Science & Technology Facilities Council

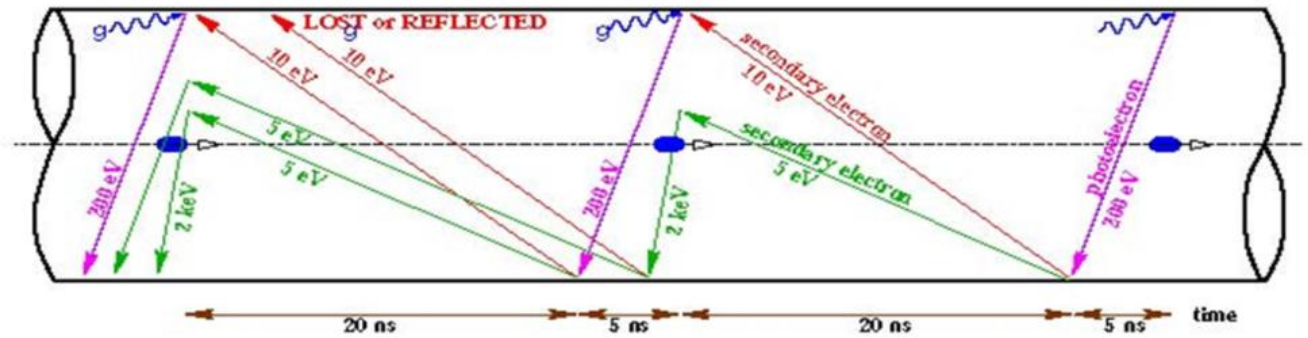
Evaluation of Laser Ablation Surface Engineering (LASE) of Copper and SS for Partical Accelerator

Reza Valizadeh

Patrick Krkotic
Prof M. Pont
Dr J.M O'Callaghan
Taaj Sian
Dr Oleg Malyshev
Adrian Hannah
Jennifer Much
James Conlon

Dr David Whitehead (Manchester)
Neil Sykes (Micronanics)
Dr Paul Apte (Rideo)
Dr Walter Perrie (Liverpool)

Main Goal



Curtesy to
F. Ruggero

Mitigation of ECLOUD by Engineering a Low Secondary Electron Yield (SEY) Surface.

While

Maintaining high vacuum performance:

Low ESD

Low outgassing

Low surface resistance

Low reflectivity of SR

ACTION

WE PROPOSED LASER ABLATION SURFACE ENGINEERING

LASE

Advantages Over Other method

- There is no need for vacuum or clean room facilities
- The laser is capable of fabricating the desired micro/nanostructure in a single step process.
- Machining is performed through a beam of light and thus contactless
- The process is applicable to the surfaces of any 3D object
- It is possible to lase in many different environments, such as gases, liquids, or in a vacuum.

Parameters involved in LASE

Lase is not one specific surface. It can create virtually thousands of variety of surface.

- 1) Laser beam parameters:
- Average power
- Pulsed energy
- Beam profile
- Pulse duration
- Repetition rate,
- Wavelength
- Polarisation of the light
- Collimated beam parameters

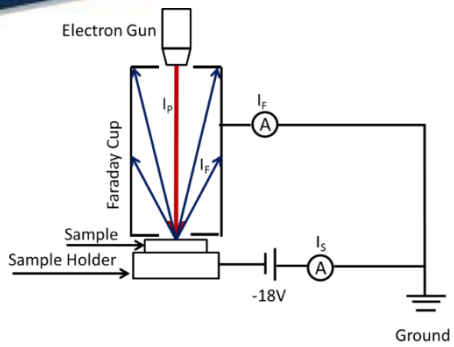
- 2) sample parameters:
- Sample material
- Sample roughness
- Surface chemistry

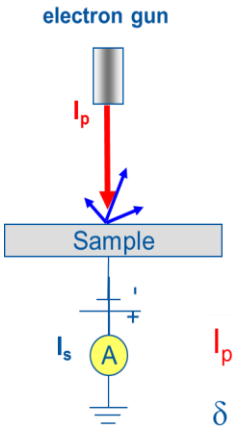
- 3) Scanning parameters:
- Scan velocity
- Scanner distance from the focusing lens,
- Angle of incident,
- Overlap and number of scan

4) Process parameters:

- Micromachining environment
- Gas pressure
- Temperature of the sample
- Mobility of sample relative to beam

SEY Measurements

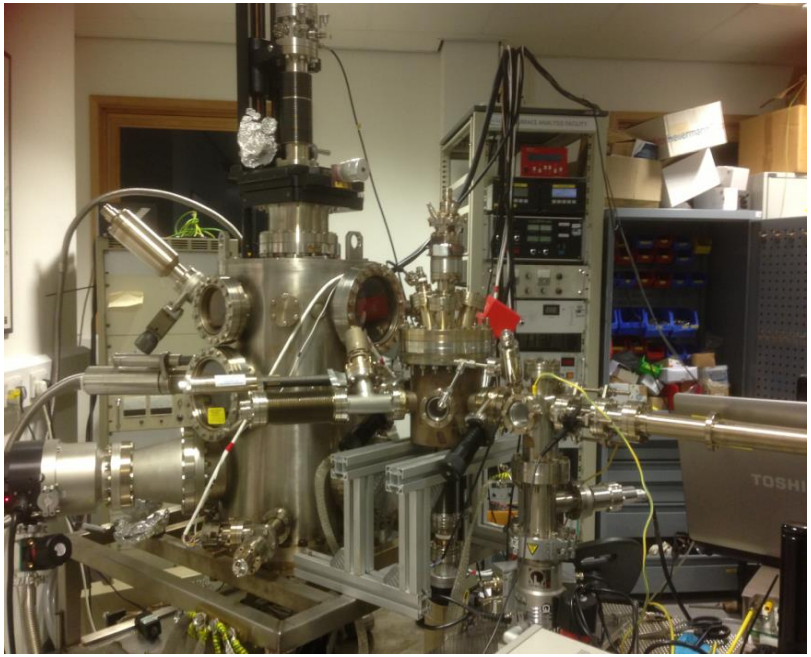




I_p with Faraday cup

$\delta = 1 - I_s/I_p$

$$\delta = \frac{I_F}{I_P} = \frac{I_F}{I_F + I_S}$$



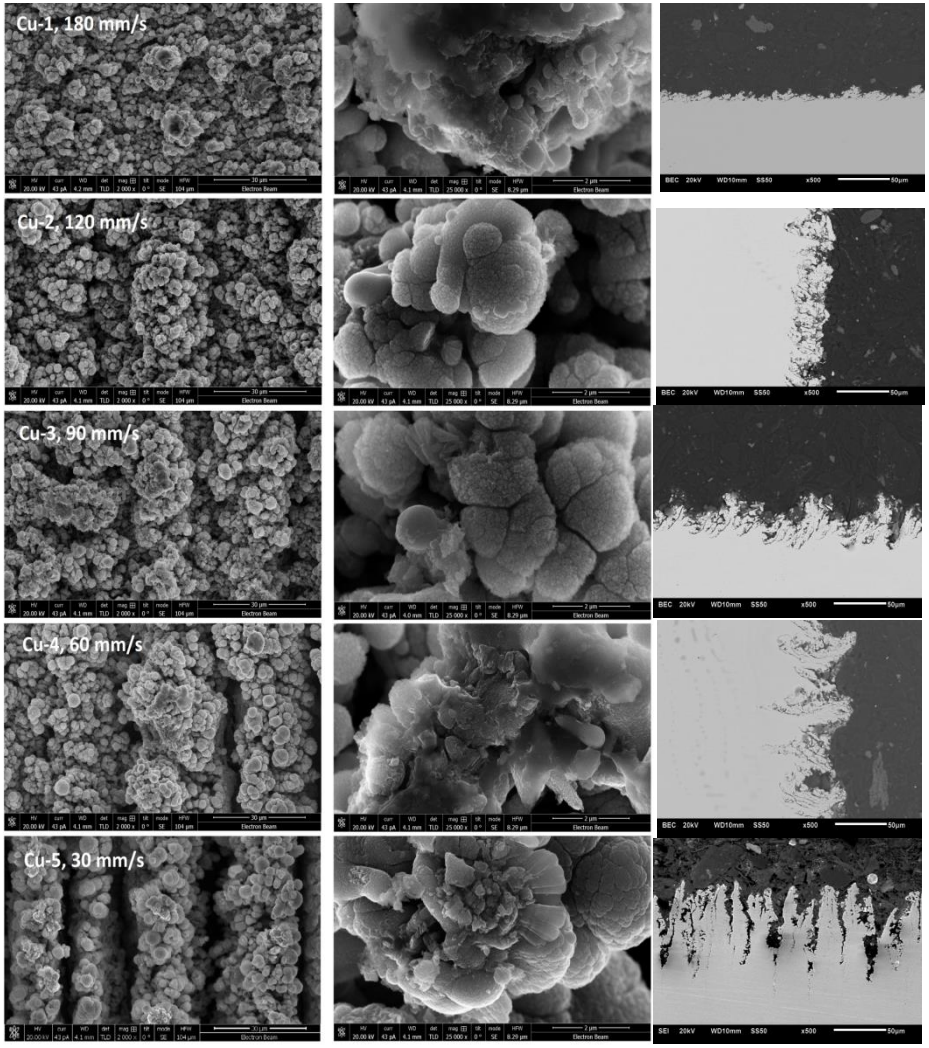
I_P is the primary beam current
I_F is the secondary electron current including elastic and inelastic processes, measured on the Faraday cup
I_S is the currents on the sample

