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

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N.Sykes (Micronanics)

Dr. Philippe Goudket (ASTeC)

Lewis Gurran (ASTeC)

ASTeC

Micronanics Laser Solutions Centre

Evaluation of LASE
for particle accelerator application

We have evaluated LASE in terms of :

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- SEY

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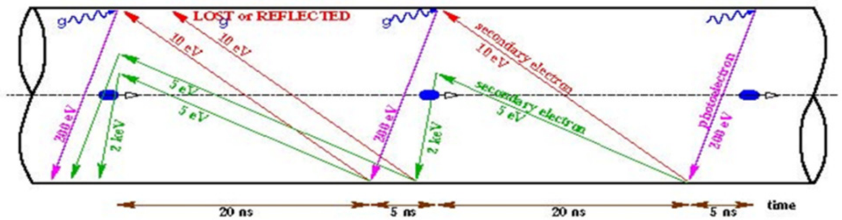
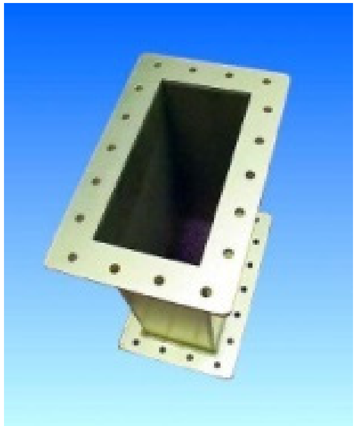
- Surface Chemistry

Main Goal



Curtesy to
F. Ruggero



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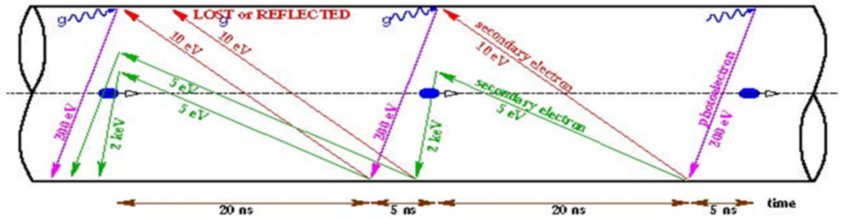

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   To reduce:

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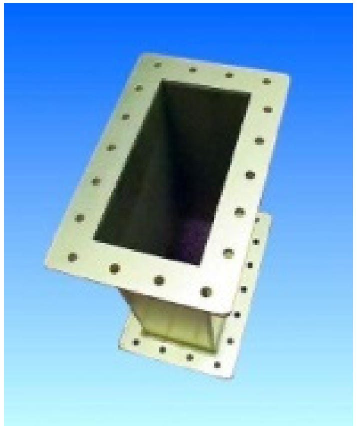

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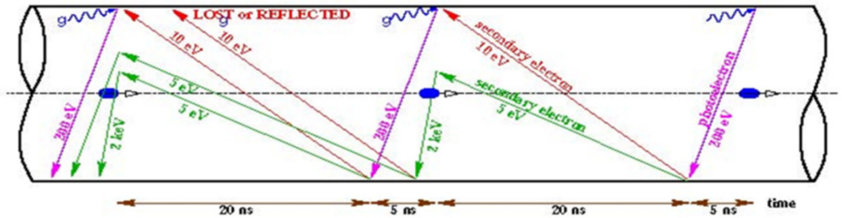

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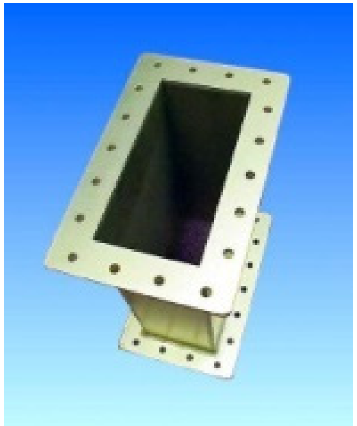

Existing Mitigation method

- ***By Passive means:***

- **Advantages**

- **Disadvantages**

○ Stainless steel as received
□ Stainless steel conditioned lab 5E-2 C/mm2 e-
△ Stainless Steel conditioned SPS
● DCCMS
■ DCMS dipolele's field
▲ DCMS permanent magnets
♦ DCHCS
● PECVD
● HOPG (Graphite)

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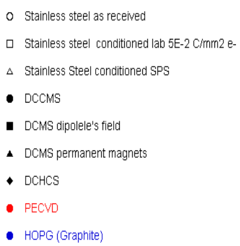
- ***By Passive means:***
- Low SEY Material (Cladding)
- Low SEY coating(single/multiple step)
- Grooved Surfaces (coated /uncoated)
- Special shape of vacuum Chamber

    An antichamber allows reducing PEY



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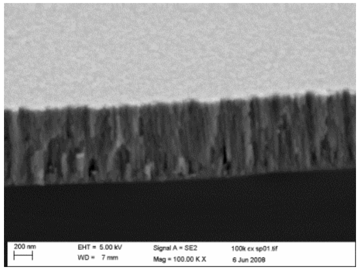

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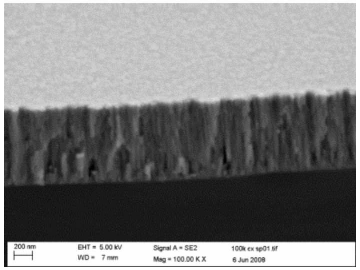

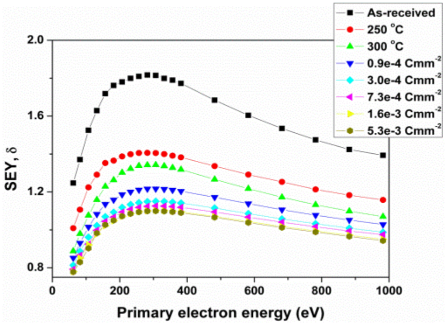

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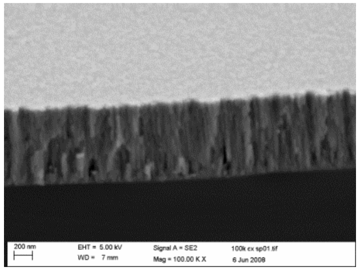

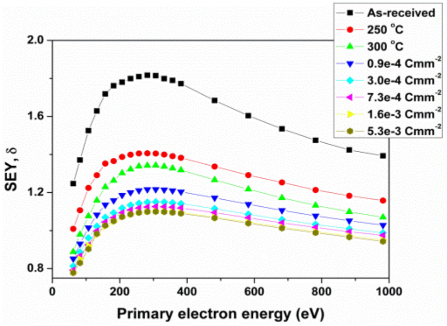

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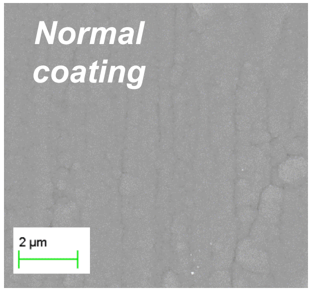

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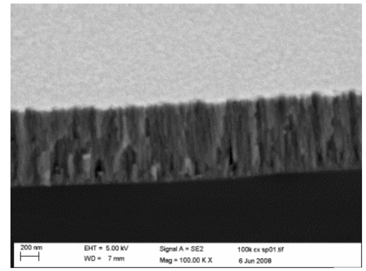

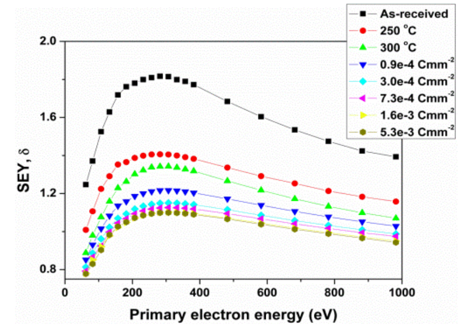

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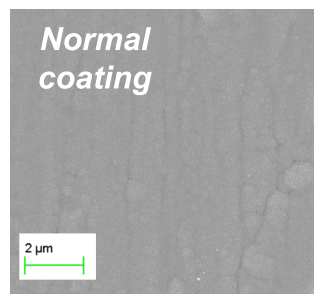

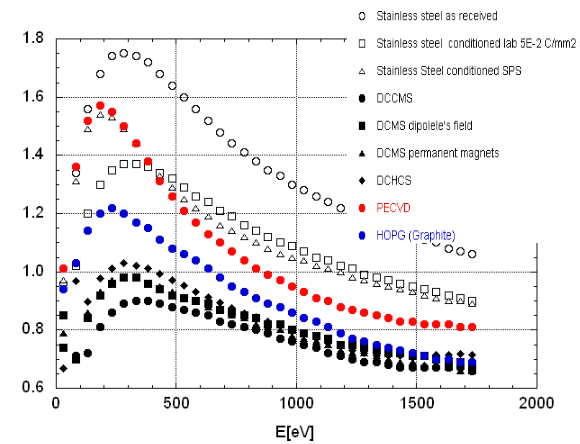

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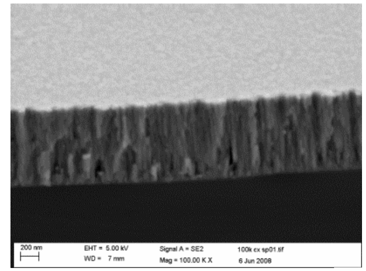

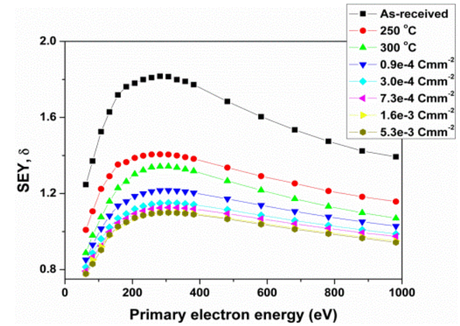

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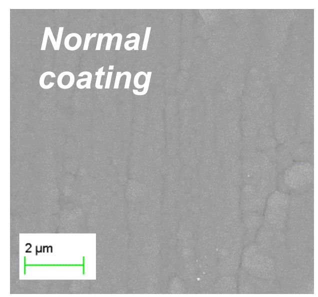

