REDUCTION OF SECONDARY ELECTRON YIELD (SEY) FIGURES ON SMOOTH METALLIC SURFACES BY MEANS OF MAGNETIC ROUGHNESS

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Abstract

High secondary electron yield of metallic surfaces used in accelerator and also in space applications is of general concern. In addition to several well-known coating preparation techniques and microscopic or macroscopic mechanical roughness (grooves) which may significantly increase microwave losses the concept of magnetic surface roughness has been proposed recently to lower the effective secondary electron yield (SEY). In this concept a smooth and very good conducting surface with low microwave losses is maintained, but underneath this surface a large number of tiny permanent magnets are located to build a rough magnetic equipotential structure. In this paper we present and discuss measurement of the SEY and the improvement in terms of SEY for different parameter ranges.

INTRODUCTION

The secondary electron yield (SEY) is the physical quantity governing multipacting in radiofrequency devices, charging in space applications and electron-cloud in particle accelerators. Lowering the SEY enables to mitigate or eradicate these effects and can be achieved by appropriate thin film coatings [1, 2], surfaces with microscopic tuned roughness [3] or macroscopic grooves [4]. An alternative, called magnetic roughness, has been proposed [5] for the cases where roughness would lead to major RF power losses. Compared to low SEY thin films the magnetic roughness has the advantage of being insensitive to air exposure conditions. Possible applications are waveguide filters and devices in satellites, where it appears possible to implant a pattern of small permanent magnets. Since the necessary magnetic field is well localized at the surface, the magnetic roughness could be applied in accelerator technology to RF couplers and particular spots of the machine which are prone to develop e-cloud. Beam orbit magnets are obviously excluded. The magnetic roughness scheme can also be applied to insulators, which are known to exhibit extremely high SEY values. We present laboratory measurements, which illustrate the technique and its effectiveness.

EXPERIMENTAL SETUP

For this study three different arrangements of magnets were measured: 1) perpendicular to the surface all parallel along the same row, but antiparallel to the adjacent row, 2) perpendicular to the surface anti-parallel to each nearest neighbour and 3) in-plane parallel to each other in each row when they are placed end to end. In all cases a non-magnetic checkerboard arrangement was used.

The samples named A (including A1, A2 and A3 configurations) measured in ICMM of CSIC were made of a square 50 x 50 mm^2 of aluminium with a hole array to insert the magnets and were covered by an aluminium plate, as shown in figure 1 top left. The magnets and the aluminum substrate were sequentially ultrasonically cleaned in acetone, methanol, and de-ionized water, and dried in nitrogen gas flow. 81 cylindrical permanent magnets of 2 mm diameter and 5 mm length of NdFeB were located in the holes of this 9 x 9 matrix. The spacing of the holes hole was 5mm (Fig. 1 top). Sample B, measured at CERN, has a similar antiparallel configuration as A2, however with different magnets size and spacing: 20 cylindrical permanent magnets of 2 mm diameter and 2 mm length made of NdFeB were assembled in a periodic array with a spacing of 3 mm, as shown in the figure 1 bottom, and covered by a stainless steel 316LN plate. It has been chemically cleaned in detergents, as for UHV components. The measured sample surface can be positioned at different distances with respect to the topmost face of the magnets by using intermediate spacer discs made of 316LN stainless steel.

The SEY measurements for samples A were performed on the surface of the covering aluminium plate at normal incidence by measuring the sample current with a bias of -27 V on the sample and acquiring the total beam current using a conventional Faraday cup and also a Pt reference sample for the same gun settings. The SEY was measured with a primary energy ranging from in a range of 5 eV to 950 eV and at different locations on the sample surface, by using a micrometric XYZ manipulator. The selected electron probe beam diameter was 10 mm. The SEY on sample B was measured at normal incidence for primary energies between 100 eV and 1600 eV at several locations on the sample, by moving it laterally step by step (0.5 mm/step). The profile of the electron gun beam is roughly Gaussian with a FWHM of 2 mm between 200 eV and 800 eV. At higher energies the FWHM increases up to 3 mm and at 100 eV the profile is wider and no longer Gaussian. For the SEY measurement the sample is set at a bias voltage of -18V and the sample current and collector current are measured simultaneously. In both instruments the electron dose per measured point is kept below 10^{-7} C/mm^2.

