Novel laser-engineered surfaces for electron cloud mitigation

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LA^{3}NET conference, Mallorca, 26 Mar 2015

FUNCTIONAL MATERIALS
for
OPTICAL & PARTICLE BEAMS

Manufacturing with Light

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Materials & Photonics Systems (MAPS) Group

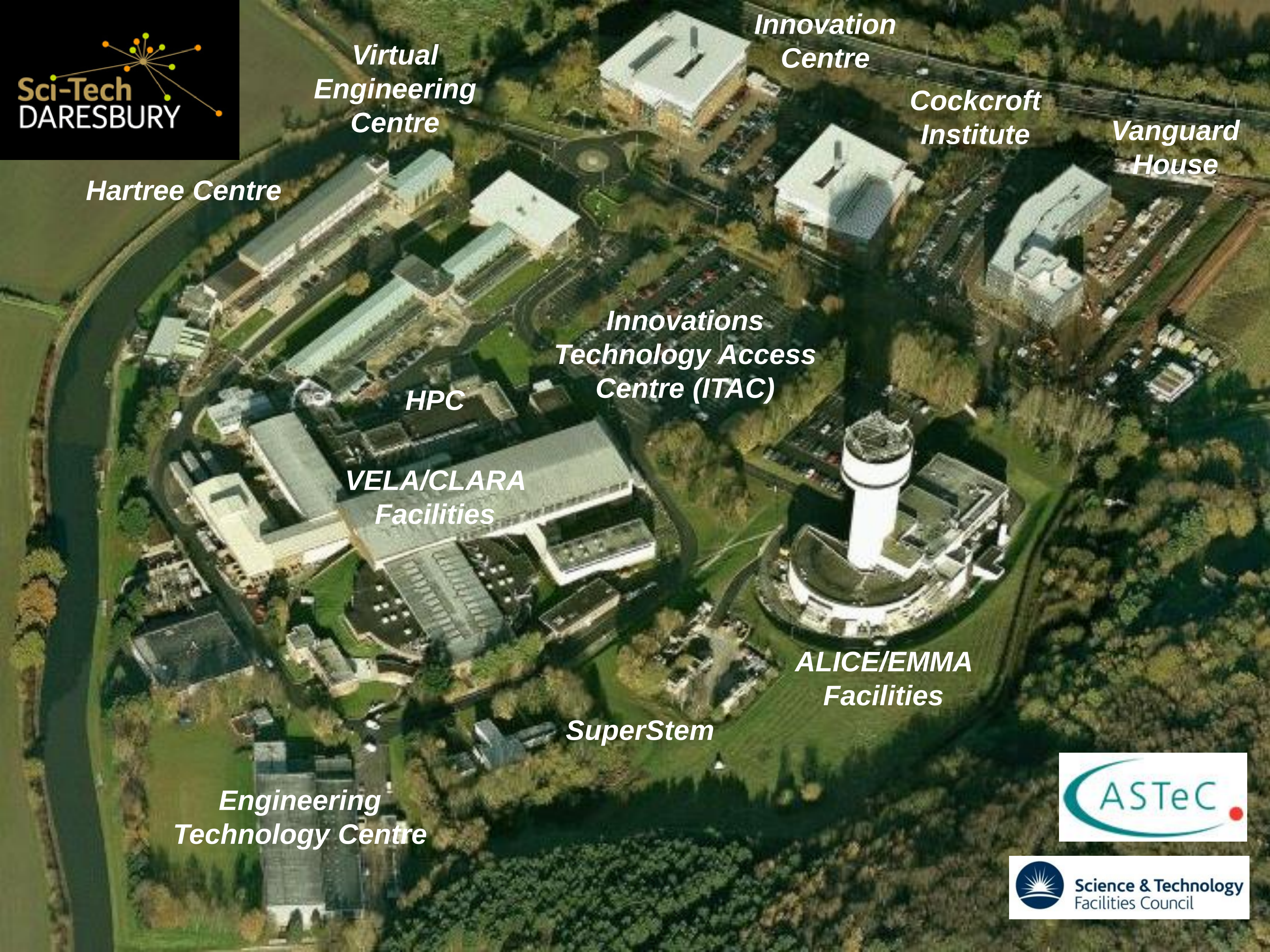
MAPS

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.