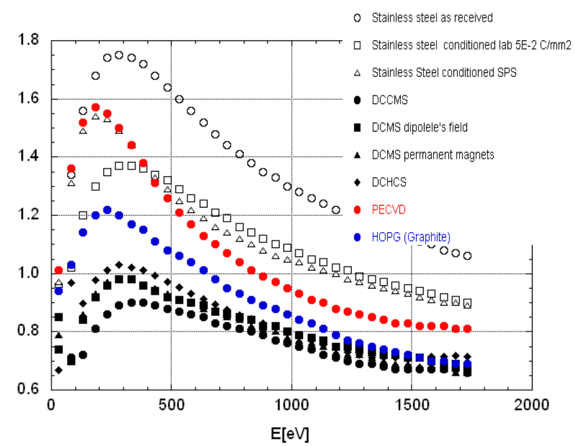

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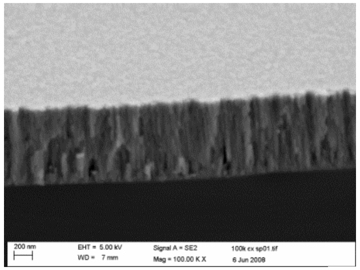

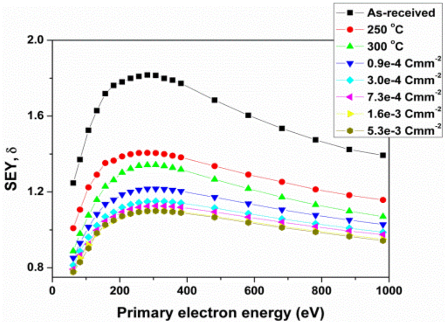

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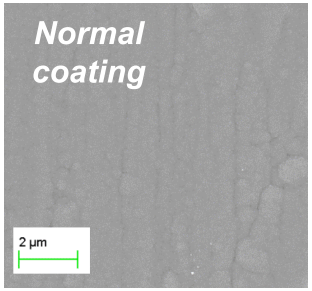

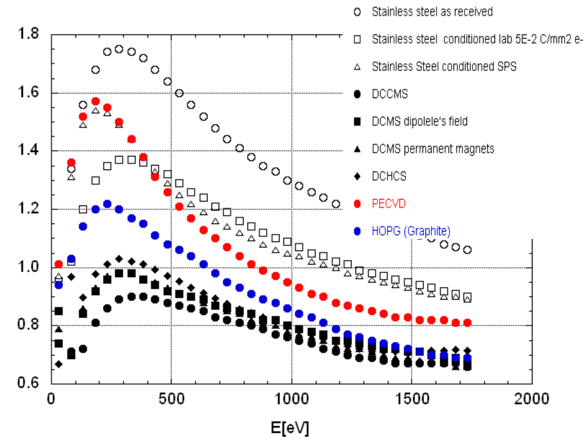

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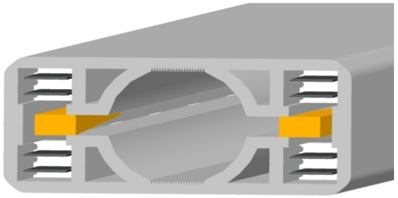

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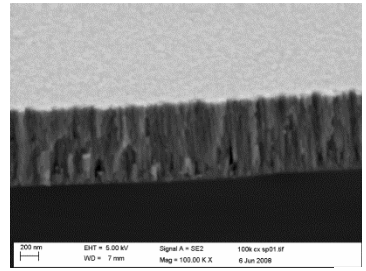

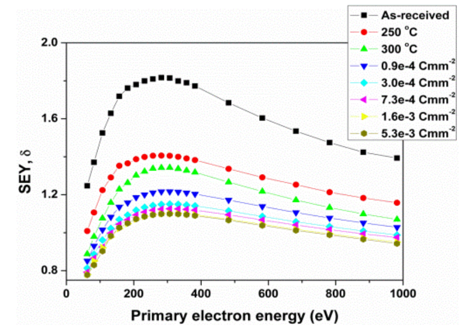

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- No Controllers,
- No power supplies,
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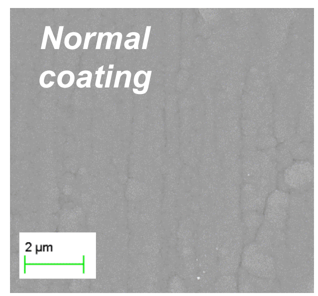

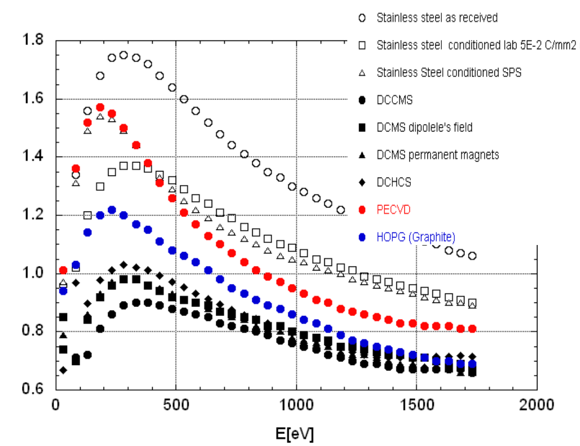

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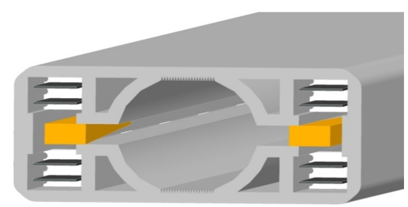

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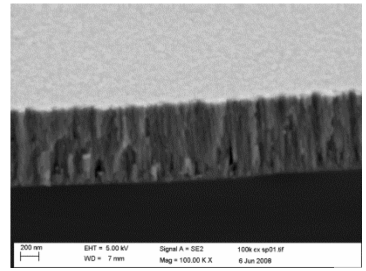

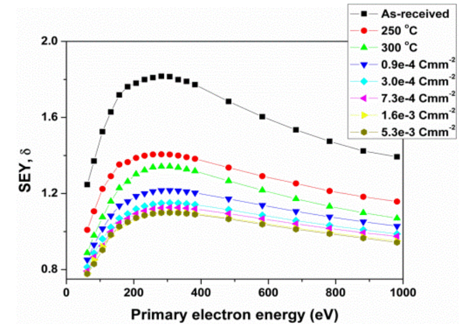

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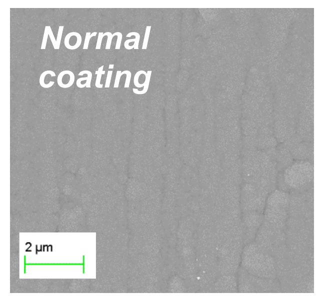
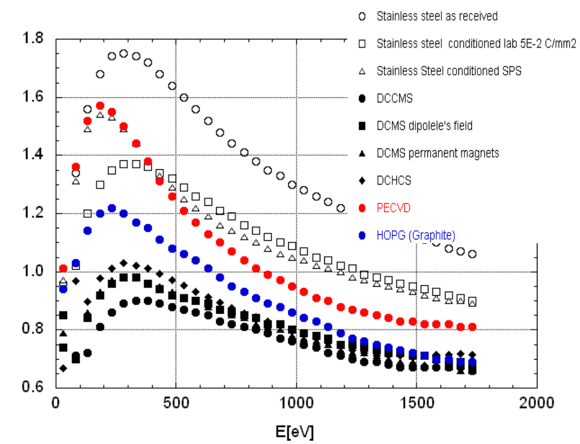
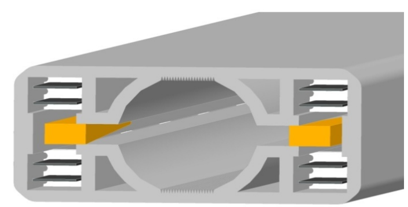




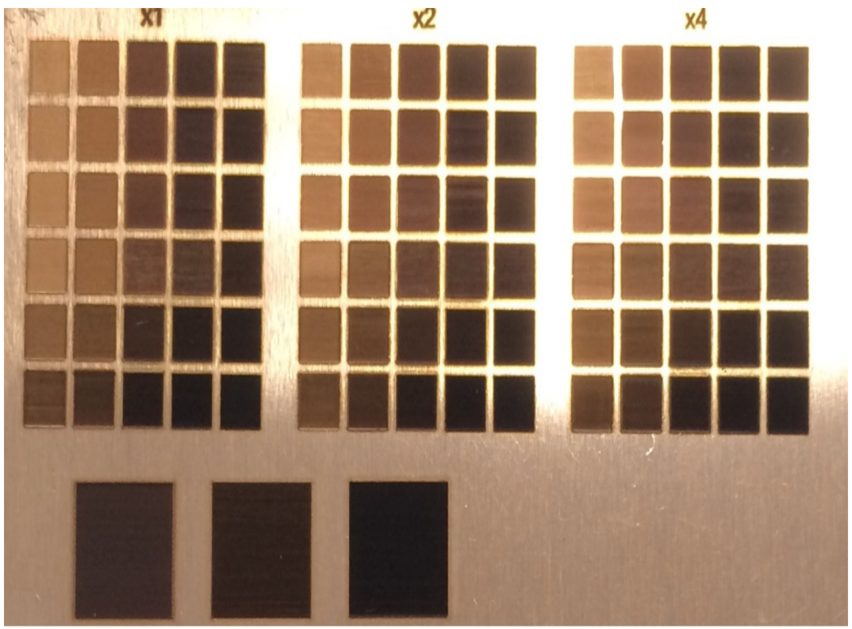
•Disadvantages

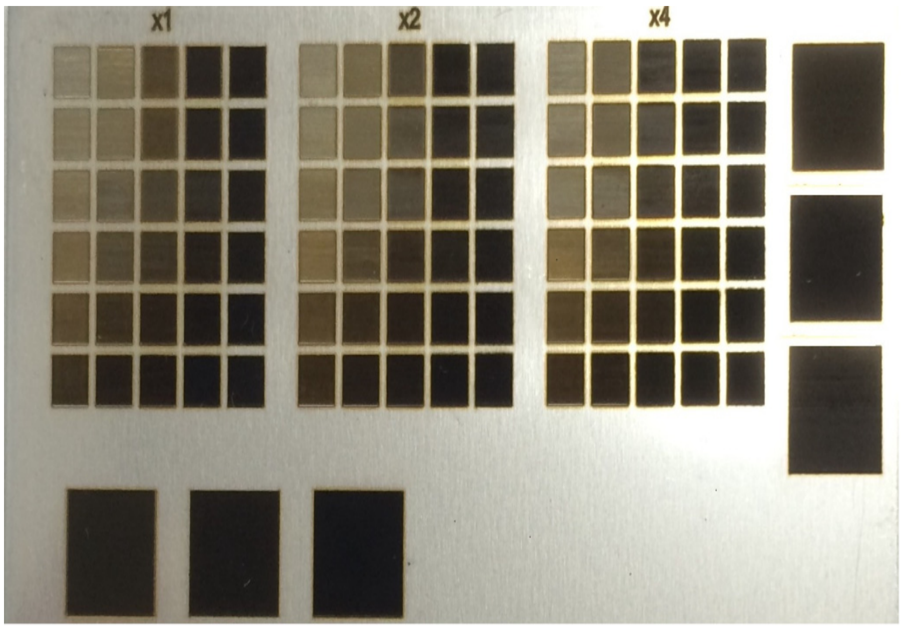
- In-vacuum deposition
- Difficult to apply on existing facilities
- Durations of surface treatments
- Cost



