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Suppression of the Effective Secondary Emission Yield for a Grooved Metal Surface

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SUPPRESSION OF THE EFFECTIVE SECONDARY EMISSION YIELD FOR A GROOVED METAL SURFACE

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INTRODUCTION

Suppression of the secondary electron emission is an important technique of mitigating deleterious effect of the electron cloud in modern accelerators. Several methods are routinely used in practice to lower the secondary emission yield (SEY) which include special coatings of the metal surface, surface cleaning and beam scrubbing. In this paper we study another approach to suppress effective SEY which uses grooves on the surface of the metal. This method can complement the surface coating and lead to even smaller total secondary emission.

The idea of using grooves to lower the electron emission has been previously discussed in the literature [1, 2]. In a recent paper [2] Krasnov developed an analytical model which demonstrates lower SEY as a function of the geometric characteristics of the grooves. Our analysis in this paper is based on a computer simulation which tracks orbits of the secondary electrons and uses a detailed model for the energy and angular distribution of the secondaries [3].

SECONDARY EMISSION FROM GROOVED SURFACE

A surface with grooves is shown in Fig. 1. In this paper we consider two types of grooves—triangular groves with angle α, and rectangular grooves characterized by the period b, width a and depth h. An initial electron whose trajectory in Fig. 1 is shown in red hits the surface at point A and produces secondary electrons shown with blue lines. Depending on the emission angle, some of the secondary electrons can escape the groove and move away from the surface. Other secondary electrons would hit an inner side of the groove. With some probability they will be absorbed, or they can generate another secondary electrons (which we call the *second generation* secondaries) whose trajectories are shown in green. The process may repeat several times until the energy of higher generations of the secondaries becomes too low and they are eventually absorbed by the surface.

Note that although collisions of secondaries with side walls of the grooves would lead to suppression of the SEY, there is a competing mechanism for triangular grooves that
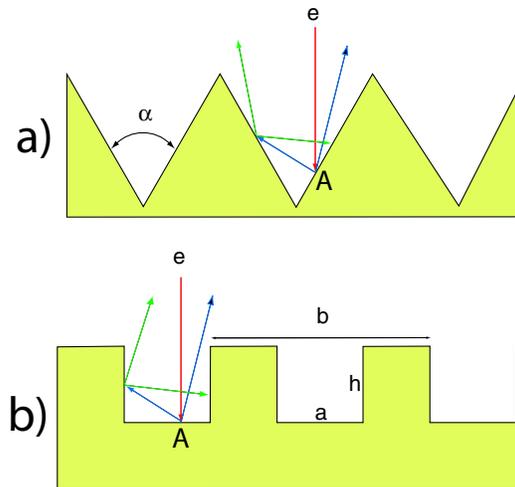
Figure 1: Triangular (a) and rectangular (b) grooves on the surface. Triangular grooves are characterized by the angle α. Rectangular grooves have a period b, width a and depth h.

increases the yield. It is due to the fact that an initial electron that travels perpendicular to the horizontal plane in Fig. 1a would hit the surface of the groove at an angle $(\pi - \alpha)/2$ relative to the normal to the surface. Since SEY typically increases with the incidence angle, this means that the number of first generation secondaries will be larger than in the case of the flat surface. This observation shows that it is not obvious whether triangular grooves suppress the effective emission or increase it for a given angle α, and the result might depend on the specific model of secondary emission.

In our simulation code we used a subroutine from the POSINST computer code [4] to calculate the probability of the secondary emission with a given energy and angular coordinates of the secondary electron. The model implemented in this subroutine is described in Ref. [3]. The angular distribution of secondaries is assumed $\propto \cos\theta$, where θ is the angle with the normal to the surface, and the incidence-angle dependence of the secondary emission yield δ is given by the relation $\delta \propto [1 + r_1(1 - \cos^{r_2}\theta_0)]$ where r_1 and r_2 are positive numbers that depend on the properties of the surface. In the simulation we assumed that primary electrons hit the surface normal to the averaged plane (as shown in Fig. 1). To speed the calculations, we simulated only the first 2 or 3 generations of emitted electrons with about 2×10^4 incident electrons per groove. Effective SEY was averaged over the groove period.

SEY FOR GROOVED SURFACES

In the case of triangular groove surface, the effective SEY does not depend on the size of the grooves and it is only a function of the angle α. This gives certain flexibility in the practical choice of the dimensions of the grooves. Of course, this independence of SEY on the size of the grooves holds only within some limits and breaks down when the size of the grove becomes comparable with the penetration depth of the incident electrons in metal.

