MULTIPACTOR SUPPRESSION BY LASER ABLATION SURFACE ENGINEERING FOR SPACE APPLICATIONS

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Abstract

Developing a surface with low Secondary Electron Yield (SEY) is one of the main ways of mitigating electron cloud and beam-induced electron multipacting in high-energy charged particle accelerators and space-borne RF equipment for communication purposes. In this study we report on the secondary electron yield (SEY) measured from silver coated aluminium alloy as-received and after laser ablation surface engineering (LASE). Analysis shows the SEY can be reduced by 43% using LASE. EDX and SEM analysis shows it is possible to reduce the SEY whilst maintaining the original surface composition.

INTRODUCTION

Multipactor discharges in microwave components constitute a severe breakdown problem in many modern microwave systems involving high powers; a typical example being space-borne RF equipment for communication purposes. The discharge is caused by free electrons oscillating in vacuum between surfaces in the device, knocking out secondary electrons when hitting the surfaces, and creating an avalanche-like growth of the electron density in the device, provided certain threshold conditions are fulfilled. The concomitant breakdown discharge tends to generate noise, change the device impedance, heat the device walls and may even permanently damage the hardware. Thus, an important part of the design and development of RF components is to establish the critical RF power at which the breakdown process is initiated. This step has become increasingly important in view of the development of modern space-borne microwave technologies towards higher data rates, which makes increasing RF power levels necessary in order to maintain a sufficient signal-to-noise ratio. The development of electron multipactor discharges is ultimately dependent on electron growth and loss rates. Breakdown threshold is defined as the voltage at which electron population growth exceeds losses, leading to a runaway electron population. The electron loss rate is, in part, controlled by electron emission, which affects released electron trajectories, as well as multipactor gap geometry, which can limit trajectories that can contribute to multipactor growth. The loss rate needs to balance electron growth, this is controlled by the resonance established by RF voltage and spacing, as secondary electron yield (SEY) of the material [1-4]. The objective of this study is to mitigate the multipactor discharge by reducing the SEY of the surface by employing laser ablation surface engineering (LASE) [5-8]. It has been shown in recent years that the SEY of surfaces can be controlled by LASE. The laser surface structuring in the nanosecond pulse range is achieved by thermal ablation where a quantum of energy interacts with the irradiated surface, which is then removed by vaporization. This creates micro-size grooves covered with nano-size coral shaped particles at the surface. The higher the aspect ratio of the groove, the higher the level of reduction in SEY due to multiple scattering of the emitted electrons within the groove [5,6]. The reduction is most efficient for low energy emitted electrons. The thickness of the nano-size particle layer also plays an important role in further reducing SEY, helping to minimize the increase of surface resistance as well as to minimise the dependence of SEY on incident angle. The substrate in this study is a silver-coated aluminium alloy plate. The thickness of the silver layer was estimated to be 8 μm. Due to lack of availability of required SEY values for suppression of multipacting, the objective is not to determine the lowest achievable SEY but rather to achieve the minimum SEY value while confining the depth of engineered surface to within the thickness of the high conductive silver layer.

LASE Set Up and Parameters

The laser used for this study has the following properties, 1063 nm wavelength, 0.5 W average power, with a pulse duration of 10 ns at repetition rate of 10 kHz (50 μJ per pulse). This results in a fluence of 64 J/cm^2 for a spot diameter of 10 μm at 1/e^2 intensity (where e is the maximum intensity. The laser beam had a Gaussian intensity profile ($M^2 < 1.3$). It was focused onto the silver-coated aluminium (12 mm × 12 mm) surface using a flat-field scanning lens system equipped with a tele-centric F-theta lens. The laser beam was then raster scanned over the surface of the samples at 100 mm/s in a line hatched (LH) pattern using a computer-controlled scanner system.

Five samples were irradiated with the above process parameters for two different LH and pass numbers as shown in Table 1.

SEY (or δ) was measured using an ELG-2 (0-2 keV) Kimball Physics Inc. electron gun. The measurements were performed using the configuration shown in the Fig. 1

where the I_p (1-40 nA) and I_s are the currents registered on the Faraday cup and the sample (biased to -48 eV) respectively. The surface topography and composition was examined with a high-resolution Hitachi Regulus 8230 scanning electron microscope (SEM) and a Bruker FlatQUAD energy dispersive x-ray (EDX) respectively.

Table 1: Parameters Used for LASE Samples and the Reduction of SEY in Comparison to as-Received Sample

Sample	Line Hatch distance (μm)	Number of Passes	Decrease of δ(max) %
18-1	18	1	23
15-1	15	1	35
15-2	15	2	39
15-4	15	4	40
10-1	10	1	43

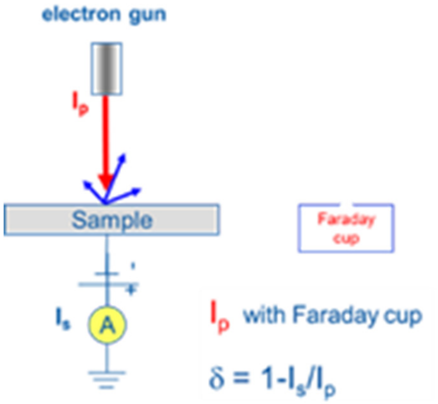

Figure 1: SEY measurement setup.