Introducing a new technology

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





Parameters involved in Micromachining

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- Average power
- Pulsed energy
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- Pulse duration
- Repetition rate,
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- 4) Process Parameters:
  - Micromachining environment
  - Gas pressure
  - Temperature of the sample
  - Mobility of sample relative to beam

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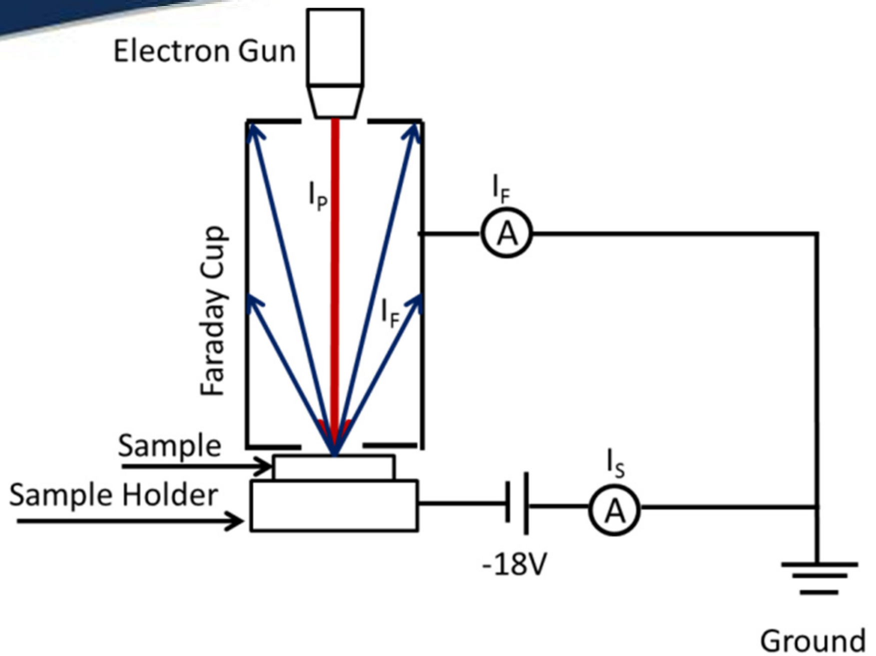
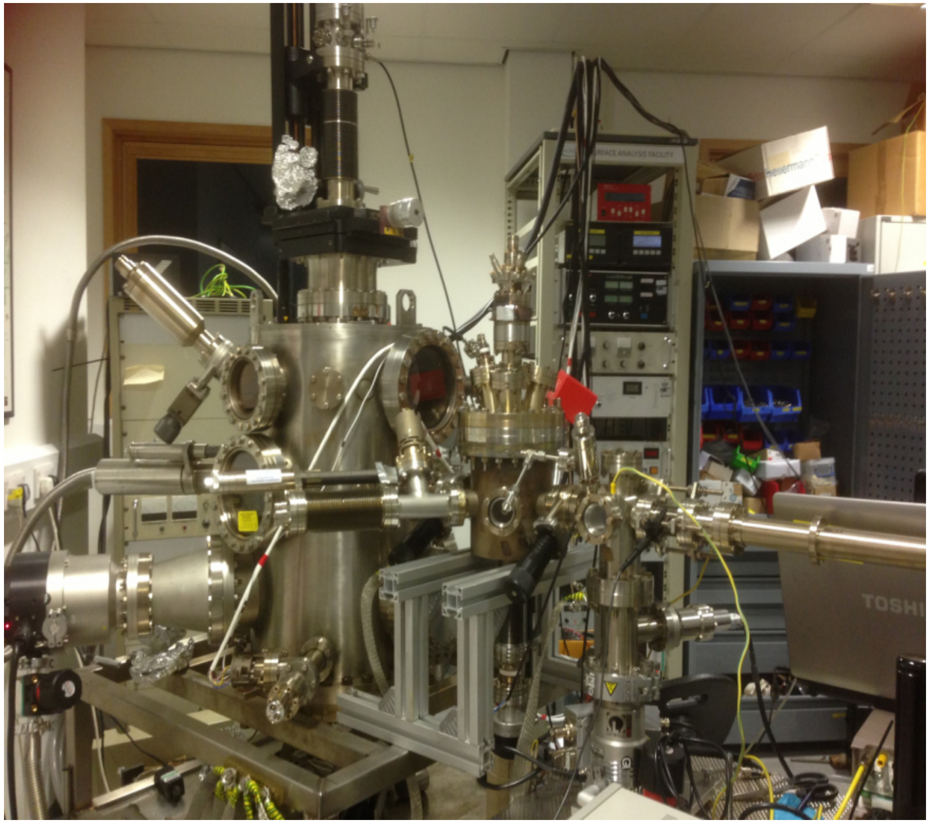
- It is possible to lase in many different environments, such as gases, liquids, or in a vacuum.

SEY Measurements



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

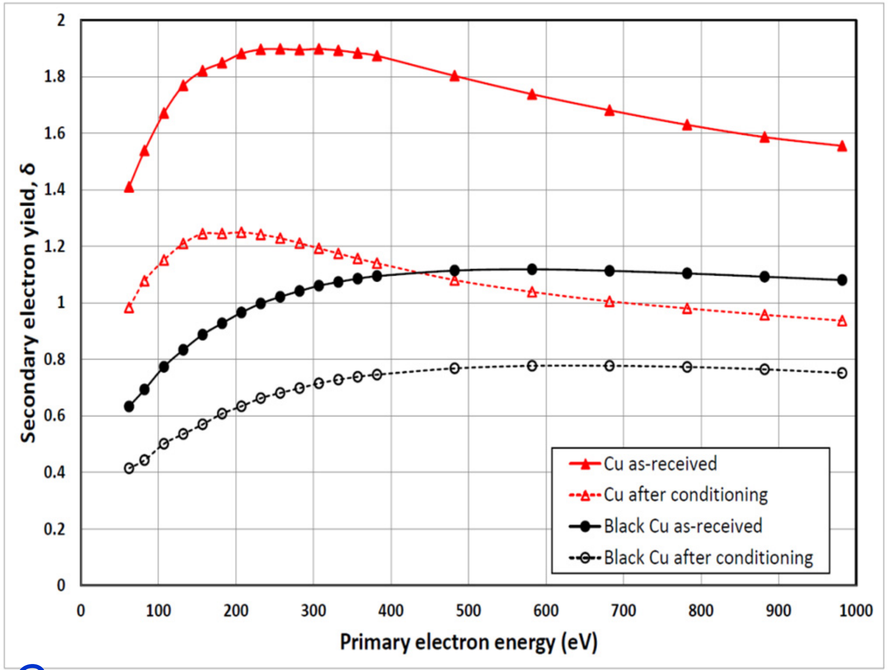


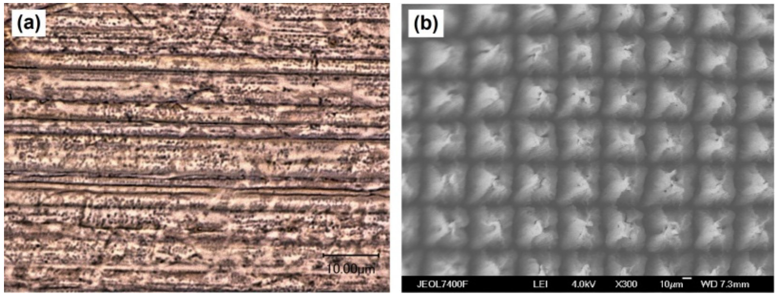
I_P is the primary beam current
I_F is the secondary electron current including elastic and inelastic processes, measured on the Faraday cup
I_S is the currents on the sample

Analysis chamber with

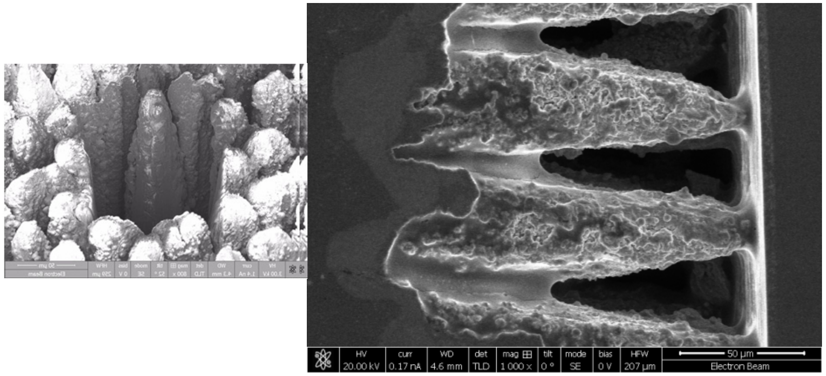
- XPS,
- Flood e-gun,
- Sample heater,
- Ar ion beam.

