



Novel laser-engineered surfaces for electron cloud mitigation

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FUNCTIONAL MATERIALS *for* OPTICAL & PARTICLE BEAMS

Manufacturing with Light

Collaborators:

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- ① Fabrication & processing of novel functional materials
- ② Laser functionalisation of traditional materials
- ③ Complex photonics

IMPACT & POTENTIAL APPLICATIONS: storage of information, sensing, circuitry & security, energy sector, particle accelerators, healthcare & creative industries
fundamental optical studies, beam shaping, laser technology.





*Virtual
Engineering
Centre*

*Innovation
Centre*

*Cockcroft
Institute*

*Vanguard
House*

Hartree Centre

*Innovations
Technology Access
Centre (ITAC)*

HPC

*VELA/CLARA
Facilities*

*ALICE/EMMA
Facilities*

SuperStem

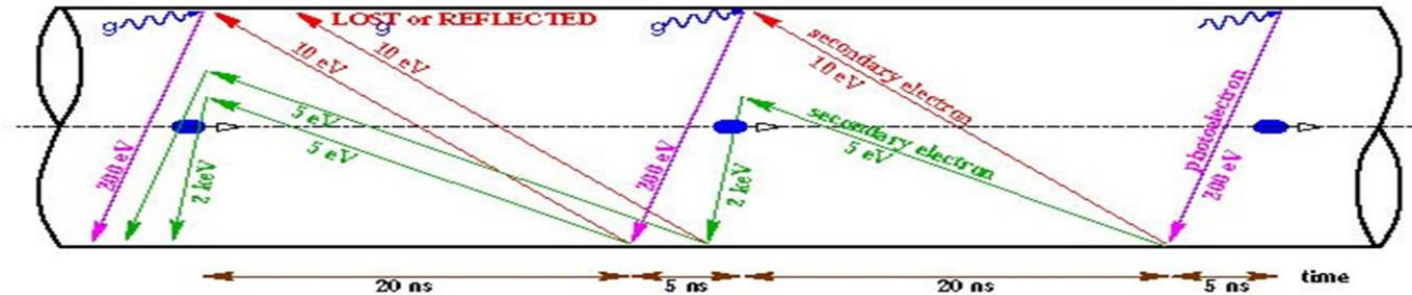
*Engineering
Technology Centre*



STFC Daresbury Laboratory

- ASTeC Vacuum Science Group
 - SEY measurement and surface analysis facility
 - Electron stimulated desorption
 - RF impedance measurement facility
 - Expertise in e-cloud mitigation in particle accelerators
 - Design of particle accelerator vacuum systems
- STFC grant for Proof of Concept work (2014)

Basic aim of our studies



1. Mitigation of beam-induced electron multipacting and electron cloud build-up in a particle accelerator beam chamber due to photo- and secondary electron emission
2. Reduction in beam instability, beam losses and emittance growth, & reduction in beam lifetime or heat loads on cryogenic vacuum chambers
3. Multipactor mitigation in RF wave guides and space-related high power RF hardware.
4. Reducing PEY and SEY in other instruments and devices, where necessary

Standard Objective Reduce The Secondary Electron Yield (e.g. $\delta_{\max} < 1.3$ for CERN SPS):

- by Changing surface Chemistry (deposition of lower SEY material)
- by Engineering the surface roughness
- by a Mixture of the above

Existing Mitigation Methods

By active means:

- Weak solenoid field (10 - 20G) along the vacuum chamber
- Biased clearing electrodes
- Charged particle beam train parameters
 - Bunch charge and sizes
 - Distance between bunches

Advantages:

- Solenoids can be installed on existing facilities (if there is space for them)
- Beam parameters have some flexibility

Disadvantages:

- Requires:
 - controllers
 - power supplies
 - cables
 - vacuum-compatible feedthroughs

i.e. should be avoided if possible

By passive means:

- Low SEY material
- Low SEY coating
- Grooved surfaces
- Special shapes of vacuum chambers
 - an antechamber allows reducing PEY

Advantages:

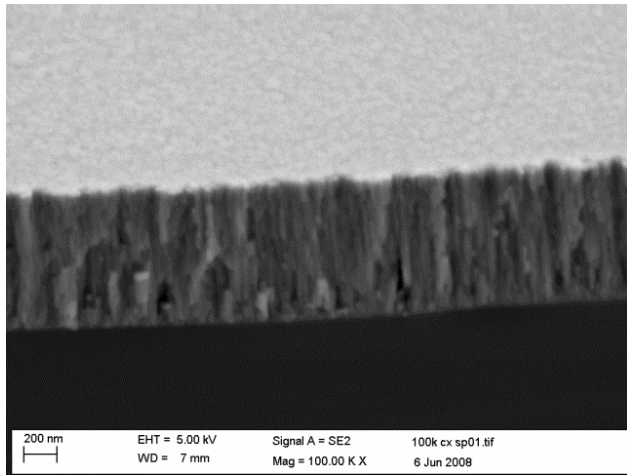
- No Controllers,
no power supplies,
no cables

Disadvantages:

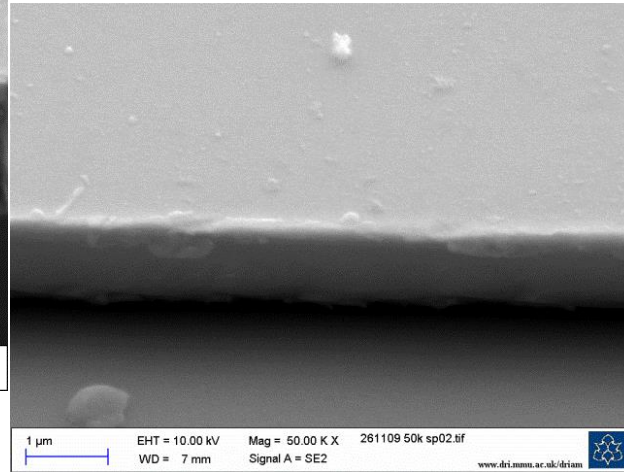
- in-vacuum deposition
- difficult to apply on existing facilities
- inconvenient & expensive chamber modifications

