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Reduction of Secondary Electron Yield For e-Cloud Mitigation by Laser Ablation Surface Engineering (LASE)

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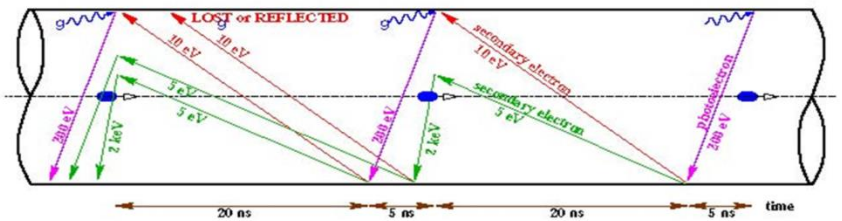
Philippe Goudket (ASTeC)

Lewis Gurran (ASTeC)

ASTeC

Micronanics Laser Solutions Centre

Main Goal

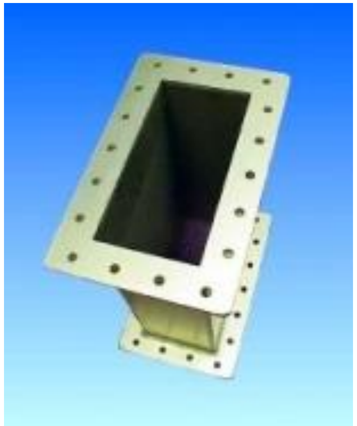


Curtesy to
F. Ruggero

Mitigation of beam-induced electron cloud built-up in a particle accelerator beam chamber due to photo- and secondary electron emission to reduce

- beam losses
  - beam instability
    - reduction in beam life time
      - heat loads on cryogenic vacuum chamber

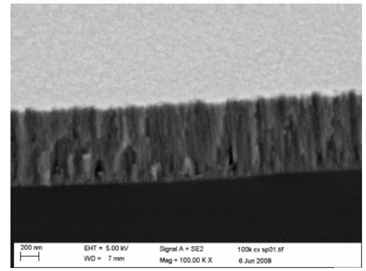
Multipactor mitigation in RF wave guide and space-related high power RF hardware.

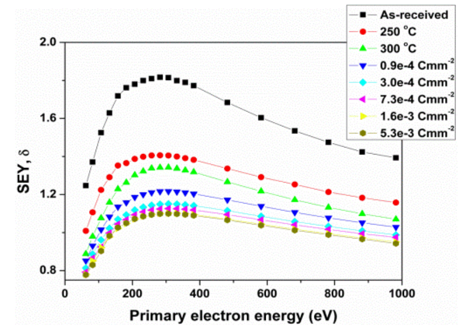


Existing Mitigation method

•*By Passive means:*

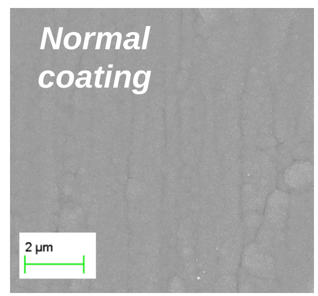
•Low SEY Material (Cladding)
•Low SEY coating(single/multiple step)
•Grooved Surfaces (coated /uncoated)
•Special shape of vacuum Chamber
  An antichamber allows reducing PEY

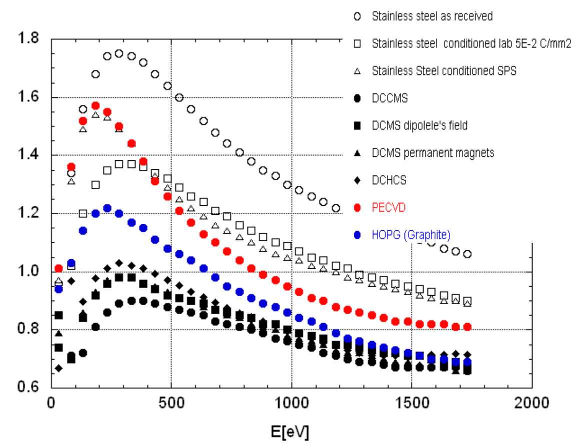




•Advantages

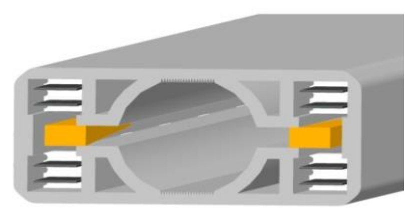
- No Controllers,
- No power supplies,
- No cables





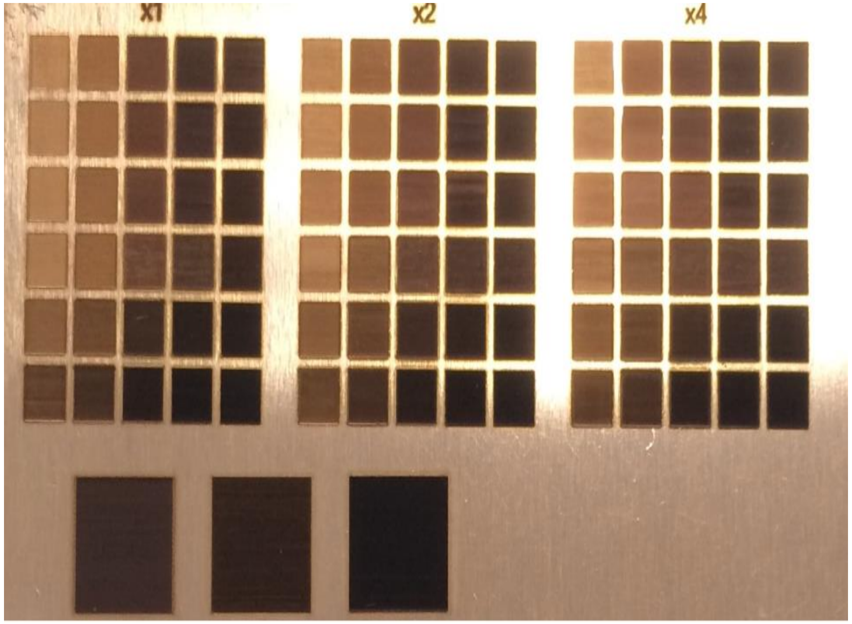
•Disadvantages

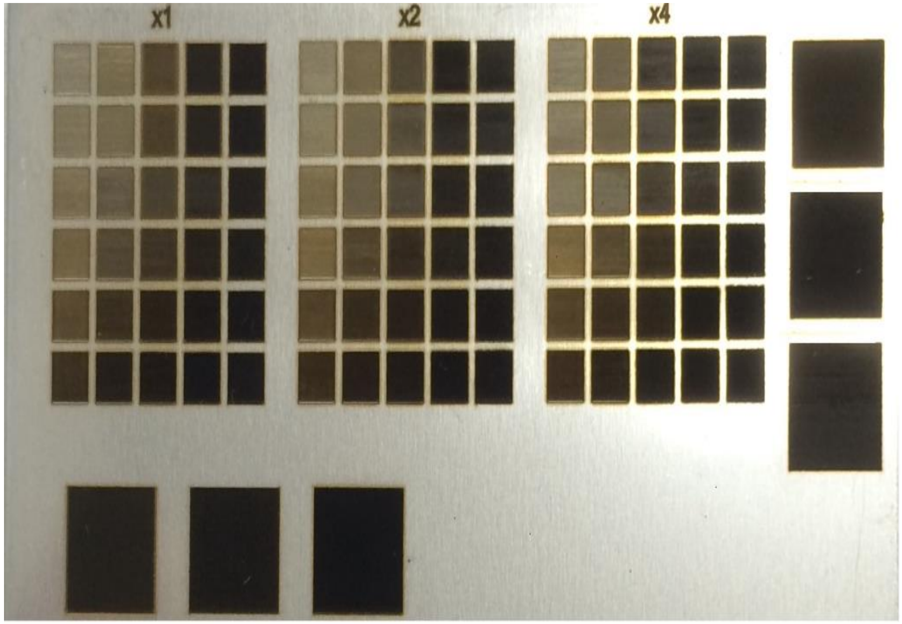
- In-vacuum deposition
- Difficult to apply on existing facilities
- Durations of surface treatments
- Cost



Introducing a new technology

- Recent discovery of ASTeC:
- Laser treatment of metals in air or noble gas atmosphere





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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.
- Hierarchical structures containing both micro- and nanostructures can be created in a single machining step
- 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.