SEY of Cu as a function of incident electron energy





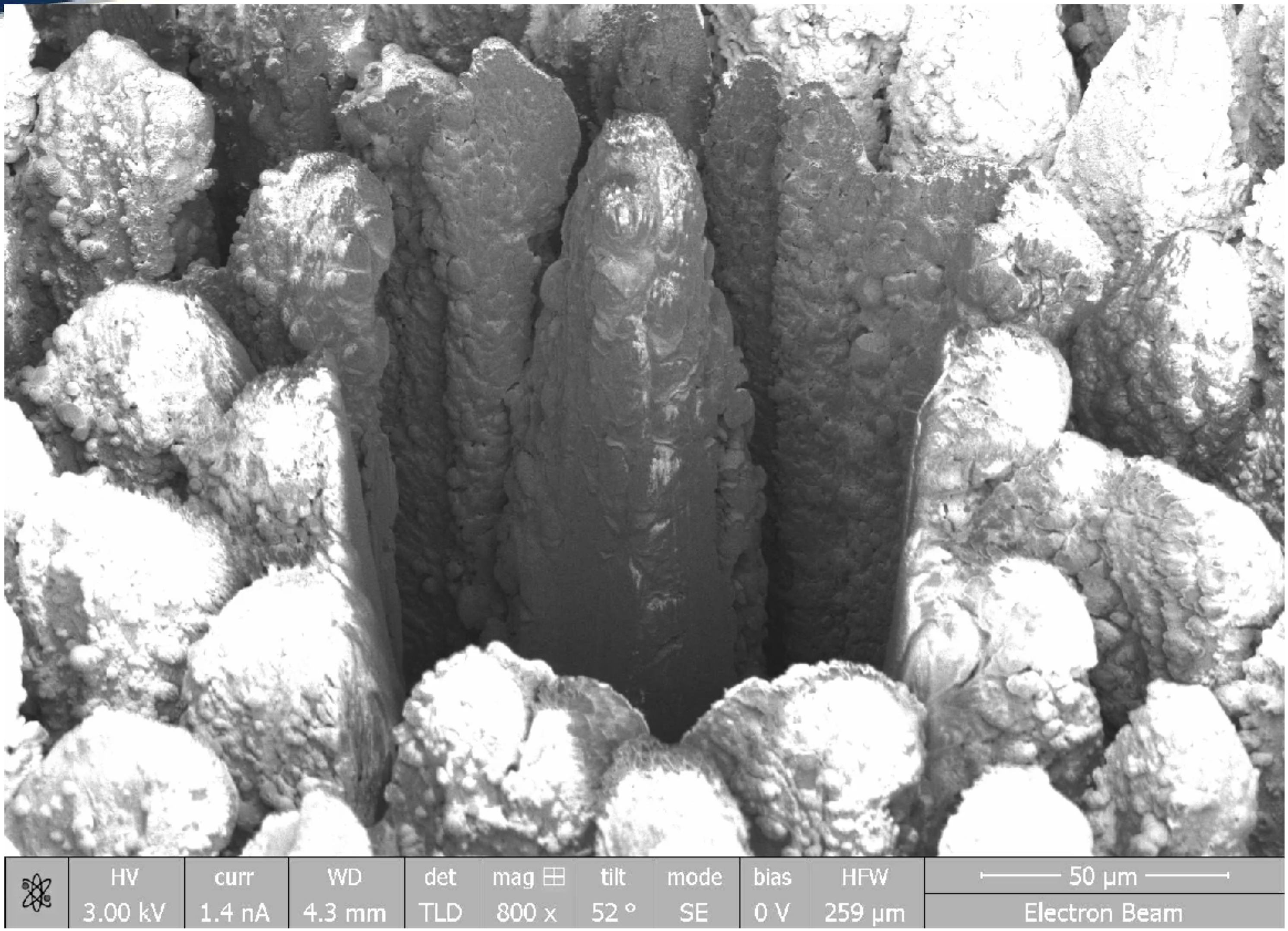
Untreated Laser treated



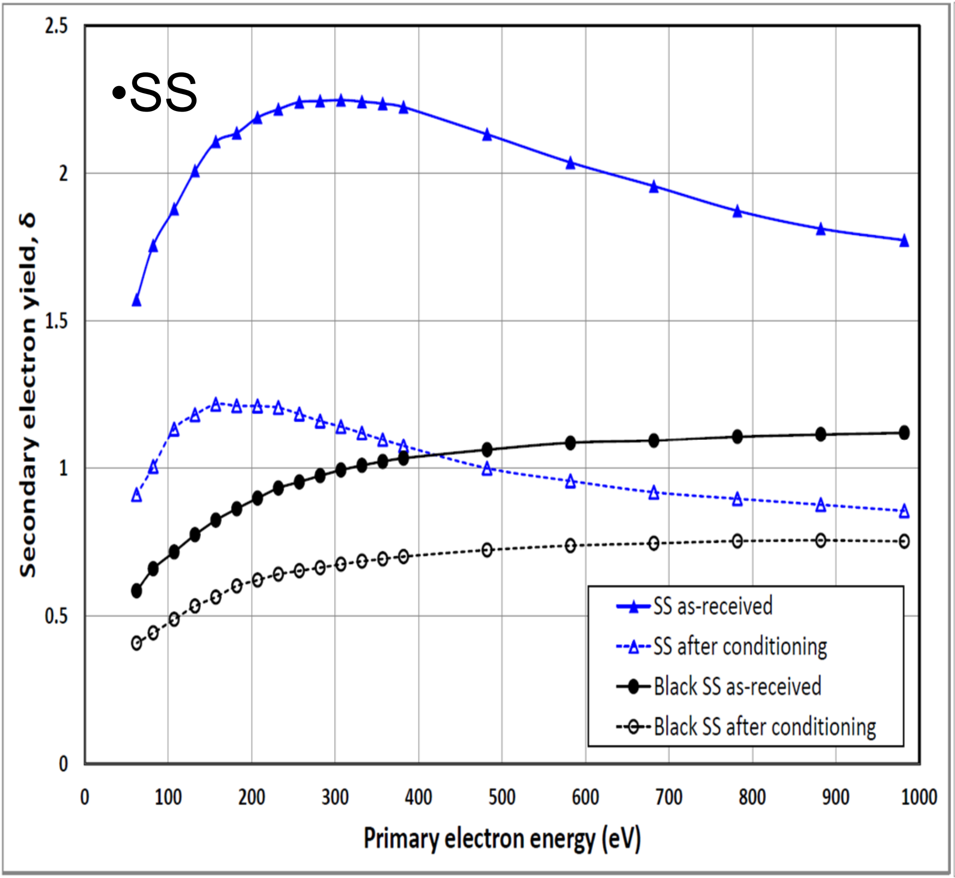
Original data June 2014
Applied Physics Letters 12/2014; 105(23): 231605

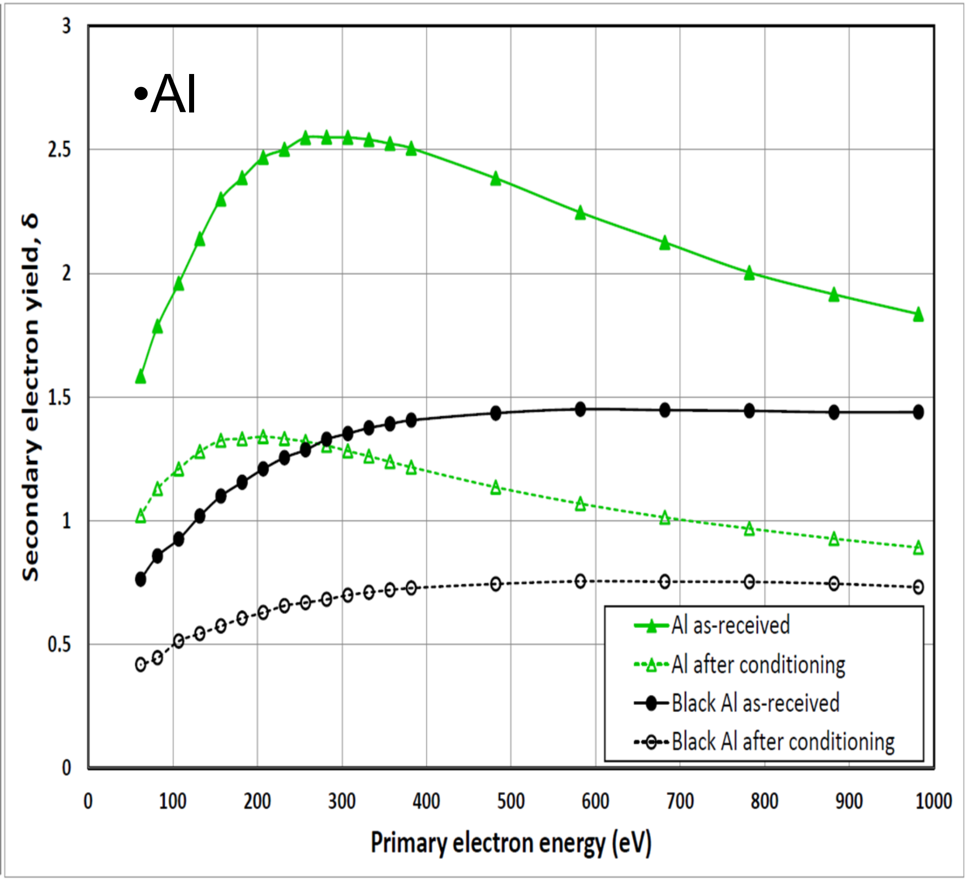
For Copper
Nd:YVO4 Laser

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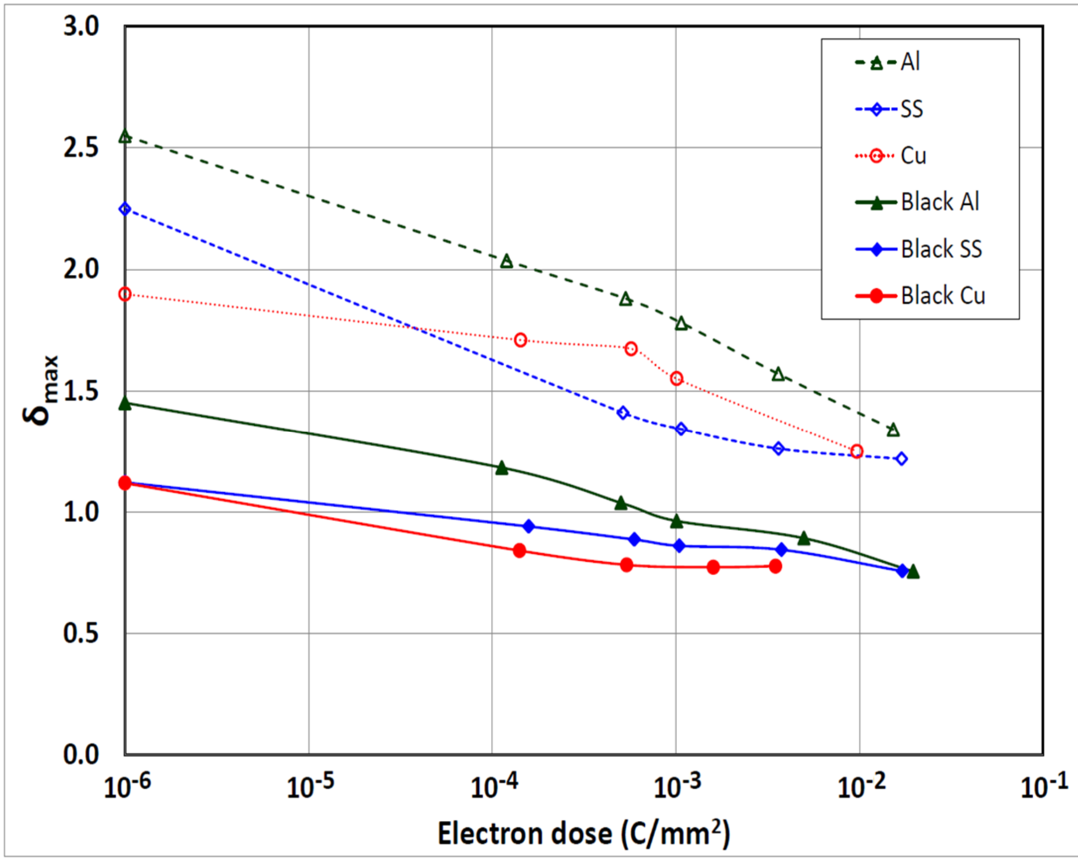
δ_{max} as a function of electron dose for Al, 306L SS and Cu