RESULTS

Figure 2 represents SEY (δ) for the as-received and laser treated samples. For the as received, the yield rises from $\delta = 0.55$ at the lowest measured primary electron energy $E_{PE} = 20$ eV, reaches a maximum $\delta_m = 2.3$ at primary electron energy $E_{PE} = 450$ eV, and then falls monotonically at higher energies.

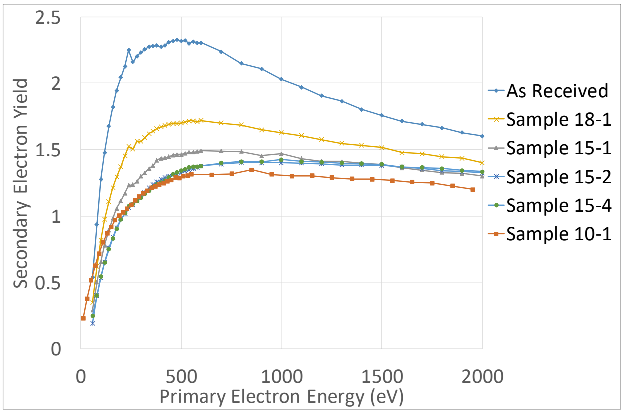

Figure 2: Secondary electron yield (δ) versus primary electron enegy E_{PE} (eV) for as received Ag coated Al sample and 5 laser treated samples.

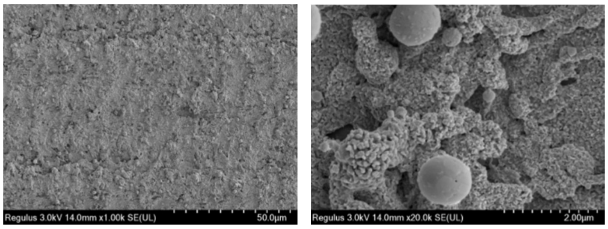

Figure 3: SEM planar micrograph of sample 18-1 at various magnifications a) low mag (1K) and c) high mag (20K).

Figure 3 represents the low (1K), high (20K) magnification respectively of the silver coating after being irradiated with the laser parameters set above with an 18 μm pitch. The laser was scanned only once. No obvious grooves can be observed.

The characteristic peak gradually flattens around 300 eV after the initial increase for laser irradiated samples and δ decreases with either decrease in the pitch distance or increase in the number scan for each pitch distance. This is due to the increase of the amount of overlap of each scan with its predecessor.

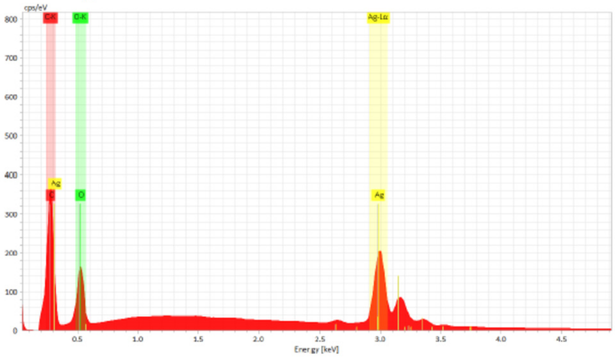

Figure 4: EDX analysis of sample 18-1.

The melting and solidification of the silver layer surface during laser irradiation has created a porous coral surface structure with micron and sub-micron spheres randomly dotted on the surface. The EDX analysis in Fig. 4 shows that the integrity of the silver coating remains intact. This is evident from the chemical analysis which depicts only silver, carbon and oxygen.

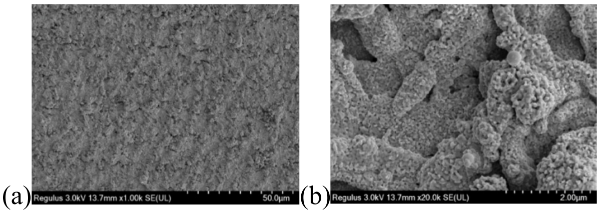

Figure 5: SEM planar micrograph of sample 15-1 at (a) low mag (1K) and (b) high mag (20K).