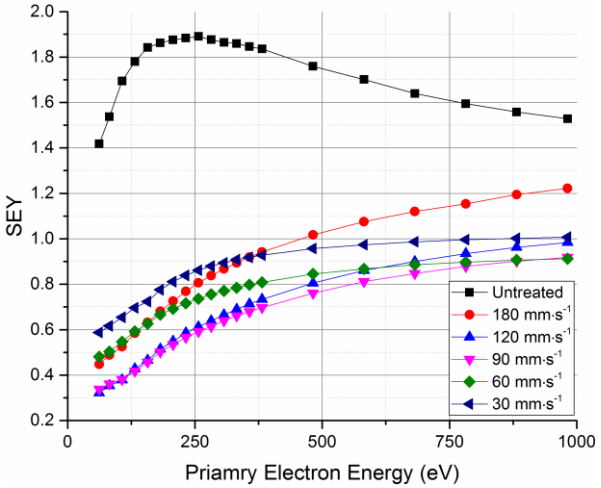
Analysis chamber with

- XPS,
- Flood e-gun,
- Sample heater,
- Ar ion beam.

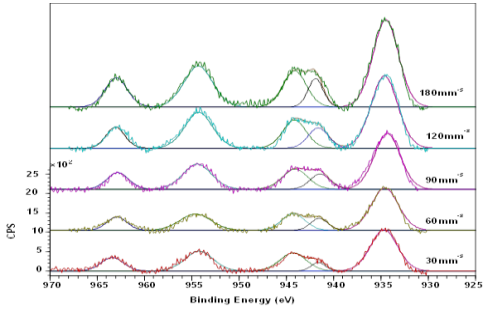
Effect of scan speed

Laser treatment condition	λ (nm)	Average power (W)	Spot size (μm)	Pulse duration (ns)	Pulse repetition (kHz)	Pitch width (μm)	Scan speed (mm/s)	Energy per pulse (μJ)	Fluence (J/cm²)
1	355	3	15	25	40	10	30,60,90, 120, 180	75	42

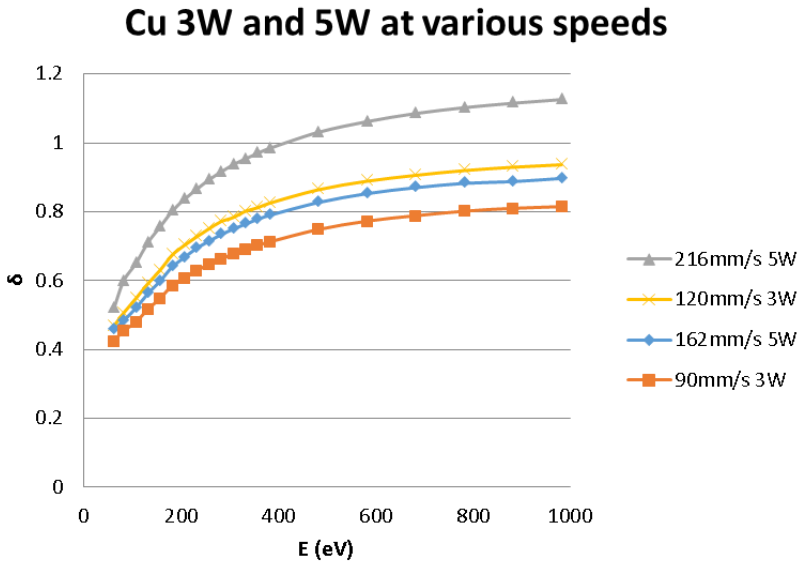


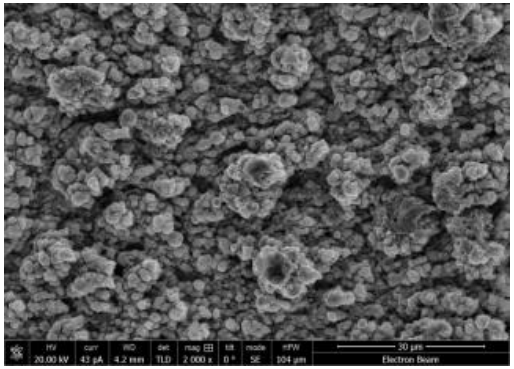


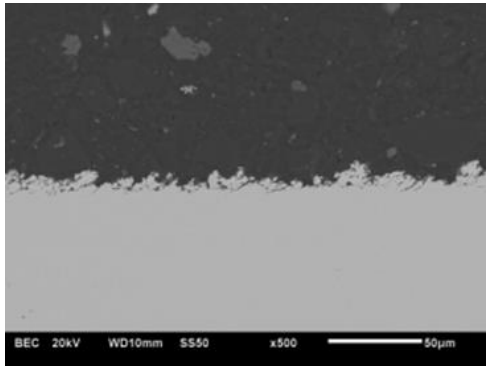
Sample	6	5	4	3	2
Scan speed (mm/s)	30	60	90	120	180
Groove depth (μm)	100	60	35	20	8
δ at E_p = 60 eV	0.6	0.5	0.3	0.3	0.4
δ at E_p =1000 eV	1.0	0.91	0.9	0.98	1.22



Effect of scan speed and average power







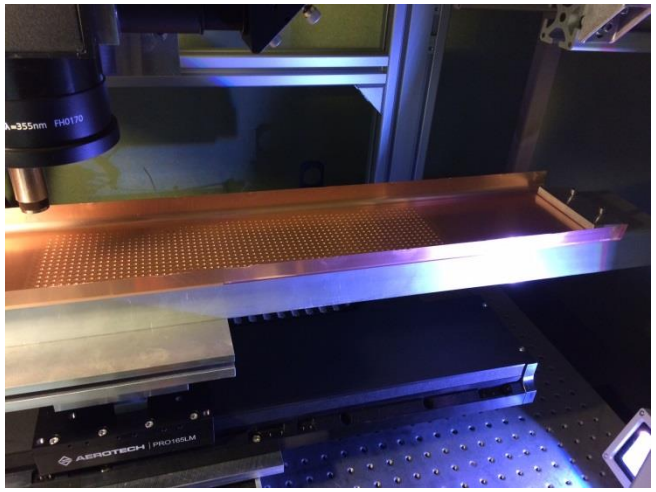
Wavelength of 355 nm, repetition rate 40kHz
Pitch 10 microns and beam spot 15 microns

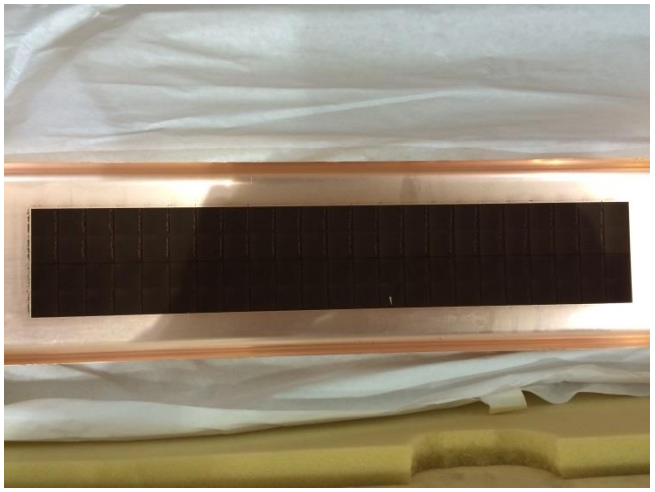
More power lower SEY
Slower speed lower SEY
The highest measured δ 216, 120, 162 and 90 mm/s 1.25, 0.94, 0.89 and 0.81 respectively.

