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SEARCH FOR NEW E-CLOUD MITIGATOR MATERIALS FOR HIGH INTENSITY PARTICLE ACCELERATORS*

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Abstract

Electron cloud has a ubiquitous effect in positively charged particle accelerators and has been observed to induce unwanted detrimental effects on beam quality, stability, vacuum etc. A great effort has been recently devoted to the search of new material morphology and/or coatings which can intrinsically mitigate beam instabilities deriving from electron cloud effects. In this context, we present some characterization of commercially available Cu foams and their qualification mainly in terms of secondary electron yield (SEY), along with the vacuum behavior, their impact on the impedance budget, photo-desorption yield, etc. More experimental efforts are required to finally qualify foams as a mature technology to be integrated into accelerator systems. Our preliminary results suggest potentially interesting use in the accelerator technology.

INTRODUCTION

Low energy electrons are always present in accelerators either produced by Synchrotron Radiation (SR) or by ionization of residual gas, etc. Such particles can be accelerated by the electric field of the bunch in the direction perpendicular to the beam direction, creating secondary electrons at the accelerator walls. Under certain conditions, a resonance phenomenon called multipacting can be established, giving raise to the formation of a so called e^- cloud that may cause detrimental effects on the accelerated beam quality and stability [1]. Clearly, one of the most important parameters defining the significance of e^- cloud effects (ECE) on the beam quality is the number of electrons produced by the accelerator walls when hit by other electrons. This quantity is the secondary electron yield (SEY) [2], and is commonly denoted by δ. Its value, its time stability and its dependence on primary electron dose and energy are indeed a crucial issue and an essential ingredient to correctly predict and mitigate ECE. In this context and also in absence of multipacting, a high Photo Yield (PY), which is the number of photoelectrons produced by SR can cause single beam instabilities [3] affecting beam quality. Hence, also photo yield of accelerator wall materials should be as limited as possible, being also one of the main contributors for unwanted photo induced gas desorption. It has been shown [1] that all modifications that decrease SEY do actually also reduce PY. This can be ascribed to the partial common process of secondary electron production even if exited by different means (e^- in one case or photons in the other), so that a good SEY mitigator will normally give a reduced PY. This is important, since even in absence of multipacting, geometrical modifications can be necessary to reduce PY or material photo induced desorption, and may be needed non only in machines potentially suffering from ECE and/or from single beam instabilities, but also in very intense SR facilities, where an intense photon (and/or e^-) induced desorption can be an issue.

Recently, a number of strategies to produce intrinsically low SEY surfaces have been studied and applied [1]. One such proposal is to reduce SEY by macroscopic geometrical modification of the accelerators walls, machining triangular or rectangular grooves on the otherwise flat accelerator wall surface. In a series of pioneering work on this topic, [4–7] different types of macroscopically machined grooves have been theoretically analyzed, produced and successfully measured. In line with this research, recent studies have considered the creation of geometrical modification at a micro or sub micron scale by chemical etching [8–10]. Such promising research lines still need substantial effort not only to reproducibly manufacture such additional roughness but to carefully study its effect on impedance, conductivity and all other stringent requirements an accelerator wall has to fulfill.

Here we propose and study a completely different material family: open cell metal foams (OCMF), and in particular Cu foams. Such materials, increasingly used in aerospace and automotive technology, are nowadays easily available and produced by several technologies [11]. Some of them also ensure foam metallic purity, absence of contaminants and of nearly closed porous (virtual leaks) which will be not acceptable for Ultra High Vacuum (UHV) use [11]. The typical foam is the highly connected trabecular structure of solid metal filaments, which encircle the pores. The structure (see, as an example, the photograph shown in the inset of fig. 1) is highly gas-permeable, and has remarkable mechanical, electrical and thermal properties. The solid metal is only a small fraction of the total volume (typically, some 10% or less). Their key morphological parameters are given in terms of: their pore size (typical diameter between 10^{-3} and 10^{-6} m) and

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their porosity (typical volume fraction of pores is 0.8-0.99). Interestingly, it is possible to model such structures to simulate their behavior using, as building blocks, equal-sized (and possibly unequal shaped) pores by using the Weaire-Phelan (WP) space-filling honeycombs [12].