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RESULTS

Figure 2 shows the SEY as a function of the primary energy, E_p, for the three alternating pole sequences A1, A2 and A3 (Fig.1 top). In these experiments the electron probe beam was located in the center of the magnets array to minimize the edge-effects, and is averaging over an area of about 4 magnets. In this particular place, a marked reduction of SEY by about a factor 2 is observed in samples A1 and A2 compared to the case of the air exposed aluminum surface (without magnets), which is close to 2.6, as shown in figure 2. Sample A3 also shows lower SEY values than those for the raw aluminium substrate without magnets, although a maximum SEY of 2.0 was observed for a primary energy of 750 eV. From this e-beam position the highest reduction is obtained for the A2 configuration. In addition, the beam position was moved along a straight line on the surface for the A2 configuration, and it was observed a periodic variation of SEY at constant primary energy. In any case the result proves that a magnetic roughness can indeed provoke a decrease of the effective SEY. A XY map of SEY (E_p) curves all across the various arrangements is necessary to confirm which is the most favourable geometry.

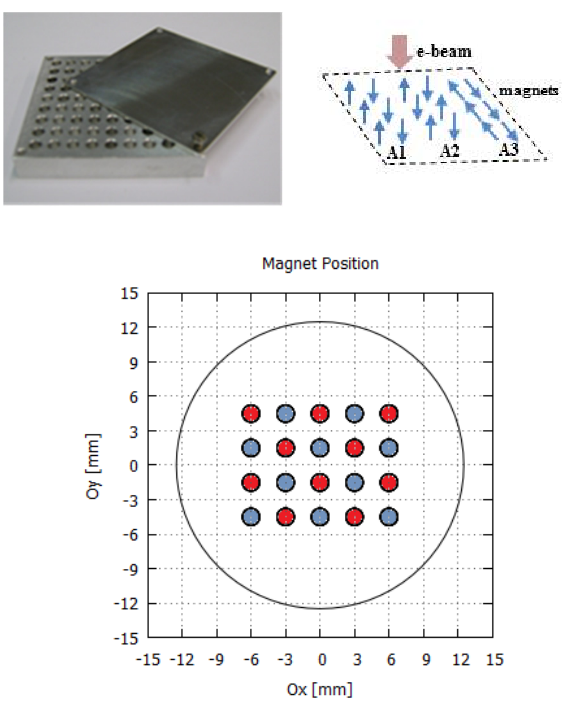

Figure 1: top) photo of sample A without magnets (left) and the scheme of the orientation of the magnets (right); bottom) top-view scheme of sample B, colours represent the respective magnetic field orientation

Maps of the SEY were obtained on sample B, by moving step by step the sample in front of the beam. The pattern for some selected energies is shown in figure 3. The pattern of the arrangement of the magnets is well reproduced at primary energies between 200 eV (Fig. 3) and 800 eV, whereas the image appears more blurred for lower and higher energies. As mentioned above this can be ascribed to the electron beam profile.

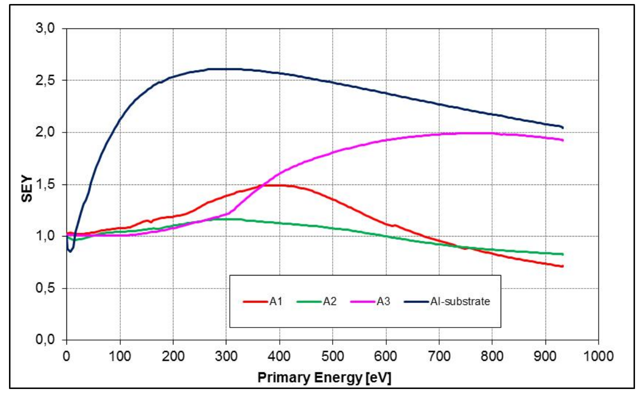

Figure 2: SEY of samples A (see Fig.1) and aluminium substrate as a function of the primary energy.

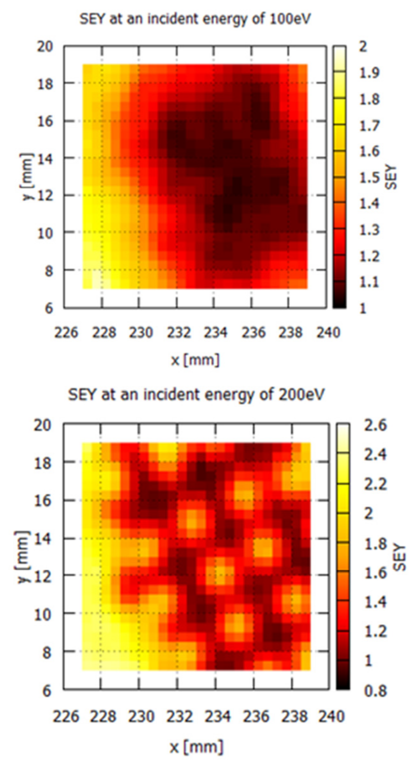

Figure 3: SEY of sample B (colour coded) as a function of the position for a primary energy of 100 eV (top) and 200 eV (bottom)