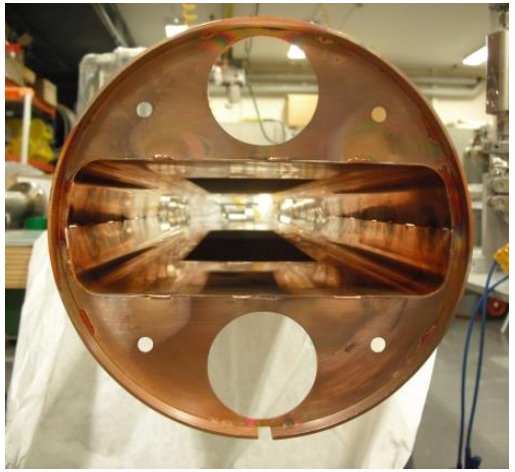
Science & Technology Facilities Council

Large scale test in SPS at CERN

Laser treatment condition	λ (nm)	Average power (W)	Spot size (μm)	Pulse duration (ns)	Pulse repetition (kHz)	Pitch width (μm)	Scan speed (mm/s)	Energy per pulse (μJ)	Fluence (J/cm²)
1	355	3	15	25	40	10	90, 120,	75	42



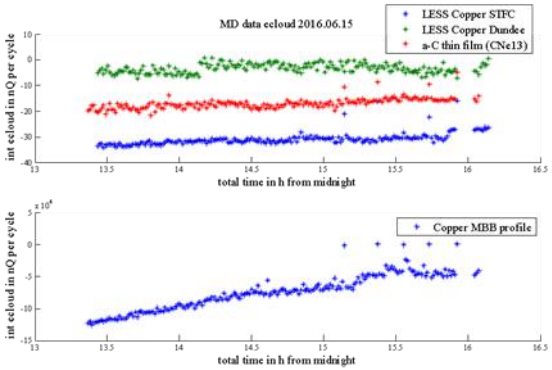


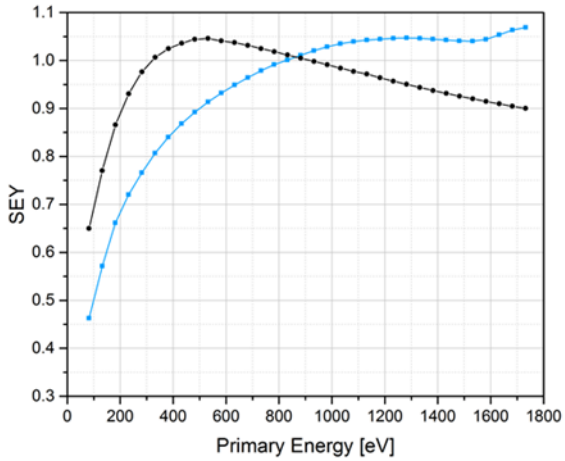


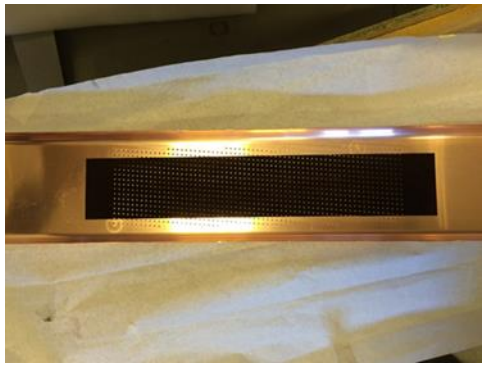
IMG_4269.MOV

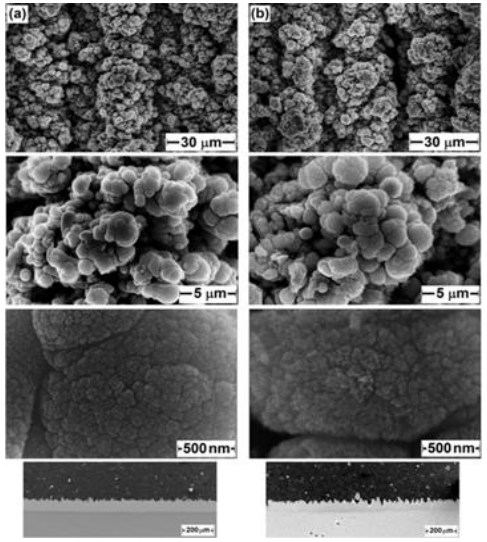
- SPS liner as test sample has been laser treated
- Two areas of 40 x 490 mm^2 was treated with conditions above

First accelerator test of vacuum components with laser-engineered surfaces for e-cloud mitigation (Physical Review Accelerators and Beams)



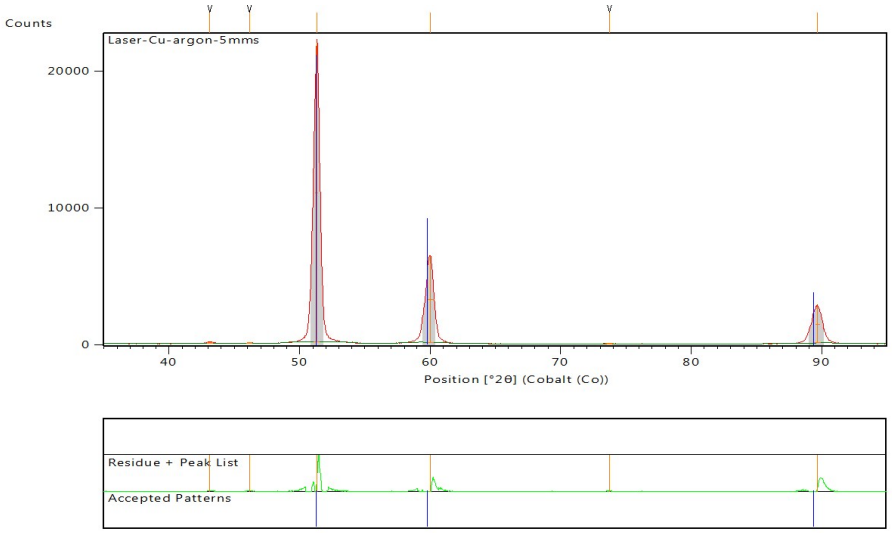






- Electron cloud mitigation based on LASE has been successfully demonstrated in particle accelerator for the first time
- SEY < 1 can be consistently achieved for practical implementations on technical surfaces.
- The e-cloud induced by the SPS proton beam was suppressed as efficiently as by the a-C coating
- The results also show that the LASE induced structure are robust, highly reproducible and scalable.

