ELECTRON CLOUD MITIGATION WITH LASER ABLATED SURFACE ENGINEERING TECHNOLOGY*

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Abstract

Parameters of the high intensity accelerators with positively charged beams could be compromised by electron cloud (e-cloud) effect. One of the most efficient mitigation method is providing the beam vacuum chamber walls with low secondary electron yield (SEY). A discovery of low SEY surfaces produced with Laser Ablated Surface Engineering (LASE) brought a new technological solution for e-cloud mitigation. This paper highlights the main results obtained since its discovery in 2014.

INTRODUCTION

Electron cloud (e-cloud) and beam induced electron multipacting (BIEM) are two coupled effects that can badly affect the performance of high intensity particle accelerators with positively charged beams [1,2]. Among many developed methods for the e-cloud and BIEM mitigation, one of preferred solutions is an inner surface with a low secondary electron emission (SEY) yield. The advantage of this method that after implementing it requires no controllers, no power sources, no cables, no feedthroughs, etc. Low SEY surface is a result of using low SEY materials for vacuum chamber, a thin film of low SEY materials on inner walls of vacuum chamber or surface geometry engineering (grooves or special surface structures). Many research teams are involved in these activities around the world, different techniques (machining, etching, thin film coating, etc.) allow to reach SEY ≤ 1. In this paper a short overview of Laser Ablated Surface Engineering (LASE) is given.

LASE AS A LOW SEY SOLUTION FOR E-CLOUD MITIGATION

What is LASE?

Nanostructuring of material surfaces by Laser Ablated Surface Engineering (LASE) is well established science and manufacturing with more than 25 years of experience, see review papers in Ref. [3-6]. However, it was not looked at as a surface treatment for accelerator vacuum chambers.

Discovery of LASE for SEY mitigation

In 2014 it was discovered that LASE on copper, aluminium and stainless steel surfaces may lead to dramatic reduction of SEY, with its maximum value $\delta_{max} < 0.8$ [7,8]. Figure 1 shows an untreated and LASE copper samples and Fig. 2 shows SEY for untreated and LASE copper samples as a function of incident electron energy for two conditions: as-received (i.e. measured shortly after installing on SEY measurement facility and after conditioning (electron bombardment with a dose of 1.0×10^{-2} C/mm^2 for Cu and 3.5×10^{-3} C/mm^2 for black Cu). One can see that even as-received LASE sample demonstrate $\delta_{max} < 1.1$ in comparison to $\delta_{max} = 1.9$ for the untreated sample, and the electron conditioning lead to further reduction of SEY: $\delta_{max} < 0.8$ for LASE sample in comparison to $\delta_{max} < 1.25$ for the untreated sample. The main result reported in Ref. [7,8] that SEY < 1 can be achieved on Cu, Al and stainless steel with LASE, and this technology could be applied for suppression of PEY/SEY and solving the e-cloud problem.

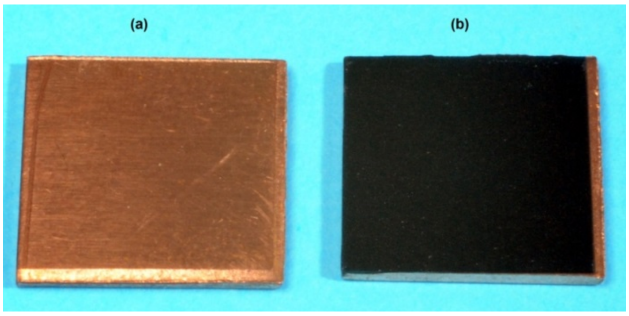

Figure 1: (a) Untreated and (b) LASE copper samples.

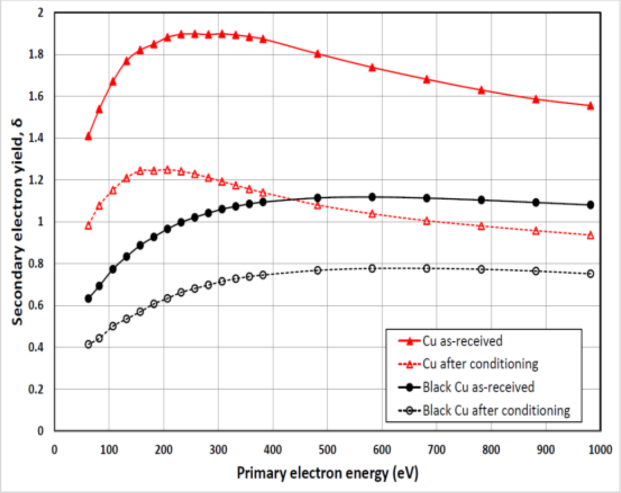

Figure 2: SEY for Cu as a function of incident electron energy: Cu – untreated surface, black Cu – laser treated surface, and conditioning – electron bombardment with a dose of 1.0×10^{-2} C/mm^2 for Cu and 3.5×10^{-3} C/mm^2 for black Cu. Reproduced from Ref. [8].