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Parameters involved in Micromachining

•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

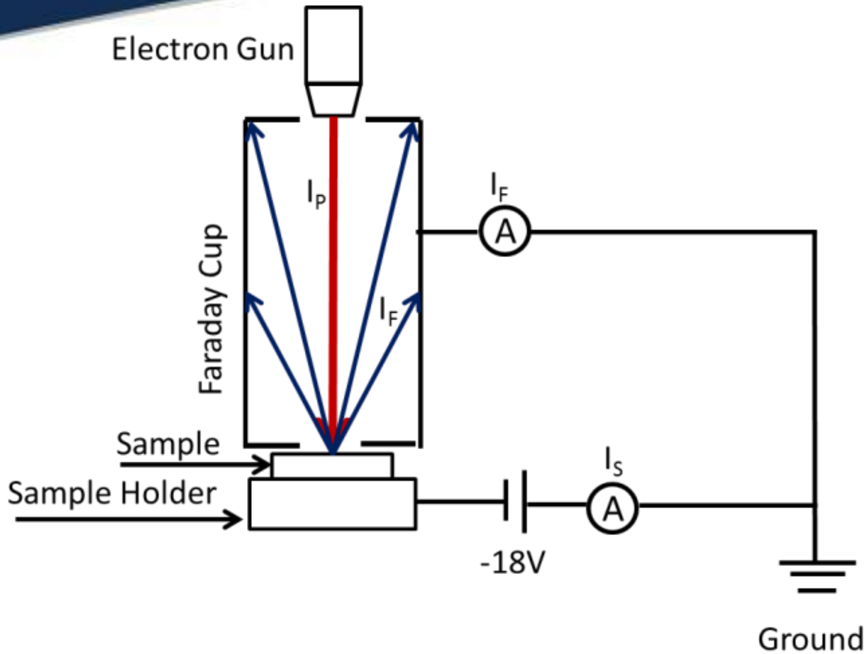
4) Process parameters:

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

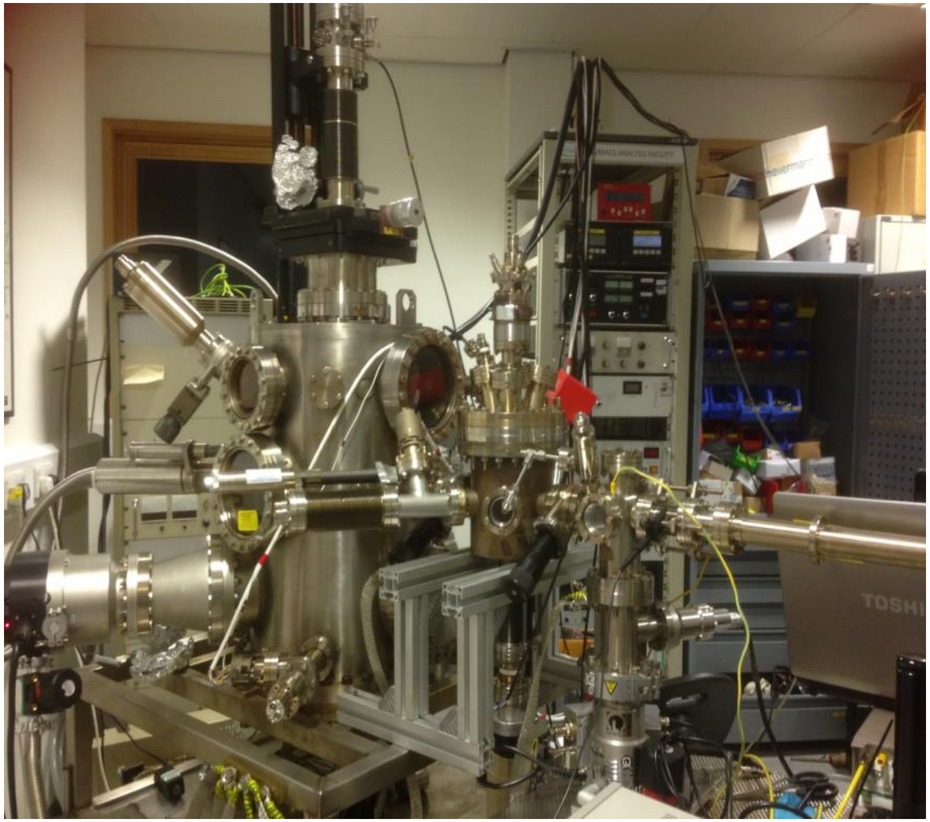
Evaluation of LASE for particle accelerator application

- SEY measurements
- Surface chemistry
- Geometrical factor
- Surface resistance

SEY Measurements



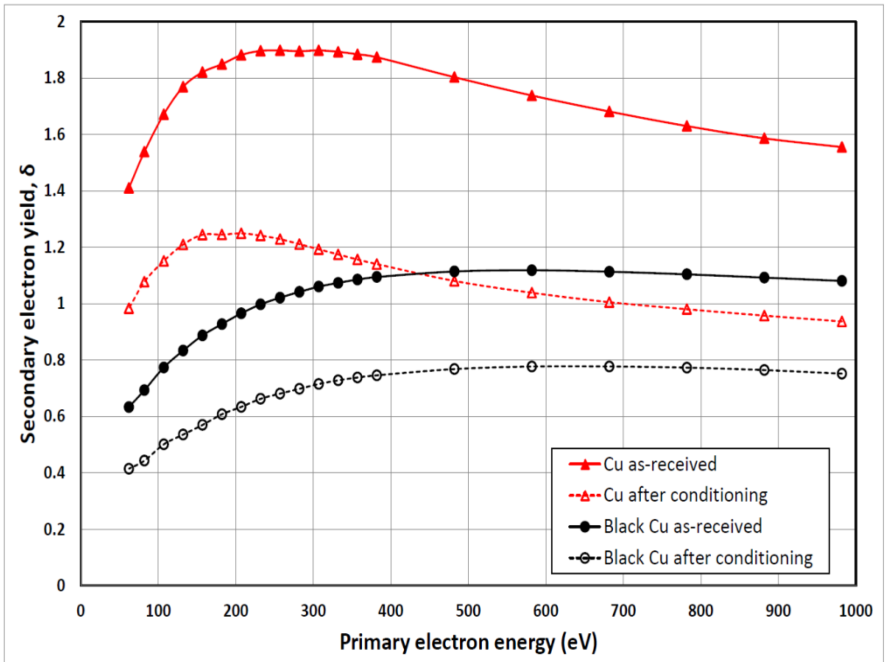
$$\delta = \frac{I_F}{I_P} = \frac{I_F}{I_F + I_S}$$

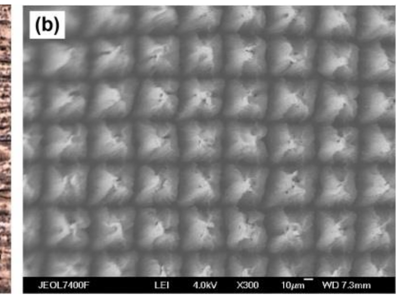


I_P is the primary beam current
I_F is the secondary electron current including elastic and inelastic processes, measured on the Faraday cup
I_S is the currents on the sample

