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LASE SURFACES FOR MITIGATION OF ELECTRON CLOUD IN ACCELERATORS

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Abstract

Vacuum chamber surface characteristics such as the photon and secondary electron yields (PEY and SEY) are critical parameters in the formation of an electron cloud, a serious problem that limits the performance of proton and positron accelerators. A few years ago it was discovered by the Vacuum Solutions Group at Daresbury laboratory that Laser Ablation Surface Engineering (LASE) could provide surfaces with SEY<1 [1,2]. The LASE surfaces are considered as a baseline solution for electron cloud mitigation in the Future Circular Collider (FCC). However, these surfaces are undergoing further optimisation for the FCC application. While keeping SEY<1 the surfaces should meet the following criteria: Low outgassing, Low particulate generation and low surface resistance. In this paper we will report a number of new surfaces created using the LASE technique with different laser parameters (wavelength, scan speed, pitch, repetition rate, power, and pulse length) and their effect on the SEY, surface resistance and vacuum properties, etc.

INTRODUCTION

Secondary electron emission is a limiting factor in many particle accelerators because it plays a significant role in beam induced electron multipacting and the build-up of an Electron Cloud (EC). Synchrotron radiation from the particle beam generates primary electrons as photoelectrons from the wall of the beam pipe or through ionisation of the residual gas by beam-gas interactions. The charged particle beam then accelerates the primary electrons whose energy remains outside of the effective capture and transport regime of the accelerator, ultimately resulting with these primary electrons colliding with the wall of the chamber producing secondary electrons, which in turn can be accelerated by the following bunch. This leads to electron multipacting and the formation of an EC [3].

The build-up of the EC in a particle accelerator causes: increase in the emittance, beam instabilities, pressure rises and additional load on the cryogenic system [4]. Multipacting can also absorb RF power in RF cavities and lead to damaging of the surface in both cavities and waveguides. The electrons can also desorb gas from the walls increasing the pressure in the beam pipe or RF cavities [5].

Secondary Electron Yield (SEY) is defined as the ratio of electrons leaving the sample to the number of electrons incident on the sample. The SEY as a function of primary electron energy can be described with its maximum value δ_{max} and corresponding primary electron energy, which lies in the range between 200 and 400 eV for commonly used vacuum chamber materials such as copper, aluminium and stainless steel. The most efficient mitigation parameter would be to ensure the SEY is below 1 in the whole range of primary electron energies [6].

The SEY of a material depends upon the atomic number of material, surface chemistry, the surface topology and to a lesser effect on the work function of the material. By changing the surface topology, LASE surfaces have already been shown to have SEY<1. In this paper we report the results of using an Nd:YAG laser to generate surfaces with SEY<1.

EXPERIMENTAL

LASE Surface Preparation

The copper substrates used in these measurements are commercially available oxygen free copper with dimensions 20 x 15 mm and a thickness of 1 mm. The samples were degreased prior to laser exposure and the laser parameters used are shown in Table 1. The samples were irradiated in air at room temperature with an exhaust system pumping air away from the sample. The laser was operated at a wavelength of 1064 nm and the spacing between each line of rastering by the laser was 10 µm.

Table 1: Sample Parameters

Name	Power (W)	Pulse (ns)	Repetition (kHz)	Speed (mm/s)
A	1000	19	290	80
B	1000	19	290	160
C	1000	19	290	320
D	1000	63	50	80
E	500	35	50	80

SEY Measurement Procedure and Particle Counts

Particle counts were undertaken at atmospheric pressure by blowing filtered nitrogen at a glancing incidence towards the sample at 1.5 then at 5 bar of pressure for 30 s. The nitrogen source was 10 cm away from the sample and the particle counter was placed 5 cm away from the sample such that the nitrogen was blowing into the detector. Results for these tests are presented in Table 2 and Table 3.

The facility for SEY studies was described in details in ref. [2]. The samples were loaded into the load lock chamber then the chamber was pumped to a pressure of 2×10^{-8} mbar which took approximately 4 hours. The sample was then transferred to the SEY measurement chamber and placed below the Faraday cup. The sample was biased with a potential of -18 V and the Faraday cup was held at ground. The negative bias was applied to facilitate efficient extraction of electrons from the sample and aid transport to the Faraday cup for measurement. The electron beam energy was set to a discreet number of energies in the range 80-1000 eV. The current from the sample to ground and the Faraday to ground were measured at each energy.

