NEG coatings and Laser Ablation Surface Engineering (LASE) electron cloud mitigation techniques

O.B. Malyshev, R. Valizadeh, A. Hannah, T. Sian and R. Širvinskaitė

EuroCirCol Task 4.3: Mitigate beam-induced vacuum effects

ASTeC Vacuum Science Group,
STFC Daresbury Laboratory, UK

FCC Week 2018, 9-13 April 2018,
Beurs van Berlage, Amsterdam, Netherlands
SEY studies:

e-cloud mitigation
by reducing Secondary Electron Yield (SEY)
Laser Ablation Surface Engineering (LASE)
Discovery of LASE for SEY mitigation

- Nanostructuring of Material Surfaces by Laser Ablation is well established science and manufacturing
- The new is applying these surfaces to suppress PEY/SEY and to solve the e-cloud problem
- Main result: SEY < 1 can be achieved on Cu, Al and stainless steel


O.B. Malyshev

FCC week 2018, 9-13 Apr 2018, Amsterdam
Recent low SEY studies

- Emphasis on the following problems:
  - How and why SEY is reduced on LASE surfaces
  - Reduce SEY with various lasers
  - Study an effect of cleaning
  - Study an effect of aging
  - Reduce surface resistance to minimise an impact on beam impedance
  - Reduce particulate generation
  - Apply for machine tests

A role of laser scan speed on copper samples

<table>
<thead>
<tr>
<th>Sample</th>
<th>Scan speed [mm/s]</th>
<th>Groove depth [µm]</th>
<th>Rs [Ω]</th>
</tr>
</thead>
<tbody>
<tr>
<td>untreated</td>
<td>-</td>
<td>-</td>
<td>0.033</td>
</tr>
<tr>
<td>(a) 180</td>
<td>8</td>
<td>0.078</td>
<td></td>
</tr>
<tr>
<td>(b) 120</td>
<td>20</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>(c) 90</td>
<td>35</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>(d) 60</td>
<td>60</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>(e) 30</td>
<td>100</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Treatment of copper using a $\lambda = 355$ nm laser resulted in creation of three different scales structures:

- 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
A role of laser wavelength

Similar surfaces with similar results for SEY can be produce using various lasers with different wavelength, such as $\lambda=355$ nm and $\lambda=1064$ nm.

<table>
<thead>
<tr>
<th>Sample</th>
<th>$\lambda$ (nm)</th>
<th>Av. power (W)</th>
<th>Spot size ($\mu$m)</th>
<th>Pulse duration (ns)</th>
<th>f (kHz)</th>
<th>Pitch width ($\mu$m)</th>
<th>Scan speed (mm/s)</th>
<th>Energy per pulse ($\mu$J)</th>
<th>Fluence (J/cm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>355</td>
<td>3</td>
<td>15</td>
<td>25</td>
<td>40</td>
<td>10</td>
<td>60</td>
<td>75</td>
<td>42</td>
</tr>
<tr>
<td>9</td>
<td>1064</td>
<td>3.6</td>
<td>25</td>
<td>70</td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>360</td>
<td>73</td>
</tr>
</tbody>
</table>
• More samples produced at Micronanics, Liverpool and Manchester Universities:
  • and being characterised on SEY and particulates
  • See posters:
    • Taaj Sian. New LASE surfaces obtained with various lasers and their parameters
    • Reza Valizadeh. A progress with further developing of laser ablating surface engineering (LASE) for e-cloud eradication in particle accelerator
  • A new Laser treatment facility was built
### Samples produced with various lasers