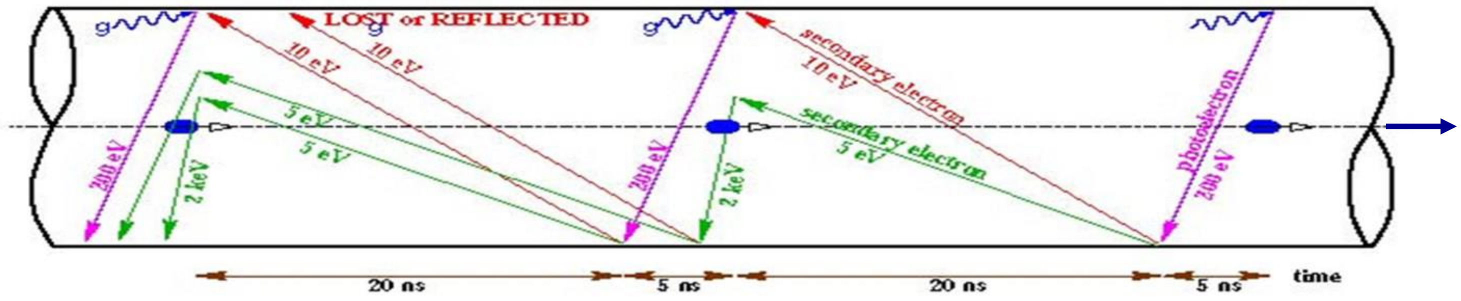

Sci-Tech DARESBURY
Virtual Engineering Centre
Innovation Centre
Cockcroft Institute
Vanguard House
Hartree Centre
Innovations Technology Access Centre (ITAC)
HPC
VELA/CLARA Facilities
ALICE/EMMA Facilities
SuperStem
Engineering Technology Centre
ASTeC
Science & Technology Facilities Council

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 – reduction in SEY



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 the 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:

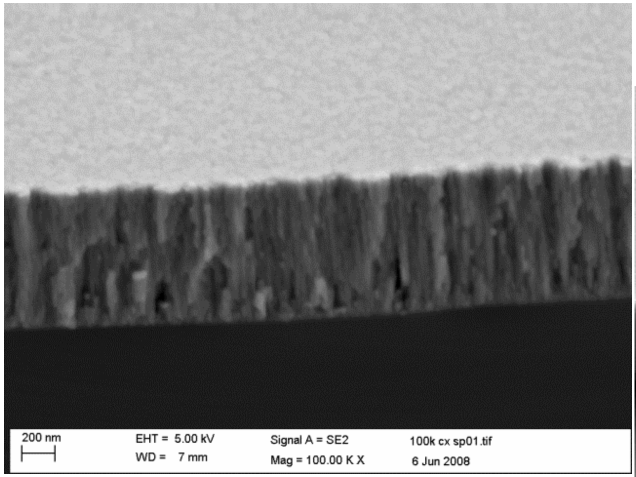
- No Controllers,
  no power supplies,
  no cables

Disadvantages:

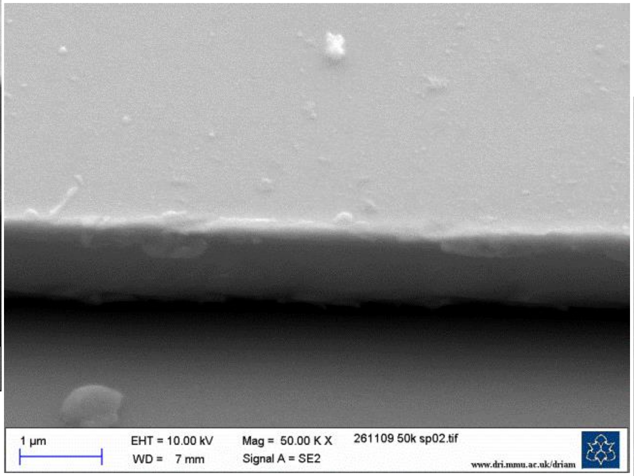
- in-vacuum deposition
- difficult to apply on existing facilities
- inconvenient & expensive chamber modifications