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

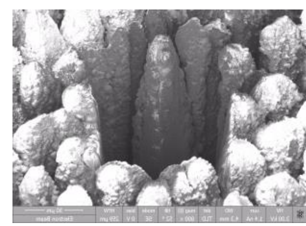
SEY of Cu as a function of incident electron energy

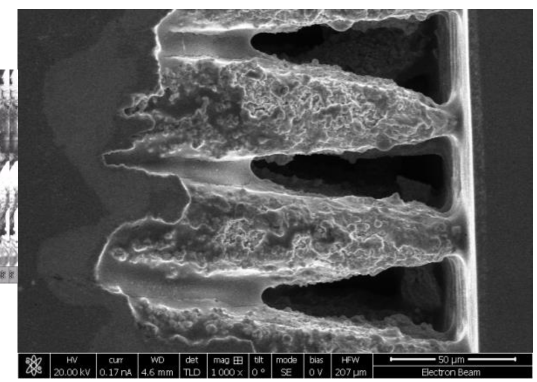




Untreated

Laser treated



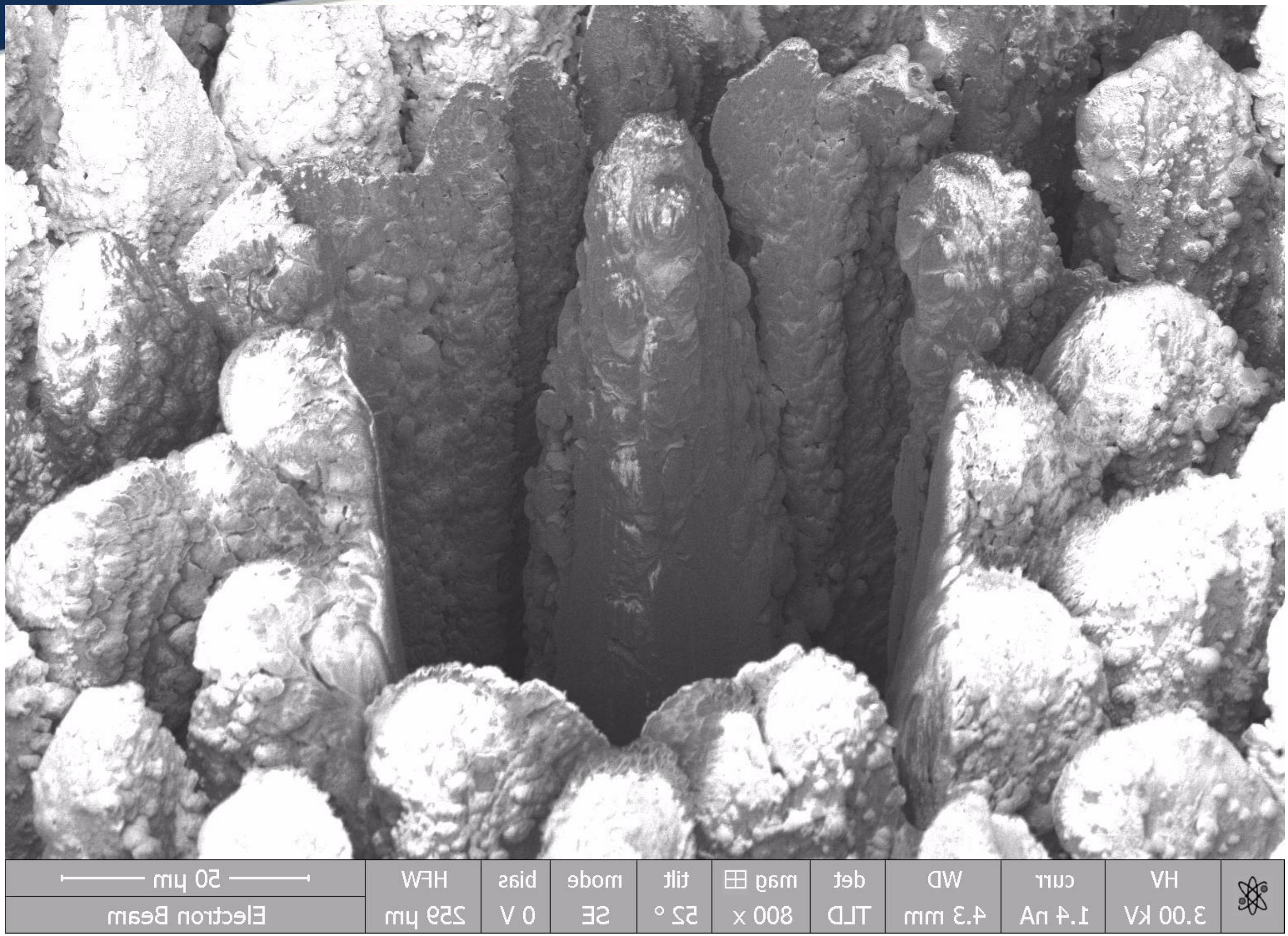


Original data June 2014
Applied Physics Letters 12/2014; 105(23): 231605

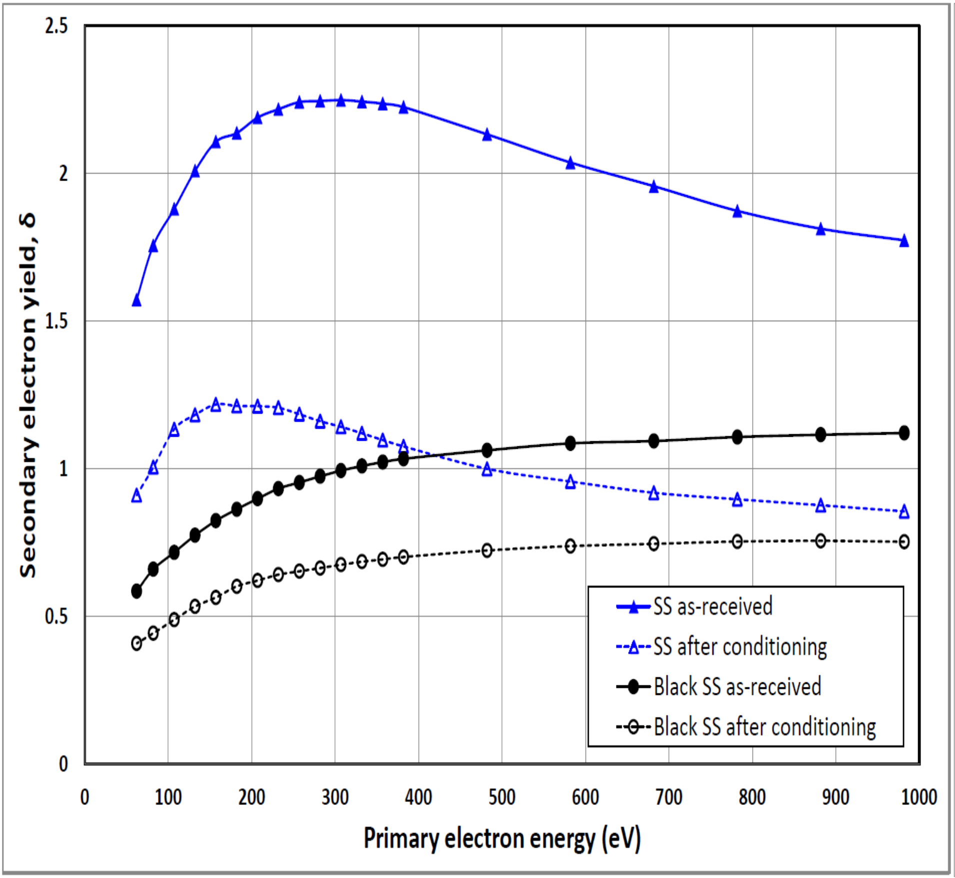
For Copper

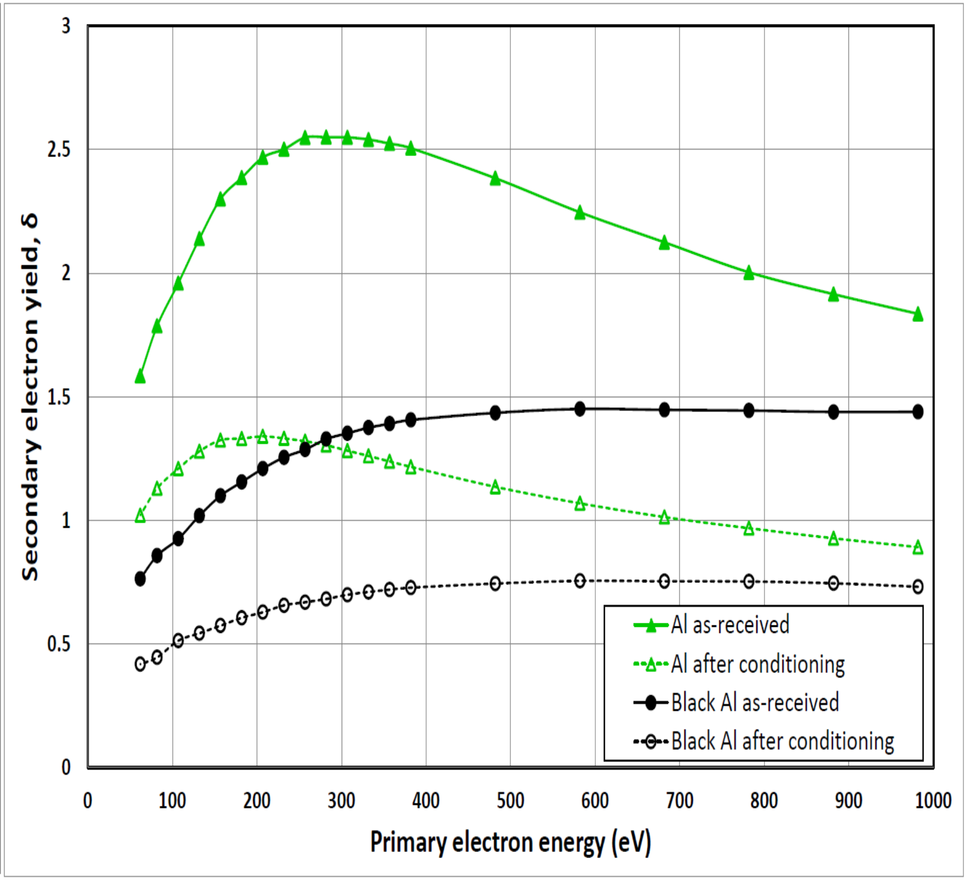
Nd:YVO4 Laser

- Max Average Power = 10 W at λ = 532 nm