<table>
<thead>
<tr>
<th>Sample</th>
<th>( \lambda ) (nm)</th>
<th>Average power (W)</th>
<th>Spot size (( \mu )m)</th>
<th>Pulse duration (ns)</th>
<th>Pulse repetition (KHz)</th>
<th>Pitch width (( \mu )m)</th>
<th>Scan speed (mm/s)</th>
<th>Energy per pulse (( \mu )J)</th>
<th>Fluence (J/cm(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>355</td>
<td>3</td>
<td>15</td>
<td>25</td>
<td>40</td>
<td>10</td>
<td>30</td>
<td>75</td>
<td>42</td>
</tr>
<tr>
<td>2</td>
<td>355</td>
<td>3</td>
<td>15</td>
<td>25</td>
<td>40</td>
<td>10</td>
<td>60</td>
<td>75</td>
<td>42</td>
</tr>
<tr>
<td>3</td>
<td>355</td>
<td>3</td>
<td>15</td>
<td>25</td>
<td>40</td>
<td>10</td>
<td>90</td>
<td>75</td>
<td>42</td>
</tr>
<tr>
<td>4</td>
<td>355</td>
<td>3</td>
<td>15</td>
<td>25</td>
<td>40</td>
<td>10</td>
<td>120</td>
<td>75</td>
<td>42</td>
</tr>
<tr>
<td>5</td>
<td>355</td>
<td>3</td>
<td>15</td>
<td>25</td>
<td>40</td>
<td>10</td>
<td>180</td>
<td>75</td>
<td>42</td>
</tr>
<tr>
<td>6</td>
<td>1064</td>
<td>1.9</td>
<td>25</td>
<td>70</td>
<td>2.5</td>
<td>20</td>
<td>125</td>
<td>760</td>
<td>154</td>
</tr>
<tr>
<td>7</td>
<td>1064</td>
<td>2.4</td>
<td>25</td>
<td>70</td>
<td>5.0</td>
<td>20</td>
<td>125</td>
<td>480</td>
<td>97</td>
</tr>
<tr>
<td>8</td>
<td>1064</td>
<td>3.6</td>
<td>25</td>
<td>70</td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>360</td>
<td>73</td>
</tr>
<tr>
<td>9</td>
<td>1064</td>
<td>3</td>
<td>25</td>
<td>70</td>
<td>20</td>
<td>10</td>
<td>500</td>
<td>150</td>
<td>30</td>
</tr>
<tr>
<td>10</td>
<td>1064</td>
<td>1</td>
<td>25</td>
<td>70</td>
<td>100</td>
<td>10</td>
<td>500</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Date</td>
<td>Wavelength</td>
<td>power</td>
<td>spotsize</td>
<td>pulse duration</td>
<td>rep</td>
<td>pitch</td>
<td>speed</td>
<td>thickness</td>
<td>treatment</td>
</tr>
<tr>
<td>-----------------</td>
<td>------------</td>
<td>-------</td>
<td>----------</td>
<td>----------------</td>
<td>-----</td>
<td>-------</td>
<td>-------</td>
<td>-----------</td>
<td>-----------</td>
</tr>
<tr>
<td>23/09/2015</td>
<td>355</td>
<td>3</td>
<td></td>
<td>2ns</td>
<td>40 kHz</td>
<td>5</td>
<td>120</td>
<td>50 micron thick</td>
<td></td>
</tr>
<tr>
<td>24/09/2016</td>
<td>355</td>
<td>3</td>
<td></td>
<td>2ns</td>
<td>40 kHz</td>
<td>5</td>
<td>90</td>
<td>100 micron thick</td>
<td></td>
</tr>
<tr>
<td>25/09/2016</td>
<td>355</td>
<td>3</td>
<td></td>
<td>2ns</td>
<td>40 kHz</td>
<td>5</td>
<td>90</td>
<td>100 micron thick</td>
<td></td>
</tr>
<tr>
<td>01/10/2016</td>
<td>355</td>
<td>3</td>
<td></td>
<td>2ns</td>
<td>40 kHz</td>
<td>5</td>
<td>90</td>
<td>50 micron thick</td>
<td></td>
</tr>
<tr>
<td>07/10/2015</td>
<td>355</td>
<td>3</td>
<td></td>
<td>2ns</td>
<td>40 kHz</td>
<td>5</td>
<td>90</td>
<td>50 micron thick</td>
<td>after acetone</td>
</tr>
<tr>
<td>08/10/2015</td>
<td>355</td>
<td></td>
<td></td>
<td></td>
<td>40 kHz</td>
<td></td>
<td>90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30/10/2015</td>
<td>355</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>02/11/2016</td>
<td>355</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>162</td>
<td></td>
<td></td>
</tr>
<tr>
<td>02/11/2015</td>
<td>355</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>216</td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/11/2015</td>
<td>355</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>04/02/2016</td>
<td>Chester Uni</td>
<td>1064</td>
<td>5</td>
<td>15</td>
<td>&gt;5ps</td>
<td>100 kHz</td>
<td>5</td>
<td>30</td>
