

LOW SECONDARY ELECTRON YIELD OF LASER TREATED SURFACES OF COPPER, ALUMINIUM AND STAINLESS STEEL

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Abstract

Reduction of SEY was achieved by surface engineering through laser ablation with a laser operating at $\lambda = 355$ nm. It was shown that the SEY can be reduced to near or below 1 on copper, aluminium and 316LN stainless steel. The laser treated surfaces show an increased surface resistance, with a wide variation in resistance found depending on the exact treatment details. However, a treated copper surface with similar surface resistance to aluminium was produced.

INTRODUCTION

The reduction of secondary electron yield (SEY) is a very effective way of mitigation of electron cloud (e-cloud) and electron multipacting in accelerator beam chambers and RF wave guides. Our recent discovery demonstrated that SEY can be efficiently reduced by surface engineering through laser ablation [1,2]. The major limitation of our original treatment was high surface resistance, therefore the further work aimed at producing low SEY surfaces with a smaller increase in surface resistance (R_s).

SAMPLE PREPARATION

The samples were made of oxygen free copper (Cu), aluminium (Al) and 316LN stainless steel (SS) plates, cleaned in acetone and isopropyl alcohol in an ultrasonic bath followed by a rinse with de-ionised water. The samples were treated using a Coherent Aviva NX laser operating at $\lambda = 355$ nm, $f = 40$ kHz, pulse duration of 75 ns and 3W average power. The $1/e^2$ diameter of the focused laser spot on a sample was set at 15 μm . The laser was rastered in one direction and the hatch distance was 10 μm . The applied parameters were the same for all samples except the laser scanning speed, which is shown in Table 1.

The 15 mm \times 15 mm samples were used for SEY measurements. However, these samples are too small for the surface resistance measurements, and so the 100 mm \times 100 mm large samples Cu-1L, Cu-2L and Cu-3L were produced with exactly the same laser treatment parameters as the samples Cu-1, Cu-2 and Cu-3, respectively.

Table 1: List of Samples

Sample	Scan speed
Cu-1, Cu-1L	180 mm/s
Cu-2, Cu-2L	120 mm/s
Cu-3, Cu-3L	90 mm/s
Cu-4	60 mm/s
Cu-5	30 mm/s
Al-1	30 mm/s
Al-2	60 mm/s
SS	60 mm/s

METHOD AND SET-UPS

SEY Measurements

The SEY measurements were performed after installing and overnight pumping in the SEY study facility described in Ref. [1], where the primary electrons were provided by a Kimble electron gun (ELG-2/EGPS-2). The FWHM electron beam size was set to be less than 2 mm diameter with a current of a 10 nA. The primary energy was varied between 60 and 1000 eV. The sample was biased to -18 V with respect to the Faraday cup which was kept at ground potential. The total dose was limited to 10^{-6} C $\cdot\text{mm}^{-2}$ to minimise the effect of beam induced scrubbing during the data collection.

Surface Resistance Measurements

Two types of cavities were used to measure the surface resistance of the samples; a 7.8 GHz circular choked pill-box cavity detailed in [3] was used for anisotropic measurements, while a half-pill-box cavity provides a strong directional preference for the current paths on the sample surface.

Cavity 1 for non-directional measurements. The 3-choke cavity operates in a TM_{010} -like mode. It therefore has a circular H-field distribution on the sample plate, which induces radial currents, as can be seen in Fig. 1.

Cavity 2 for directional measurements. A half-pillbox cavity was used to take some measurements of the surface resistance with a well-defined current direction. The sample piece is placed on the symmetry plane parallel to the cavity axis. This causes the fundamental mode

of the cavity to be the TM_{110} mode, which has a strong transverse H-field (often used in deflecting or crab cavities). In our case, it also causes a strong electric current to flow in the axial direction on the surface of the sample plate (see Fig. 2).

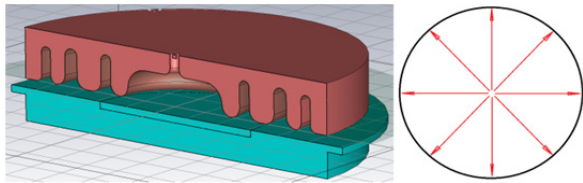


Figure 1: The 3-choke cavity and the current path on the sample plate.

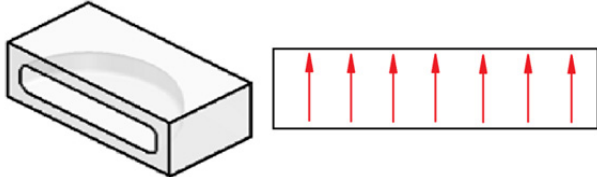


Figure 2: A half-pillbox cavity and the current path on the sample plate.