- Pulse length =12 ns at Repetition Rate = 30 kHz
- Argon or air atmosphere
- Beam Raster scanned in both horizontal and vertical direction


HV
3.00 kV
curr
1.4 nA
WD
4.3 mm
det
TLD
mag
800 x
tilt
52 °
mode
SE
bias
0 V
HFW
259 µm
50 µm
Electron Beam

SEY of SS and Al as a function of incident electron energy





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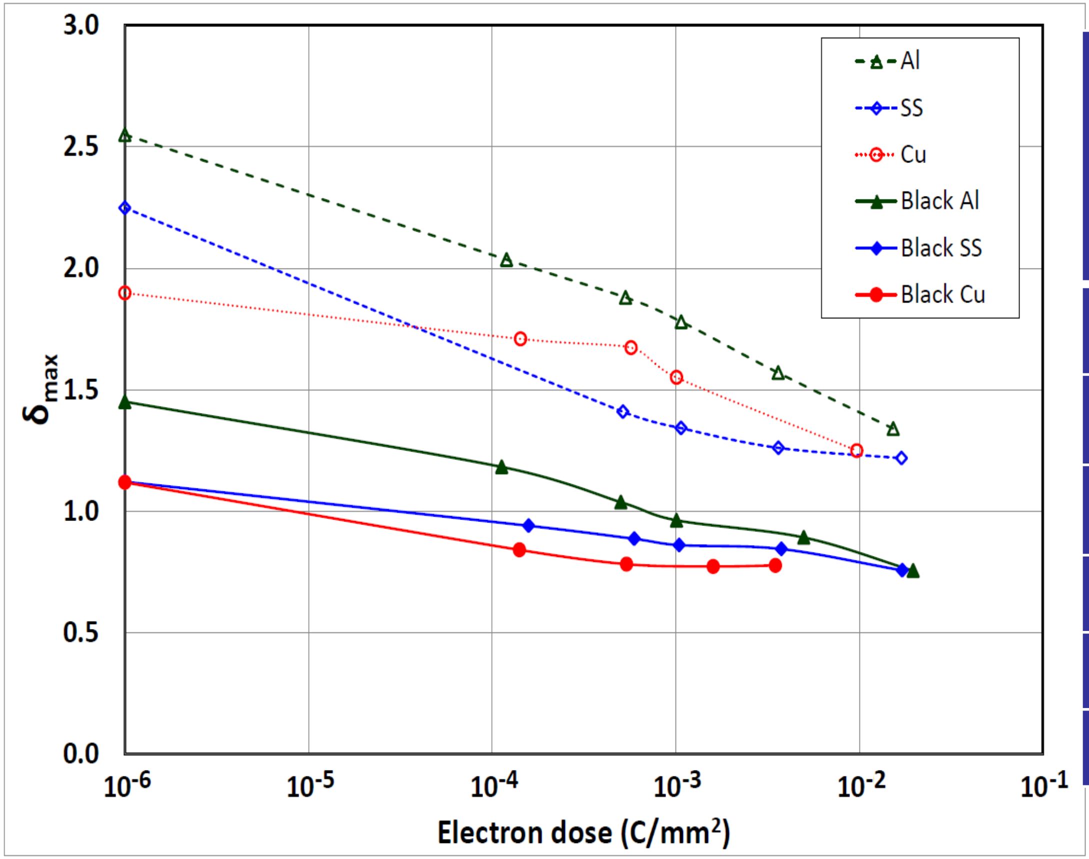
δ_{max} as a function of electron dose for Al, 306L SS and Cu

