LOW-SECONDARY ELECTRON YIELD OF FERROMAGNETIC MATERIALS AND MAGNETIZED SURFACES

I.Montero[1], F.Caspers[2], L.Aguilera[1], L.Galán[3], D.Raboso[4] and E. Montesinos[2], [1]Instituto de Ciencia de Materiales de Madrid-CSIC, Spain. [2]CERN, Geneva, Switzerland. [3]Departamento de Física Aplicada. Universidad Autónoma de Madrid. Spain, [4]European Space Agency/ESTEC, Noordwijk, The Netherlands

Abstract

Low-secondary emission materials are required to avoid multipactor effects in large particle accelerators and communications. We are presenting direct measurements of the secondary electron emission yield (SEY) for several magnetic materials like permanent ferrite magnets and soft ferrites of different composition at energies of primary electrons from 5 to 1000 eV. In order to minimize the impact of the surface charging, the primary electron beam had a short pulse of length 270 ns. This paper discusses a method of developing a secondary-electron-suppressing, highly textured ferrite surface with low SEY, by depositing a layer of ferrite particles onto a metallic substrate. As a remarkable fact it has been found that particulated ferrites have maximum SEY values lower than unity up to 1000eV. In addition, the influence of external magnetic field on LHC main power coupler performance is also studied.

INTRODUCTION

In high intensity positron or proton storage rings, the positive beam potential can trap an electron cloud due to multipacting. There are a number of possible techniques to suppress the electron cloud including clearing electrodes, direct reduction of the secondary electron yield (SEY) by coatings or cleaning the surface or by increasing the surface roughness. The effect of surface roughness on the secondary electron emission from a sawtooth and isosceles triangular surface as well as a rectangular surface in a magnetic field under electron bombardment was investigated using a Monte-Carlo method [1]. In all cases, some of the secondary electrons emitted from the surface return to the surface within their first few gyrations, resulting in a low effective secondary electron yield. Increasing the surface roughness is another way to reduce the effective SEY. The effect of the surface roughness on the secondary emission in the field free case has been studied [2]. In addition a technique for mitigating multipactor by means of magnetic surface roughness was proposed [3]. In this work, SEY properties of certain ferromagnetic magnetic materials have been studied looking for low effective secondary emission materials to avoid multipactor. In addition, the influence of a static, but spatially alternating magnetic field in the LHC cavity RF power coupler to avoid multipactor effects, was studied.

EXPERIMENTAL PART

NiZn and MnZn powder soft ferrite and FeSr powder ferrite were deposited on adhesive conductive surfaces. SEY studies were carried out in an UHV chamber with two different electron guns inside, operating in the range 0-5000 eV, and also a cylindrical mirror energy analyzer (CMA) with coaxial electron gun normally operating at 3 keV. The sample can be rotated in front of the Auger electron spectrometer for the cleanliness examination, and in front of the programmable electron gun for the SEY measurements.

The measurement of SEY (σ) was carried by measuring the sample current to ground after biasing the sample (-30 eV) in two separate experiments depending on the sample conductivity. The measurements were made via computer-controlled data acquisition, the sample was connected to a precision electrometer (conductive samples), or an oscilloscope through a variable-gain high speed current amplifier (with variable gain from 10^2 to 10^8 H/L) for pulsed current measurements (dielectric samples). The electron beam was pulsed by counter-bias of the wehnelt. Only one current pulse was used to irradiate the sample to minimize the dose received by the sample. The pulse duration was adjusted to 270 ns. The primary beam current was measured by a Faraday cup attached to the system. The SEY (σ) is defined as $\sigma = (I_0 - I_s)/I_0$. The current I_0 is always negative, while I_s can be positive or negative depending on the primary energy and SEY values of the sample.

The LHC power coupler is a 400 MHz mobile RF power coupler for with very high power requirements used in superconducting cavities. The general layout of the latter has already been described in details [4], [5].