Further LASE development

In the following years, the emphasis was focused on better understanding of the following:

- How and why SEY is reduced on LASE surfaces
- Further reduction of SEY
- Study how LASE surface may affect other characteristics which are important for an accelerator:
  - RF surface resistance
  - Particulate generation

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- Vacuum properties

It was demonstrated [9-10] that a treatment of copper using a λ = 355 nm laser resulted in creation of three different scales structures show in Fig. 3:

- microstructure grooves ranging from 8 to 100 µm deep,
- coral-like submicron particles superimposed on the grooves which is made of agglomeration of
- nano-spheres.

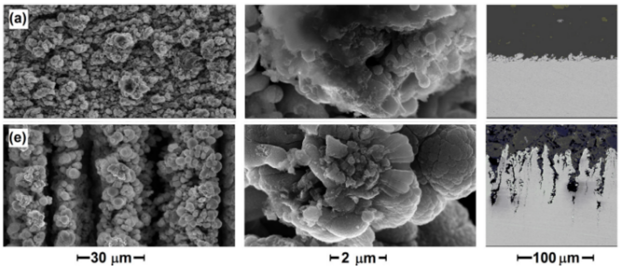

Figure 3: Low (on the left) and high (in the middle) resolution planar and X-Section (on the right) SEM micrographs of 1 mm thick copper samples treated with a laser using different scan speeds: (a) 180 mm/s and (e) 30 mm/s. Reproduced from Ref. [10].

It was demonstrated, as reported in Ref [10]:

- The SEY reduction is happening due to a superposition of these structures.
- Low SEY surfaces can be produced using various lasers with different wavelength, such as λ=355 nm and λ=1064 nm, different power, with a variety of other parameters.

First accelerator test

Two of the LASE surfaces reported in Ref. [10] has been selected for the first accelerator test of vacuum components with LASE surfaces for electron-cloud mitigation [11]. A specially designed SPS liner was treated on two areas of 40 mm × 490 mm with different LASE parameters, see Fig. 4.

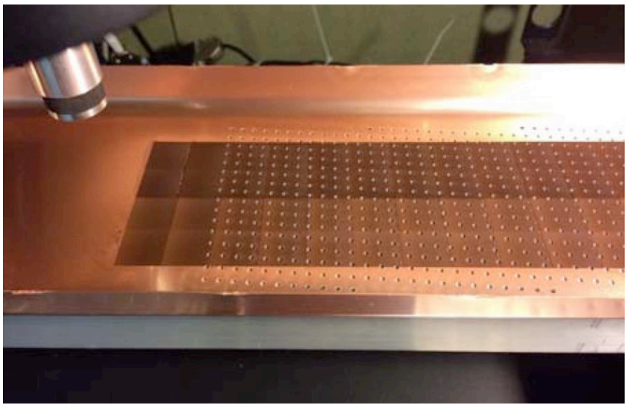

Figure 4: Perforated side of the SPS liners treated by ASTeC. The two regions treated with a different set of laser parameters are clearly visible. Reproduced from Ref. [11].

The following test at SPS accelerator has demonstrated a complete eradication of e-cloud achieved with both set of LASE parameters [11]. That was the first demonstration of efficiency of e-cloud mitigation with LASE technology.

RF surface resistance

Vacuum chamber RF surface resistance should be below a certain threshold to avoid two possible problems:

- An increase of beam energy spread due to beam impedance induced by the RF surface resistance;
- Significant resistive heal loss of beam image current on vacuum chamber walls.

The depth of microstructure grooves produced by LASE ranging from 8 to 100 µm. the RF surface resistance has been measured at 7.8 GHz with a 3-choke cavity as shown in Fig. 5. It was shown that the RF surface resistance R_s can be reduced with reducing the groove depth (main source of surface resistance) and the depth of other LASE structures, see Fig. 6 [9,10].