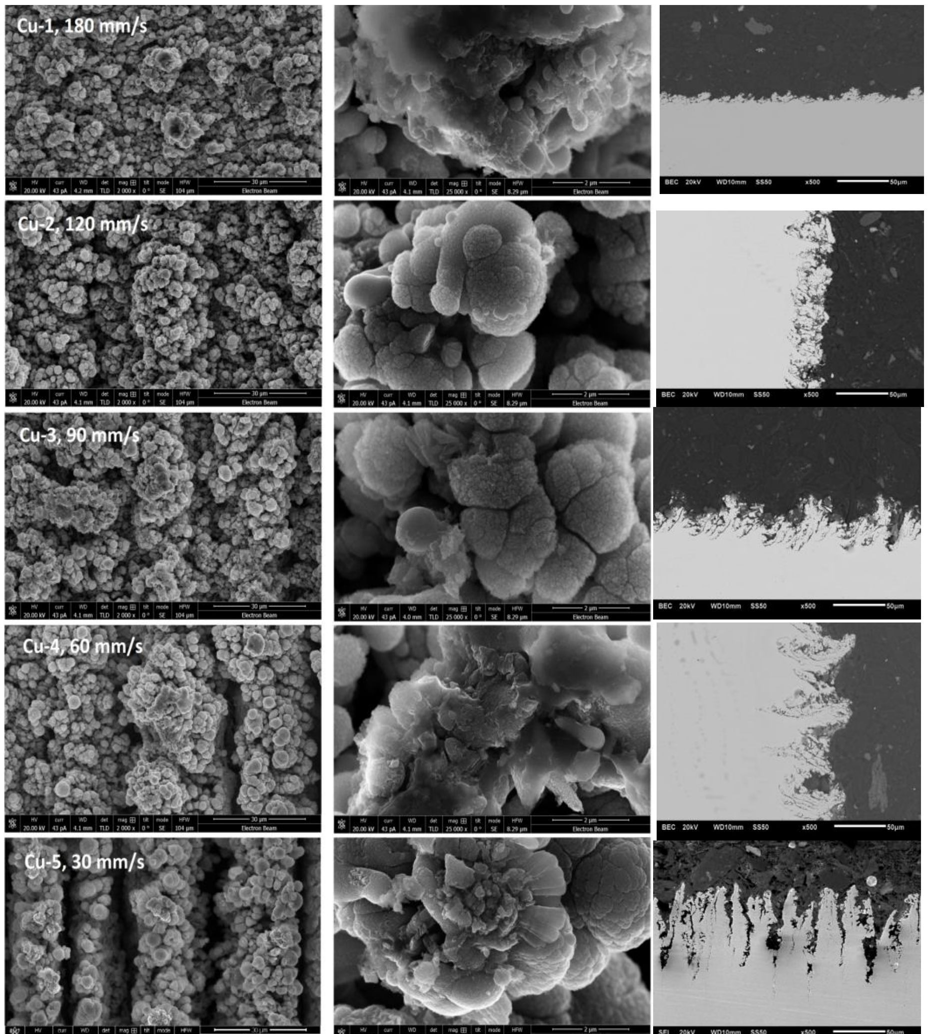


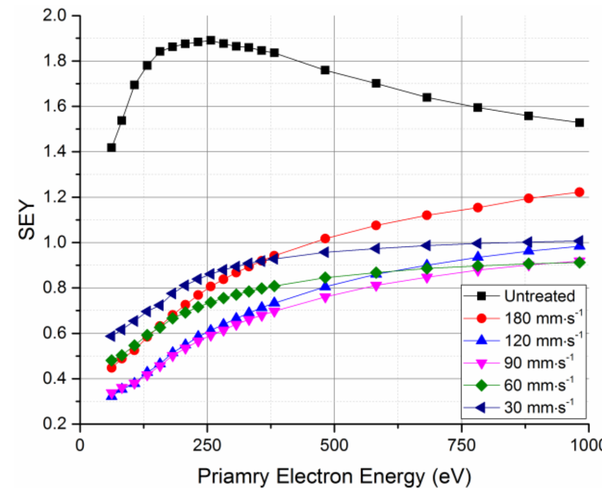
Sample	Initial		After conditioning to Q_{max}		
	δ_{max}	E_{max} (eV)	δ_{max}	E_{max} (eV)	Q_{max} ($C \cdot mm^{-2}$)
Black Cu	1.12	600	0.78	600	3.5×10^{-3}
Black SS	1.12	900	0.76	900	1.7×10^{-2}
Black Al	1.45	900	0.76	600	2.0×10^{-2}
Cu	1.90	300	1.25	200	1.0×10^{-2}
SS	2.25	300	1.22	200	1.7×10^{-2}
Al	2.55	300	1.34	200	1.5×10^{-2}

Reduction of δ_{max} after conditioning is attributed to change in surface chemistry due to electron-beam induced transformation of CuO to sub-stoichiometric oxide, and build-up of a thin graphite C-C bonding layer on the surface.

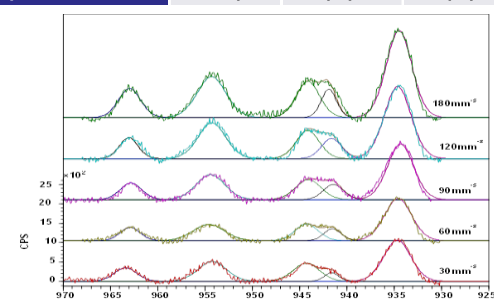
Effect of scan speed

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/cm^2)
1	355	3	15	25	40	10	30,60,90, 120, 180	75	42



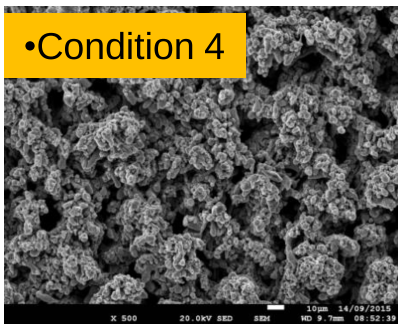


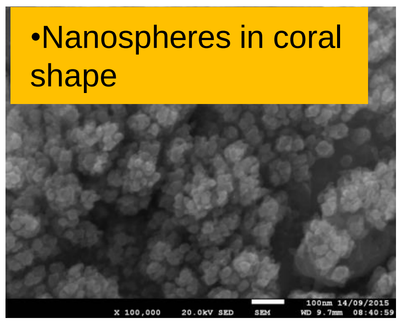
Sample	6	5	4	3	2
Scan speed (mm/s)	30	60	90	120	180
Groove depth (μm)	100	60	35	20	8
δ at E_p = 60 eV	0.6	0.5	0.3	0.3	0.4
δ at E_p =1000 eV	1.0	0.91	0.9	0.98	1.22

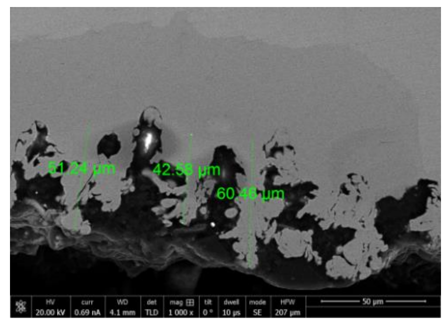


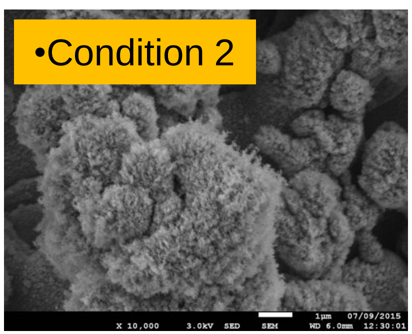
Effect of power and repetition rate

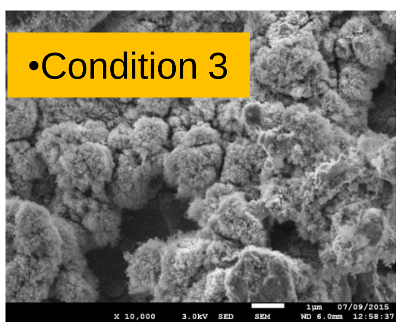
Laser treatment condition	λ (nm)	Average power (W)	Spot size (µm)	Pulse duration (ns)	Pulse repetition (kHz)	Pitch width (µm)	Scan speed (mm/s)	Energy per pulse (µJ)	Fluence (J/cm^2)
2	1064	1.9	25	70	2.5	20	125	760	154
3	1064	2.4	25	70	5.0	20	125	480	97
4	1064	3.6	25	70	10	20	30	360	73