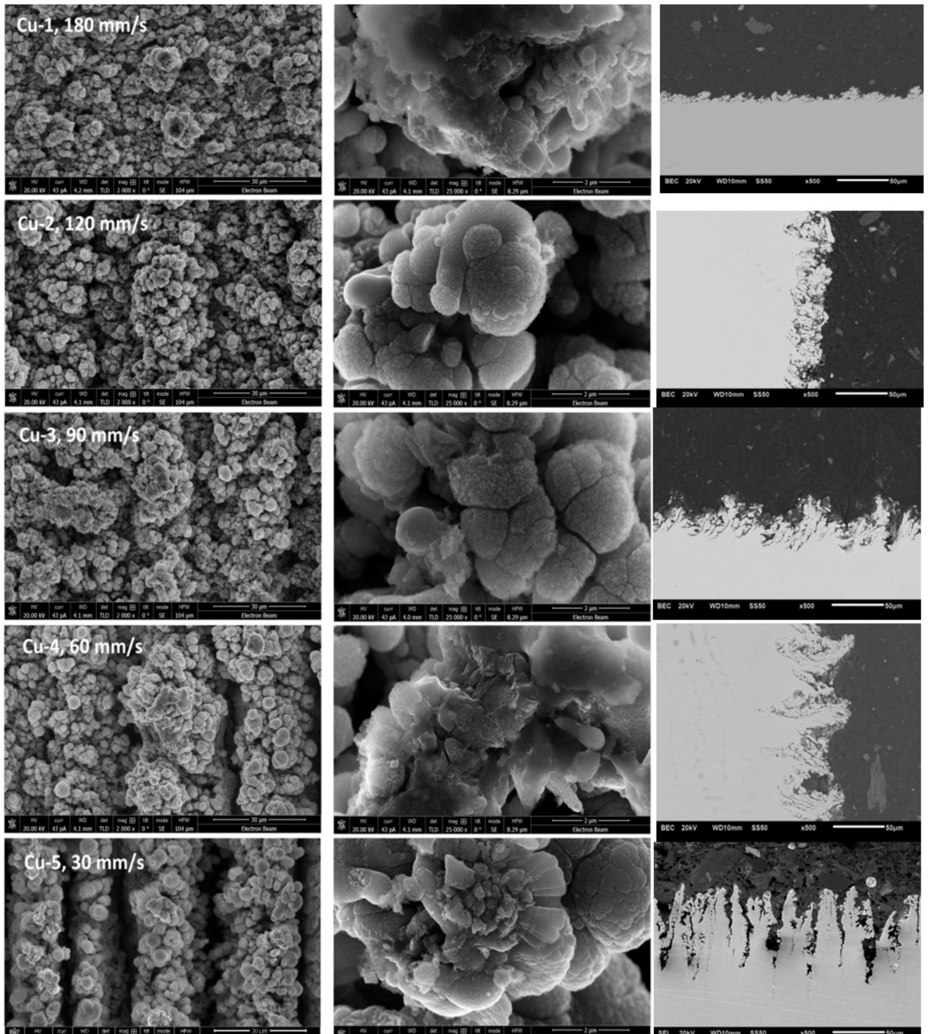


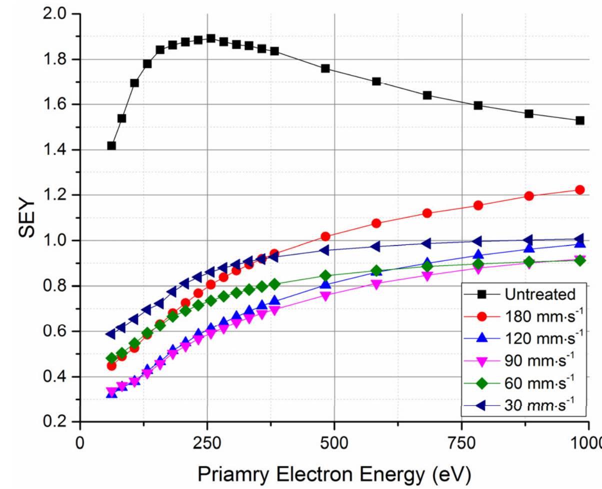
Sample	Initial		After conditioning to Q_{max}		
	δ_{max}	E_{max} (eV)	δ_{max}	E_{max} (eV)	Q_{max} (C·mm^{-2})
Black Cu	1.12	600	0.78	600	3.5×10^{-3}
Black SS	1.12	900	0.76	900	1.7×10^{-2}
Black Al	1.45	900	0.76	600	2.0×10^{-2}
Cu	1.90	300	1.25	200	1.0×10^{-2}
SS	2.25	300	1.22	200	1.7×10^{-2}
Al	2.55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

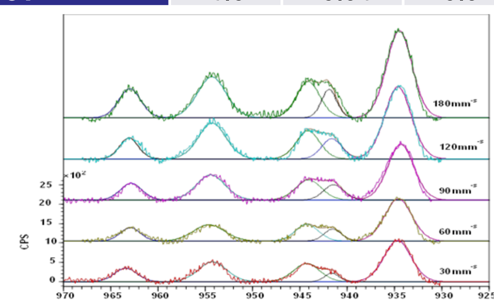
Effect of scan speed

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/cm²)
1	355	3	15	25	40	10	30,60,90, 120, 180	75	42



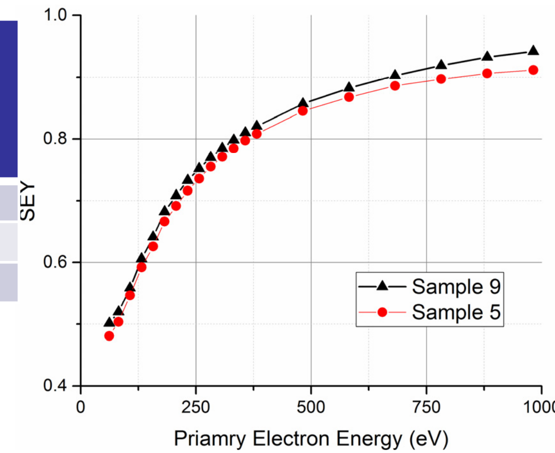


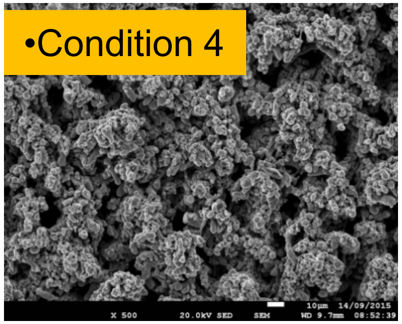
Sample	6	5	4	3	2
Scan speed (mm/s)	30	60	90	120	180
Groove depth (μm)	100	60	35	20	8
δ at E_p = 60 eV	0.6	0.5	0.3	0.3	0.4
δ at E_p =1000 eV	1.0	0.91	0.9	0.98	1.22

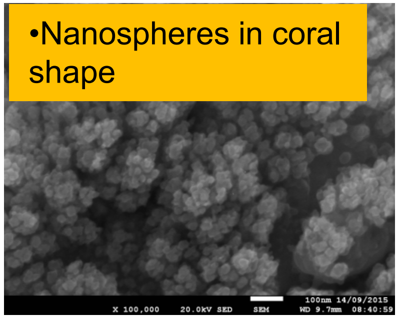


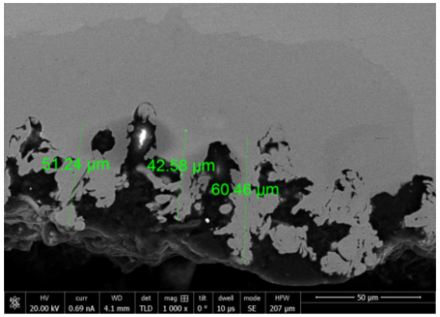
Effect of power and repetition rate

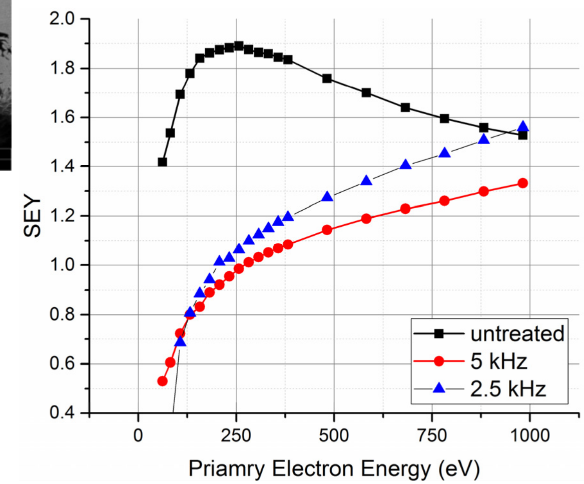
Laser treatment condition	λ (nm)	Average power (W)	Spot size (μm)	Pulse duration (ns)	Pulse repetition (kHz)	Pitch width (μm)	Scan speed (mm/s)	Energy per pulse (μJ)	Fluence (J/cm^2)
2	1064	1.9	25	70	2.5	20	125	760	154
3	1064	2.4	25	70	5.0	20	125	480	97
4	1064	3.6	25	70	10	20	30	360	73