Existing Mitigation Methods

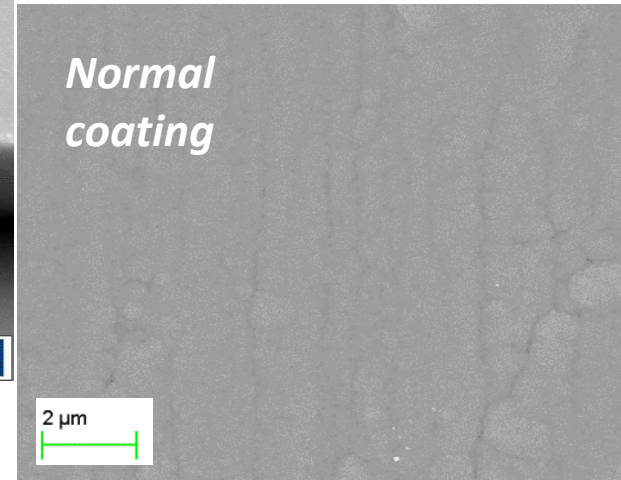
1. Coating with Low SEY Material



Ti-Zr-V-Hf



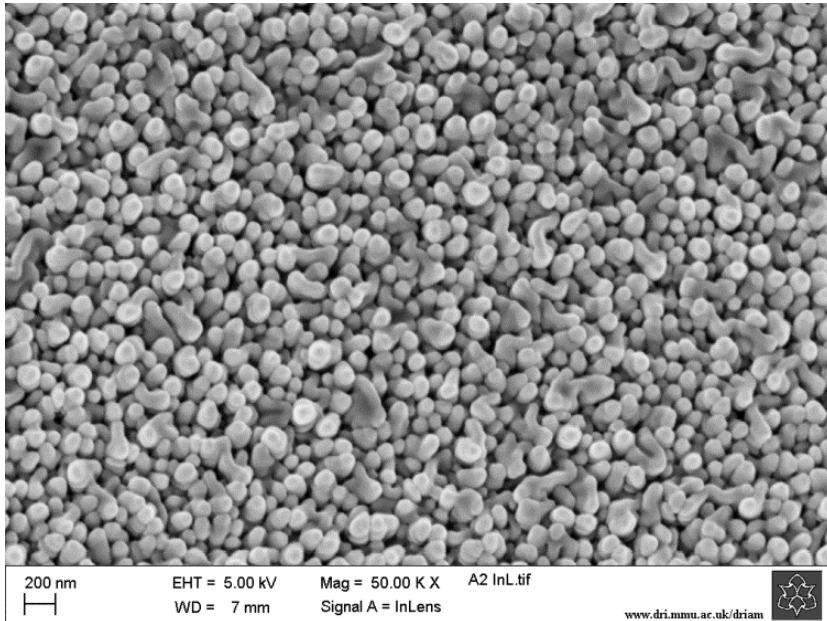
Ti-Zr-Hf-V-N



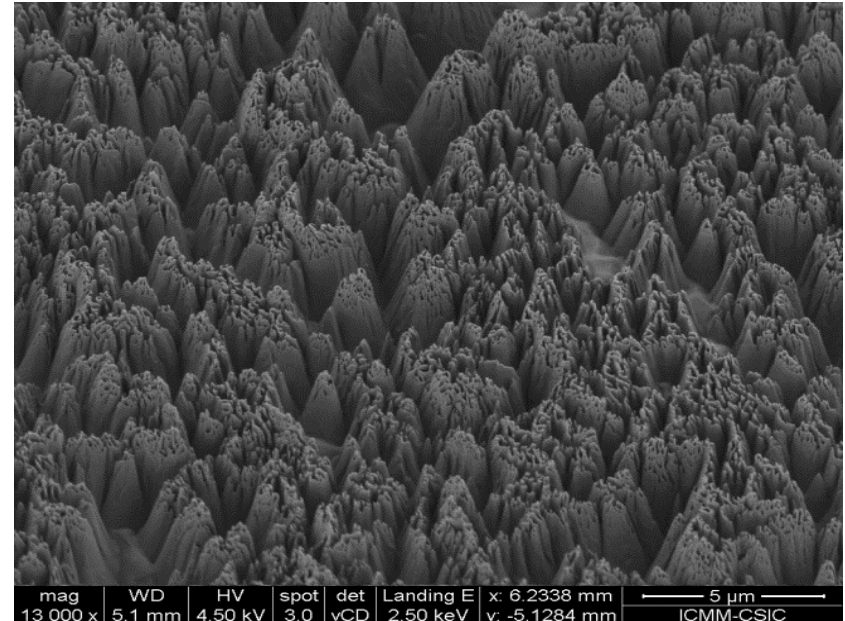
a-C at CERN

Existing Mitigation Methods

2. Coating with a low SEY material with sub-micron size structure



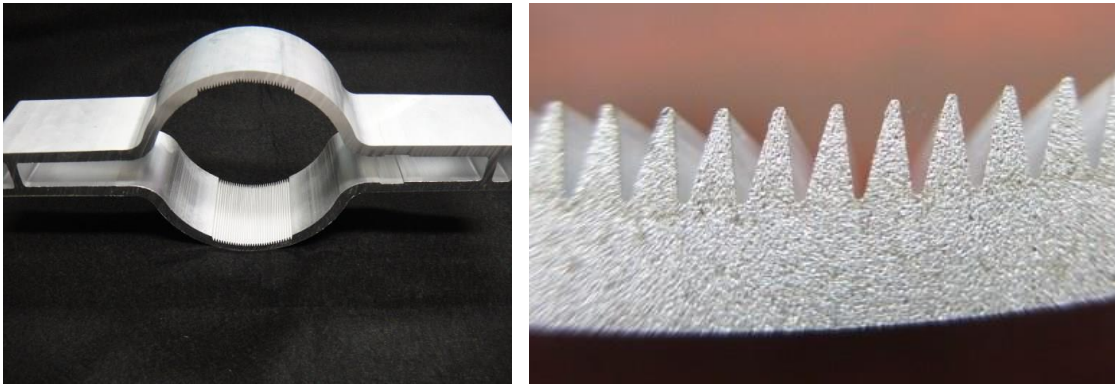
Ti-Zr-V black



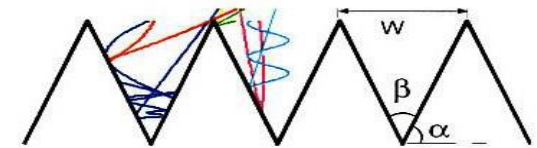
Ag plating, ion etched with Mo Mask
I. Montero et. al, Proc. e-Cloud12

Existing Mitigation Methods

3. Modifying the surface geometry making mechanical grooves

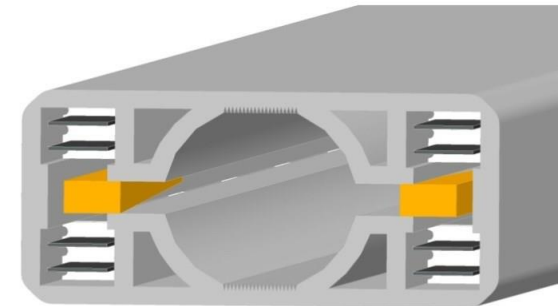


KEKB vacuum chamber (by courtesy of Y. Suetsugu)



By A. Krasnov and
by L Wang et.al

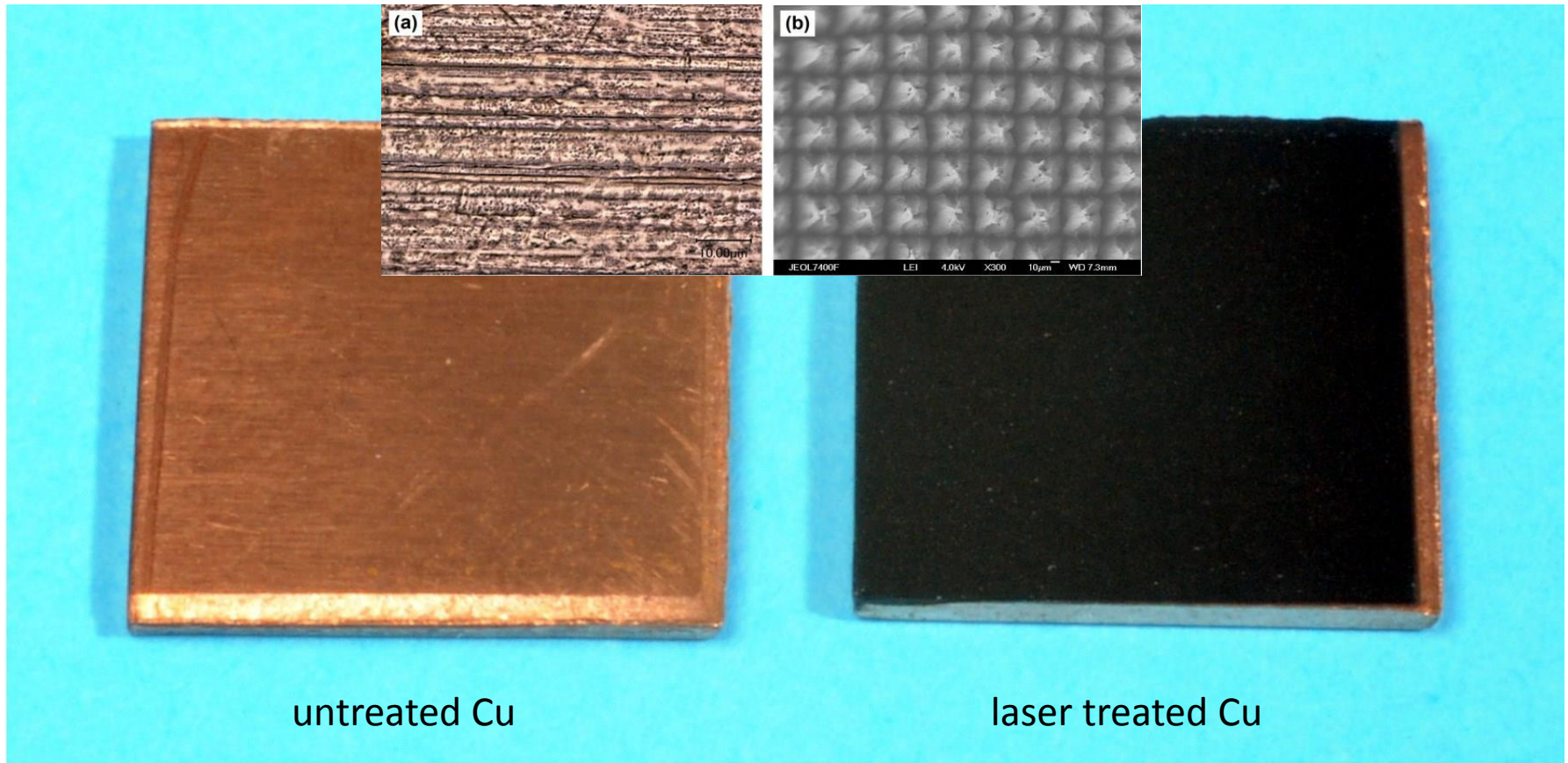
4. Modifying the vacuum chamber geometry making an antechamber