RESULTS

Copper Samples

Figure 3 shows low and high resolution planar scanning electron micrographs (SEM) of treated Cu surfaces as described in Table 1. The laser treatment resulted in a topography that consists of a microstructure of grooves superimposed with submicron and nanometre sized structures. In comparison to the surfaces reported in Ref. [1], where the grooves were as deep as 100-200 μm , the surfaces reported here have much shallower grooves ranging from 5 to 60 μm .

The results of SEY measurement of Cu as a function of primary electron energy, E_p , are shown in Fig. 4. Sample Cu-3, treated at 90 mm/s, has the lowest or equal lowest SEY over the measured range of primary electron energy.

A lower scanning speed of 60 mm/s (sample Cu-4) results in an increase of SEY at low primary electron energy. Conversely, a higher scanning speed of 120 mm/s (sample Cu-2) results in the increase of SEY at high primary electron energy. The further reduction of scanning speed to 30 mm/s (sample Cu-5) and increase to 180 mm/s (sample Cu-1) both result in further increases in SEY over the entire measured range of primary electron energy.

The results of the surface resistance measurements are shown in Table 2. The samples Cu-1L, Cu-2L and Cu-3L were first measured using the contactless Cavity 1 to give the resistance averaged over all directions relative to the laser patterning. Then the samples Cu-1L and Cu-3L were measured using Cavity 2, which provides directional surface resistance measurements with 0° referring to when the current induced by the cavity is flowing along the laser scan path. Since Cavity 2 operates at 3.9 GHz, the R_s was normalised to 7.8 GHz to make it easy to compare results from both cavities. For comparison, the results for untreated Cu, Al and SS are also shown in Table 2.

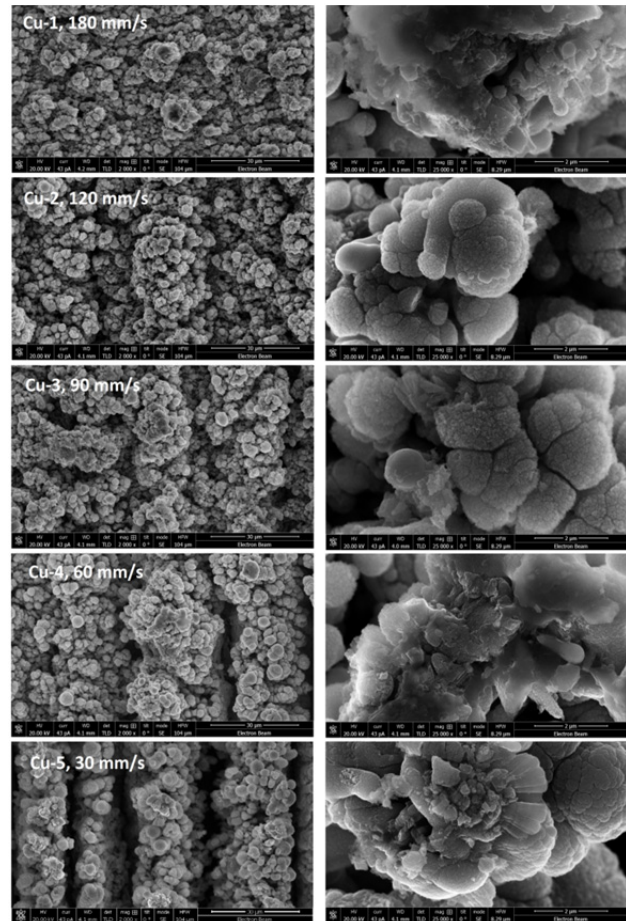


Figure 3: Low (on the left) and high (on the right) resolution planar SEM micrographs of 1 mm thick Cu samples.

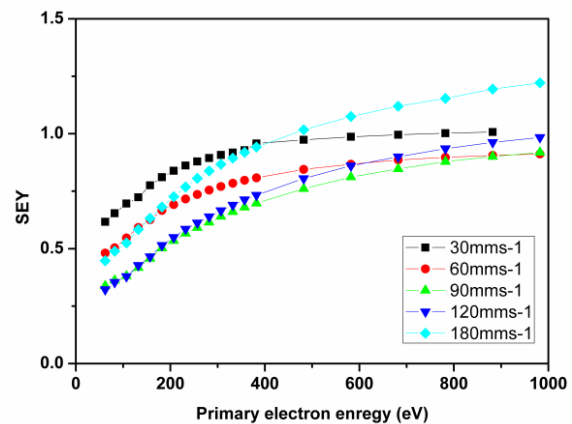


Figure 4: SEY measurement of Cu samples as a function of primary electron energy.

The results show that the surface resistance reduces with laser scan speed, which is directly associated with the depth of the grooves. The shallowest grooves on Sample Cu-1 produced R_s comparable to untreated aluminium, while all other tested samples have R_s lower than untreated stainless steel. Another result is that there is no strong directionality in the surface resistance of the samples Cu-1L and Cu-3L; the difference varies within 15-25%.