Existing Mitigation Methods

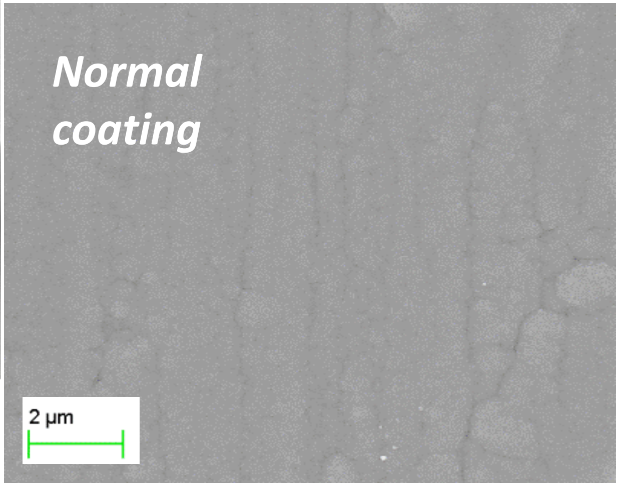
1. Coating with Low SEY Material



Ti-Zr-V-Hf



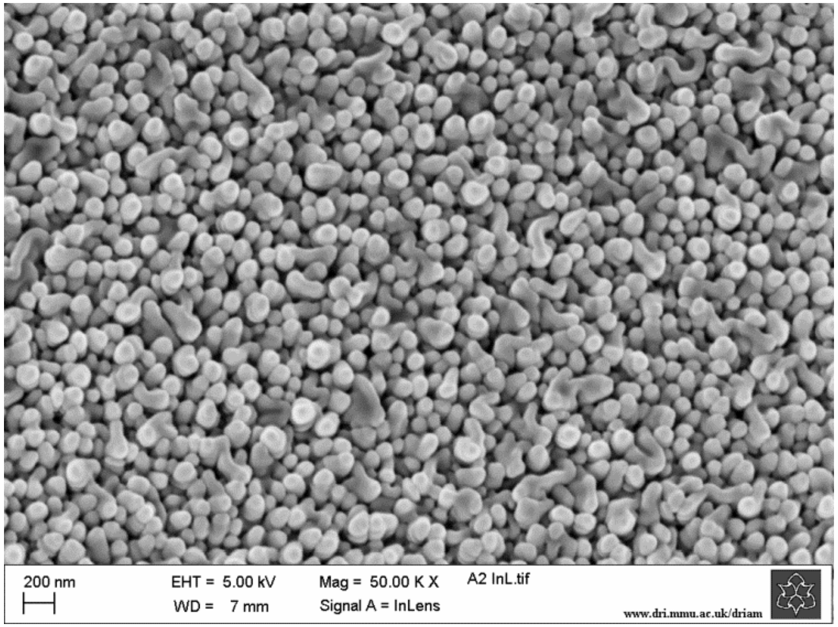
Ti-Zr-Hf-V-N



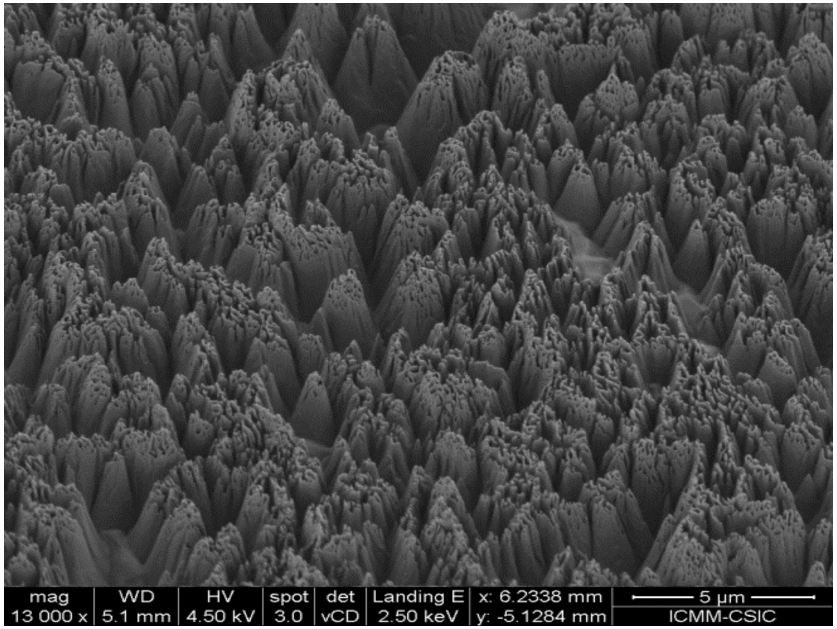
a-C at CERN

Existing Mitigation Methods

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



Ti-Zr-V black

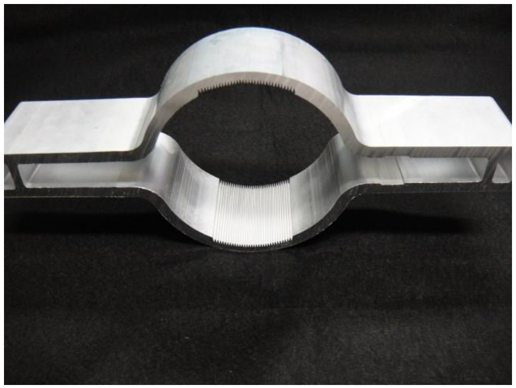