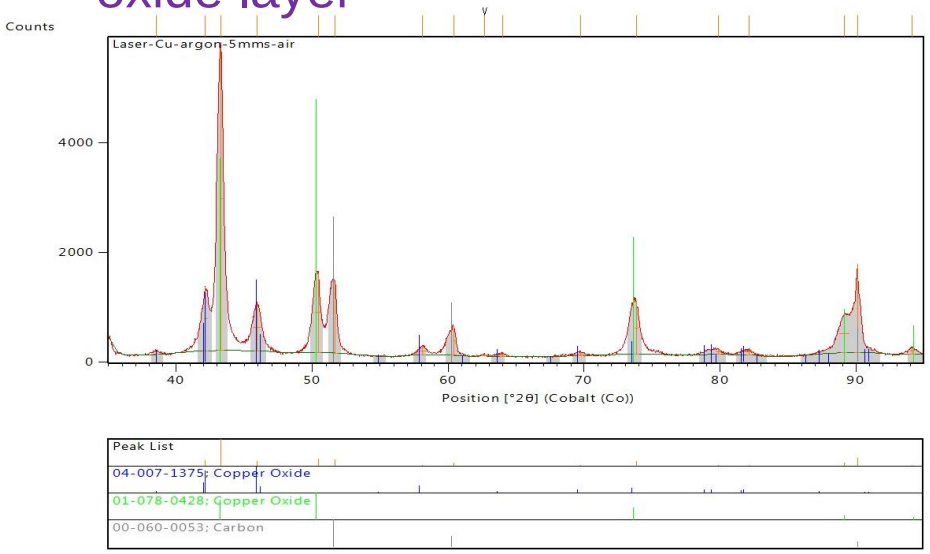
Effect of Process Atmosphere



•XRD of Cu laser ablated in Ar atmosphere

•LASE in AR atmosphere inhibit the formation of oxide layer

•LASE I air atmosphere results in an stable detectable by XRD oxide layer

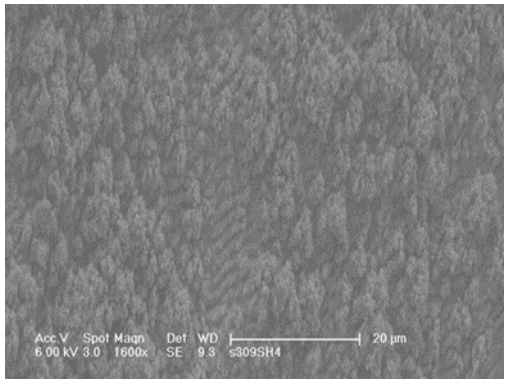


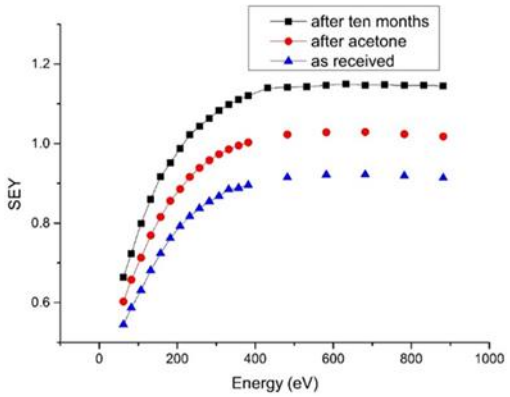
•XRD of Cu ablated in Air

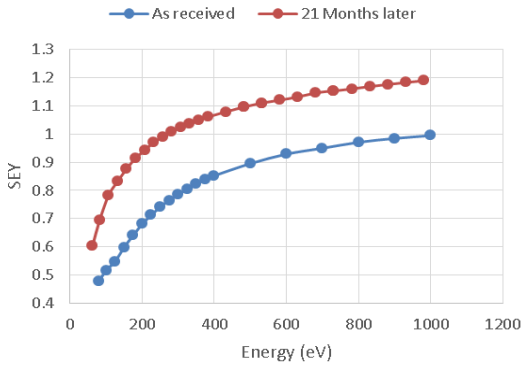
Effect of Aging on SEY

Sample	Date	pulse duration/ ps	Spot/ μ m	Scan speed/ mms^{-1}	wave length/ nm	Pitch spacing/ μ m	Repetition/ kHz	Power/ W
#1	2016.02.24	5	15	30	1064	5	1.25	5

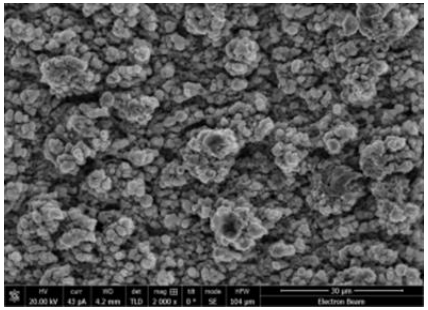
Cu 335nm laser 5μm pitch 90mm/s





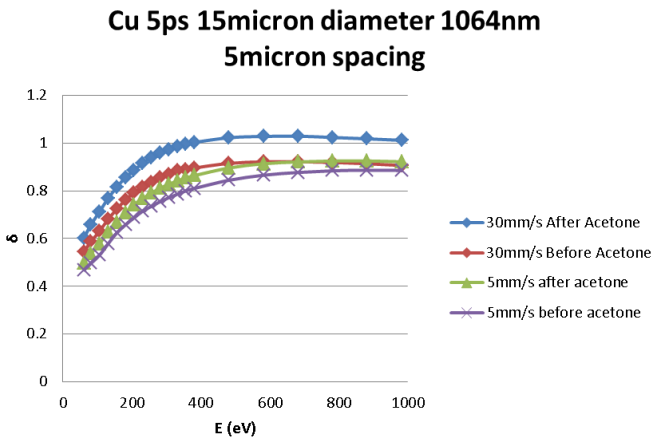


Conditions	as reveived	after acetone	ten months later
δ_{max}	0.92	1.03	1.15
E_{max} (eV)	682	682	632

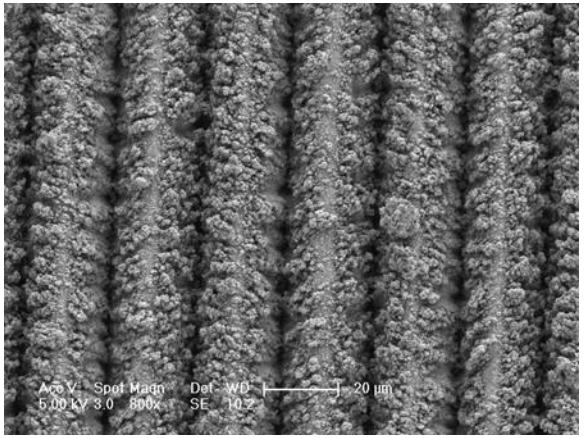


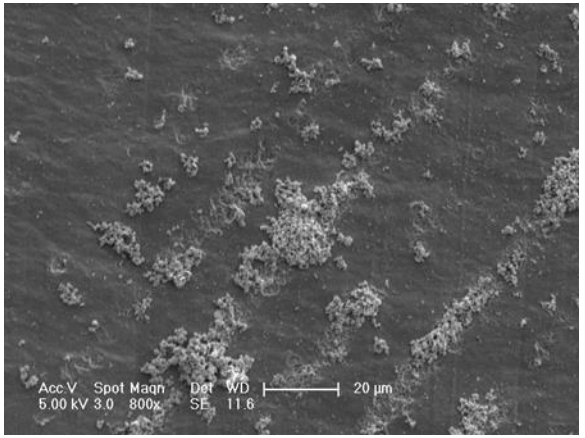
- The increase in SEY is attributed to the growth of hydrocarbon on the surface which also contribute to super hydrophobicity of laser ablated surfaces

Effect of Acetone and ultrasonic bath on SEY



	Cu 2p	O 1s	C 1s	N 1s
30 mm/s before acetone	20.7	41.9	0	37.5
30 mm/s after acetone	28.8	55.5	15.7	0
5 mm/s before acetone	45.9	54.4	0	0
5 mm/s after acetone	40.7	49.9	9.4	0





The increase in SEY can be attributed to two factors:

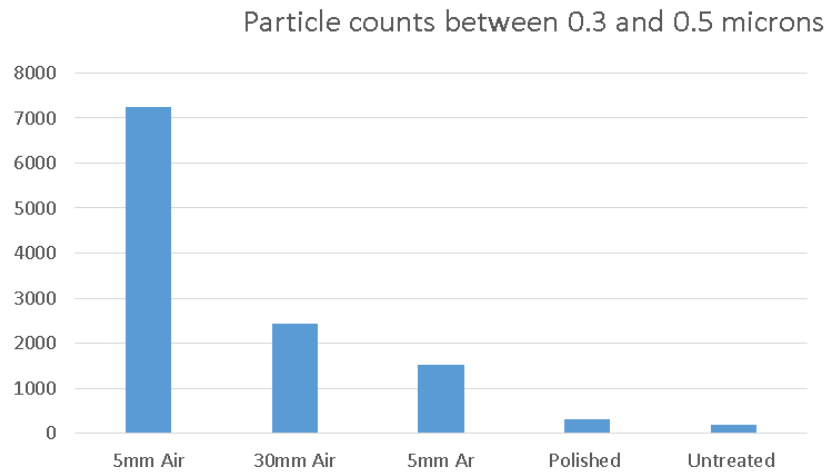
- Loss of particulate as can be seen on the foil left behind after ultrasonic bath cleaning
- Built up of hydrocarbon on the surface afer solvent cleaning