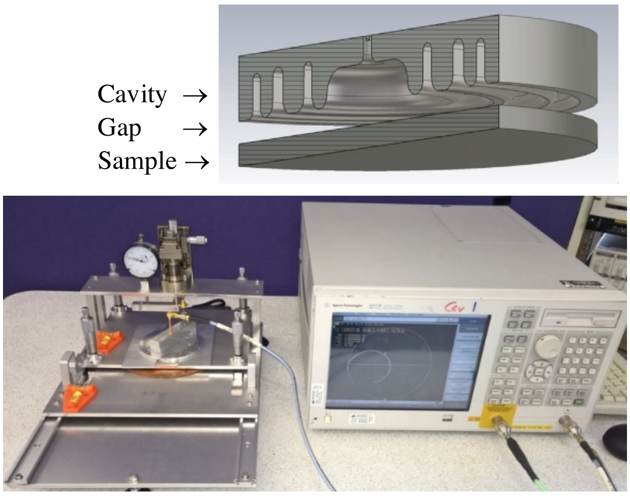

Figure 5: The 3-choke cavity (top) and a facility (bottom) for contactless surface resistance measurements.

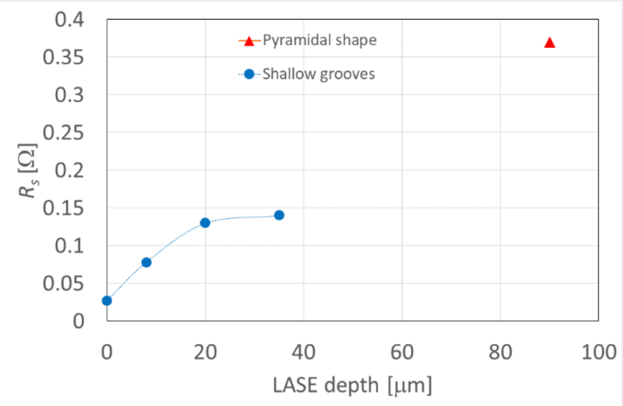

Figure 6: The RF surface resistance as a depth of LASE structures.

EUROCIRCOL STUDIES FOR FCC

The successful results on SEY mitigation with LASE lead to consider LASE as baseline solution for FCC-hh beam chamber in the H2020 EuroCirCol programme. More than 120 different LASE samples were produced and tested in STFC. The sample were produced with different lasers (nanosecond lasers with $\lambda = 355$ nm and 1064 nm, picosecond lasers with $\lambda = 355$ nm and 1064 nm), in different atmospheres (air, vacuum, Ar, CH_4). More than 60 samples demonstrated $\delta_{\max} < 1$ [12-13].

A number of samples has been investigated by the EuroCirCol WP4 partners:

- A compatibility of LASE surfaces with cryogenic vacuum in future high-energy particle accelerators has been studied in INFN [14-16];
- Reflectivity and photoelectron yield has been studied under synchrotron radiation at INFN [17];
- Thermal outgassing and electron stimulated desorption measurements has been performed at STFC [18];
- A 2-m long porotype of the FCC-hh vacuum chamber for photodesorption measurements at KARA:
    - a tube in two halves,
    - it has been LASE treated with a laser (λ = 1064 nm), treated area of each half is 2 m × 20 mm.

ADVANTAGES OF LASE OVER OTHER PASSIVE MITIGATION METHODS

- LASE can be done in air or selected gas atmosphere, i.e. there is no need for vacuum or clean room facilities:
    - reduced cost
- The laser is capable of fabricating the desired micro/nanostructure in a single step process:
    - reduced processing time
- Surface engineering is performed by photons and, thus, contactless:
    - no contamination from the tools or the process materials
- The process is applicable to the surfaces of any 3D object:
    - i.e. inner walls of beam vacuum chambers
- It is possible to lase in many different environments, such as gases, liquids, or in a vacuum
    - i.e. controlling surface composition (oxides, nitrides, carbonises…) and surface formation.

CONCLUSIONS

LASE is an e-cloud mitigation technology for future high intensity accelerators. It has been demonstrated that low SEY surfaces can be produced with different lasers (different wavelength, power, frequency and other parameters). The technology is ready for scaling up to be applied on large vacuum chambers.

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