The result of simulations for triangular grooves with angle $\alpha = 60°$ on copper surface with maximum SEY
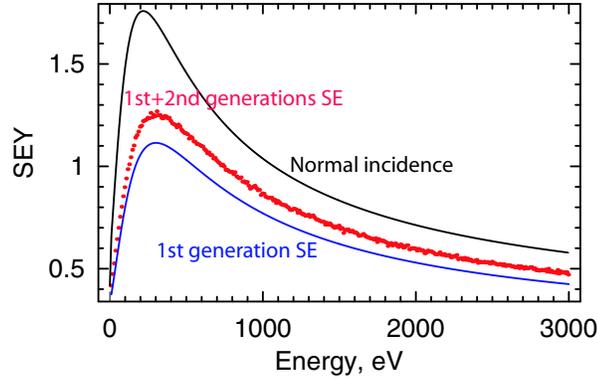
Figure 2: SEY as a function of incident energy for triangular grooves with $\alpha = 60°$.

$\delta_{\max} = 1.75$ is shown in Fig. 2. The top curve gives the reference value of $\delta(E)$ (where E is the incident energy of the electron) for a flat surface (without grooves) for normal incidence. The blue curve is the effective SEY with grooves when only first generation of secondaries is taken into account (that is each secondary electron is assumed to disappear when it hits a wall). The red dots show the result of simulation with two generations of secondaries taken into account (second generation secondary electrons do not produce secondaries when they hit the wall). As it is shown in the picture, the maximum effective SEY decreases to a value of about 1.3 in this case.
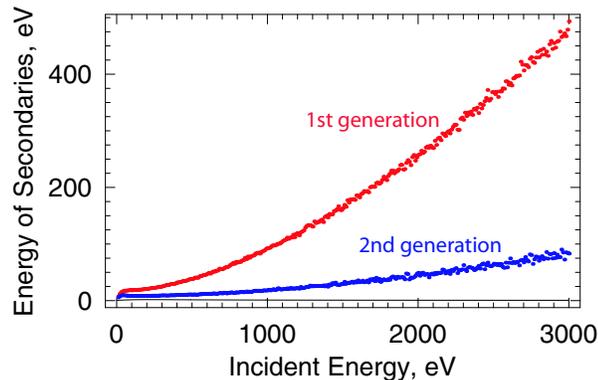
Figure 3: Energy of secondary electrons for triangular grooves with an angle $\alpha = 60°$.

Fig. 3 shows the energy of the secondary electrons of the first and second generations as a function of the primary electron energy. The average emitted electron energy decreases as more generations of electrons are considered and for the second generation it is smaller than $E_{\max}$—the energy corresponding to the maximum of the SEY (≈ 200 eV). For this reason, higher electron generations should not contribute much to the total effective yield for a triangular grooved surface.

In fig. 4 we compare results for grooves with an angle
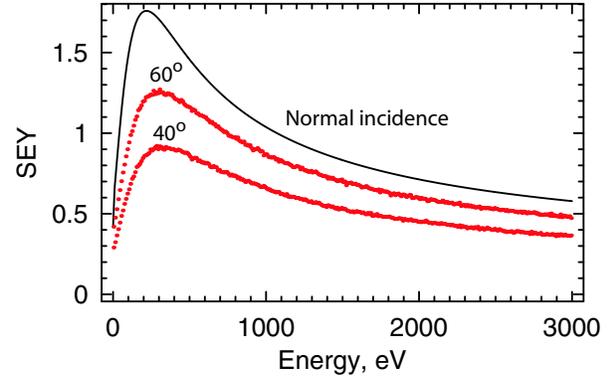
Figure 4: Comparison of the effective SEY for $60°$ and $40°$ groves.

$\alpha = 40°$ and $60°$ (and the reference case of the flat surface). As one may expect, smaller angles result in a stronger suppression of the emission, with a maximum SEY $\delta_{\max} = 0.9$ for $\alpha = 40°$.

Fig. 5 shows results of the simulation for rectangular grooves assuming $a = \frac{2}{3}b$. Red dotted lines correspond
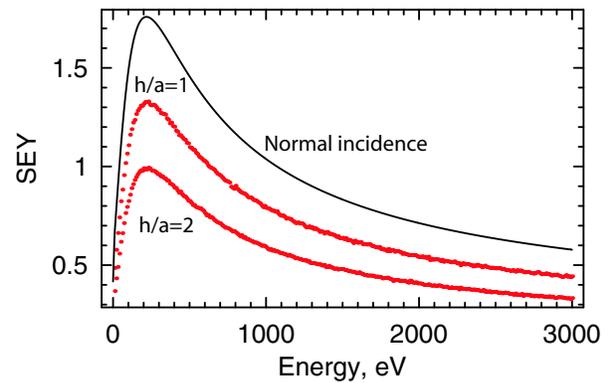
Figure 5: Rectangular groves.

to different aspect ratios of the rectangular grooves: the bottom line is for $h/a = 2$ and the middle one corresponds to $h/a = 1$, while the top curve corresponds to a reference flat surface. As in the case of triangular shapes, deeper grooves show higher suppression of secondary emission.