RESULTS AND DISCUSSION

Morphology and chemical composition

Figures 1-a and 1-b show the SEM (scanning electron microscope) images of NiZn and MnZn powder, respectively, after being coated with a 20 nm thick Au layer. Both NiZn and MnZn particles have a spherical shape, with an average particle diameter about 100 µm and 1 mm, respectively. In the case of the FeSr permanent ferrite magnet, the microparticles show a very irregular shape. The atomic composition of these samples is shown in Tab 1.

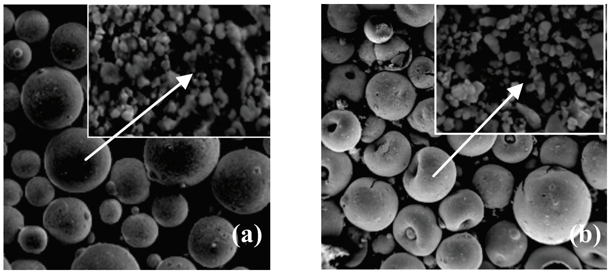


Figure 1: SEM images of NiZn (a) and MnZn powder (b). The inserts show the surface morphology of the particles.

Table 1: Composition in percent of the NiZn and MgZn soft ferrites and FeSr permanent ferrite magnet measured by EDX (EDX=energy dispersive X-ray absorption)

Element	*MnZn*	*NiZn*	*FeSr*
C	21.56	40.27	14.42
O	49.04	39.21	68.46
Mn	5.65		-
Fe	20.71	13.77	16.15
Ni	-	2.12	-
Sr	-	-	0.97
Zn	3.04	4.63	-

Secondary emission of magnetic surfaces

Figure 2 shows the SEY as a function of primary electron energy for NiZn/Cu powder and NiZn/Cu gold coated fixed on an adhesive carbon film substrate. The traces follow the trend of a typical SEY dependence on primary energy. We can observe that SEY of NiZn coated with Au decreases for primary energies lower than about 200 eV. However, the typically sharp-edged SEY traces of particulated materials appear smoothed. Figure 3 displays the SEY results of FeSr particulated ferrite as a function of the primary energy. In this case, we can observe values lower than 1 up to 1keV of primary energy. It is well known that the SEY of any optically black coating is much smaller than the yield of a smooth coherent layer. In this frame the very low values of the SEY of particulated ferrite can be related to the surface morphology. Due to the rough surface of these particulated samples the electron may be intercepted and absorbed by surrounding walls. In this case a possible influence of the magnetic field on SEY cannot be discriminated. However, also the magnetic field can contribute to the decrease of the SEY of these samples. In the case of the ferrite, the surface magnetic field can modify the secondary electron trajectory. In this frame, the SEY suppression will be achieved through the re-absorption of the secondary electrons emitted. On the contrary, the reduction of SEY in the case of soft magnetic materials can be related to their surface morphology.

In order to observe any influence of the magnetized surfaces on the SEY, the radius of gyration of the electron should be much lower than the sample size.

Figure 4 shows the effect of the magnetized surface (rough (a) and flat surface (b)) on the electron trajectories. The emitted electrons will return to the sample and can be absorbed. It is well known, that the radius of gyration of an electron, r, in magnetic field, B, is $r=m_0v/eB$, where m_0 is the mass of the electron, v is the transverse velocity, and e is the mass of the electron. Most secondary electrons have energies below 50 eV, but backscattered electron energies can be up to the primary energy. Under these conditions, B should be higher than 10^{-2}T.

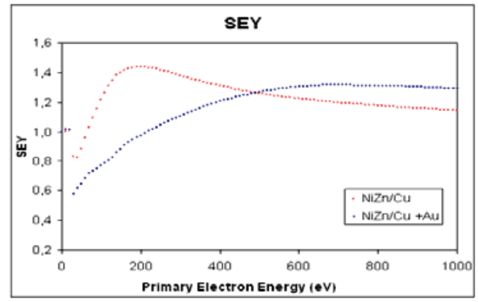


Figure 2: SEY of NiZn/Cu and NiZn/Cu coated with gold as a function of the primary electron energy.