EXPERIMENTAL

Cu foam samples were cut in different sizes from a 6 mm thick slabs of different porosity (4, 8, 16 pores/cm) supplied from Goodfellow Inc. The experiments shown here were performed by the Material Science INFN-LNF laboratory of Frascati (Roma). The experimental apparata are described in details elsewhere together with the detailed experimental procedures used to measure SEY [1, 13–15]. SEY ($\delta(E)$), is defined as the ratio of the number of electrons leaving the sample surface ($I_{out}(E)$) to the number of incident electrons ($I_p(E)$) per unit area. $I_{out}(E)$ is the number of electrons emitted from the surface but also the balance between the current impinging on the sample, $I_p(E)$ minus the current flowing from the sample $I_s(E)$. So that:

$$\delta(E) = I_{out}(E)/I_p(E) = 1 - I_s(E)/I_p(E) \quad (1)$$

Other experimental setups available at CERN and within the collaboration have and will be used to validate and complete our data and to obtain the complementary information required for a safe use in UHV and in accelerator technology.

RESULTS

SEY results

Experimentally, dealing with such non uniform and nearly transparent material is intrinsically quite difficult and several aspects, new to those materials, have to be taken into account in order to produce significant SEY data. The first obvious difficulty in measuring SEY on foams is due to the fact that the e^- beam used in SEY experiments is extremely small with respect to the macroscopic size and density of the pores in the foam, and of the shape and orientation of the Cu mesh forming them. To tackle this difficulty we collected a series of repeated SEY spectra moving the e^- beam in small steps in a 2x3 mm^2 area within the sample (as shown in the inset of fig. 1), so to be able to mediate on the expected surface inhomogeneity collecting many spectra from nearly overlapping irradiation areas. The results obtained in this way are shown in fig 1, were we plot all the SEY spectra collected on a Cu foam of 8 pores/cm. By taking the mean value of this and of similar dataset we are then able to measure a mean SEY and from the spread of SEY values to estimate the error bar relative to our data. The second problem, which is intrinsic to the foam and to their high transparency is that the results tend to depend on sample size and on the way such samples are mounted on the sample holder. Here we show data from embedded Cu foam with different porosity

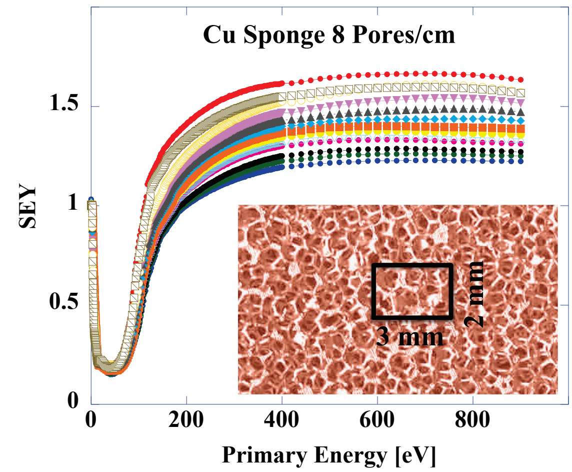

Figure 1: SEY spectra obtained by moving the e^- beam in small steps in a 2 x 3 mm^2 area within a 8 pores/cm Cu foam mounted in a 6 x 6 x 6 mm^3 Cu cage, and their mean value. The inset shows the picture of the 8 pores/cm Cu foam, and the geometrical region (black rectangle) where the SEY curves have been measured.