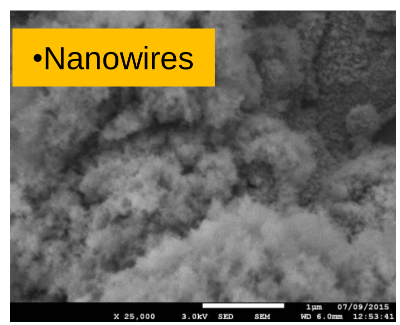


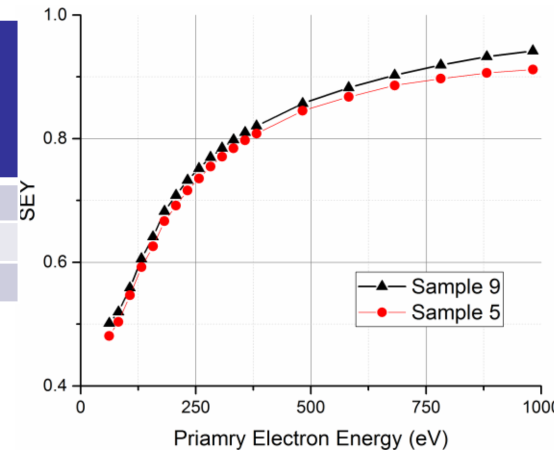


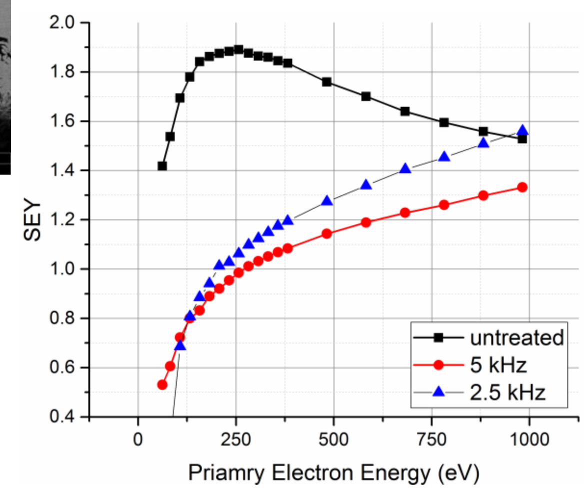






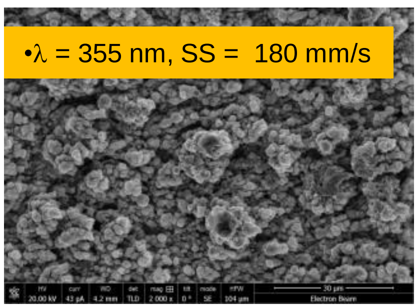


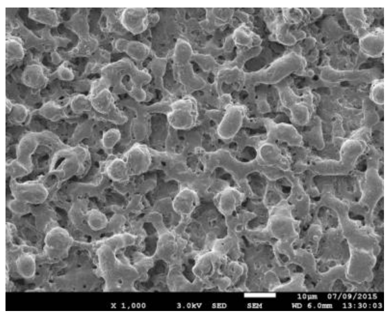


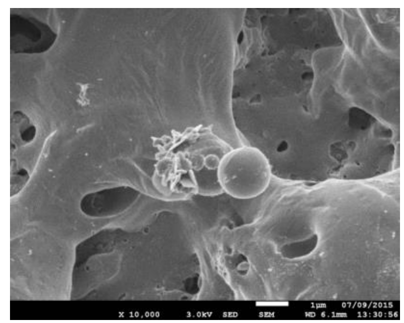


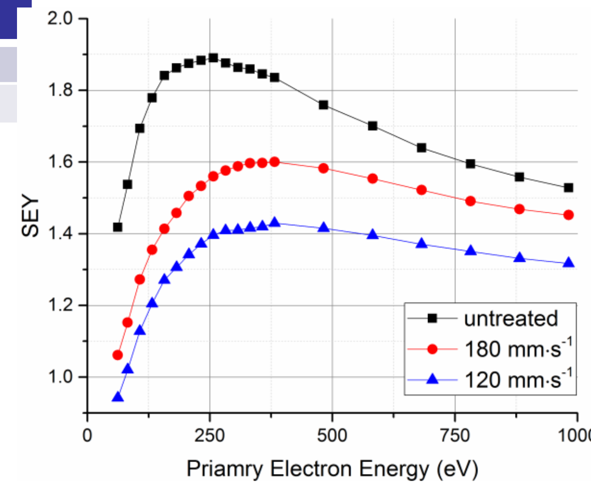
Importance of nano structure

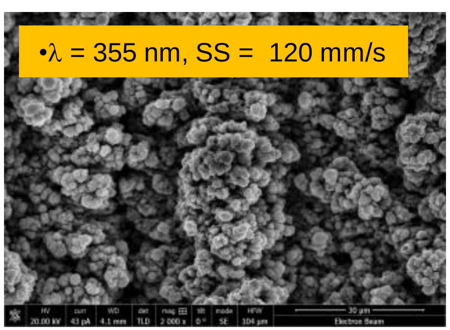
Laser treatment condition	λ (nm)	Average power (W)	Spot size (μm)	Pulse duration (ns)	Pulse repetition (kHz)	Pitch width (μm)	Scan speed (mm/s)	Energy per pulse (μJ)	Fluence (J/cm^2)
5	1064	3	25	70	20	10	500	150	30
6	1064	1	25	70	100	10	500	10	2

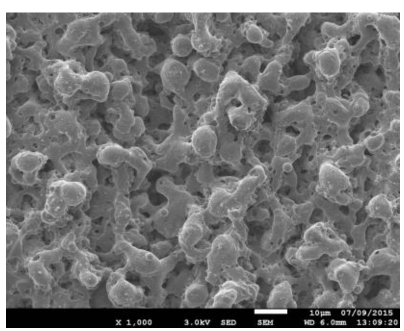


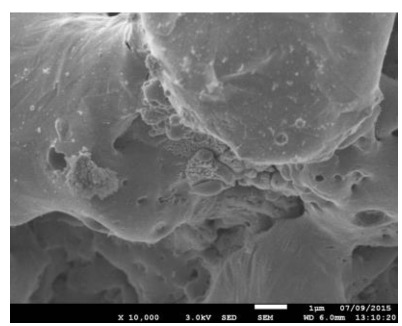










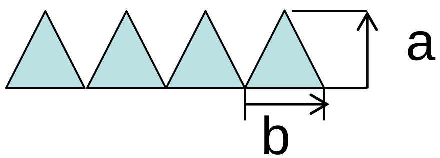


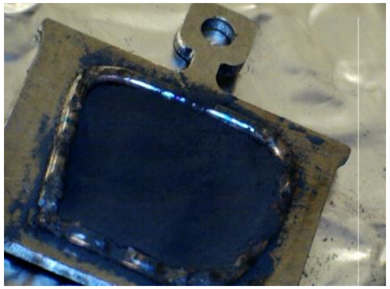
- No visible Nanostructure (due to re-melt)
- SEY resemble to untreated sample