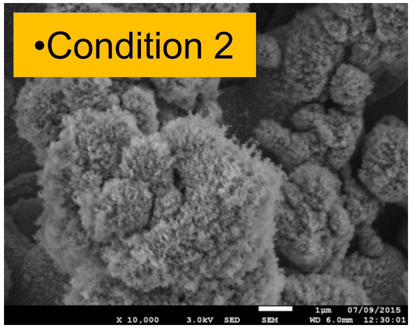


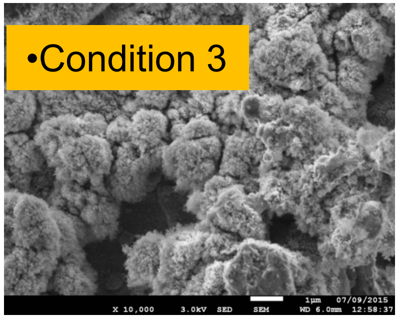


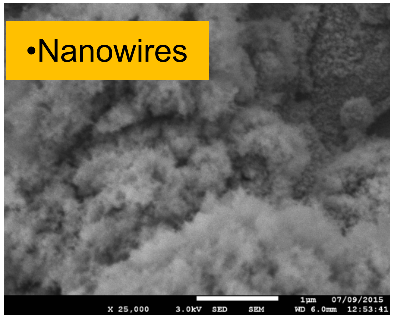






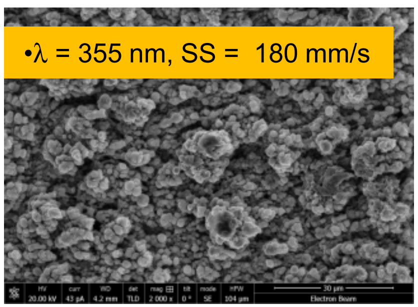


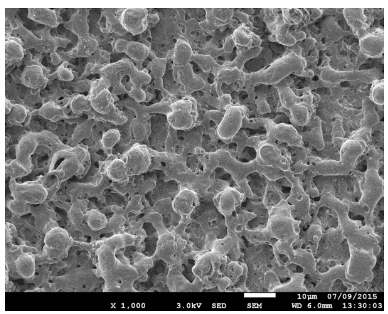


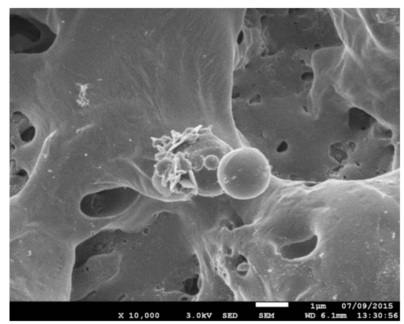


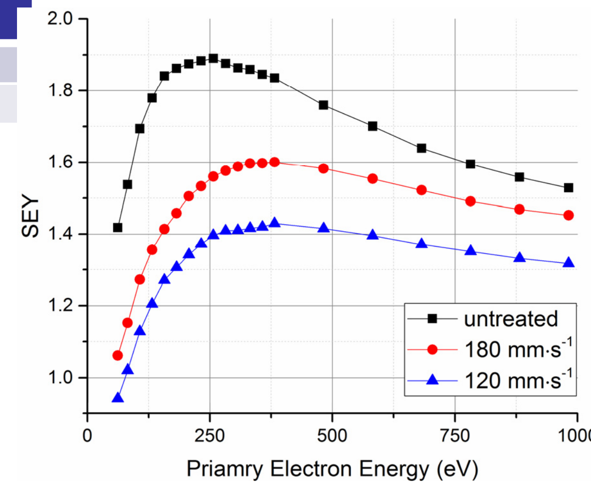
Importance of nano structure

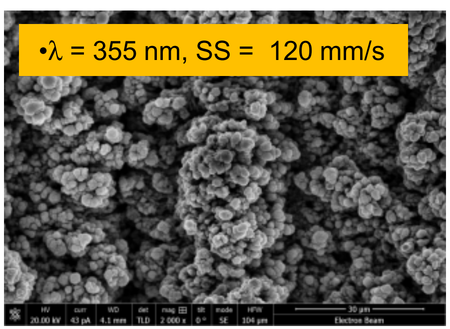
Laser treatment condition	λ (nm)	Average power (W)	Spot size (µm)	Pulse duration (ns)	Pulse repetition (kHz)	Pitch width (µm)	Scan speed (mm/s)	Energy per pulse (µJ)	Fluence (J/cm^2)
5	1064	3	25	70	20	10	500	150	30
6	1064	1	25	70	100	10	500	10	2

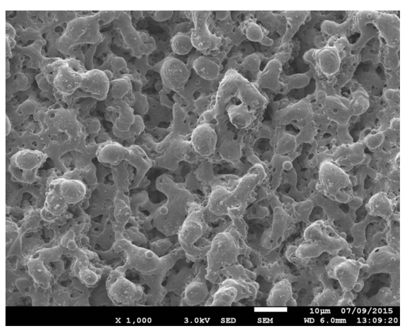


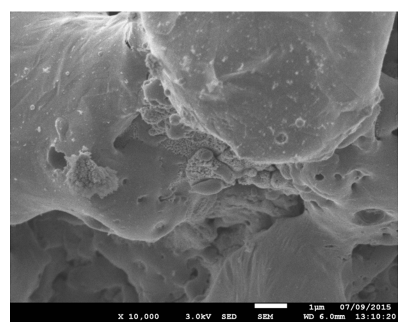








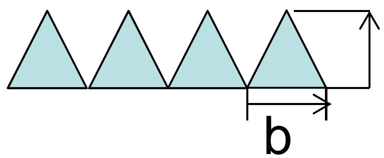


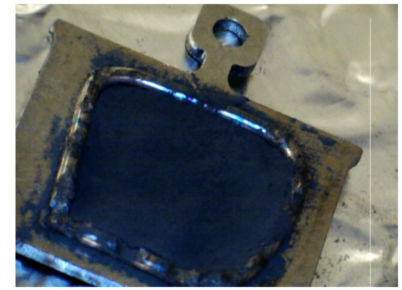


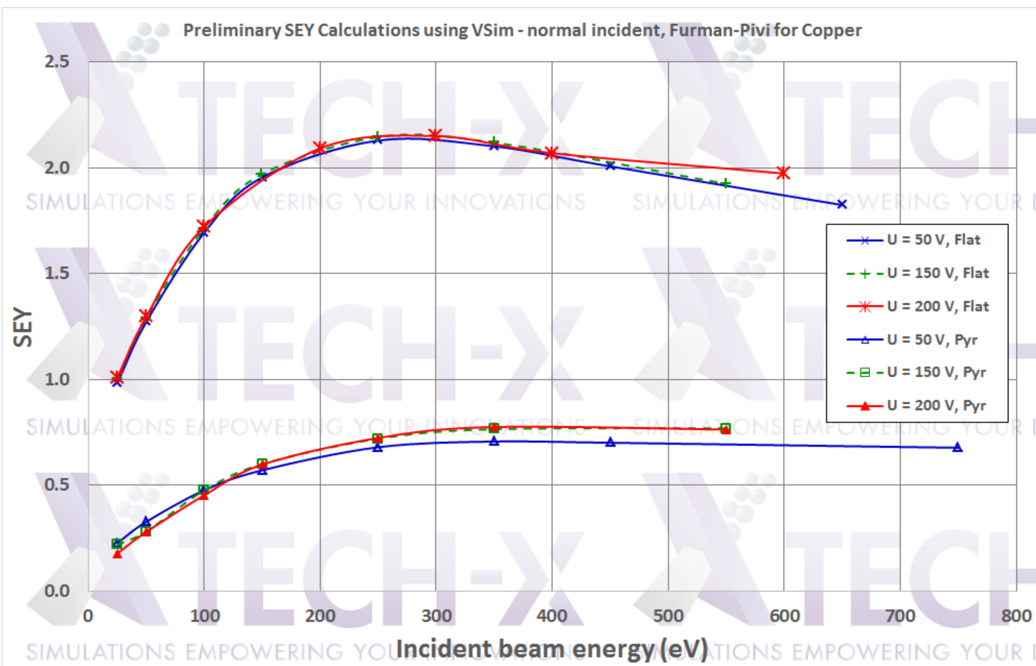
- •No visible Nanostructure (due to re-melt)
- •SEY resemble to untreated sample

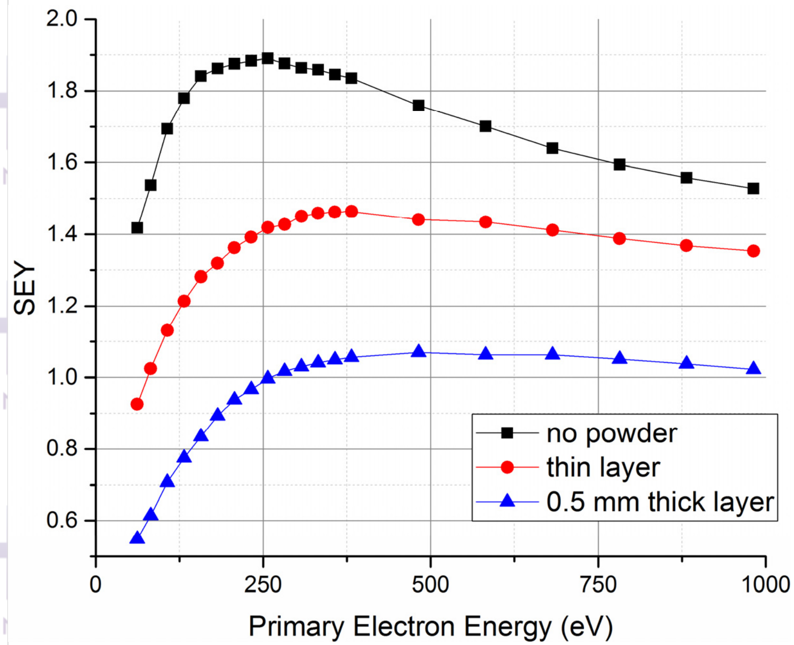
Validation of nano structure and grooves