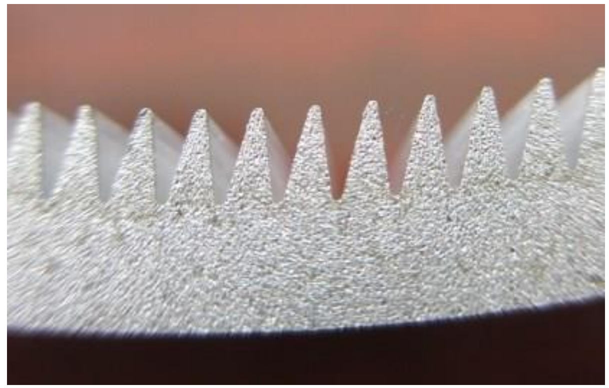
Ag plating, ion etched with Mo Mask
I. Montero et. al, Proc. e-Cloud12

Existing Mitigation Methods

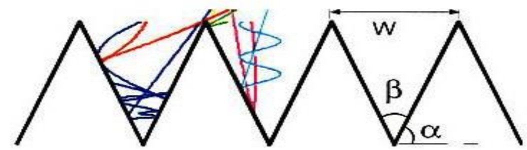
3. Modifying the surface geometry

making mechanical grooves





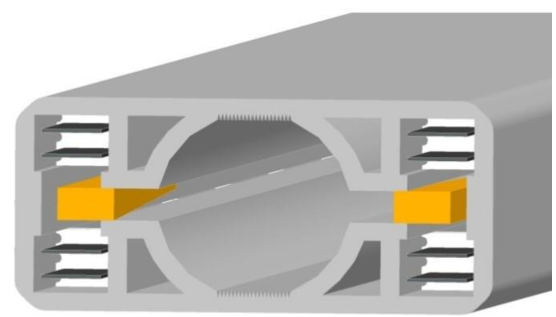
KEKB vacuum chamber (by courtesy of Y. Suetsugu)