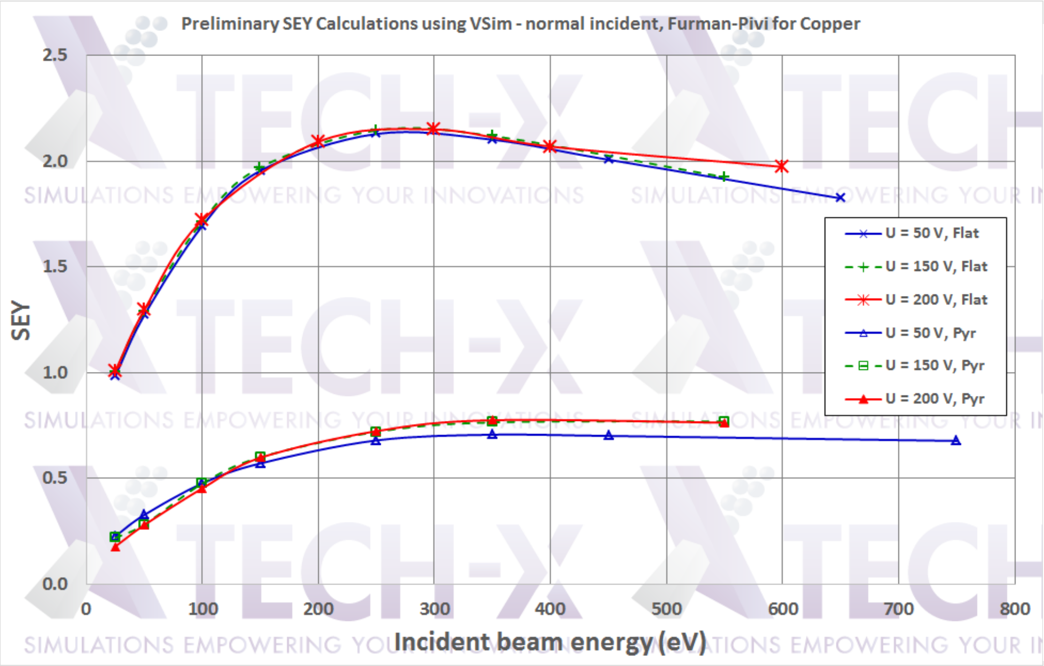
Validation of nano structure and grooves

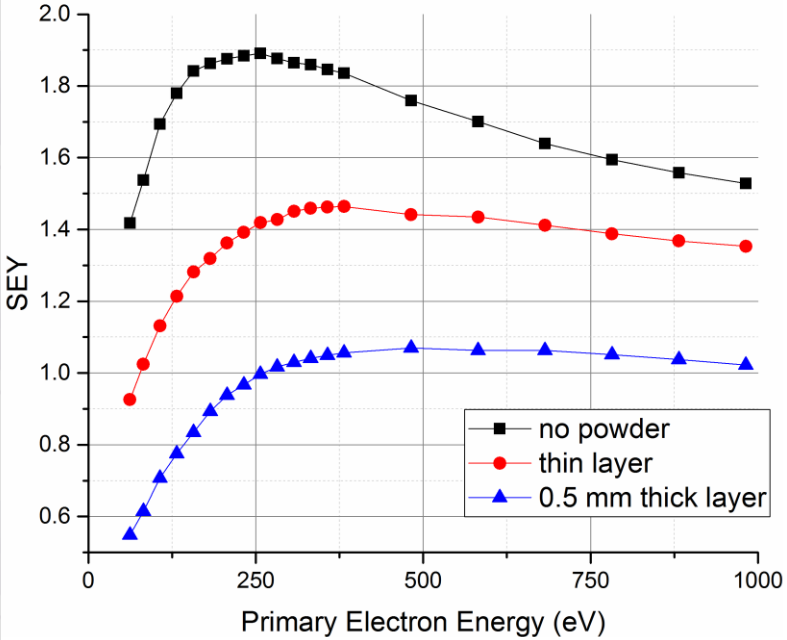
Flat surface was compared to
Pyramidal structure with high-to-base ratio
a/b= 1

for $\alpha_0 = 90°$

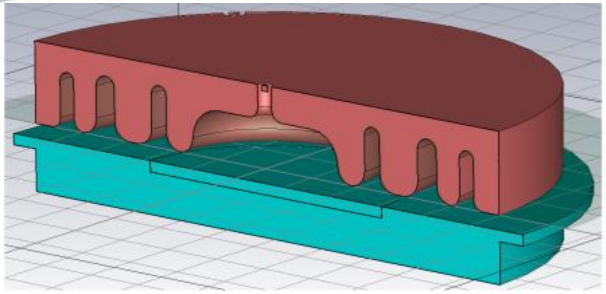


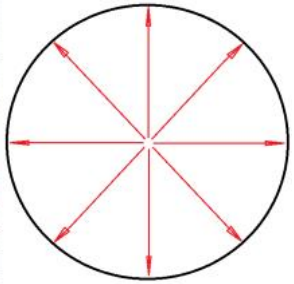




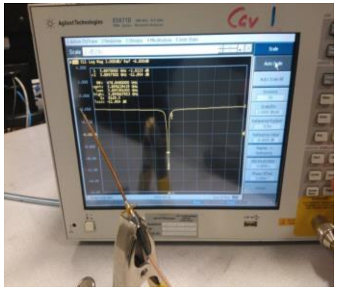


Surface resistance measurements





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

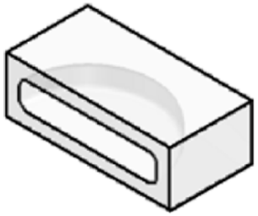


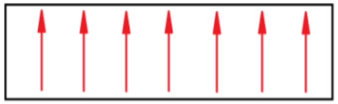
Test cavities (3.9 and 7.8 GHz):

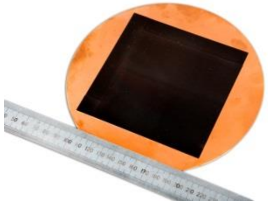
- The simulation results obtained with Microwave Studio
- Fabricated from Al.
- 3 choke cavity operating in TM_{010} mode, has circular H field distribution hence Induces radial current.
- Half pill box cavity operating in TM_{110} mode, has strong transverse H field hence induces axial electric current

Samples:

- 3 of 100-mm² laser treated copper surface

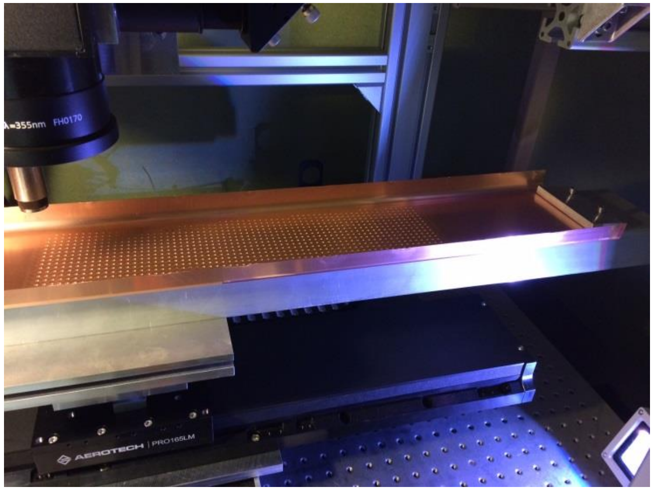


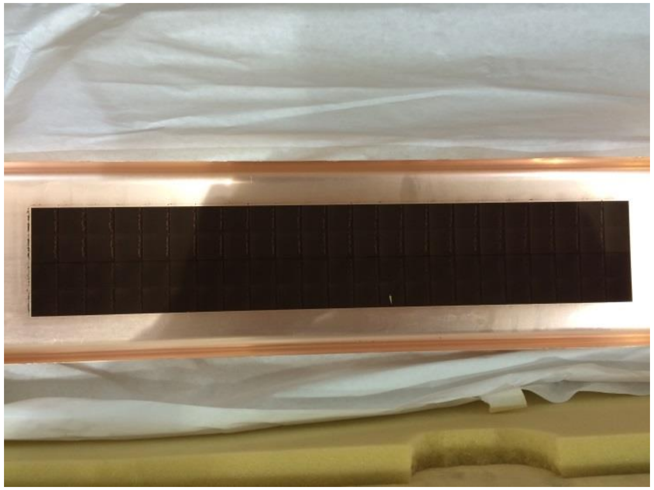


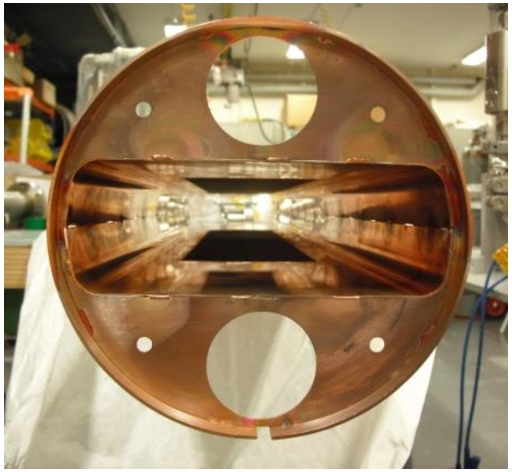


Large scale test in SPS at CERN

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/cm^2)
1	355	3	15	25	40	10	90, 120,	75	42