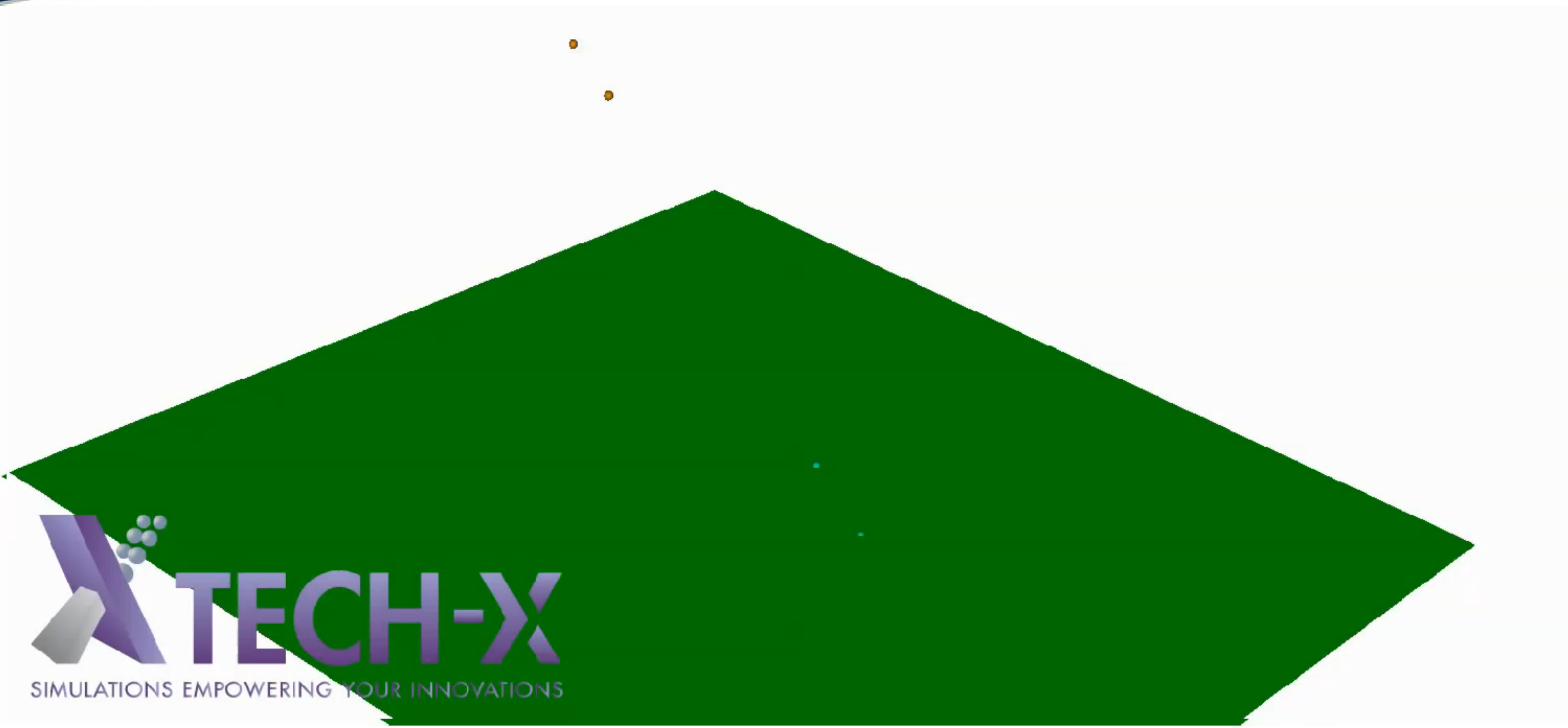
Flat surface was compared to
Pyramidal structure with high-to-base ratio
a/b= 1
for $\alpha_0 = 90°$

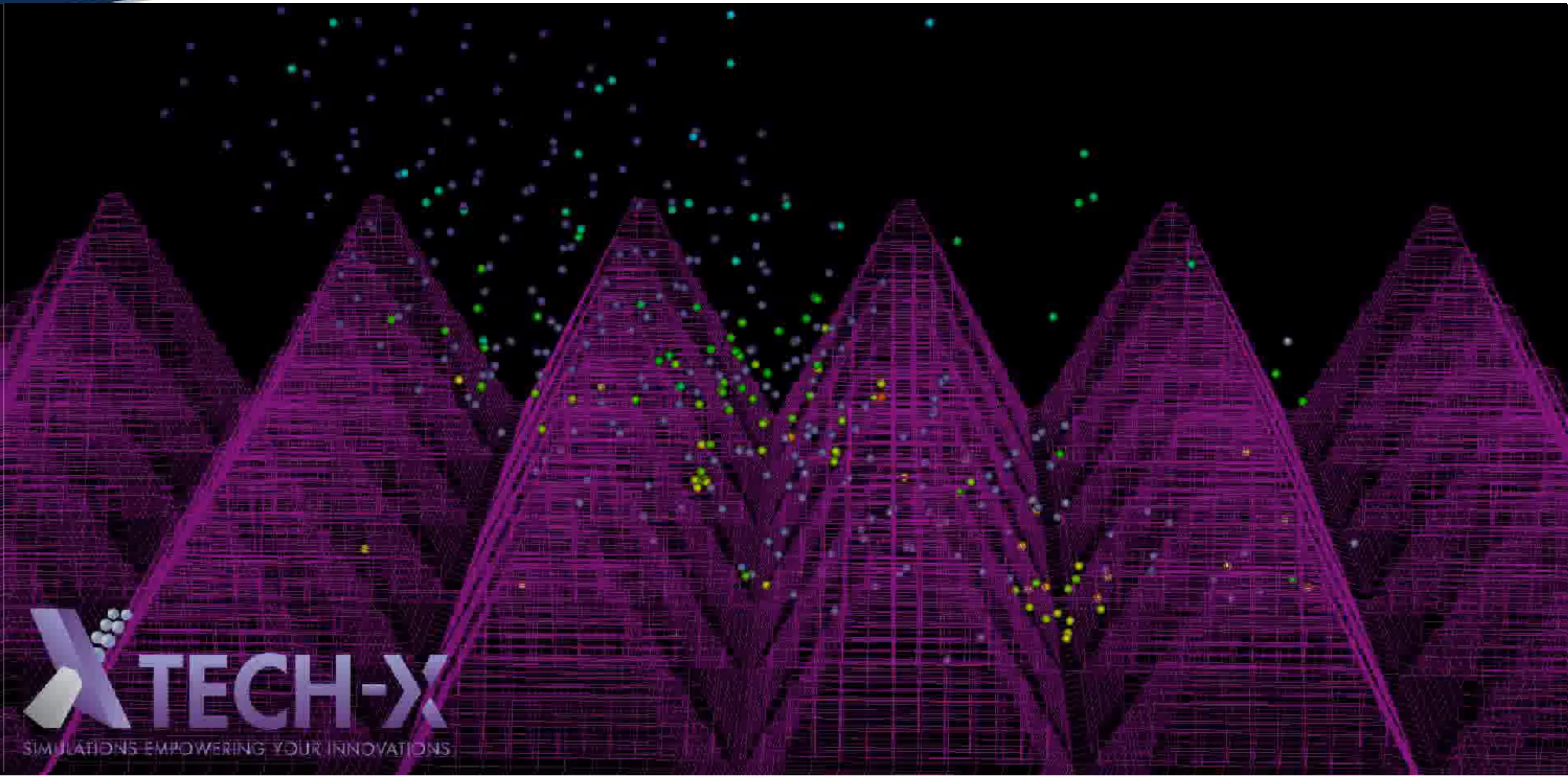




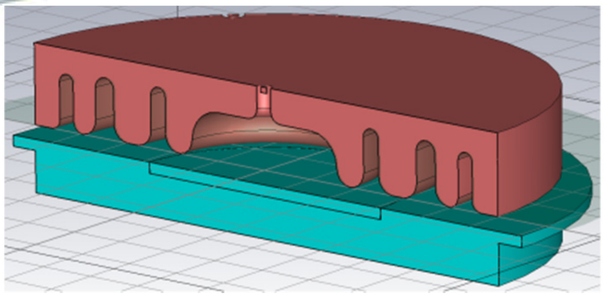


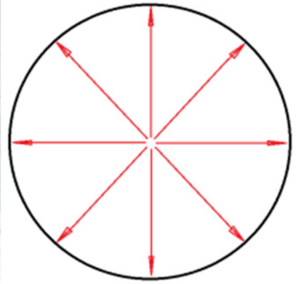



TECH-X
SIMULATIONS EMPOWERING YOUR INNOVATIONS


TECH-X
SIMULATIONS EMPOWERING YOUR INNOVATIONS

Surface resistance measurements

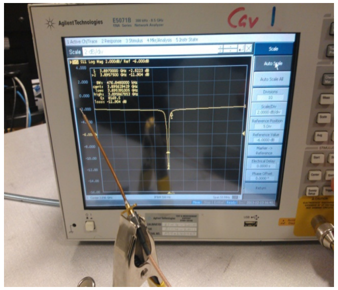




Test cavities (3.9 and 7.8 GHz):

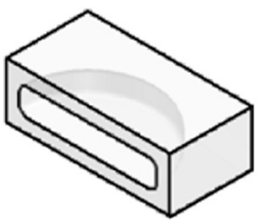
- The simulation results obtained with Microwave Studio
- Fabricated from Al.
- 3 choke cavity operating in TM_{010} mode, has circular H field distribution hence Induces radial current.
- Half pill box cavity operating in TM_{110} mode, has strong transverse H field hence induces axial electric current

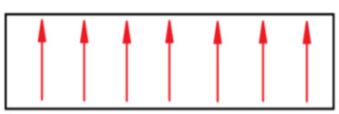
Sample	Cavity	Measurement	R_S [Ω]
Cu-1L	1	average	7.8×10^{-2}
	2	0°	0.11
	2	45°	0.11
	2	90°	9.5×10^{-2}
Cu-2L	1	average	0.13
Cu-3L	1	average	0.14
	2	0°	0.15
	2	45°	0.19
	2	90°	0.2
Cu untreated	1	average	3.3×10^{-2}
Al untreated	1	average	7.2×10^{-2}
SS untreated	1	average	0.17

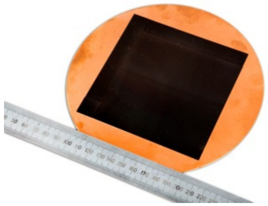


Samples:

- 3 of 100-mm² laser treated copper surface

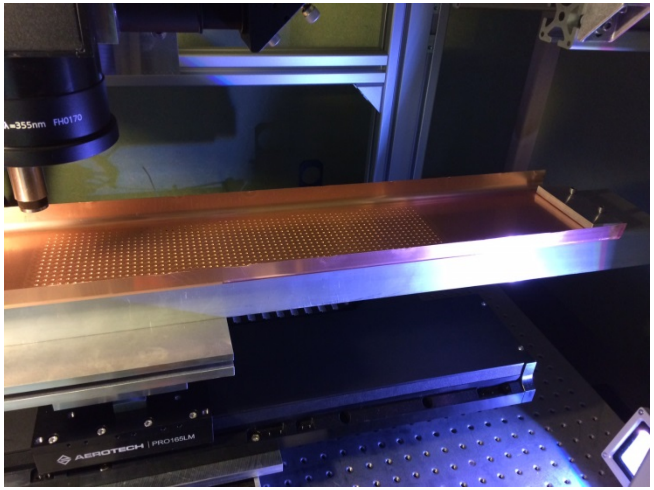
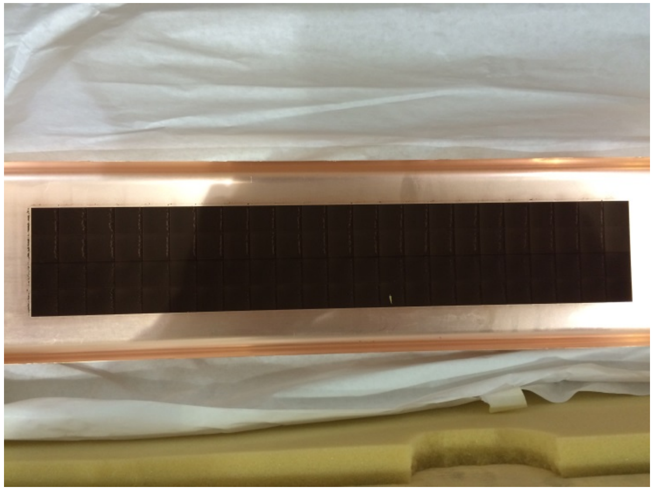
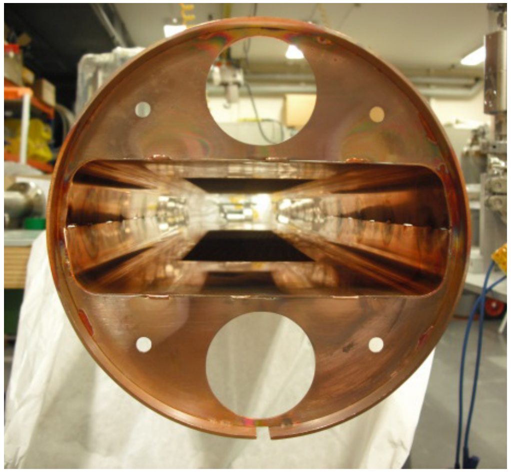