The electron gun (Kimball Physics ELG-2) delivered a beam current to the sample between 7 and 15 nA - this low current minimises the effects of sample conditioning. The electron beam was at normal incidence to the sample, with the beam focused over an area of 0.28 cm^2. During the SEY measurements the pressure in the testing chamber was ~1 x 10^{-8} mbar.

The bias of -18 V was applied to the sample using a circuit consisting of batteries and resistors. The 9-V batteries were used since the mains-powered supplies generate too much noise, thus necessitating a significantly higher primary electron current which subsequently causes sample conditioning throughout the measurement. The SEY can be defined as:

$$\delta = \frac{I_f}{I_p} = \frac{I_f}{I_f + I_s}. \tag{1}$$

where δ is the total SEY, I_f is the current on the Faraday cup, I_p is the beam current and I_s is the sample current.

The sample-to-ground current and the Faraday cup-to-ground current were measured using Keithley 6485 and Keihley 486 picoammeters, respectively. Eq. (1) was used to calculate the SEY at each energy. The accuracy ascribed to the SEY measurements was ± 6 %.

RESULTS

The SEY of the LASE copper samples as a function of primary electron energy in Fig. 1 shows in all cases the SEY below 1 throughout the whole range of energies used in these experiments. The decrease in the SEY from 1.9 for ‘as received’ copper samples [2] to below 1 is attributed primarily to the surface topography obtained by the laser treatment. On a flat surface the secondary electrons are emitted at various angles and have a high probability of escaping the surface. When primary electrons are incident on the LASE treated surfaces, the secondary electrons generated may not immediately escape to vacuum but have high probability to hit other surfaces of the micro and nanostructures of LASE surface and, after a few such interactions, could finally be absorbed or escape. This results in reducing SEY on the LASE surfaces.

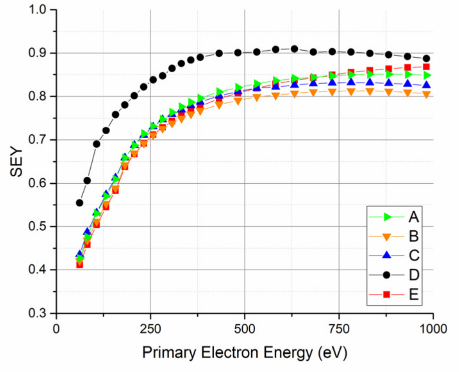

Figure 1: SEY as a function of primary electron energy for LASE-treated copper samples, for the surface structures presented in Fig. 2.

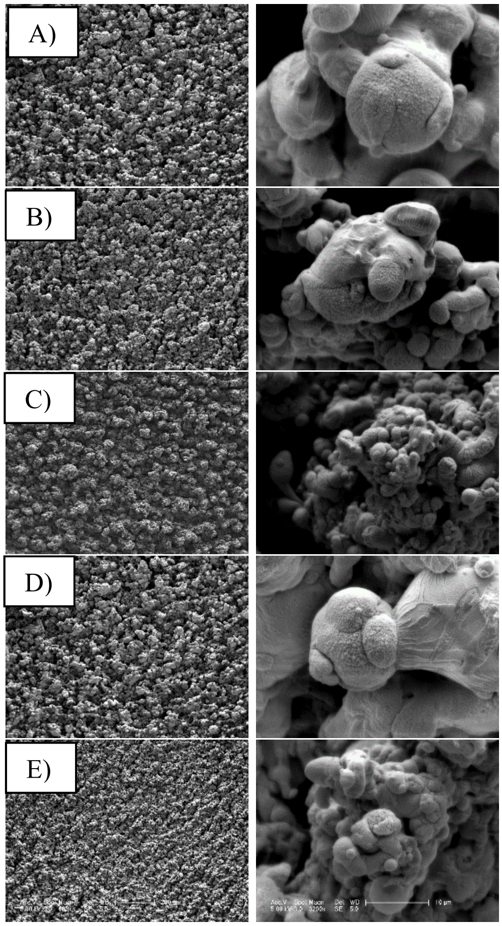

Figure 2: SEM images of the LASE samples.