ILC wiggler vacuum chamber

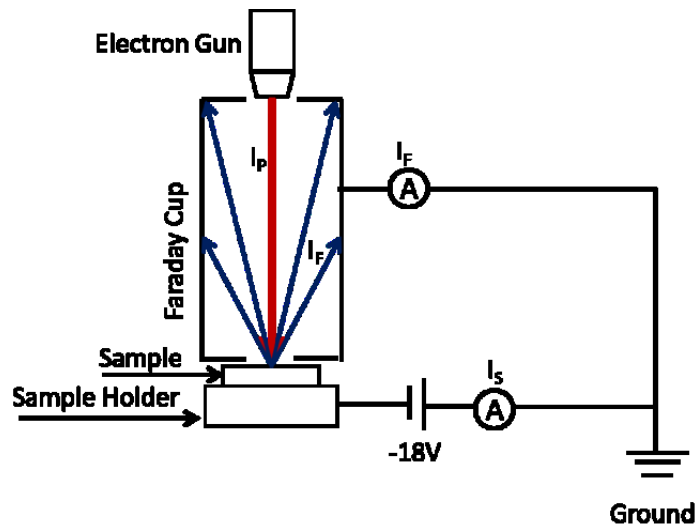
Introducing new technology

- Laser treatment of metal surfaces in air or noble gas atmosphere



- beam is raster-scanned in both horizontal and vertical directions
- with average laser energy fluence just above ablation threshold of the metal
- We call these **“Laser-engineered surface structures” (LESS)**

SEY Measurements at STFC Daresbury Laboratory



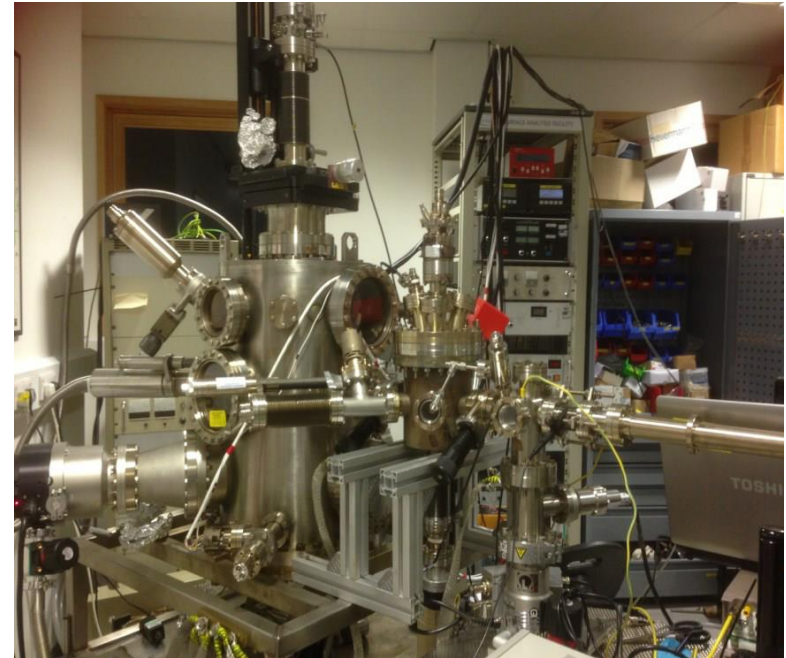
Define the **secondary electron yield**, **SEY** or δ , in the usual way

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

I_P is the primary beam current

I_F is the secondary electron current, including elastic and inelastic processes, measured on the Faraday cup

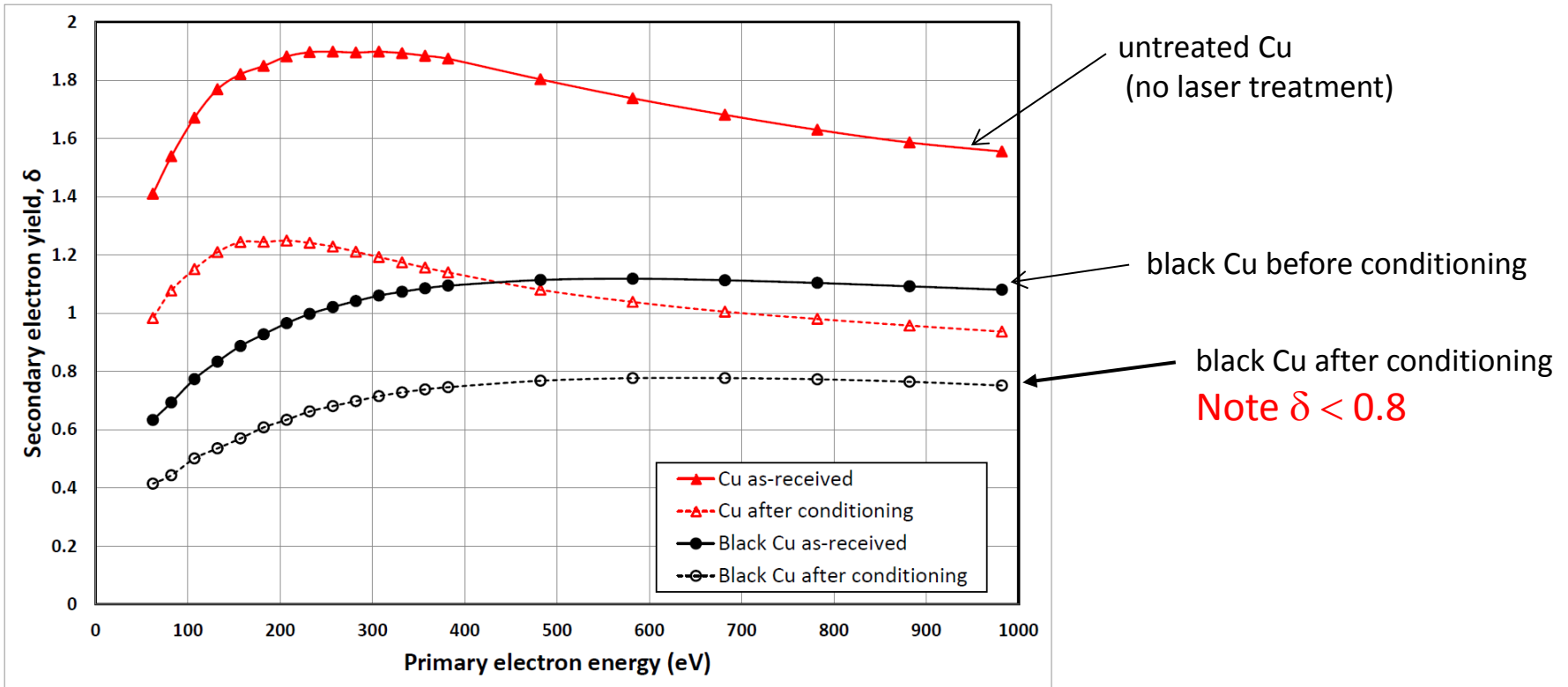
I_S is the current on the sample



Analysis chamber with:

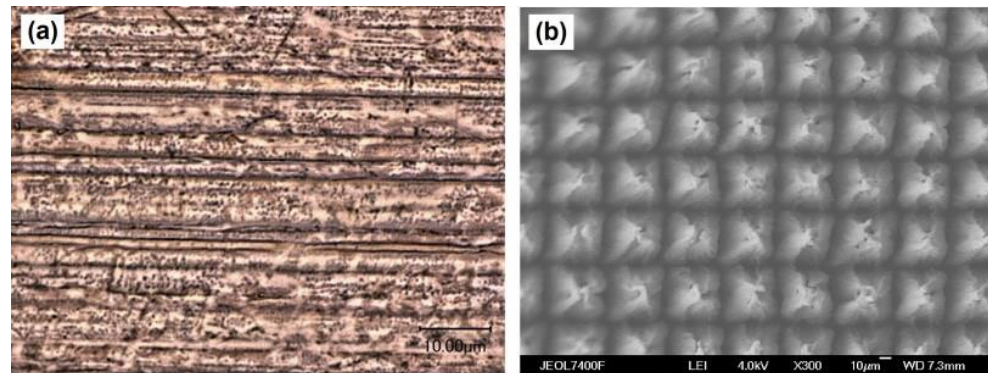
- XPS,
- Flood e-gun (0.5 – 2.0 keV)
- Sample heater
- Ar ion beam

RESULTS: SEY of Cu as a function of incident electron energy



Original Data
June 2014

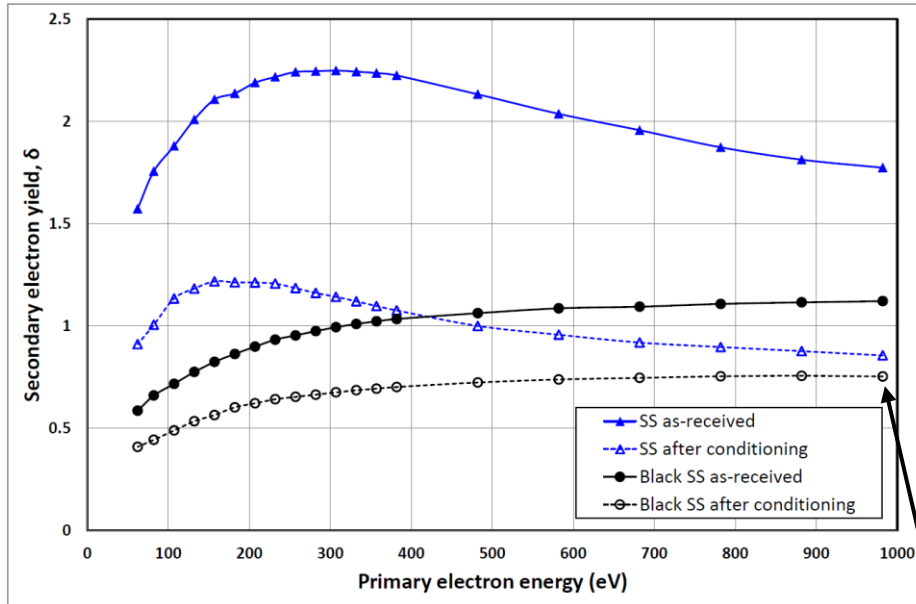
We have complete control over the highly regular surface topography