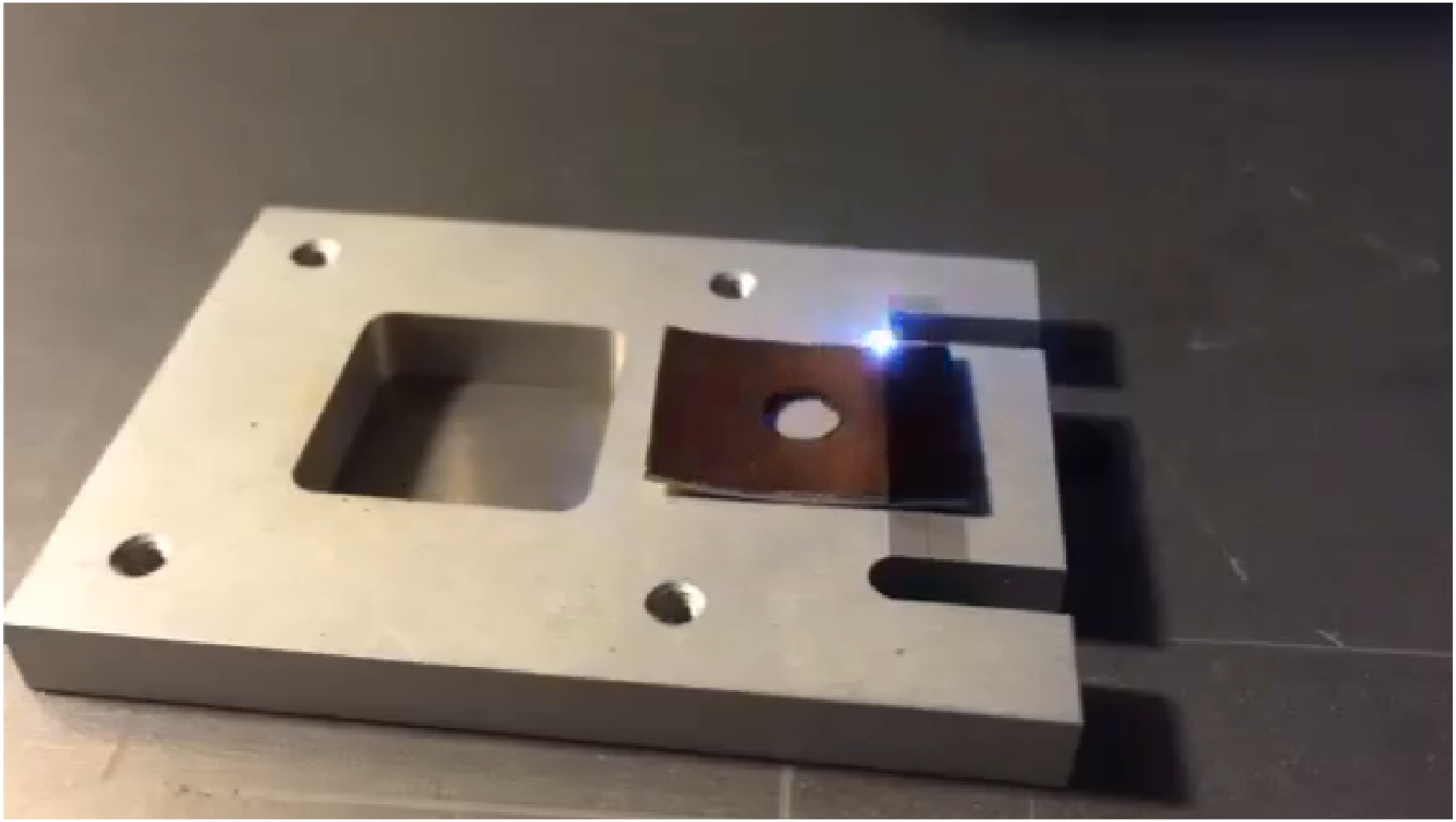


Large scale test in SPS at CERN

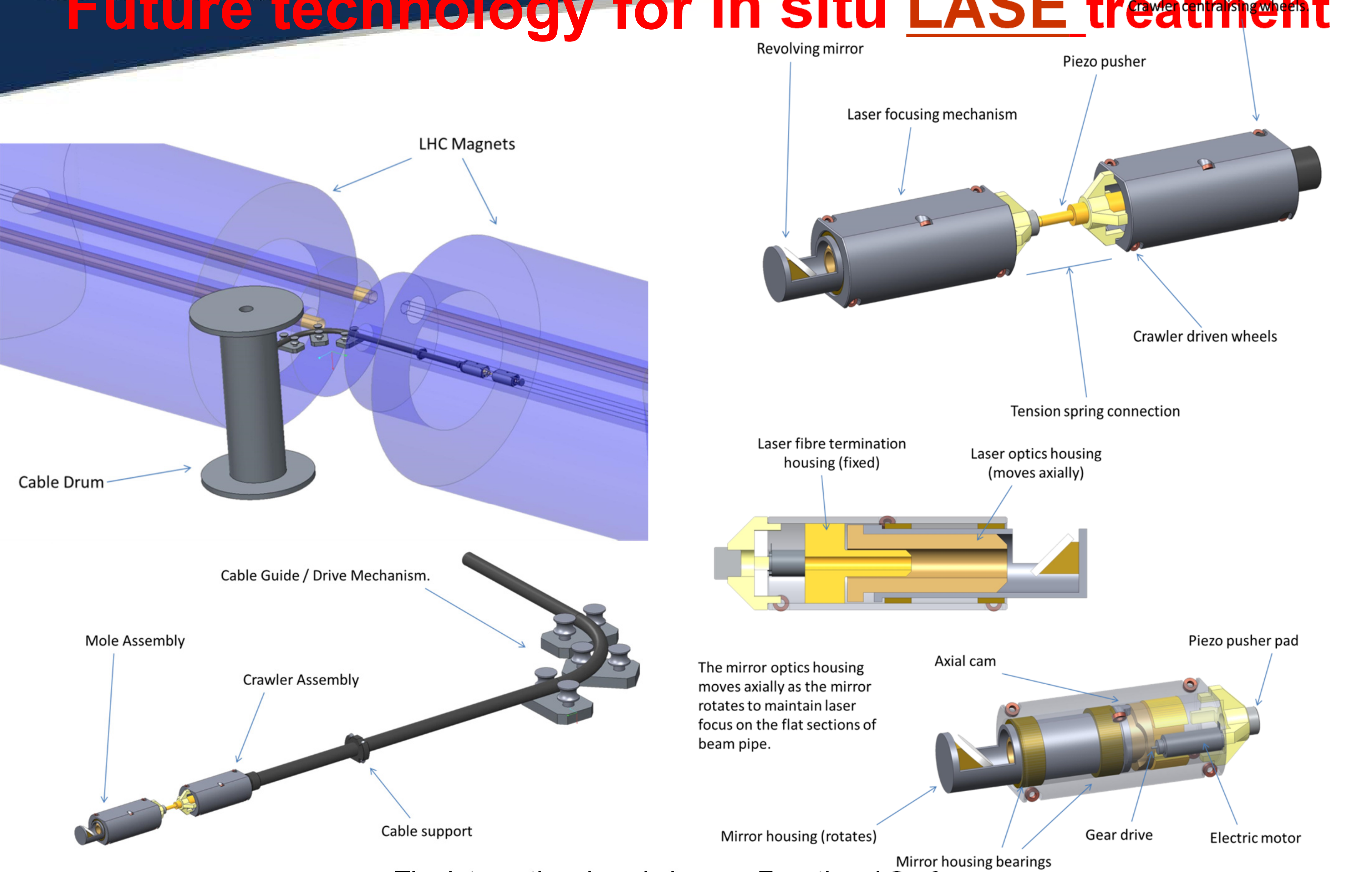
Laser treatment condition	λ (nm)	Average power (W)	Spot size (μm)	Pulse duration (ns)	Pulse repetition (kHz)	Pitch width (μm)	Scan speed (mm/s)	Energy per pulse (μJ)	Fluence (J/cm^2)
1	355	3	15	25	40	10	90, 120,	75	42

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



Future technology for in situ LASE treatment



Summary: LASE properties

- **SEY**:

- **Surface resistance with LASE can increase**

Summary: LASE properties

- **SEY**:
  - **LASE** on a metal surface is a very viable solution for reducing the $\delta < 1$.
  - **SEY** is reduced by a combination of two geometrical effects
- **Surface resistance with LASE can increase**

Summary: LASE properties

- **SEY**:
  - **LASE** on a metal surface is a very viable solution for reducing the $\delta < 1$.
  - **SEY** is reduced by a combination of two geometrical effects
    1. **Due to the grooves** which traps the electrons by multiple side wall collision (confirmed by measurements and modelling) and
    2. **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)
    3. **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**

Summary: LASE properties

- **SEY**:
  - **LASE** on a metal surface is a very viable solution for reducing the $\delta < 1$.
  - **SEY** is reduced by a combination of two geometrical effects
    1. **Due to the grooves** which traps the electrons by multiple side wall collision (confirmed by measurements and modelling) and
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    3. **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.

The main conclusion

- **LASE** can be a key solution for the e-cloud suppression in high energy particle accelerators:
  - $\delta < 1$
  - Insignificant to moderate increase in impedance
  - Easy implementation
  - Robust
  - Highly reproducible
  - Inexpensive
  - In-situ