By A. Krasnov and by L Wang et.al

4. Modifying the vacuum chamber geometry

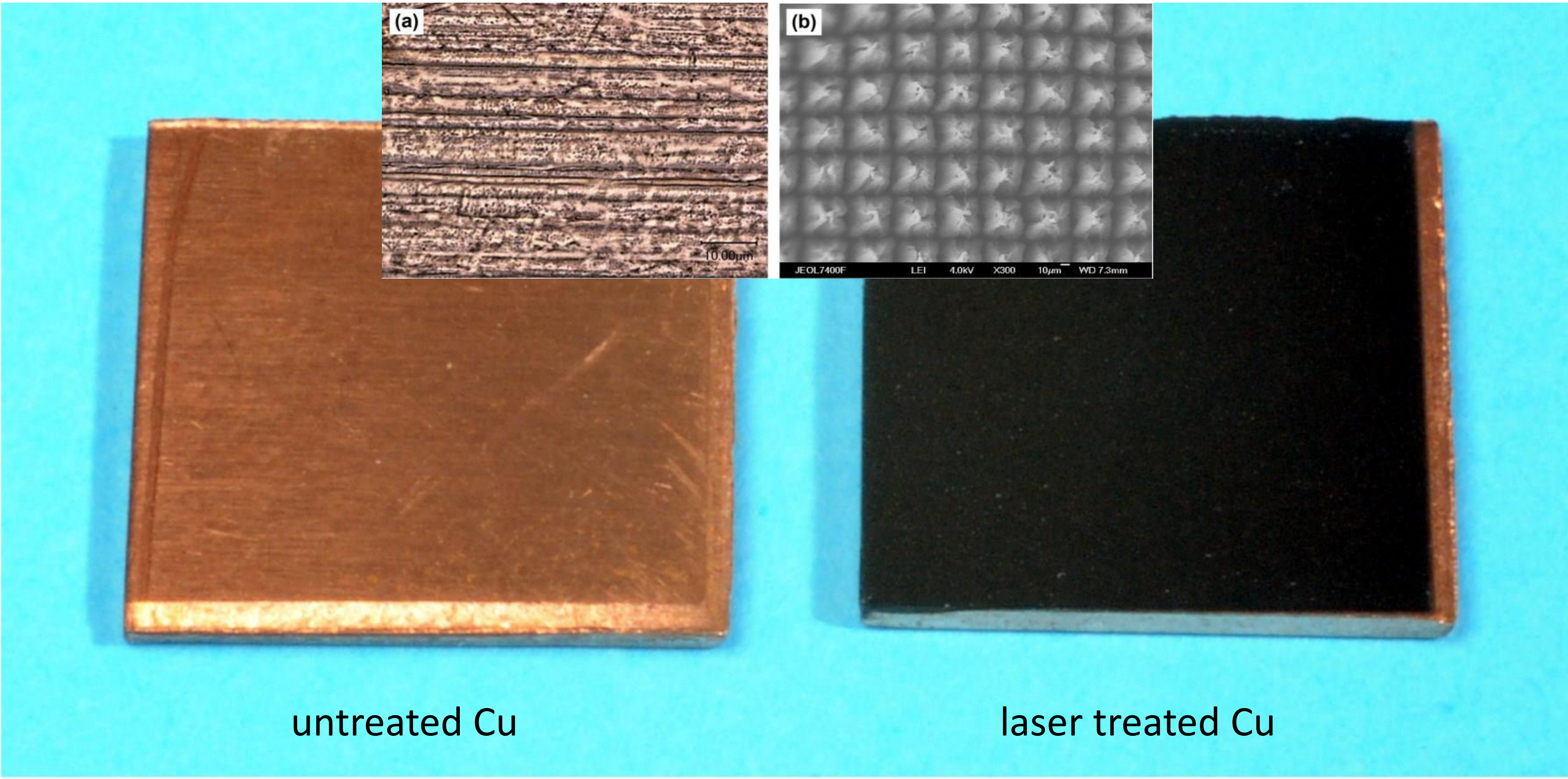
making an antechamber



ILC wiggler vacuum chamber

Introducing new technology

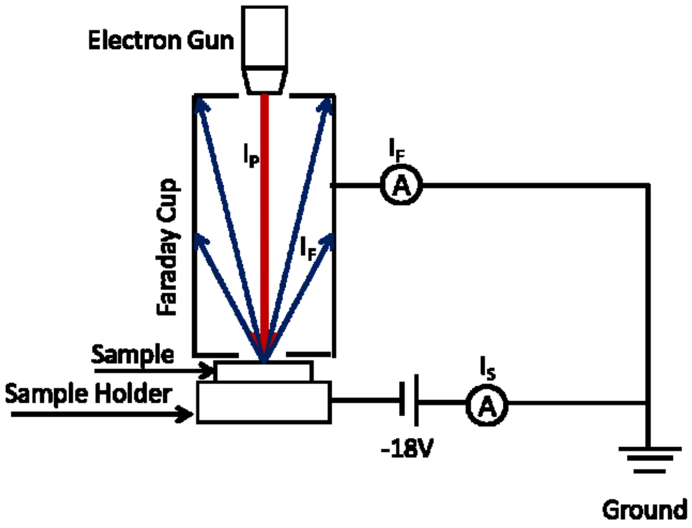