High-resolution SEM images of the Cu samples:
(a) untreated and (b) laser treated

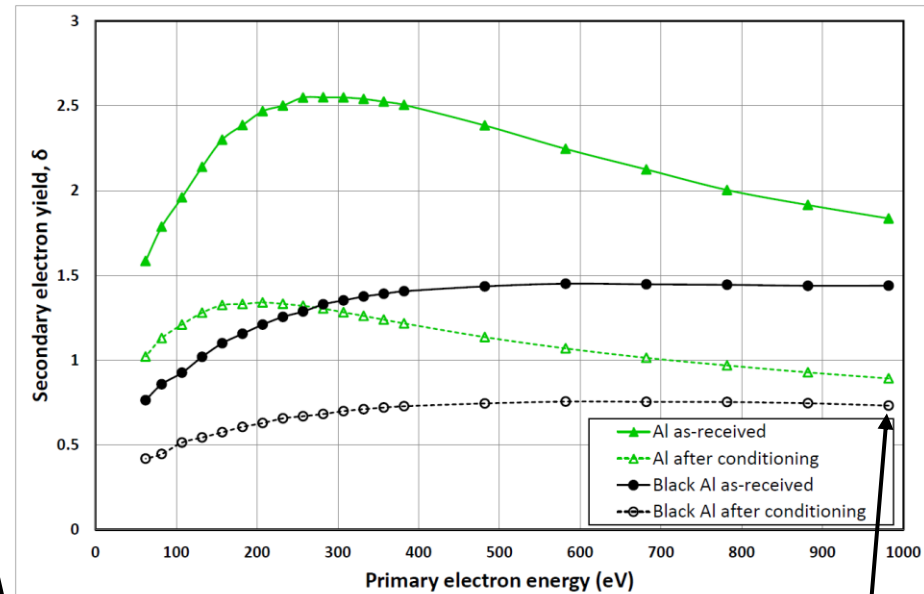
RESULTS: SEY of SS & Al as a function of incident electron energy

stainless steel



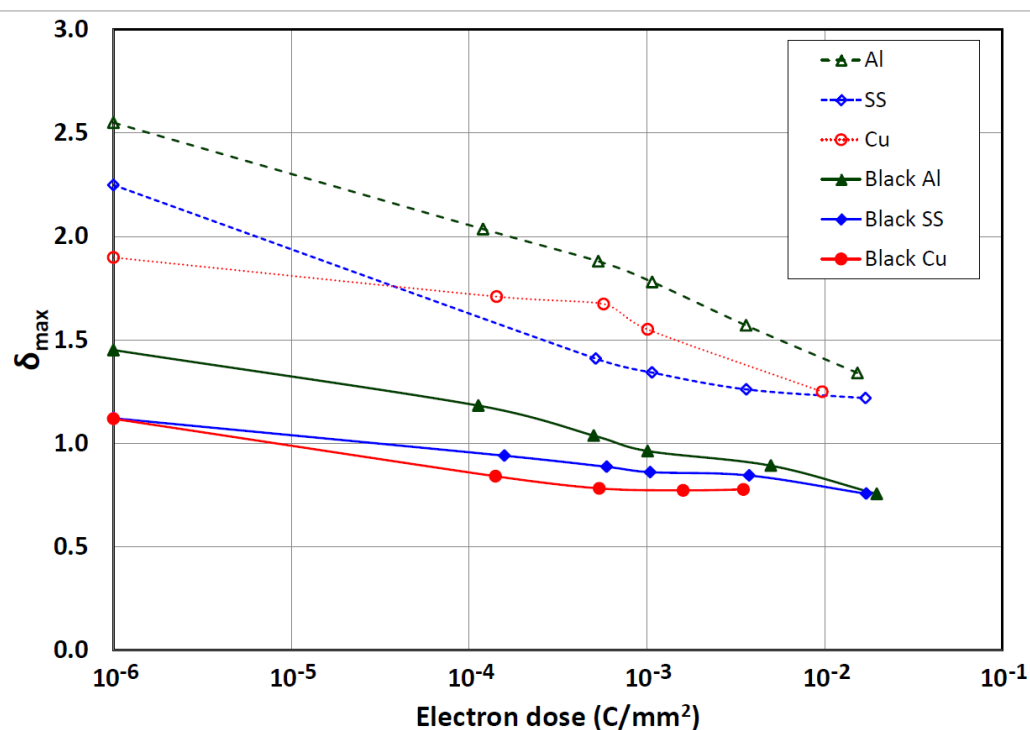
Note $\delta < 0.7$

aluminium



Note $\delta < 0.7$

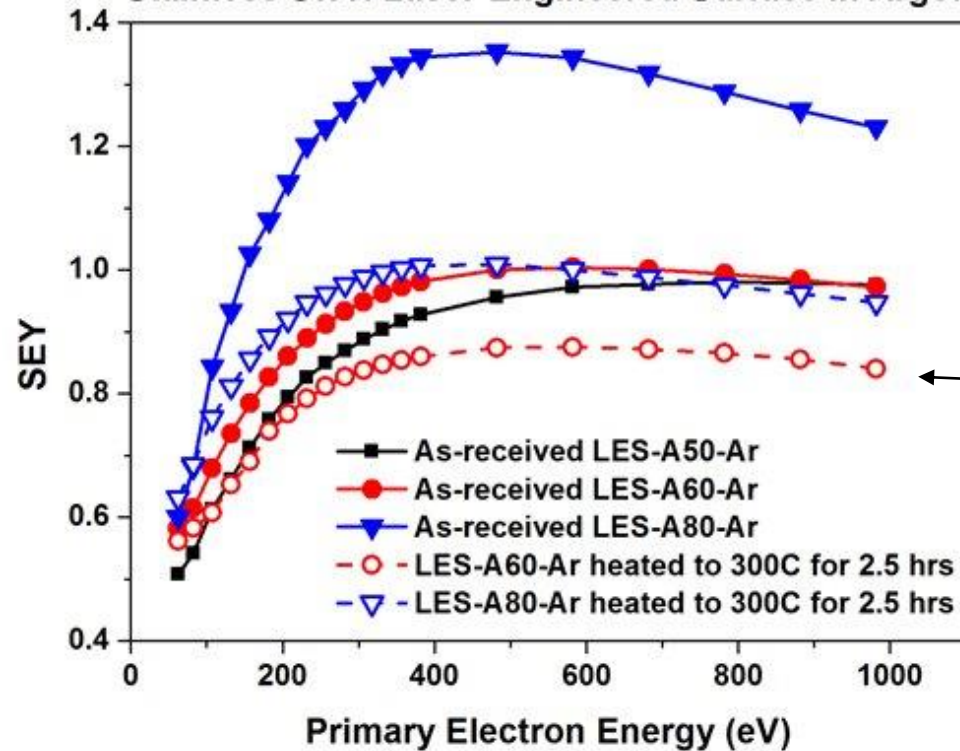
δ_{\max} as a function of electron dose for Al, 306L SS and Cu



| 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. Verified by XPS results.