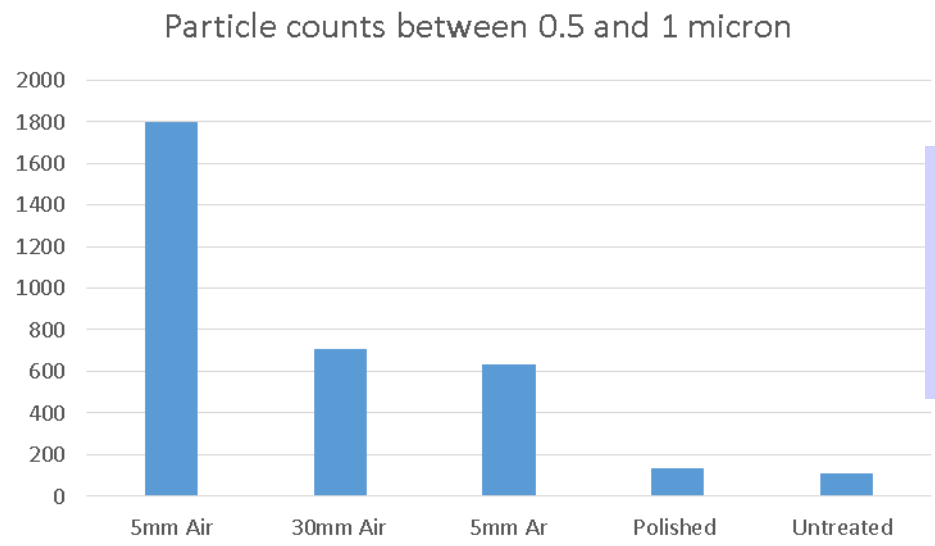
Particle counts

- Measurements taken with 0.5 bar of filtered N2 onto sample 50 mm away from the sample
- The measurements were taken for 1 minute and the counts were averaged over 3 measurements

Particle counts

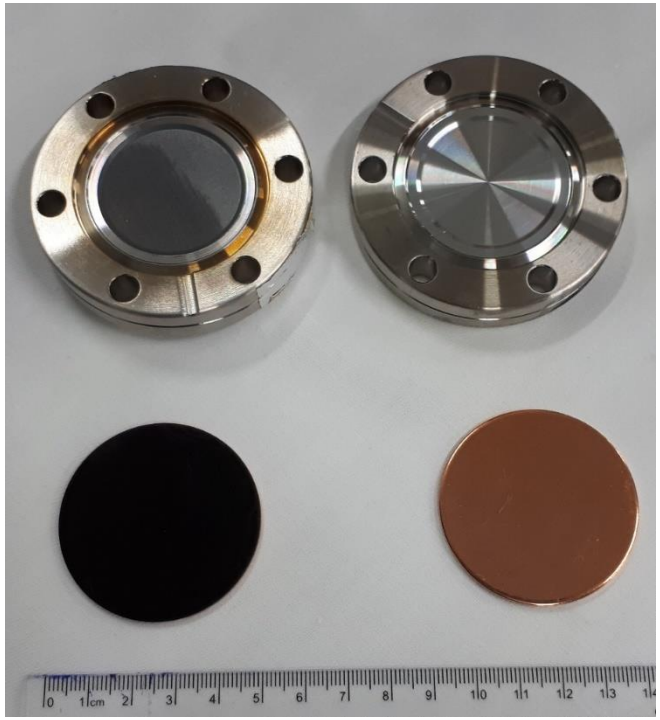
Largest particle size measured was 1 micron
The sample prepared in Ar had the lowest counts





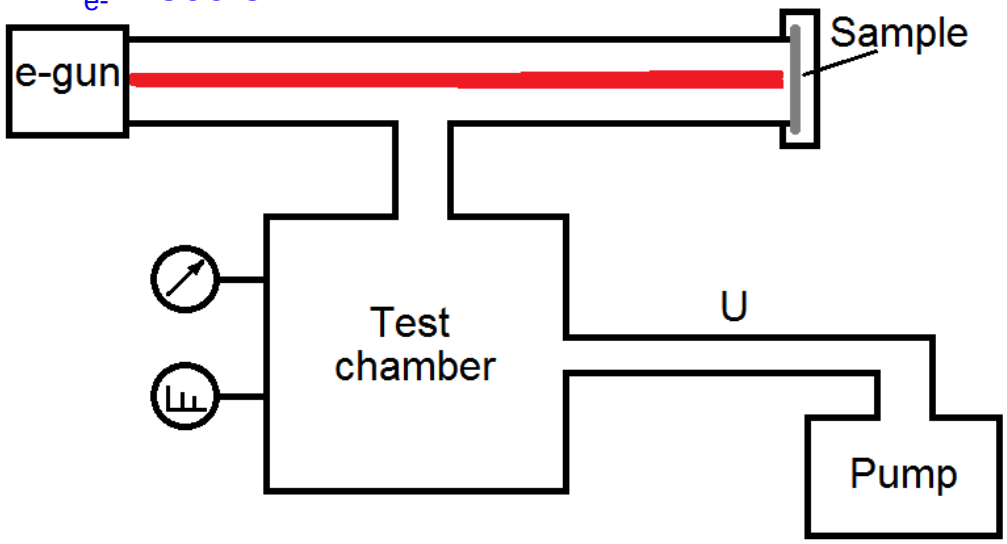
Polished and untreated samples were used as reference
The detector could measure particles up to 25 microns

LASE PARAMETERES FOR ESD



Samples were tested after a bakeout to 200°C for 24 h:

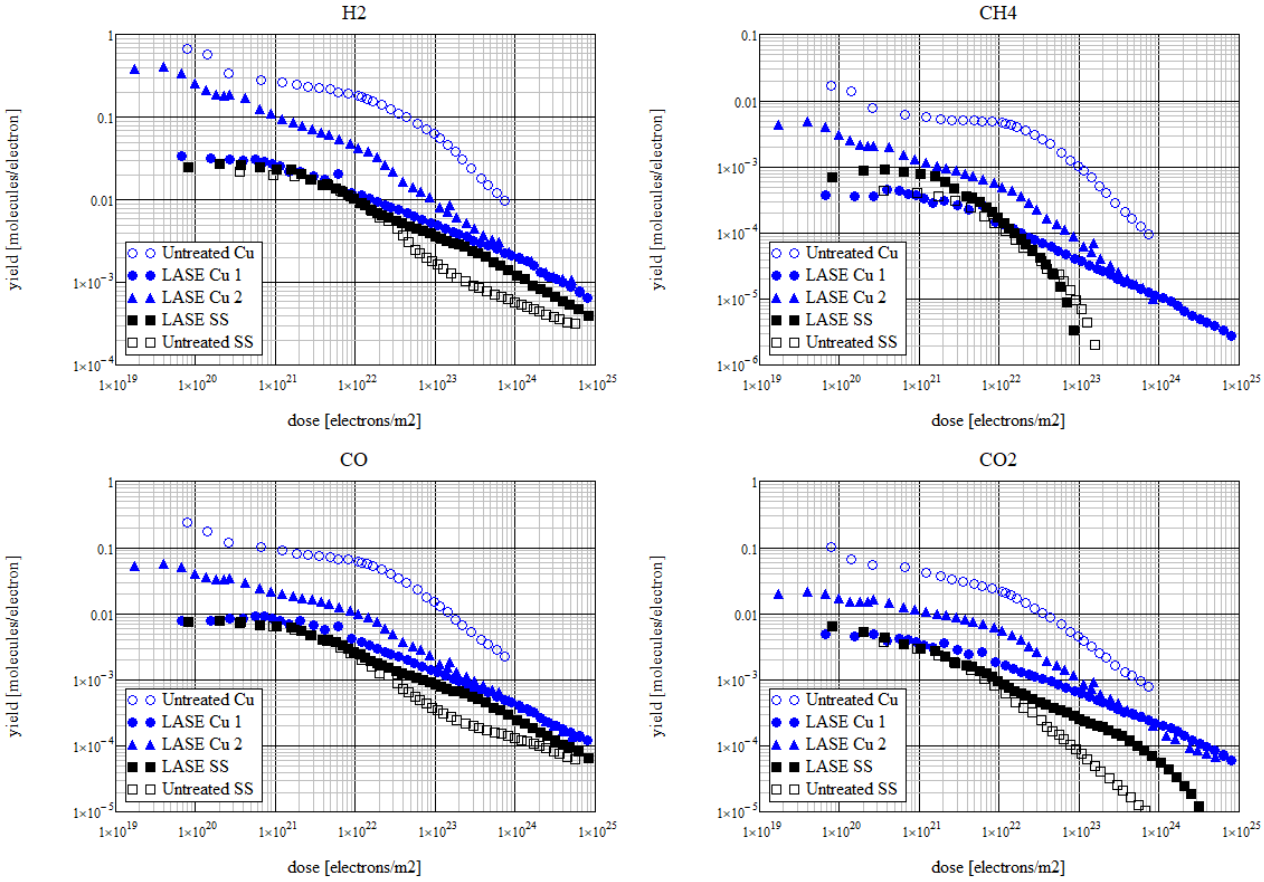
- 316LN stainless steel flanges DN40:
  - with LASE: : 30 W, 600 KHz, 0.1 ns, 40 mm/s , 10 **µm**
  - untreated
- Cu blank gaskets ∅48 mm:
  - LASE-1 treated in: 20 W, 60 KHz, 2 ns, 40 mm/s , 10 **µm**
  - LASE-2 treated in : 30 W, 40 KHz, 2 ns, 40 mm/s , 10 **µm**
  - Untreated (2 samples)
- E_{e-} = 500 eV