Previously, it was shown that an increase in scan speed reduces the SEY [2]; however, the new results show that this is not always the case: Samples A, B, C treated with speeds of 80, 160 and 320 mm/s results in δ_{max} of 0.85, 0.81 and 0.83, respectively. Regardless of the small differences which can be observed in Fig. 2 the structures are equally good for EC suppression, therefore we can use a higher speed for quicker (and thereby more economic) surface treatment.

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Table 2: Particle Counts Measured with 1.5 bar for 30s

	Particle Counts (sizes in µm)					
Name	**0.3**	**0.5**	**1**	**5**	**10**	**25**
A	24616	17276	9239	127	32	4
B	7838	2932	794	37	20	2
C	4002	1340	252	15	10	2
D	6376	2473	735	149	95	14
E	7691	2688	478	29	19	0

Table 3: Particle Counts Measured with 5 bar for 30s

	Particle Counts (sizes in µm)					
Name	**0.3**	**0.5**	**1**	**5**	**10**	**25**
A	23198	12179	5174	93	9	2
B	20997	8982	3194	99	19	0
C	17954	8841	3247	91	15	4
D	17978	8350	3126	122	27	5
E	16113	6903	2769	60	0	0

From Tables 2 and 3 it can be seen that the surfaces generate a large number of small particulates, and a much smaller number of large particulates. There are less than 100 counts of particles between 10 and 25 µm in all samples and less than 10 counts of particles greater than 25 µm in all except sample D. It appears that the longer pulse duration creates larger particulates and the slower scan speed the more particulates however with 5 bar of pressure however this effect seems to be reduced. Further study and improvement in parameters.

These structures were applied for the production of the prototype for Karlsruhe Research Accelerator (KARA) experiments (under preparation [7]) Fig. 3 shows the photo of the FCC beam screen prototype treated with LASE. The laser parameters used for the KARA prototype were: λ=1064 nm, scan speed 180 mm/s, power 50 W, 50 kHz repetition rate, 63 ns pulse width and 20 µm pitch for the LASE surface treatment.

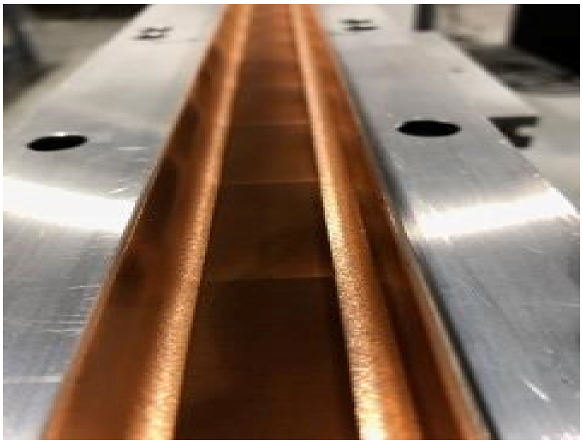

Figure 3: FCC beam screen prototype treated with LASE.

CONCLUSION

A set of laser parameters (λ=1064 nm, pitch 10 µm and ns pulse length) was found to produce LASE surfaces with SEY<1. This also demonstrates that LASE surfaces with SEY<1 can be produced with different lasers and different laser parameters. The new recipe allows surfaces to be treated at a rate several times faster than our earlier studies. This treatment was applied to the FCC beam screen prototype.

REFERENCES

[1] R Valizadeh et al, Appl. Phys. Lett. 105, 231605 (2014).

[2] R Valizadeh et al, Appl. Surf. Sci. 404, p. 370.

[3] G Rumolo et al. Phys. Rev. Special Topics-Accelerators and Beams, 4(1):012801, 2001.

[4] César Octavio et al, Electron cloud studies for the LHC and future proton colliders. PhD thesis, Ecole Polytechnique, Lausanne, Nov 2013. Presented 13 Jan 2014.

[5] C Scheuerlein et al, The Influence of an Air Exposure on the Secondary Electron Yield of Copper. PhD thesis, Berlin, Tech. U., Geneva, 1997. Presented on 10 Feb 1997.

[6] RE Simon et al, Secondary-electron emission. Nuclear Science, IEEE Transactions on, 15(3):167–170, 1968.

[7] Francis Perez et al, measurement setup at light source operational, EuroCirCol Milestone Report, 24 Aug 2016.