Stainless Steel Laser-Engineered Surface in Argon



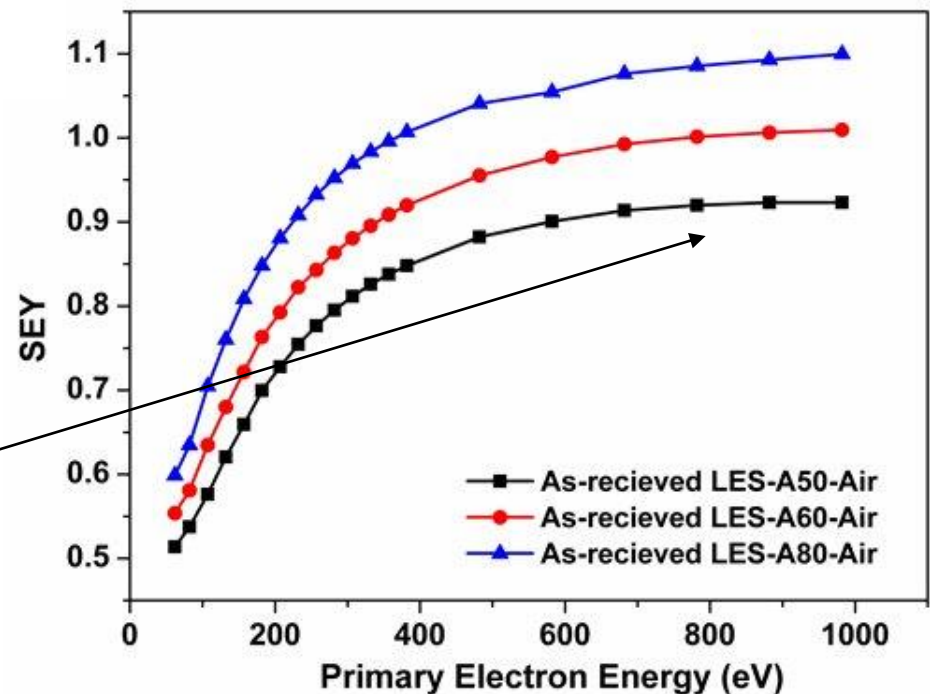
Stainless steel data

Note $\delta < 0.85$

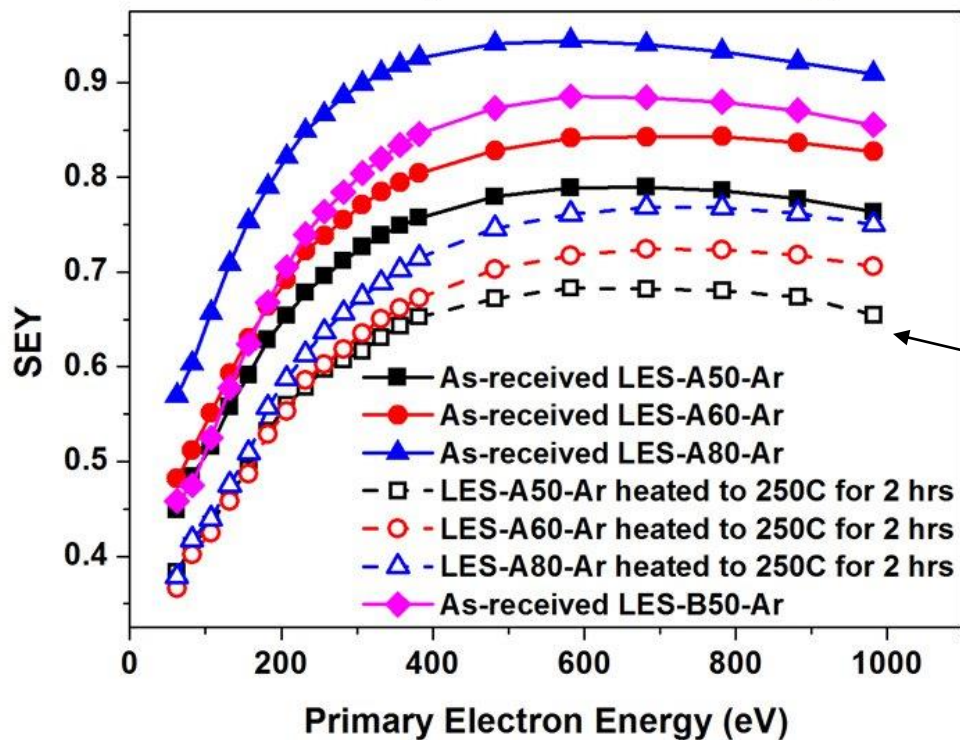
Recent Data
Nov-Dec 2014

Note $\delta < 0.9$

Stainless Steel Laser Engineered Surface in Air



Cu Laser-Engineered Surfaces in Argon

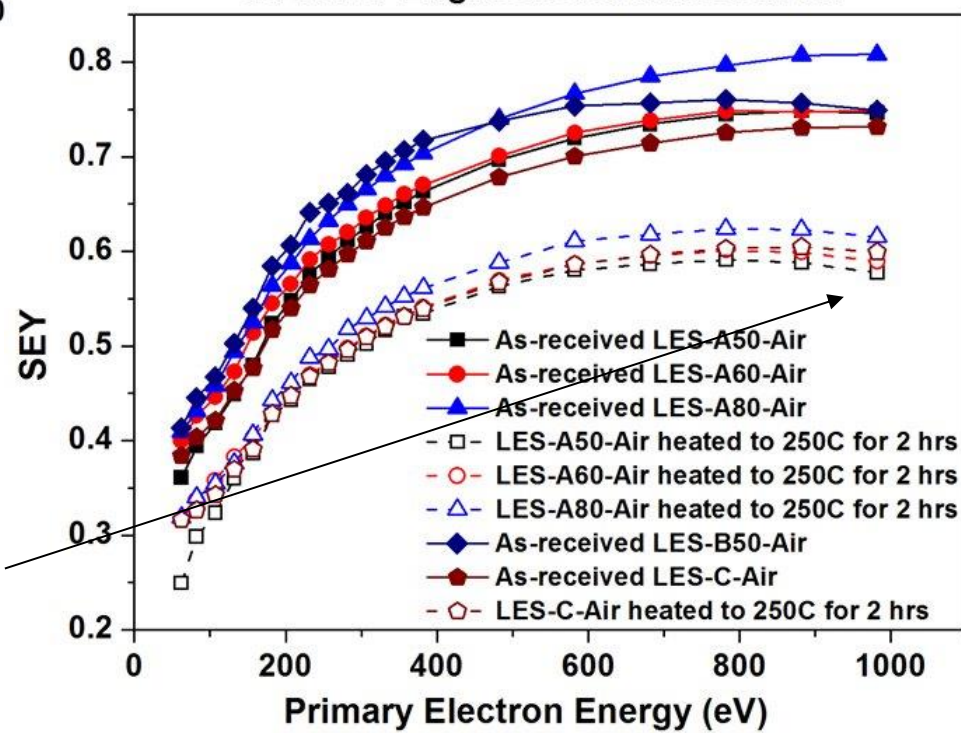


Copper data

Recent Data
Nov-Dec 2014

Note $\delta < 0.55$

Cu Laser-Engineered Surfaces in Air

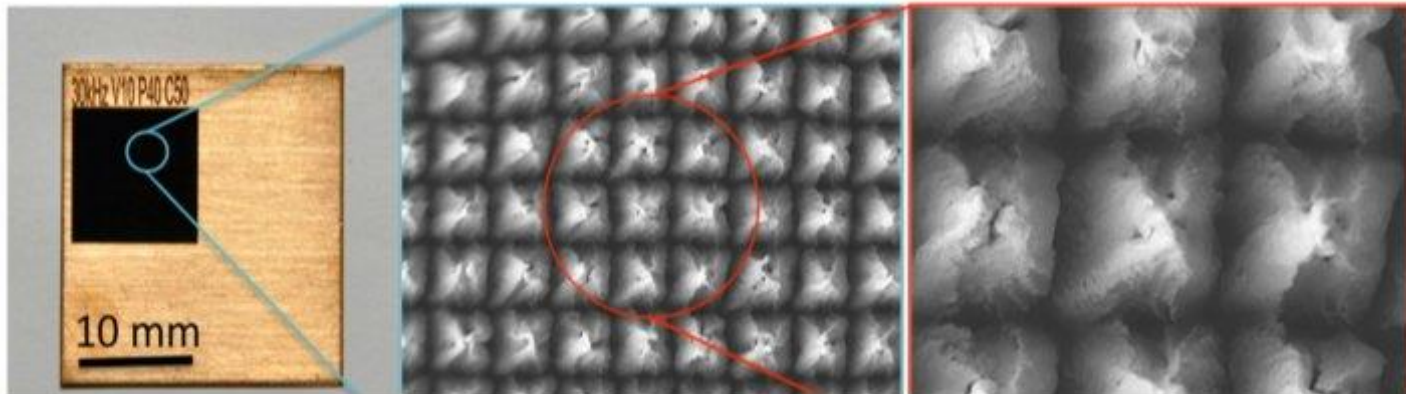


How do we do this?

Laser processing of Copper

beam is raster-scanned in both horizontal and vertical directions

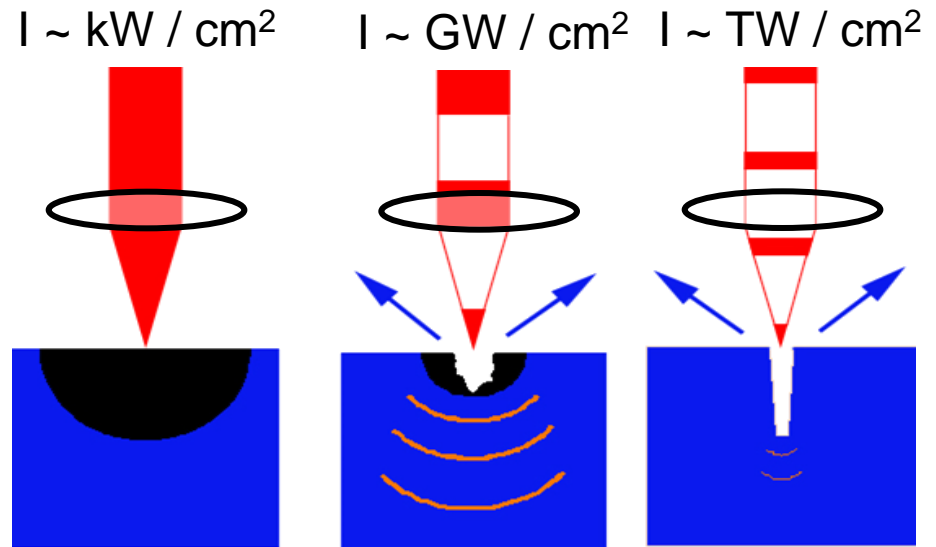
with average laser energy fluence just above ablation threshold of the metal



Appl. Phys. Lett. 101, 2319021 (2012). **Physics Highlights – Physics Today** (February 2013).
Opt. Mater. Exp. 1,1425 (2011).