Table 2: Surface Resistance at 7.8 GHz

Sample	Cavity	Measurement	R_s [Ω]
Cu-1L	1	average	7.8×10^{-2}
	2	0°	0.11
	2	45°	0.11
	2	90°	9.5×10^{-2}
Cu-2L	1	average	0.13
Cu-3L	1	average	0.14
	2	0°	0.15
	2	45°	0.19
	2	90°	0.2
Cu untreated	1	average	3.3×10^{-2}
Al untreated	1	average	7.2×10^{-2}
SS untreated	1	average	0.17

Aluminium Samples

The results of SEY measurement of Al as a function of primary electron energy are shown in Fig. 5. The higher scan speed used for sample Al-2 gave the lowest overall SEY with $\delta \approx 1$ in all the primary electron energy range. The sample Al-1 has $\delta < 1$ at $E_p \leq 200$ eV, but $\delta > 1$ at $E_p > 200$ eV reaching $\delta = 1.65$ at $E_p = 1$ keV.

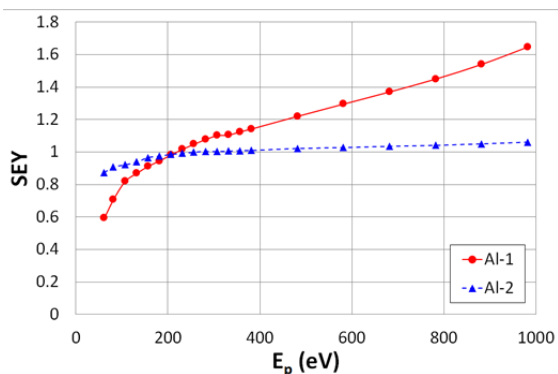


Figure 5: SEY measurement of Al samples as a function of primary electron energy.

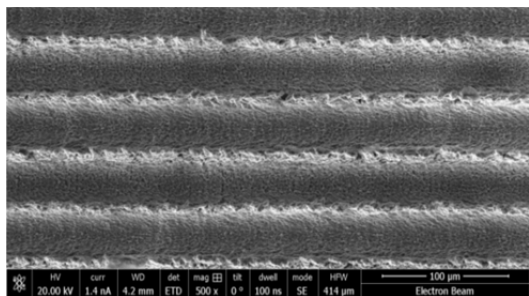


Figure 6: Low resolution planar SEM micrographs of SS sample.

Stainless Steel Samples

Figure 6 shows the planar SEM of, and Figure 7 the SEY measurement of, the treated 316LN stainless steel (SS) sample surface. This sample has $\delta < 1$ at $E_p < 250$ eV and $\delta \leq 1.1$ at $E_p \geq 250$ eV.

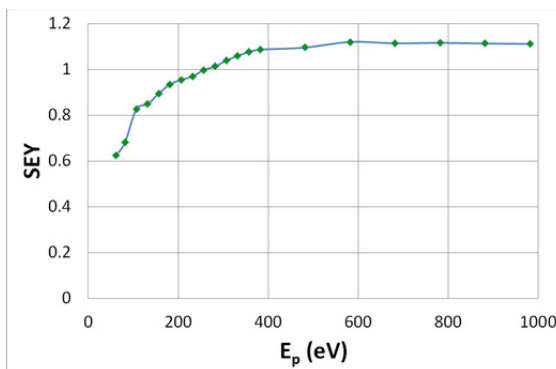


Figure 7: SEY measurement of SS sample as a function of primary electron energy.

DISCUSSION

The results of this and our previous study [1] show that laser ablation surface engineering has a large window of laser treatment parameters to produce different types of surface topography which reduces SEY below 1. For all three materials studied (Cu, Al and SS), laser ablation can produce surface topographies which can reduce the SEY to below or near 1. In all cases, the processing applied resulted in a grooved topography, on which is superimposed submicron and nanometre sized structures. The depth of the grooves was engineered by varying the laser scan speed which controlled the number of pulses per area. Higher scan speeds will result in a lower number of pulses and consequently reduce the groove depth. However, the submicron and nanometre sized structures remained similar in all samples. Both grooves and submicron and nanometre sized structures have an impact on SEY reduction which provides an optimisation between SEY and surface resistance. In the case where the lowest R_s was achieved (sample Cu-1) the SEY shows the highest value, but with $\delta < 1$ for energies up to $E_p = 500$ eV which is the critical energy range for e-cloud generation in modern particle accelerators and $\delta < 1.1$ for higher energies.

CONCLUSION

Surfaces with $\delta < 1$ on copper, aluminium and stainless steel can be produced through controlled laser ablation with a laser operating at $\lambda = 355$ nm. It was demonstrated that $\delta < 1$ can be achieved with tolerable level of surface resistance.

ACKNOWLEDGEMENT

This work was conducted under the aegis of the Science & Technology Facility Council (STFC). The authors would also like to acknowledge the support provided by EuroCirCol collaboration (European Union’s H2020 Framework Programme under grant agreement no. 654305).

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