- Laser treatment of metal surfaces in air or noble gas atmosphere



- 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



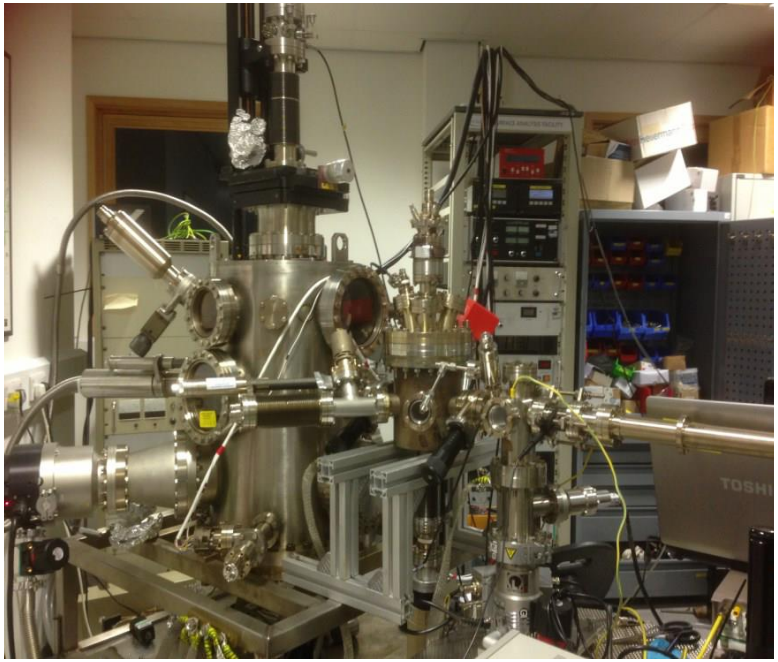
Define the secondary electron yield, **SEY or δ**, in the usual way