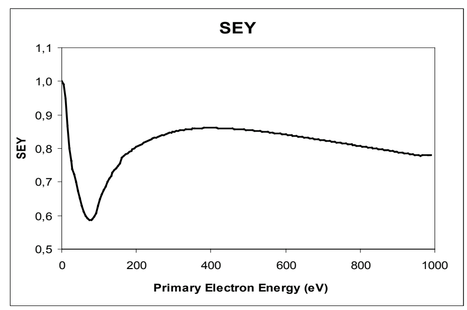
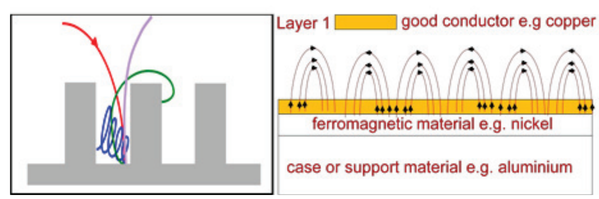


Figure 3: SEY of particulated FeSr ferrite as a function of the primary electron energy.



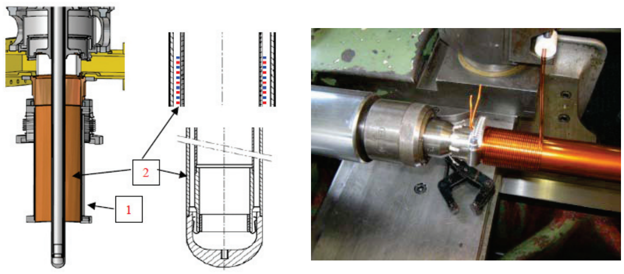
(a) (b)

Figure 4: Magnetized surface effect on the secondary electron trajectories: (a) Magnetized rough surface and (b) Magnetized flat surface.

Impact of added magneto-static fields

We present preliminary results about the influence of added magneto-static fields on LHC main power coupler performance. Two different, spatially alternating, magnetic field tests were carried out:

1. DC current through a double coil on the inner antenna cane: An RF power conditioning is necessary before increasing the power applied to a high power RF component. We propose to implement the "surface roughness magnetisation" on the LHC coupler antenna, which could replace the usual DC biasing. As shown in Figure 5 (a) and (b), we prepared a double coil (similar to a bifilar coil) on the inner cane of the air cooling antenna.



(a) (b)

Figure 5: (a) Part of the LHC Main Coupler design. The open ended 75 Ω coaxial line under vacuum is shown. 1 is the outer conductor double walled and 2 the inner conductor copper antenna. (b) Coiling of the inner cane of the air cooling antenna.

We then applied a magnetostatic field pattern in order to try to modify the multipactor conditions by "surface roughness magnetisation". Figure 6, red trace, shows the vacuum activity whether blue trace shows the RF power with 100 kW 75 µs 50 Hz. Once a stable multipacting state was achieved (A), we first applied the well known DC biasing level of 3.2 kV to the antenna to suppress multipacting and then checked the biasing effectiveness (B). One can see, with full power, vacuum activity disappears. We then switched off the DC biasing and tried several current levels (C) trough the double coil, 2 x 1A, 2 x 2A, 2 x 3A, all were without any effect to the vacuum outgasing, i.e. no effect to the multipacting.

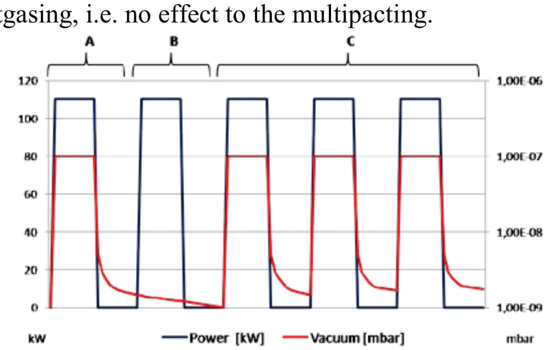


Figure 6: RF power (blue trace) and Vacuum activity (red trace) while applying several current levels along the coil.

