит большое количество компонента MgO, что позволяет рассматривать полученную структуру как Mg-MgO. Наличие окиси магния на поверхности мишени и коллектора приводит к тому, что полученная ранее зависимость отношений электронных выходов на прострел и на отражение от удельных потерь энергии иона для различных металлов не применима в случае напыленного магния. Полученные различия объясняются спецификой эмиссии из магния при наличии значительного количества MgO. Полученные результаты могут быть применены для детектирования MgO на поверхности магниевых субстратов. Были показаны и объяснены различия в экспериментальных данных для массивного магниевых коллектора и коллектора с напыленным слоем магния.

ВТОРИЧНА ЕЛЕКТРОННА ЕМІСІЯ, ІНДУЦІЙОВАНА α -ЧАСТИНКАМИ З ШАРІВ Mg-MgO

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Наведено результати експериментів з дослідження емісії електронів, що індукована α -частинками на прострел і на відбиття з напилених плівок магнію. Було показано, що в разі напылення магнію в атмосфері залишкового газу утворена плівка містить велику кількість компонента MgO, що дозволяє розглядати отриману структуру як Mg-MgO. Наявність окису магнію на поверхні мішені та колектора призводить до того, що отримана раніше залежність відносин електронних виходів на прострел і на відбиття від питомих втрат енергії іона для різних металів не може бути застосована в разі напыленого магнію. Отримані відмінності пояснюються специфікою емісії з магнію за наявності значної кількості MgO. Отримані результати можуть бути застосовані для детектування MgO на поверхні магниєвого субстрату. Було показано і пояснено відмінності в експериментальних даних для масивного магниєвого колектора і колектора з напыленим шаром магнію.