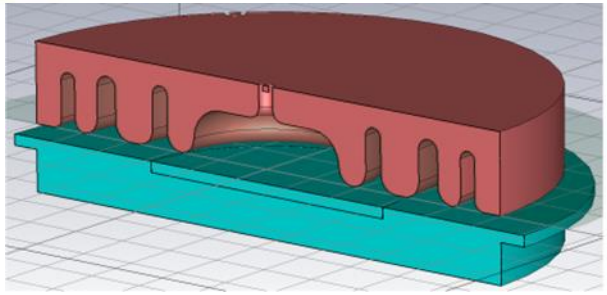
Electron Stimulated Desorption

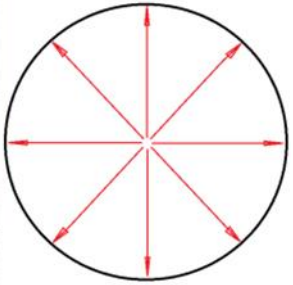
Main results:

- Copper sample with LASE demonstrated lower ESD yields than untreated sample
- ESD for 316LN stainless steel with LASE is comparable with an untreated sample.

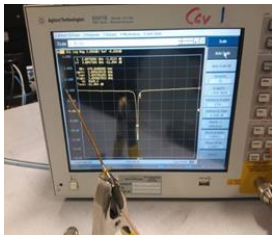


Surface resistance measurements





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

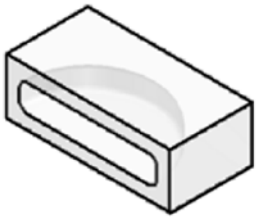


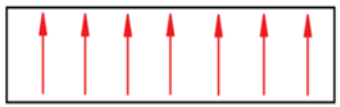
Test cavities (3.9 and 7.8 GHz):

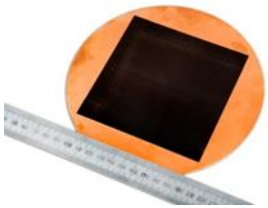
- The simulation results obtained with Microwave Studio
- Fabricated from Al.
- 3 choke cavity operating in TM_{010} mode, has circular H field distribution hence Induces radial current.
- Half pill box cavity operating in TM_{110} mode, has strong transverse H field hence induces axial electric current

Samples:

- 3 of 100-mm^2 laser treated copper surface







Dielectric Resonator – Surface Resistance Measurement Basics

- Brass cylinder
- Samples replace upper and lower plates
- Operating in the TE_{011} mode

  Insensitive to electrical contacts to the metallic enclosure

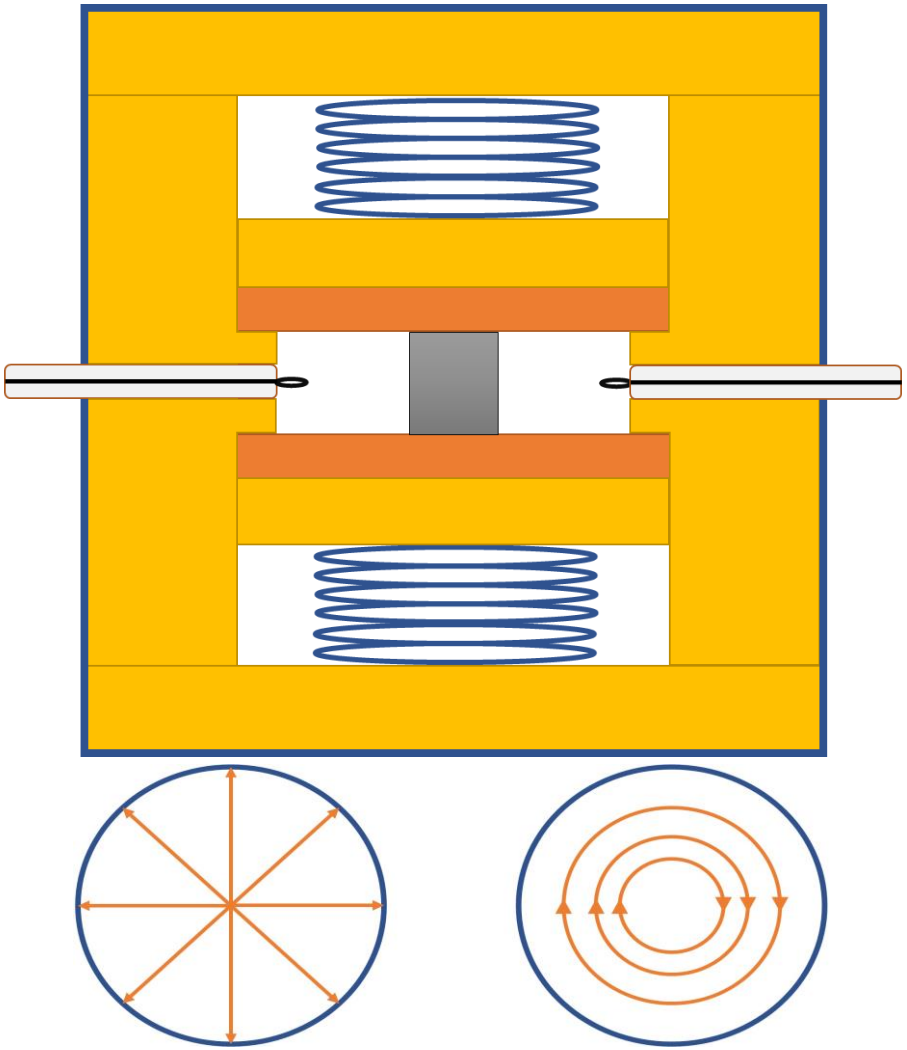
  Rutile

  Resonance frequency at 77 K is 8.0 GHz
- The unloaded Q-factor is given by

$$\frac{1}{Q_0} = \sum_i \frac{R_{S_i}}{G_i} + p \cdot \tan(\delta)$$

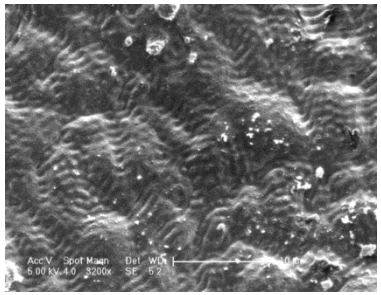
$R_{S_i} = Surface\ resistance$ $\quad$ $p = Filling\ factor$