Figure 5(a-b) represents the low (1K) and high (20K) magnification respectively of the silver coating after being irradiated with the laser parameters set above with a 15 μm pitch. The laser was scanned only once. As in the case of sample 18-1 no distinct grooves can be observed as shown in Fig. 5(a). The melting and solidification of the silver layer surface during laser irradiation has created a porous coral surface structure with microns and sub-micron spheres randomly dotted on the surface. However due to the shorter hatch distance, some overlapping of the area affected with each pass of the scanned beam the density of the porous structure at the surface is increased.

The EDX analysis shows that the integrity of the silver coating remains intact, similar to the one observed for sample 18-1. This was evident from the chemical analysis which depicted only silver, carbon and oxygen.

Figure 6 (a-b) represents high (20K) magnification of samples 15-2 and 15-4, respectively. In the case where the laser was scanned twice still no distinct grooves can be observed as shown in Fig. 7. In comparison to sample 15-1, the second pass over the coral structured surface, which was created during the first pass, results in a similar structure but with more refined sphere size.

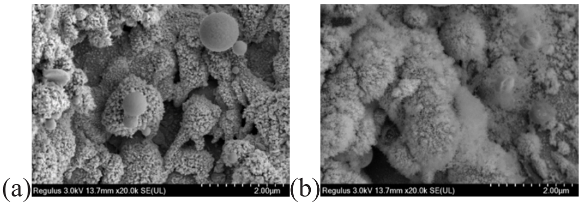

Figure 6: High mag (20K) SEM planar micrograph of (a) sample 15-2 and (b) sample 15-4.

After four passes distinct grooves can be observed as shown in Fig. 6(b). The EDX analysis show that after the second pass the affected depth is larger than the depth of silver coating layer. Repeated passes over the coral structured surface which was created during the previous scans results in a different surface structure. The nano pores are replaced by nano-whiskers covering the entire regular (spheres) and irregular randomly orientated structures.

The EDX analysis presented in Fig. 7 shows that after the fourth pass there are only traces of silver remaining at the surface. This is evident from the chemical analysis which depicts Cu as the most dominant apart from carbon and oxygen which are always present. There are two new elements, Al and Mg, believed to be from the main substrate.

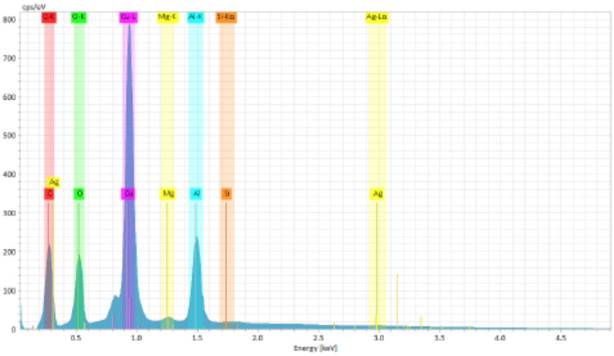

Figure 7: EDX analysis of sample 15-4.

DISCUSSION

The above study in its limited scope shows that LASE can be an effective tool to reduce SEY without destroying the integrity of the silver coating. The effectiveness of reducing the SEY by LASE is higher for lower energies (20 to 600 eV). The induced nano-particle layer, as well as the formation of grooves, produce a very efficient surface to trap the low energy electrons by multiple scattering. The well-pronounced SEY peak observed for the as-received (untreated) surface is replaced by a gradually flattened peak around 300 to 600 eV.

The target level of SEY for mitigation of the e-cloud in particle accelerators has been set to be below 1, however a similar study for mitigating multipacting in a wave guide has not been carried out. Hence the focus of this preliminary study was to achieve the lowest SEY while confining the altered layer within the silver coating. This will minimise the increase in surface resistance after using the LASE process.

In this study, two parameters were changed while all other processing parameters kept constant. These were pitch distance and number of passes for particular pitch distance. The pitch distance above the beam size will separate the treated area and the larger the distance the lower the total affected area. If the pitch distance is equal or smaller than the beam size, partial overlap will occur and this will promote a thicker engineered layer or deeper groove, both of which will increase the scattering probability of low energy secondary electron and trap them within the layer. A similar effect can be achieved by repeated scanning over the altered layer. Each pass will increase the depth of the grooves. The former was found to be more effective for this study.

Further work should be carried out either on a real waveguide where either the exact area that multipacting is generated can be treated with LASE, or, further small size samples could be prepared so the surface resistance for each of the process parameters can be determined using a high frequency cavity [9,10].

CONCLUSION

Laser ablation surface engineering (LASE) is an effective tool to control the secondary electron yield (SEY) of a silver coated aluminium alloy wave guide. A reduction of 43 percent was achieved using hatch distance equal to the effective beam diameter size. A repetitive scan results in deep grooves and can remove a large volume of material. The laser-engineered surface removes the dependence of SEY on the surface chemical state. To achieve an SEY value lower than one, a thicker layer of coating should be employed. Since in the wave-guide the source of multipacting is specific to a certain area, LASE will be the ideal technique for mitigating such phenomena.

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