•SPS liner as test sample has been laser treated

IMG_4269.MOV

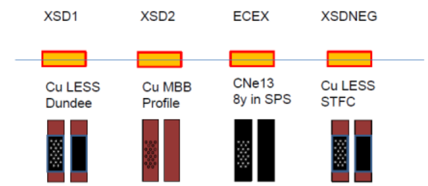
•Two areas of 40 x 490 mm^2 was treated with conditions above

Analysed Data SPS MD Run

Installed in MDHW BA5 SPS

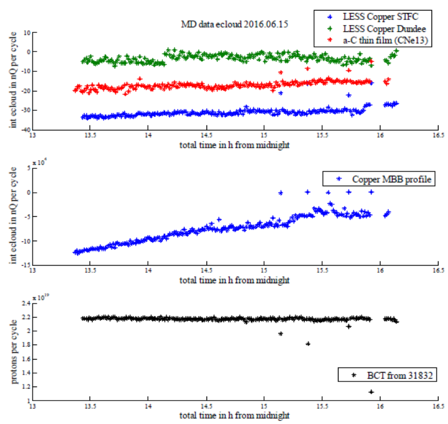
Configuration E-cloud measurements SPS

E-cloud monitors with liners in sextant 5 since January 2016:



Configuration E-cloud measurements SPS

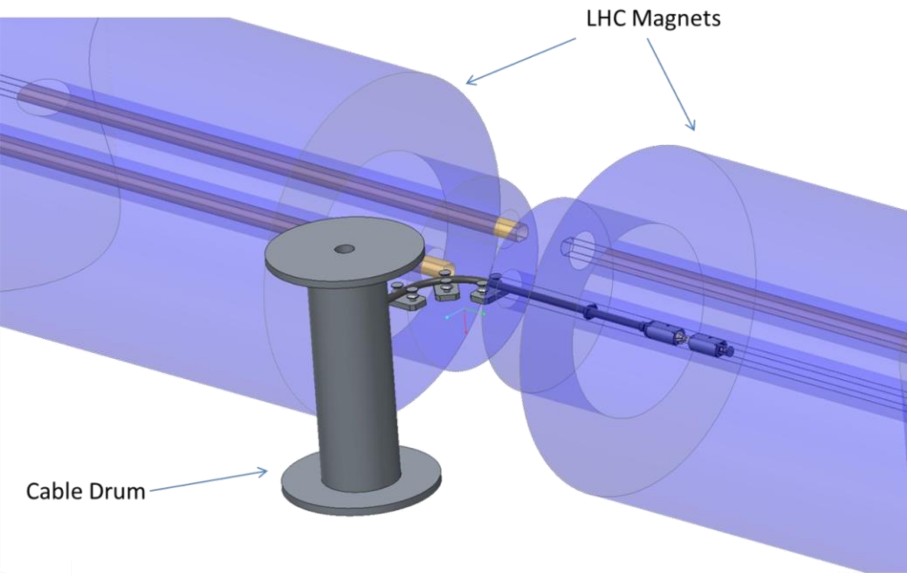
- **PSB user = LHC25_DB_B_PSB**
- **PSB user = LHC25_DB_A_PSB**
- **PS user = LHC25#72b***
- **SPS user = MD_SCRUB_26_L26400_Q20_2014_V1**
- **No Acceleration (flat bottom)**
- **Cycle length 24.5s**
- **Dump after 20s (before acceleration**
- **MDHW5183 current 25A**

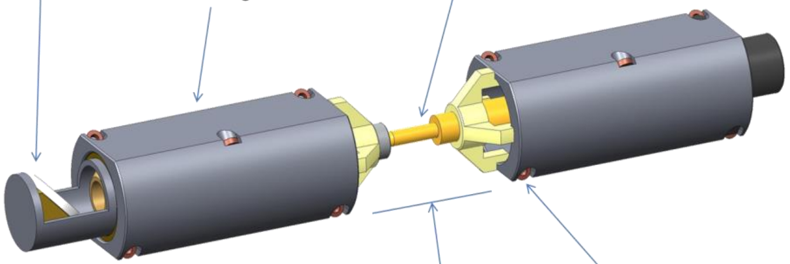


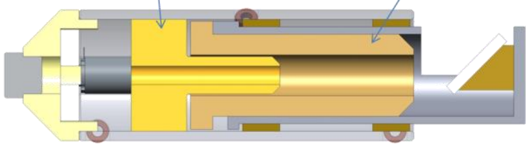
Summary

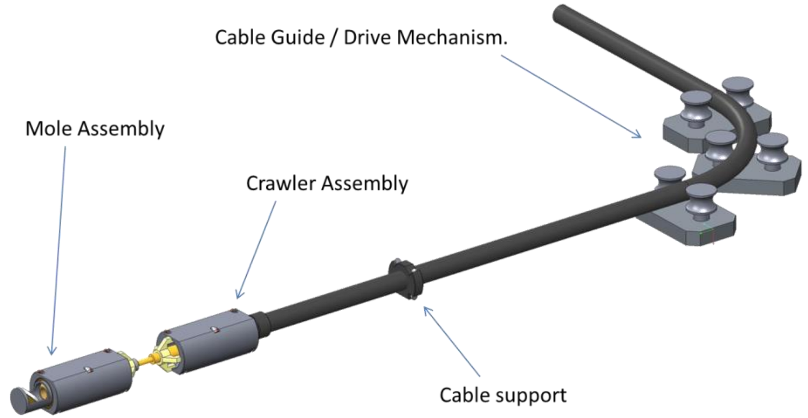
- No e-cloud on LESS treated copper liners
- No significant differences between STFC and Dundee treatment
- No significant differences between a-Carbon coating and LESS treatment in liner configuration

Future technology for in situ LASE treatment

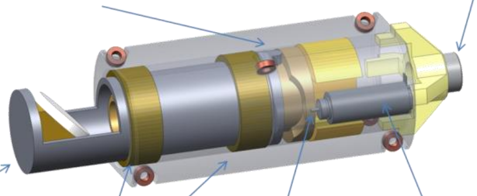








The mirror optics housing moves axially as the mirror rotates to maintain laser focus on the flat sections of beam pipe.



SUMMARY OF LASE properties

•SEY

•**LASE** on a metal surface is a very viable solution for reducing the δ < 0.6.

•Even the initial (unconditioned) δ = 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 re-melting 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 .

•**Surface resistance** with **LASE** can increase

•Measured values of surface resistance at 3.9 and 7.8 GHz shows that shallow groove type with superimposed nano-sphere is a preferable solution to minimise the surface impedance in accelerator beam pipe.

SUMMARY of 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.

- The surface is highly reproducible and offers a very stable surface chemistry which can be influenced during the process. The surface is robust and is immune to any surface delamination which can be a detrimental problem for thin film coating.

The main conclusion

- **LASE** can be a key solution for the e-cloud suppression in high energy particle accelerators:
  - $\delta < 0.6$
    - No outgassing problems
      - Insignificant to moderate increase in impedance
        - Easy implementation
          - Robust
            - Highly reproducible
              - Inexpensive
                - In-situ