EFFECT OF MAGNETIC FIELD

Even a weak magnetic field changes the orbit of the secondary emitted electrons and affects their collisions with grooved surfaces. For example, the Larmor radius of a 200 eV electron in 1 Tesla field is about $r_L = 25$ microns, which is much smaller than the size of the groove. In the limit when r_L is much smaller than the depth of the triangular grooves, the effective SEY should not depend neither on r_L nor the size of the grooves, and is only a function of the angle α. The reason is that in the limit $r_L \to 0$ most of the secondaries in their spiraling motion collide only with the tilted side surface of the groove in the vicinity of the emission point.

In our simulations, we have studied so far the effect of the magnetic field for the triangular groove profile. The results of the simulations for angles $\alpha = 60°$ and $\alpha = 40°$ are shown in Fig. 6 and 7 respectively. The black curve in these plots shows again the secondary emission yield for
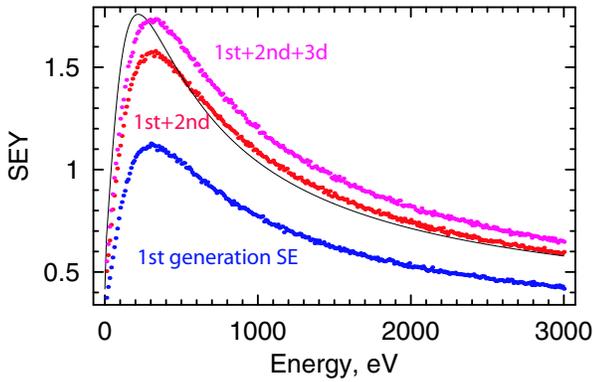
Figure 6: Secondary emission yield in a magnetic field, $\alpha = 60°$.
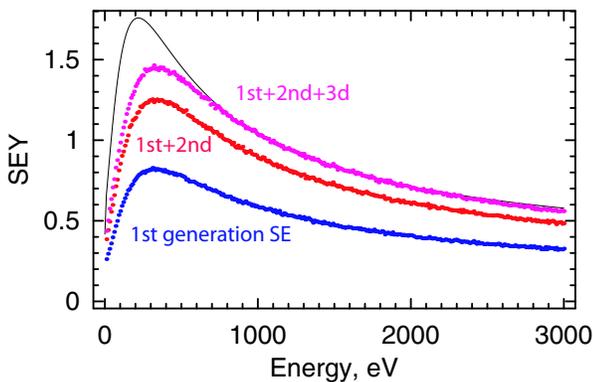
Figure 7: Secondary emission yield in magnetic field, $\alpha = 40°$.

a flat surface. Three color dotted curves show the effective SEY with 1, 2, or 3 generations of secondaries taken into account. Simulations show the contribution of higher generations of secondary electrons becomes more important if the magnetic field is applied. Our results show that for a

60° grooves, the SEY actually exceeds the emission for a flat surface for primary electrons energies above ≈ 300 eV. However, in the case of $40°$ groove angle, there is a noticeable suppression of the SEY.

We have to emphasize here that the angular distribution of secondary electrons was assumed $\propto \cos\theta$ as in the field free case. This may change in a very strong magnetic field [5], to which case our results will not be applicable.

SUMMARY AND DISCUSSION

We presented results of computer simulation results showing that one can suppress the secondary electron yield with a groove surface design of the vacuum chamber. The magnitude of suppression of the SEY depends on the angle of the triangular grooves and on the aspect ratio of rectangular grooves.

Without magnetic field, the suppression depends only on dimensionless parameters that characterize the geometry of the grooves. In the case of triangular shapes, this parameter is the angle α. For rectangular grooves there are two such parameters: the aspect ratio h/a and the fraction a/b of the surface occupied by the grooves. With magnetic field the suppression for triangular grooves depends only on the angle α, in the limit $r_L \to 0$.

For the cases considered in this paper, we found that SEY suppression in strong magnetic field is not as effective as without magnetic.

Introduction of grooves on the surface will change the properties of interaction of the beam with the wall. To minimize the impedance, grooves should be oriented along the beam orbit. Another consequence of the grooves is that the beam electric field will be concentrated on the edges of the grooves with a relatively small magnitude of the beam electric field penetrating to the bottom of the grooves. Due to this shielding, secondary electrons emitted near the bottom of the groove will feed a suppressed electric field of the beam.

ACKNOWLEDGEMENT

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