2. Permanent magnets along the inner antenna cane:
A second proposal which has been tested was an arrangement of permanent magnets along the inner cane.

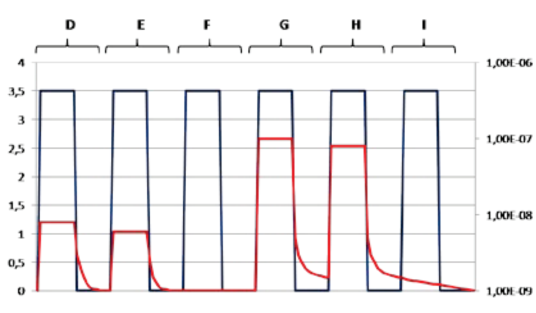


Figure 7: RF power (blue trace) and Vacuum activity (red trace) with NSNS pattern (DEF) and NNSS pattern with 2 mm spacers between each magnet (GHI).

The first stable multipacting level was this time found with 3.5 kW CW (continuous wave). As shown in Figure 7, we first checked the NSNS pattern (D, E). In this case, no effect for that level of multipacting was observed. We therefore changed the pattern to NNSS, with 2 mm spacers between each magnet. One can observe (G, H), with the same power level, vacuum activity is largely stronger, whether again, DC biasing (F, I) is effective (no out gassing while applying RF power).

CONCLUSIONS

Our results provide direct evidence of the reduction of SEY using micro-structured magnetized surfaces. Also a local magnetic field can modify the secondary electrons trajectory and let them easier be reabsorbed.

Tests on LHC power coupler (bifilar coil inside) indicate that with the maximum DC current of 3 Ampere, (limited by the couplers air cooling configuration), no multipacting related effect was seen with 100 kW / 75 µs / 50 Hz RF- pulses. However, in the case of a permanent magnet pattern along the same antenna, (NNSS with 2 mm spacers), an enhancement of the multipactor effect has been observed. These results indicate that the "magnetic surface roughness effect" due to macrocscopic permanent magnetic fields basically exists, but for the present case had led to a degradation. Intrinsic surface magnetization by microscopic particulated magnetized surfaces can reduce the multipactor effect as well as the SEY. We will launch a more general study program to understand and predict, systematically, the pattern and field strength required to mitigate multipacting via the mechanism describes above.

ACKNOWLEDGMENTS

This work was supported by Projects No. AYA2009-14736-C02-01 and 02 (space programme) of MICIIN of Spain. The authors would like to thank the CERN-BE department management for support as well as the CERN-BE-RF group mechanical workshop for the patient and diligent work in preparing the coils and magnetic inserts for the 400 MHz power coupler cane.

REFERENCES

[1] L. Wang, T.O. Raubenheimer, G. Stupakov, Nuclear Instruments and Methods in Physics Research A 571 (2007) 588–598.
[2] L. Galán, V. Nistor, I. Montero, L. Aguilera, D. Wolk, U. Wochner and D. Raboso. Proceedings of MULCOPIM' 2008. ESTEC-ESA, Noordwijk, The Netherlands (2008).
[3] F. Caspers, E.Montesinos, I.Montero, V. E. Boria, C. Ernst, D.Raboso, L. Galan, B.Gimeno, W.Bruns, C. Vicente. Proc. 23rd Particle Accelerator Conference, PAC (2009).
[4] H.-P. Kindermann, M. Stirbet, The variable power coupler for the LHC superconducting cavity, Proc. 9th Workshop on RF superconducting cavity, Santa Fe, New Mexico, USA, (1999).
[5] E. Montesinos, Status and RF power tests of the LHC variable main couplers for the LHC superconducting cavity, CERN, Genève, Switzerland, 2004.