<td>after acetone</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>04/02/2016</td>
<td>Chester Uni</td>
<td>1064</td>
<td>5</td>
<td>15</td>
<td>&gt;5ps</td>
<td>100 kHz</td>
<td>5</td>
<td>5</td>
<td>Argon atmosphere</td>
</tr>
<tr>
<td>29/03/2016</td>
<td>1064</td>
<td>5</td>
<td>15</td>
<td>&gt;5ps</td>
<td>100 kHz</td>
<td>5</td>
<td>5</td>
<td></td>
<td>after acetone</td>
</tr>
<tr>
<td>14/02/2017</td>
<td>Micronanics</td>
<td>1064</td>
<td>5</td>
<td>70 ns</td>
<td>100 kHz</td>
<td>5</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15/02/2017</td>
<td>1064</td>
<td>5</td>
<td>70 ns</td>
<td>100 kHz</td>
<td>10</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20/02/2017</td>
<td>1064</td>
<td>5</td>
<td>70 ns</td>
<td>100 kHz</td>
<td>200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23/02/2017</td>
<td>1064</td>
<td>5</td>
<td>70 ns</td>
<td>100 kHz</td>
<td>200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Micronanics with air flow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>08/03/2017</td>
<td>b</td>
<td>1064</td>
<td>6.6</td>
<td>10</td>
<td>30</td>
<td></td>
<td>air</td>
<td>no glass</td>
<td></td>
</tr>
<tr>
<td></td>
<td>c</td>
<td>1064</td>
<td>6.6</td>
<td>10</td>
<td>30</td>
<td></td>
<td>pump flow (Flow of air)</td>
<td>glass</td>
<td></td>
</tr>
<tr>
<td></td>
<td>d</td>
<td>1064</td>
<td>6.6</td>
<td>10</td>
<td>30</td>
<td></td>
<td>pump flow (Flow of air)</td>
<td>no glass</td>
<td></td>
</tr>
<tr>
<td></td>
<td>e</td>
<td>1064</td>
<td>6.6</td>
<td>10</td>
<td>30</td>
<td></td>
<td>compressed air</td>
<td>no glass</td>
<td></td>
</tr>
<tr>
<td></td>
<td>f</td>
<td>1064</td>
<td>6.6</td>
<td>10</td>
<td>30</td>
<td></td>
<td>compressed air</td>
<td>glass</td>
<td></td>
</tr>
<tr>
<td>20/06/2017</td>
<td>Manchester Uni</td>
<td>355nm</td>
<td>65</td>
<td>23 um</td>
<td>2ps</td>
<td>404 kHz</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>20/06/2017</td>
<td>355nm</td>
<td>65</td>
<td>23 um</td>
<td>2ps</td>
<td>404 kHz</td>
<td>100</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21/06/2017</td>
<td>355nm</td>
<td>65</td>
<td>23 um</td>
<td>2ps</td>
<td>404 kHz</td>
<td>100</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21/06/2017</td>
<td>355nm</td>
<td>65</td>
<td>23 um</td>
<td>2ps</td>
<td>404 kHz</td>
<td>100</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22/06/2017</td>
<td>355nm</td>
<td>65</td>
<td>23 um</td>
<td>2ps</td>
<td>404 kHz</td>
<td>50</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23/06/2017</td>
<td>355nm</td>
<td>65</td>
<td>23 um</td>
<td>2ps</td>
<td>404 kHz</td>
<td>25</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23/06/2017</td>
<td>355nm</td>
<td>65</td>
<td>23 um</td>
<td>2ps</td>
<td>404 kHz</td>
<td>50</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23/06/2017</td>
<td>355nm</td>
<td>65</td>
<td>23 um</td>
<td>2ps</td>
<td>404 kHz</td>
<td>25</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23/06/2017</td>
<td>355nm</td>
<td>65</td>
<td>23 um</td>
<td>2ps</td>
<td>404 kHz</td>
<td>100</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14/09/2017</td>
<td>IPG 40 kHz Micronanics</td>
<td>1064</td>
<td>20</td>
<td>2ns</td>
<td>40kHz</td>
<td>0.02</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14/09/2017</td>
<td>1064</td>
<td>20</td>
<td>2ns</td>
<td>40kHz</td>
<td>0.02</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19/09/2017</td>
<td>1064</td>
<td>10.5</td>
<td>2ns</td>
<td>40kHz</td>
<td>0.02</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