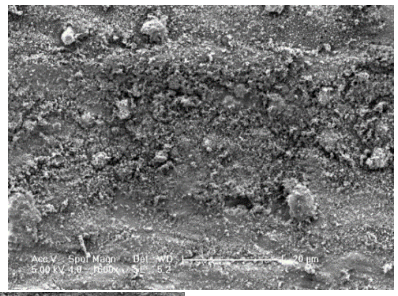
$G_i = Geometrical\ factor$ $\quad$ $\tan(\delta) = Loss\ factor$

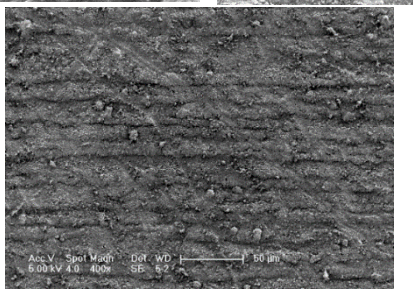


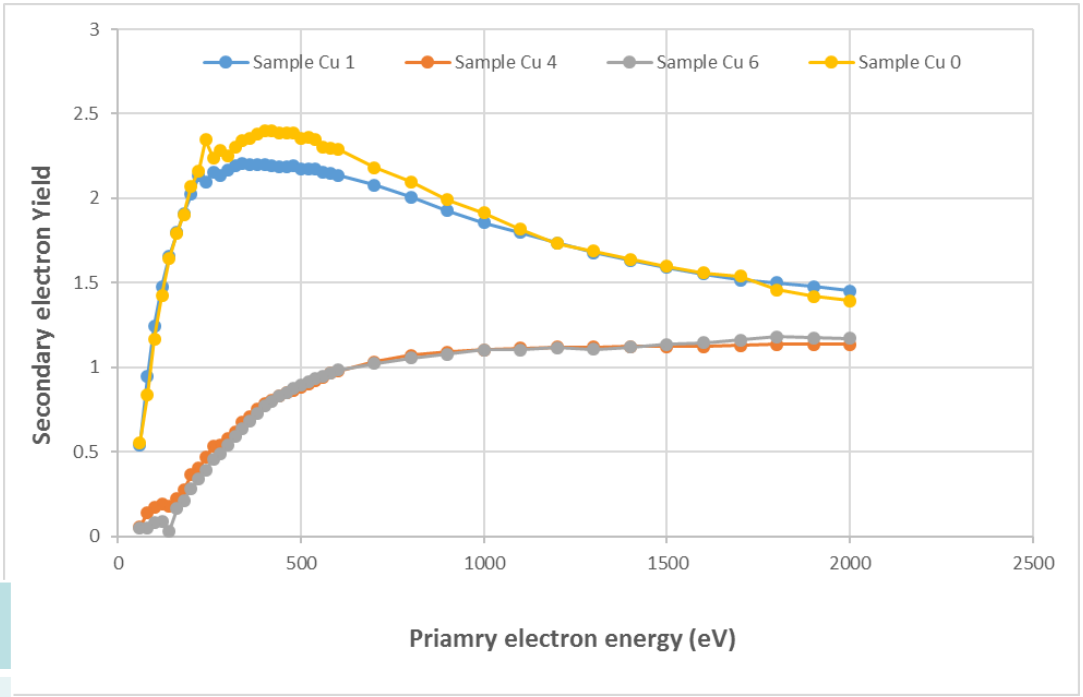
SEY AND SURFACE RESISTANCE OF LASE TREATED COPPER

Sample	Material	λ (nm)	Average Power (W)	Pulse length (ns)	Frequency (KHz)	Pitch (µm)	Beam size (µm)	Power per pulse (µJ)	Fluence per pulse (Jcm^{-2})	Speed (mms-1)
1	Cu	1063	30	0.15	600	10	15	50	28	40
4	Cu	1063	20	2	40	50	15	500	280	40
6	Cu	1063	20	2	40	10	15	500	280	40
7	Cu	0	0	0	0	0	0	0	0	0





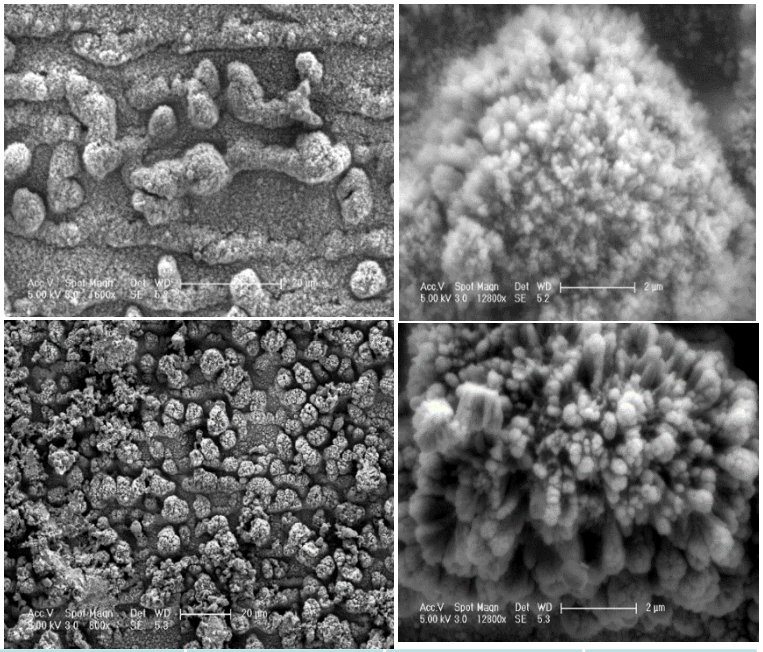


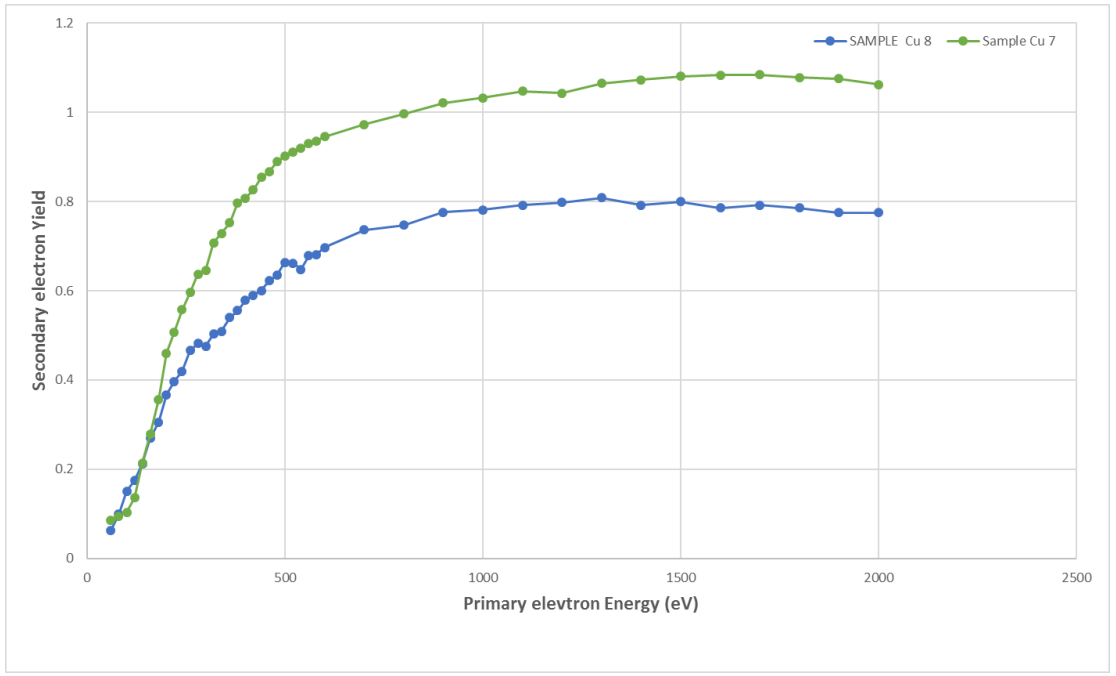


	Sample 1	Sample 4	Sample 6	Untreated
R_{SRT} [mΩ]	25.527	24.940	25.100	26.035
R_{S77K} [mΩ]	10.792	9.814	9.697	10.709