Laser Ablation of Metals - Components of light control

- Laser Wavelength
- Energy & Power
- Spot size & shape of beam
- Pulse length



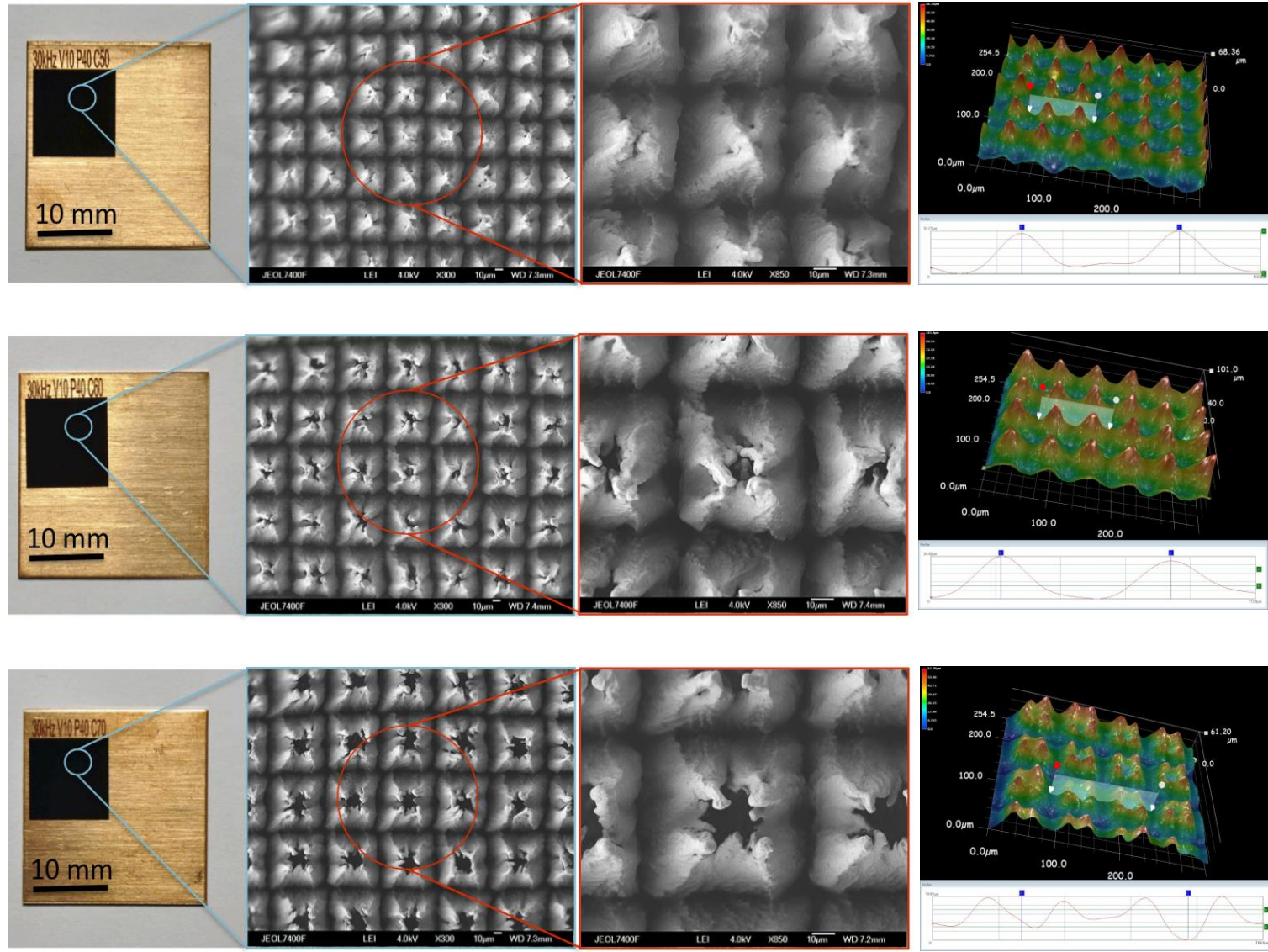
Part of this **ENERGY** (once randomised) is

- Conducted into the bulk of the material*
- Converted into directed kinetic energy by thermal expansion of the heated layer.*

TWO distinguished regimes are identifiable at high irradiances:

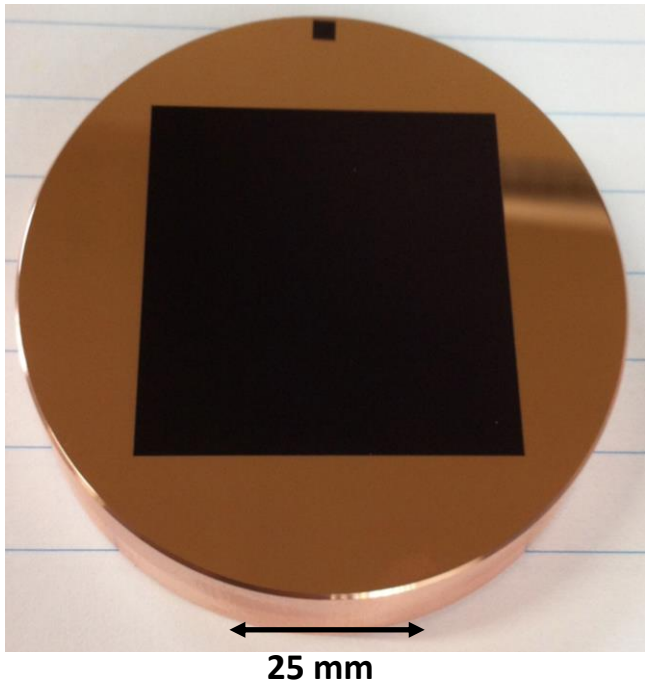
- Short (ns) pulses:** Dominated by the expansion and ablation of material;
- Ultra-short (ps & fs) pulses:** Dominated by heat conduction, as hydrodynamic motion during the pulse duration is negligible.

Material: Copper



Appl. Phys. Lett. 101, 2319021 (2012). **Physics Highlights – Physics Today** (February 2013).
Opt. Mater. Exp. 1,1425 (2011).

Metals treated so far
Copper; Aluminium; Titanium; S.Steel

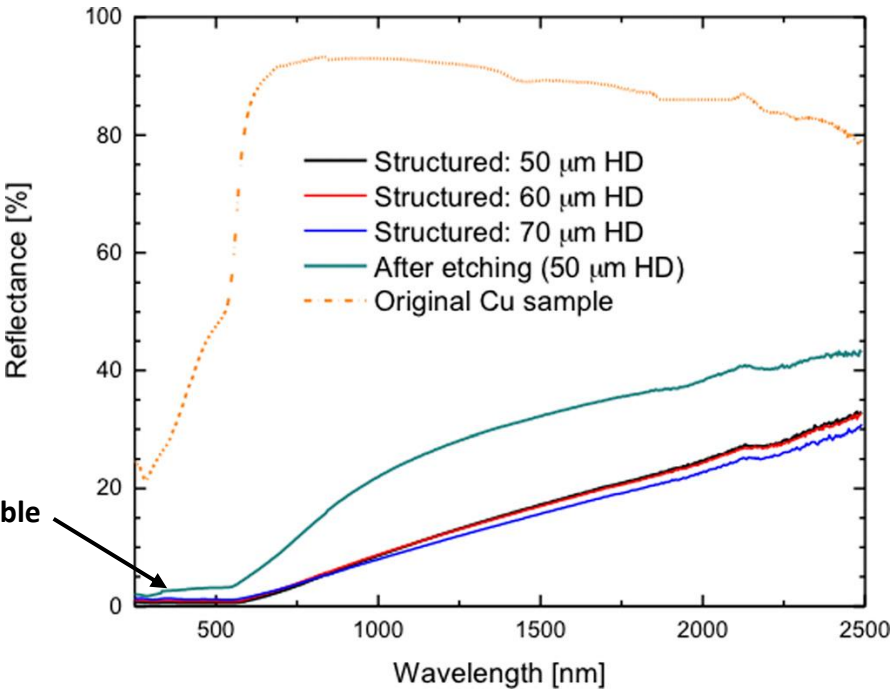


Reflectance of “black copper”