By counting the spots it is easy to conclude that the regions exhibiting a larger SEY are those which are on the axis of each cylindrical magnet, whereas the regions in between the magnets have an apparently smaller SEY. The fact that such a map reveals the pattern of the underlying magnets demonstrates that the deviation of the primary beam by the magnetic field is negligible and that the effect of reduction of the SEY is due to the deflection of the trajectories of the much slower secondary electrons. For the maps with primary energy between 200 eV and 800 eV the maximum SEY value which is obtained within the pattern, namely along the axis of the magnets, is lower than the value outside the pattern, as in the lower left edge of the map in figure 3. This could be due to the lateral resolution which is limited by the beam-size and results in a value averaged over an area of lower SEY around the maximum. An estimate of the global reduction of the SEY is given by the spatial average value. This is displayed in figure 4, for the primary energies of 100 eV, 200 eV, 400eV, 800eV and 1600eV. For a comparison the SEY curve of the same stainless steel plate without the underlying magnets is also displayed. The SEY is reduced to less than 2/3 of the initial value of the surface without magnetic roughness.

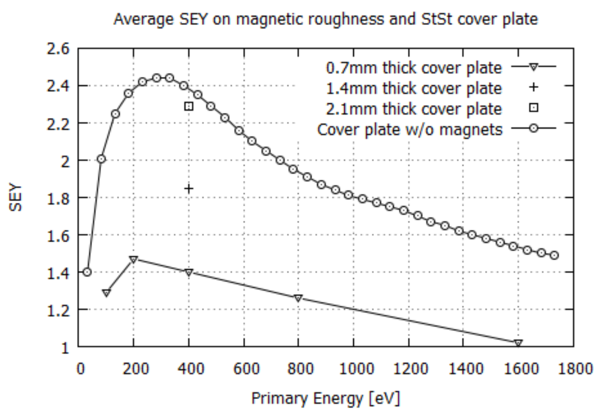

Figure 4: SEY as a function of the primary energy for a stainless steel surface (circles), spatial average for sample B (triangles), value at 400 eV for two different distances (cross and square).

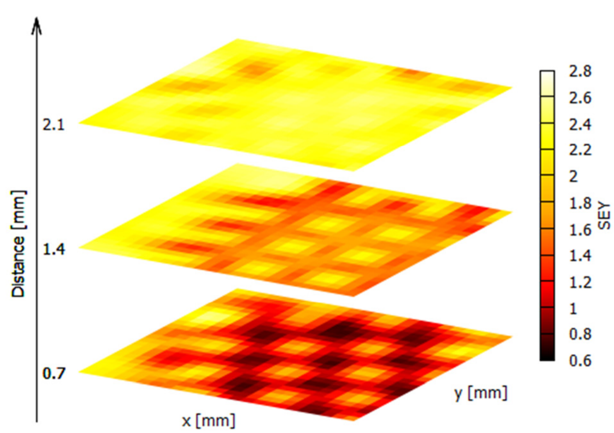

Figure 5: SEY maps of sample B for a primary energy of 400eV and for 3 different distances between the measured surface and the magnets.

All these data for sample B were obtained with a distance of 0.7 mm between the upper face of the magnets and the measured surface. Increasing the distance reduces the effect of the magnetic field on the SEY. As it is visible from the points at 400eV in figure 4 the effect becomes negligible for a distance of 2.1 mm from the upper face of the magnets. In figure 5 the evolution of the pattern observed for the local SEY is displayed for the various distances. The pattern is progressively blurred and the position of the magnets is no longer detectable. This is obviously a consequence of the decrease of the strength of the magnetic field at the point of emission of the secondary electrons, so that the effect of the field on the electron trajectory becomes irrelevant.

CONCLUSION

The effect of regular arrays of permanent magnets embedded in a metallic matrix and also covered with a flat metallic non-magnetic surface (Al, stainless steel) on SEY was experimentally studied. It is shown that these rough magnetic surfaces produce a sharp decrease in SEY as compared to that of flat metallic surfaces. The main effect is due to the bending of the trajectories of secondary electrons by the magnetic field above the surface. When increasing the distance between the surface and the location of the magnets, the reduction of SEY is less and less effective. Since the strength of the magnets cannot be easily increased (NdFeB is already among the strongest) an extended fringe field can only be obtained with spacing of the magnets in the range of mm, as in the setups presented here, or possibly larger spacing. An optimization of the geometrical magnets arrangement is being performed to select the best configuration.

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