SEY AND SURFACE RESISTANCE OF LASE TREATED COPPER

Sample	Material	λ (nm)	Average Power (W)	Pulse length (ns)	Frequency (KHz)	Pitch (μm)	Beam size (μm)	Power per pulse (μJ)	Fluence per pulse (Jcm^{-2})	Speed (mms-1)
7	Cu	1063	30	0.15	600	10	15	50	28	40
8	Cu	1063	30	0.15	600	5	15	50	28	40

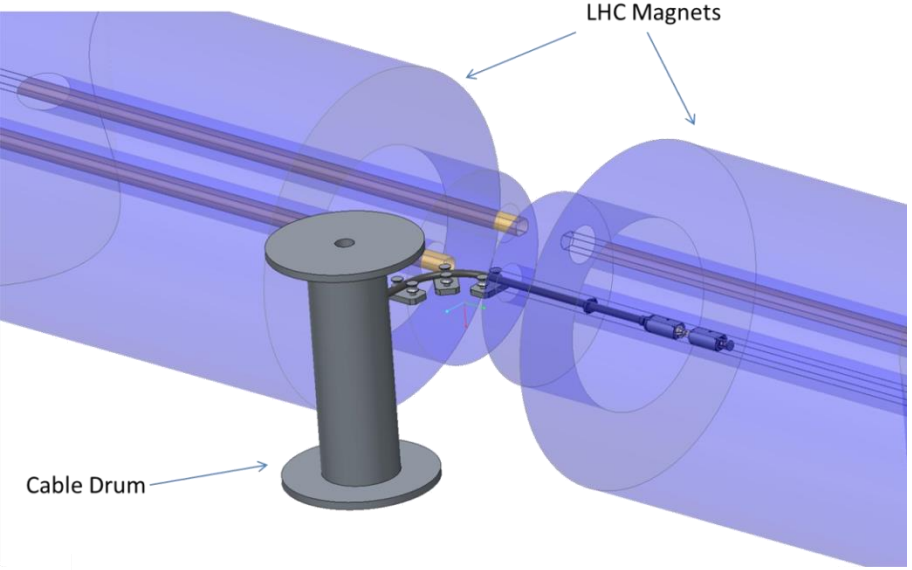


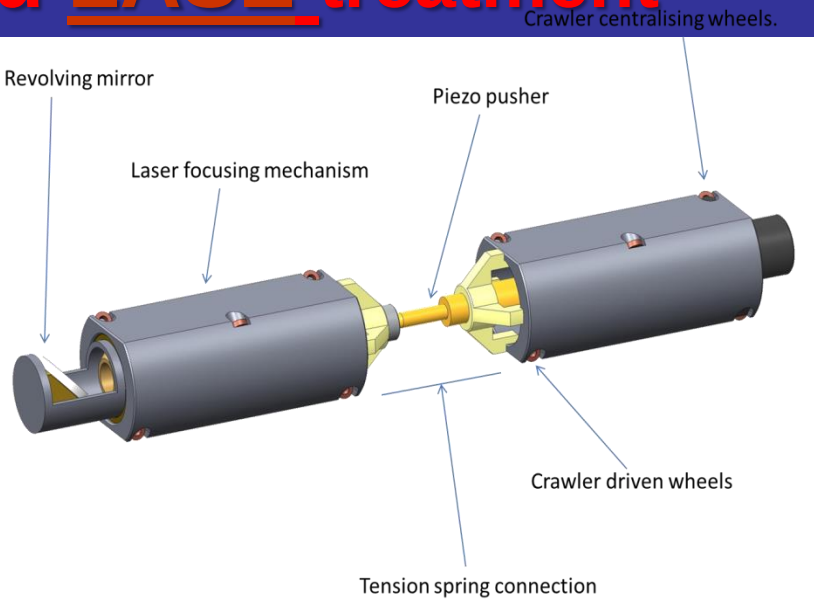


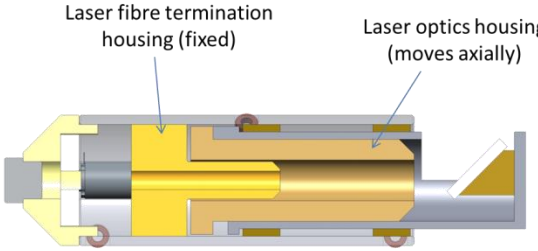
	Condition 1	Condition 2	Untreated
R_{SRT} [mΩ]	28.516	39.431	25.175
R_{S77K} [mΩ]	14.091	25.335	10.913

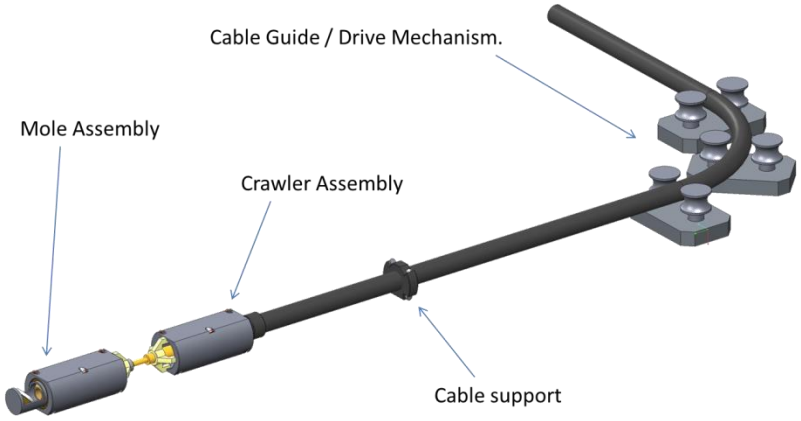
- An increase of 14% for SEY of 1.1 and 60% for SEY of 0.8

Technology for in situ LASE treatment

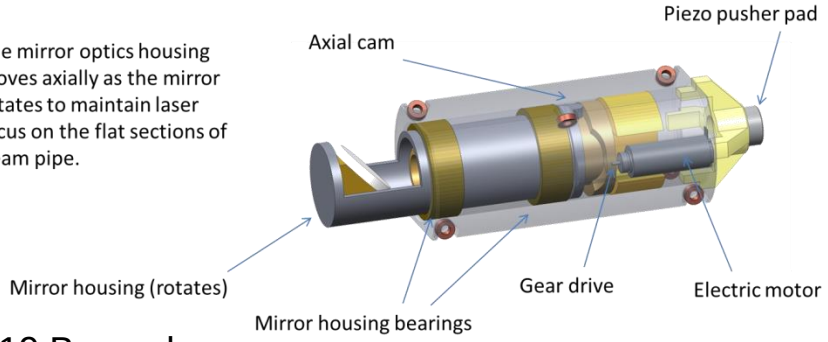








The mirror optics housing moves axially as the mirror rotates to maintain laser focus on the flat sections of beam pipe.



Summary: LASE properties

SEY:

- **LASE** on a metal surface is a very viable solution for reducing the $\delta < 0.6$.
- Even the initial (unconditioned) $\delta = 0.93$ for SS is low enough to suppress e-cloud in, e.g., the SPS, LHC, HL-LHC, ILC or FCC, etc.
- SEY is reduced by a combination of two geometrical effects
  - due to the grooves which traps the electrons by multiple side wall collision (confirmed by measurements and modelling) and
  - The Nano-sphere which are superimposed on top of the walls of the groove (confirmed by measurements of metal powder and remelting of the Nano sphere)
  - A further reduction can be achieved by the surface chemistry change during a bakeout and/or bombardment with electrons, ions and (very likely) photons .

Summary LASE properties

Surface resistance with LASE

- Lase surface resistance is strongly dependent on the type of surface created by laser parameters for a specific material.
- measured values of surface resistance at 3.9, 7.8 and 8 GHz at room and LN temperature show that SHALLOW groove type with superimposed NANO-SPHERES is a preferable solution to minimise the increases in the surface resistance (at worst 60% increase) while having SEY of 0.8.

Summary LASE properties

Electron Stimulated Desorption

LASE on Copper has lower ESD than untreated copper

LASE on SS has comparable ESD with untreated SS

Summary: LASE technology

- The technique can easily be applied to existing vacuum surfaces where the improvement has to be done *in-situ* with minimum disturbance to the beam line.
- **LASE can be done** in air at atmospheric pressure; therefore the actual cost of the mitigation is considerably lower, a fraction of the existing mitigation processes.
- The process is also readily scalable to large areas.