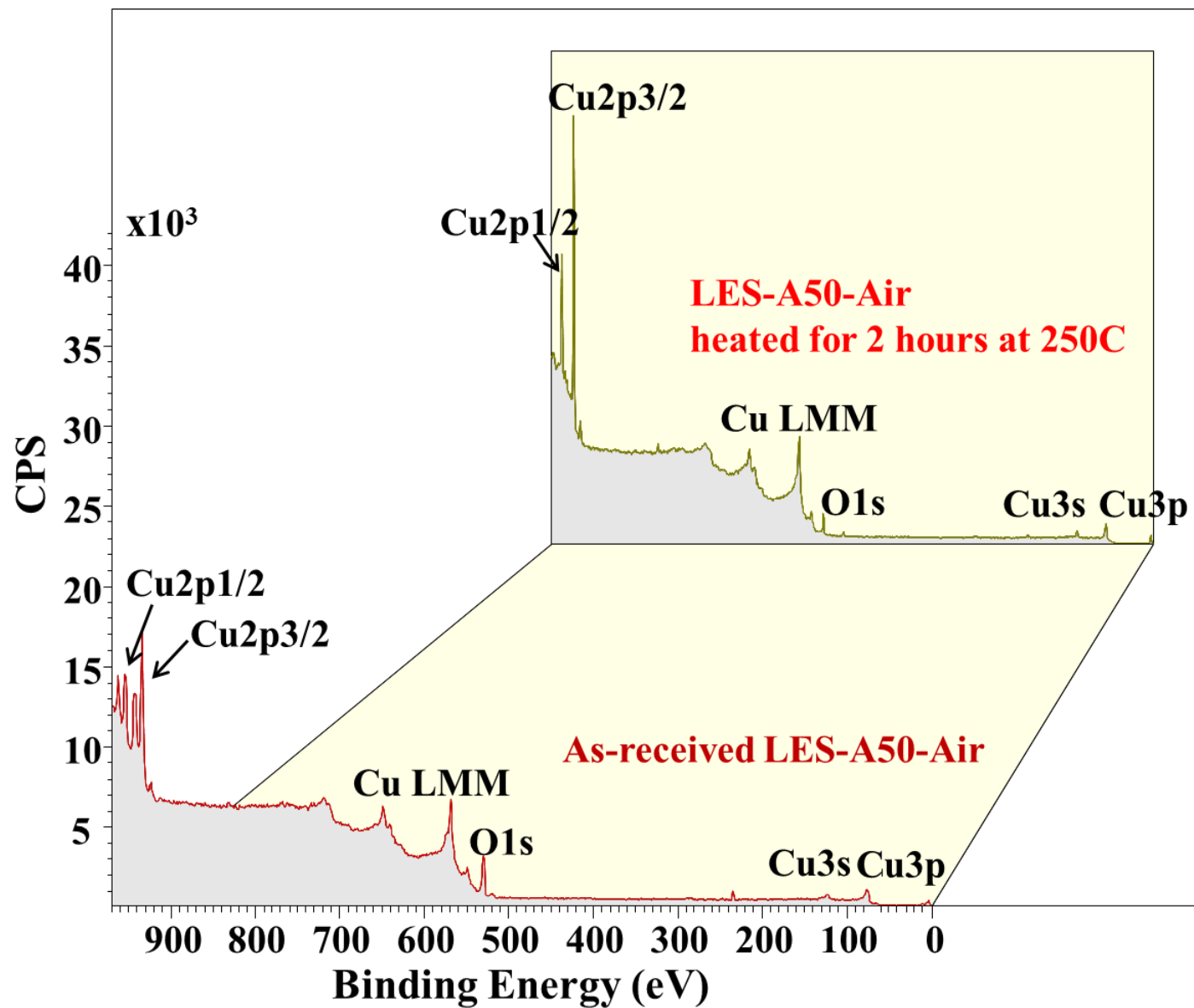
< 3% across visible

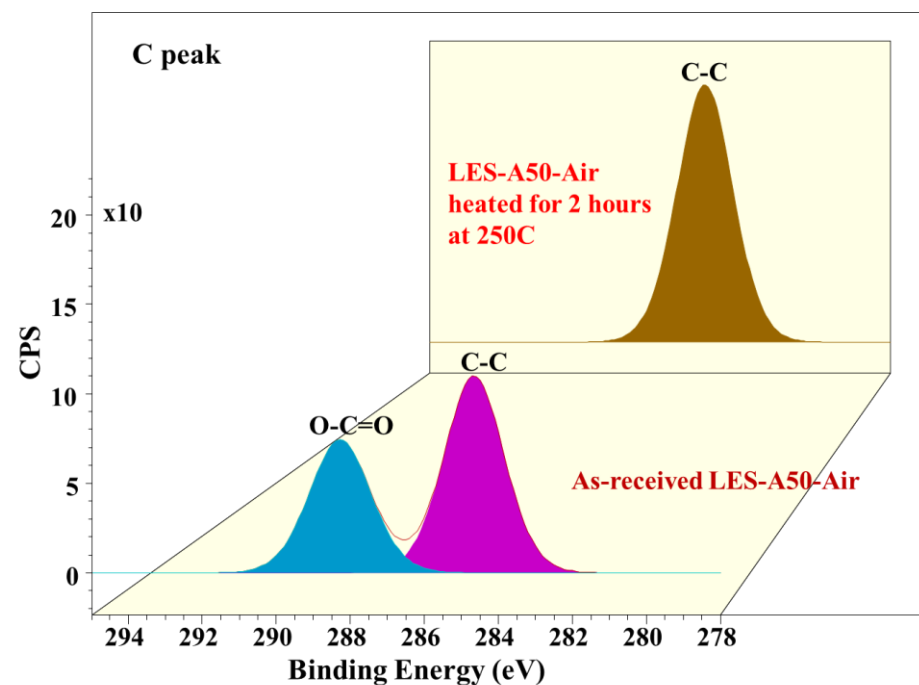
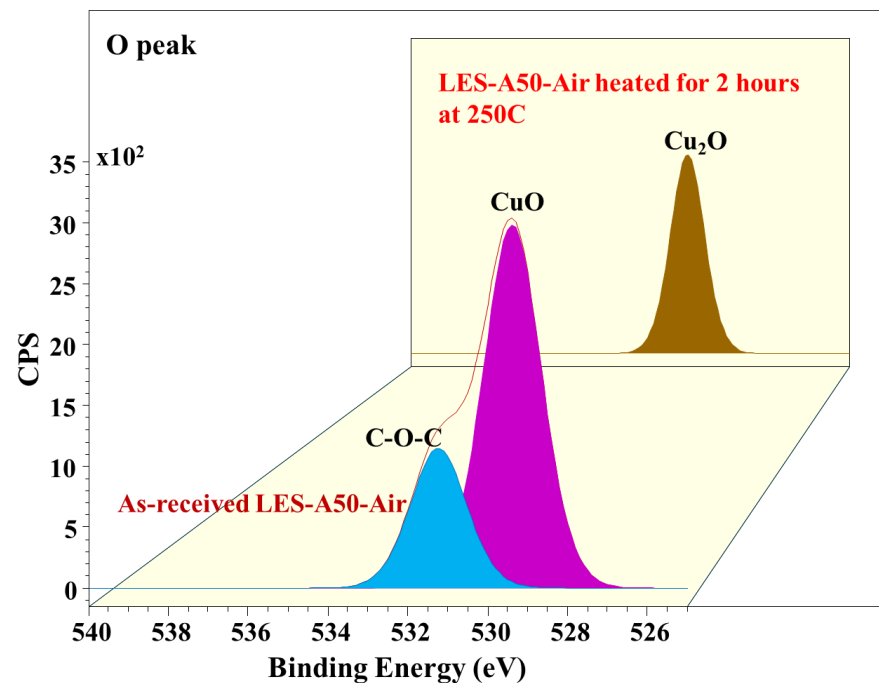
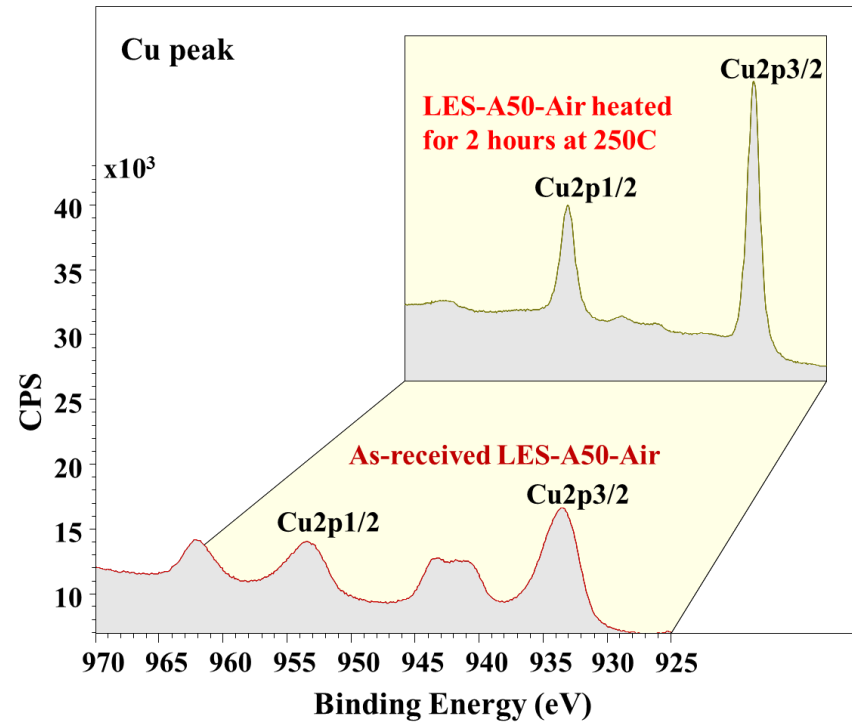
Appl. Phys. Lett. 101, 2319021 (2012).
Opt. Mater. Exp. 1,1425 (2011).
Int. J. Adv. Manu. Technol. 66, 1769 (2013).