FCC week 2018, 9–15 Apr 2018, Amsterdam
Main results

- SEY reduction due to a superposition of
  - microstructure (groves)
  - sub-micron and nano-structures

- Groves are main source in surface resistance.

- Low SEY surfaces can be produced using various lasers with different wavelength, such as $\lambda=355$ nm and $\lambda=1064$ nm, different power, with a variety of other parameters.
ESD measurements

Particle counts
Electron cloud mitigation has based on LASE has been successfully demonstrated in particle accelerator for the first time.

1) 10 samples for INFN to study an effect of cryogenic temperatures and cryosorbed gases on SEY
   • see a poster R. Cimino et al.
   • treated area 8 mm x 8 mm; Laser 355 nm or 1064 nm.

2) A sample for a reflectivity study at BESSY
   • See a poster E. La Francesca, R. Cimino, et al.)
   • Treated area 20 mm x 300 mm.
   • Laser 1064 nm.

3) 4 samples for BINP, Novosibirsk (A. Krasnov)
   • 12 mm x 12 mm; Laser 355 nm or 1064 nm.

All samples have being laser treated at Micronanics
4) Sample for KARA experiment in ANKA (KIT) – 2 m long a tube in two halves, treated area of each half is 2 m x 20 mm. Laser 1064 nm.
A new cryogenic temperature facility

RDK-305D 4K Cryocooler
(RDK-305D Cold Head with CNA-31C/D Compressor)

Bellows

Test chamber

2nd stage

Conductor from 1st stage to heat shield

1st stage

Insulation vacuum

O.B. Malyshev

FCC week 2018, 9-13 Apr 2018, Amsterdam
A new cryogenic temperature facility

Current work:
- Assembling a facility for cryogenic measurements

Next Steps:
- Completing assembly
- Testing
- Measurements at $4 \text{ K} < T < 80 \text{ K}$
  - No condensed gas
  - With condensed gas
- See a posters:
  - Taaj Sian. A facility for studying SEY from LASE surfaces at cryogenic temperatures
NEG coating studies
1) Reduces gas desorption:
   - A pure metal (Ti, Zr, V, Hf, etc.) film ~1-μm thick without contaminants.
   - A barrier for molecules from the bulk of vacuum chamber.

2) Increases distributed pumping speed, \( S \):
   - A sorbing surface on whole vacuum chamber surface
     \[
     S = \alpha \cdot A \cdot v / 4;
     \]
     where
     - \( \alpha \) – sticking probability,
     - \( A \) – surface area,
     - \( v \) – mean molecular velocity
Electron stimulated desorption of H₂

\[ P \propto \frac{\eta}{\alpha} = \] desorption yield 
sticking probability

- H₂ ESD is much lower than for 316 LN
- Distributed pumping
  - => low pressure

NEG coating for FCC-hh

• Looking for new materials
  • Lower activation temperature
    • It is 150 °C for columnar Ti-Zr-Hf-V.
  • Effect of photon and electron induced activation
    • It is possible to avoid NEG activation by heating?
• NEG coating at cryogenic temperatures
  • Reduced PSD and ESD
  • Impact on PEY and SEY
• NEG coating surface resistance
  • Developing new materials with higher electric conductivity
  • Effect of temperature
3) Reduces SEY:
   • After NEG activation
   • After beam conditioning
NEG coating studies

• Current work:
  • Studying pure Zr film on a sample tubes, ESD and pumping measurements
    • Three samples (dense and columnar film) measurements and data analysis completed.
      • See a poster of Ruta Sirvinskaite. Singe metal Zr NEG coating, its pumping properties and electron stimulated desorption
  • Four other sample with different materials have been deposited
    • One sample – pumping properties completed
    • Others will be studied over next two months

• Next Steps:
  • Assemble a facility for cryogenic (LN$_2$) measurements and start a cryogenic study
  • Design of a facility for cryogenic (dry system 4 K < T < 80 K) measurements
  • Analysis of the experimental results
Modelled pressure ratio vs. sticking probability

Pressure ratio vs. Sticking probability

1.E+04
1.E+03
1.E+02
1.E+01
1.E+00

1.E-04
1.E-03
1.E-02
1.E-01
1.E+00

O.B. Malyshev
Sample 2 - dense Zr, sample 3 - columnar Zr

Sticking probability vs Activation temperature (°C)

- Tube 2 H2
- Tube 2 CO
- Tube 2 CO2
- Tube 3 H2
- Tube 3 CO
- Tube 3 CO2

O.B. Malyshev

FCC week 2018, 9-13 Apr 2018, Amsterdam
How do we measure the surface resistance

\[ R_{S_{\text{sam}}} = \frac{G Q_0^{-1} - R_{S_{\text{cav}}} p_c}{p_s} \]

- The surface resistance of the sample \( R_{S_{\text{sam}}} \) can be calculated for known
  - test cavity surface resistances \( R_{S_{\text{cav}}} \) and
  - measured \( Q_0 \).
- The magnetic field distribution in the cavity was calculated using CST Microwave Studio.
  - For our cavity, \( G = 235 \Omega \),
  - for perfect electric conductor (PEC) boundary conditions, the field ratios are \( p_c = 0.625 \) and \( p_s = 0.375 \).
Surface resistance at 7.8 GHz for LASE and NEG coating

Dense NEG coating
\[ \sigma_d = 8 \times 10^5 \, S/m \]

Columnar NEG coating
\[ \sigma_d = 1.4 \times 10^4 \, S/m \]

LASE
NEG coating studies – surface resistance at various frequencies on copper, aluminium and stainless steel.
Surface resistance

• A possibility for $R_s$ measurement on a tubular samples on a dedicated facility are under investigation

• An open question:
  • $R_s$ as a function of temperature
    • To be addressed in future
      • Planar samples could be studied in a few months
      • Tubular sample can be considered later
Acknowledgements

The European Circular Energy-Frontier Collider Study (EuroCirCol) project has received funding from the European Union's Horizon 2020 research and innovation programme under grant No 654305. The information herein only reflects the views of its authors and the European Commission is not responsible for any use that may be made of the information.