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

I_P is the primary beam current

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

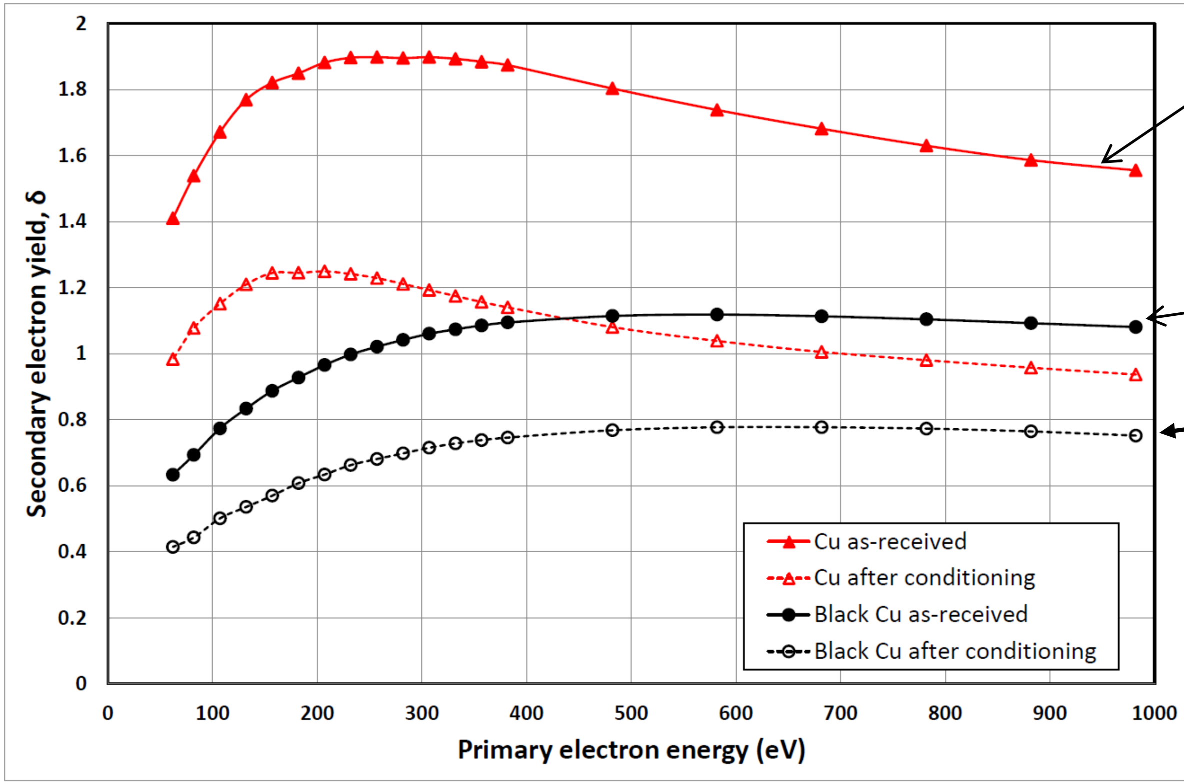
I_S is the current on the sample



Analysis chamber with:

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

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



untreated Cu
(no laser treatment)