A practical example:
Laser micro-structured copper mirror
(optical / THz separator)
Fabricated for the Beam Diagnostics
Group at ASTeC, Daresbury Laboratory.



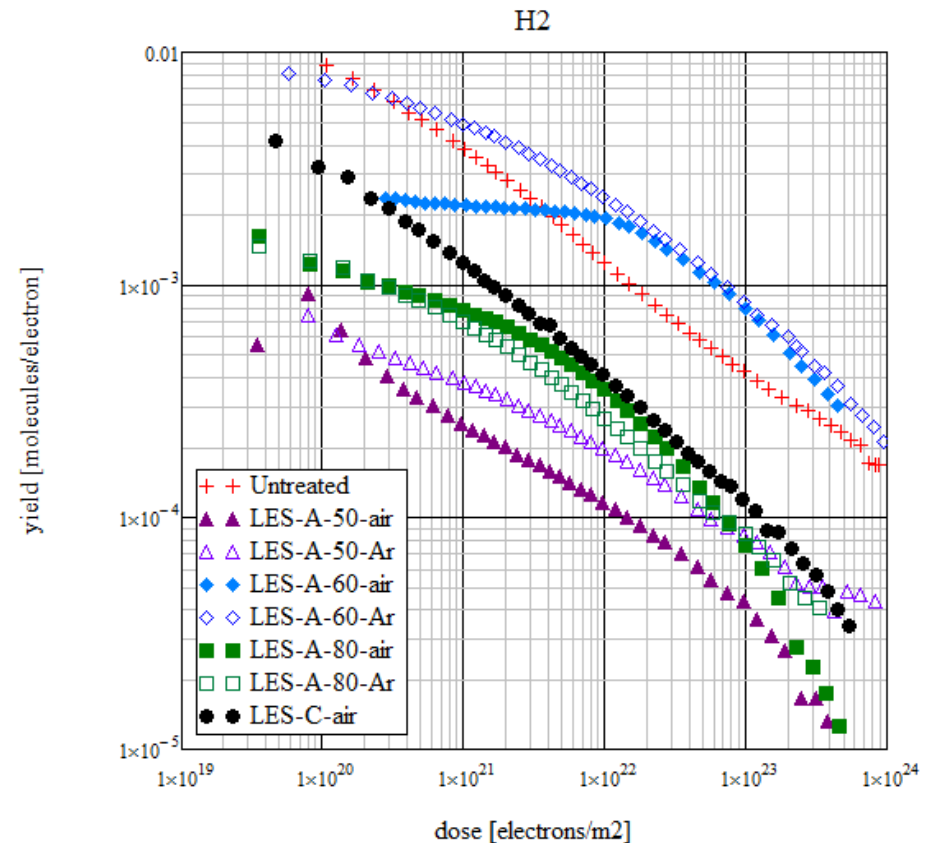
XPS analysis of Cu sample before & after conditioning





Electron Stimulated Desorption (ESD)

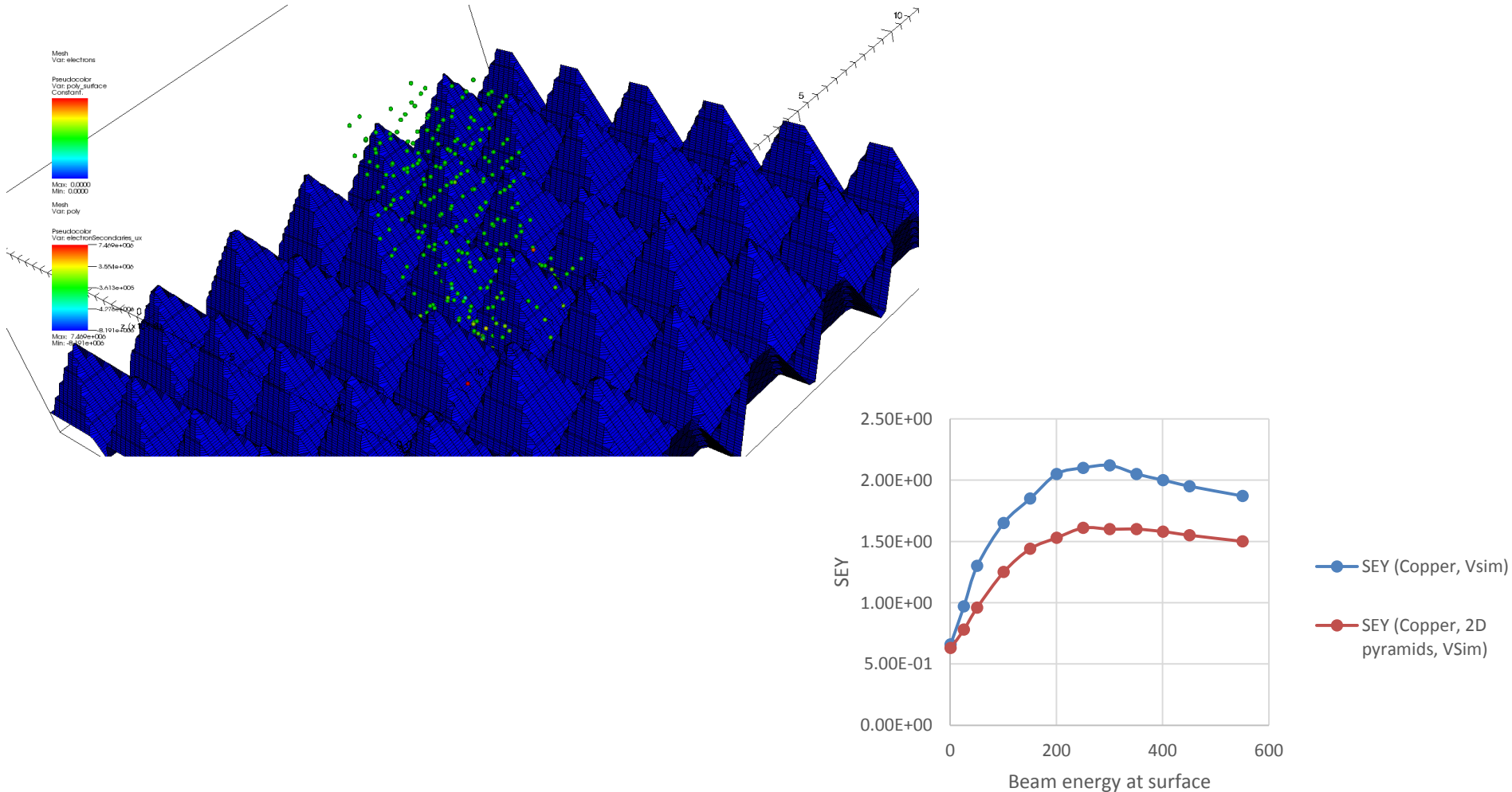
- 9 samples were tested:
 - Cu blank gaskets $\varnothing 48$ mm
 - Untreated (2 samples)
 - LES-A type treated in air or Ar atmosphere
 - LES-C type treated in air
 - $E_{e^-} = 500$ eV



- Main results:
 - LES-A-50, LES-A-50 and LES-C demonstrated lower ESD yields than untreated samples
 - LES-A-50 treated in air yielded the best results

Simulations

Very preliminary studies of e-cloud mitigation being carried out
(in VSim) by Jonathan Smith of Tech-X Corporation in the UK



Summary

- ❖ Laser conditioning of metal surfaces is a very viable solution for **reducing the SEY < 0.6**
- ❖ **Even the initial (unconditioned) SEY of 1.1 for black SS** is low enough to suppress e-cloud in, e.g., the SPS, LHC or HL-LHC.
- ❖ 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.
- ❖ The blackening process can be carried out **in air at atmospheric pressure**; the actual cost of the mitigation is therefore considerably lower, a fraction of 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 coatings.
- ❖ The treated surface **remains the same material**, therefore it is unlikely to have a significant effect on the surface impedance – recent measurements verify this.

Thank you for your attention

nanosecond processing of Al

Material: Anodised aluminium

Wavelength: 1064 nm

Pulse length: 10 ns

Focal spot diameter: 60 μm

Processing speed: 1200 mm/s