in a 6 x 6 x 6 mm^3 Cu cage. (see inset in fig. 2). The results shown are than valid for this geometry only, which was chosen being representative of the SEY of such Cu foams when lying on a copper plate and with no free sides but their surfaces. As mentioned, results for free standing foams or from foams with other sides open to vacuum than their surface, are expected (and indeed measured) to be different and in some cases even much lower rather than here shown. Average SEY from different porosity foams embedded in a 6 x 6 x 6 mm^3 Cu cage are reported in fig. 2 together with the error bars of about $\pm 20\%$ estimated from the analysis described in fig. 1. On a fully embedded foam we observe: i) a significant overall decrease of the SEY in comparison with the SEY of the Cu "as received" surface representative of the LHC beam (screen also plotted in fig. 2 and taken from the literature [1]; ii) a smaller SEY for higher porous density foam, with δ_{max} going from 2 (for LHC Cu) to 1.5 - 1.4 (for the 4 and 8 pores/cm foams) and less than 1 (for the 16 pores/cm foam). To stress here the importance of the geometry in which the measurements have been taken: if the foam were freestanding, one would expect that the lower density pores foams, having bigger holes and less material interacting with the beam, would show a lower SEY than high density pores. The presence of the cage in our experiment, does result in the opposite trend since the more transparent is the foam the more electrons will reach the Cu holder, that has a δ_{max} = 2 and the higher will be the resulting SEY. Another interesting aspect observed in fig. 2 is the gradual increase of a region of very low SEY at low e^- impinging energy, showing that for supported foams, the low energy e^- tend to be absorbed the more pores are present. The real SEY of a foam in a real environment will depend on

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its actual geometry but can be certainly expected to be less than the one measured in this work, which is representative of a fully embedded foam in a "as received" Cu cage. Our data shows the importance of the high transparency of foam materials to an e^- beam and that more precise and geometry dependent experiments must be performed, if the accurate SEY value of the foam is needed. We anyway expect (and observe) a significant reduction of SEY and PY when using foam materials as e^- cloud mitigator.

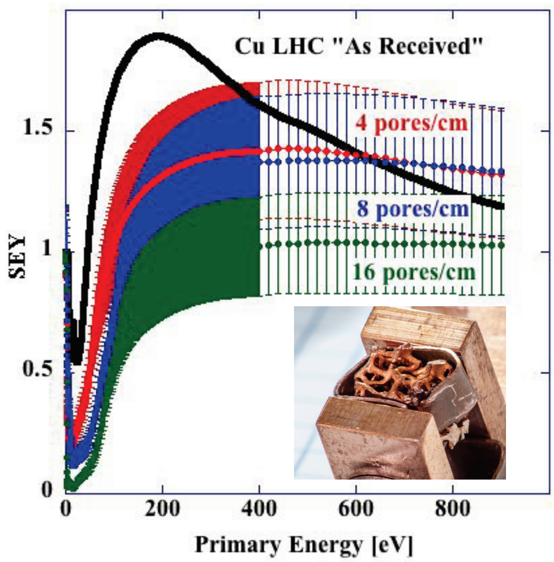

Figure 2: Mean SEY spectra obtained, as described in the text, from a 4, 8, 16 pores/cm Cu foam. The black curve shows, by comparison, the SEY measured on a flat LHC Cu. The inset shows the picture a Cu foam mounted in the 6 x 6 x 6 mm^3 Cu cage.

UHV, Impedance and Other Properties

As said, a series of other measurements and controls must be performed in order to better qualify the use of foams as e^- cloud mitigators, specially in very extreme conditions. Preliminary analysis especially confirms a vacuum degassing for Cu foams lower than 5 10^{-14} mbar l/s cm^2, which was the limiting value in our measuring system, while the study of conductance as a function of foam porosity is still under way. Impedance issue is than essential in the use of foams in highly demanding accelerator environment. If experiments on this aspect are only in program, the high conductivity of Cu foams, their intrinsic random distribution of pores and the first simulation results recently obtained [16] are indeed very promising.

CONCLUSION

The preliminary set of data here presented on SEY from Cu sponge materials embedded in a Cu cage and then, representative of a foam lying on a copper plate and with no free sides but its surface, show a significant SEY reduction and interesting peculiarities of such modified metallic structures. Experimental issues, which are intrinsic to the high inhomogeneous and partly transparent foam structure, have been identified. More data, with different experimental geometries and measuring setups, are then required to better qualify the materials in terms of their SEY and all other properties of interest. Our preliminary results suggests that, when compatible with geometrical constrains, Cu foams can be utilized when low desorption yields are required and as e^- cloud moderator in future particle accelerators.

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