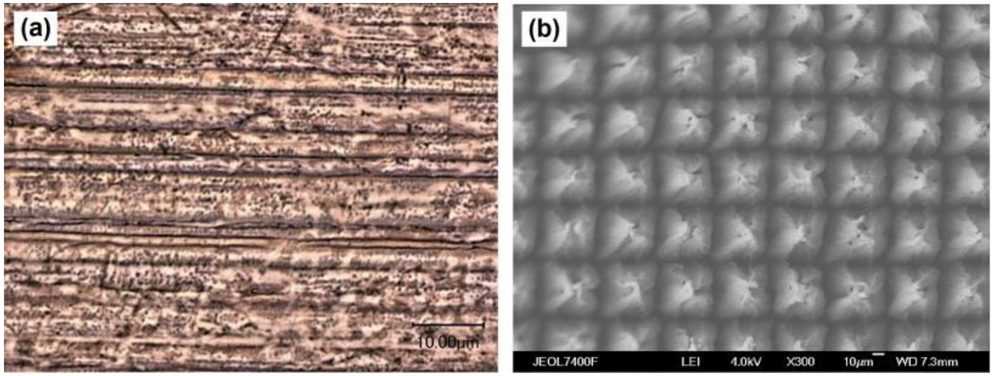
black Cu before conditioning

black Cu after conditioning

Note $\delta < 0.8$

Original Data
June 2014

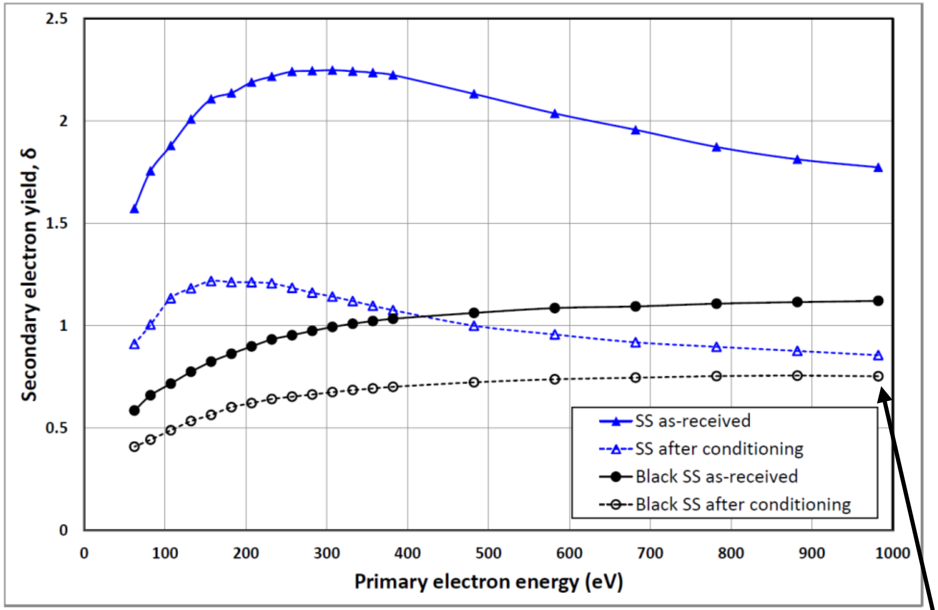
We have complete control over the highly regular surface topography



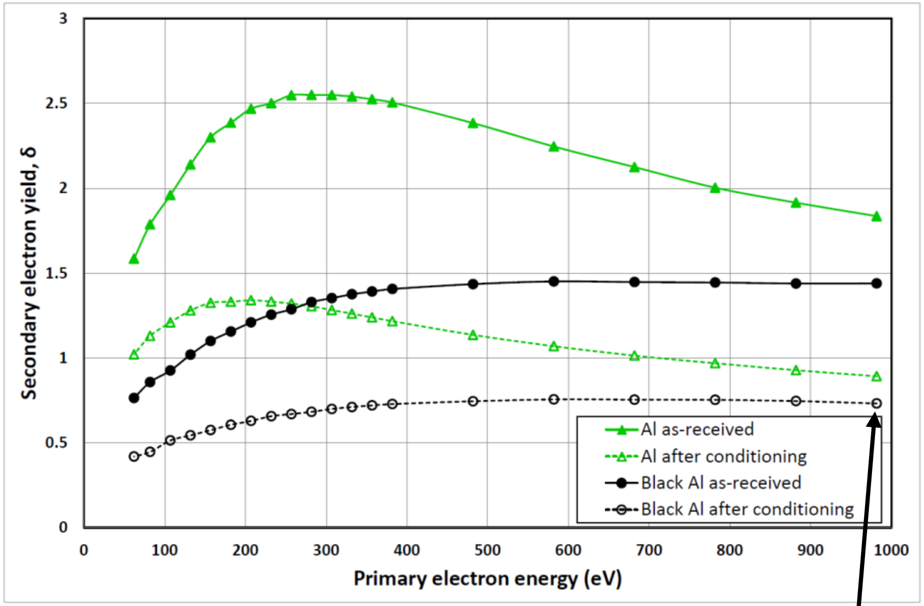
High-resolution SEM images of the Cu samples:
(a) untreated and (b) laser treated

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

stainless steel



aluminium



Note $\delta < 0.7$

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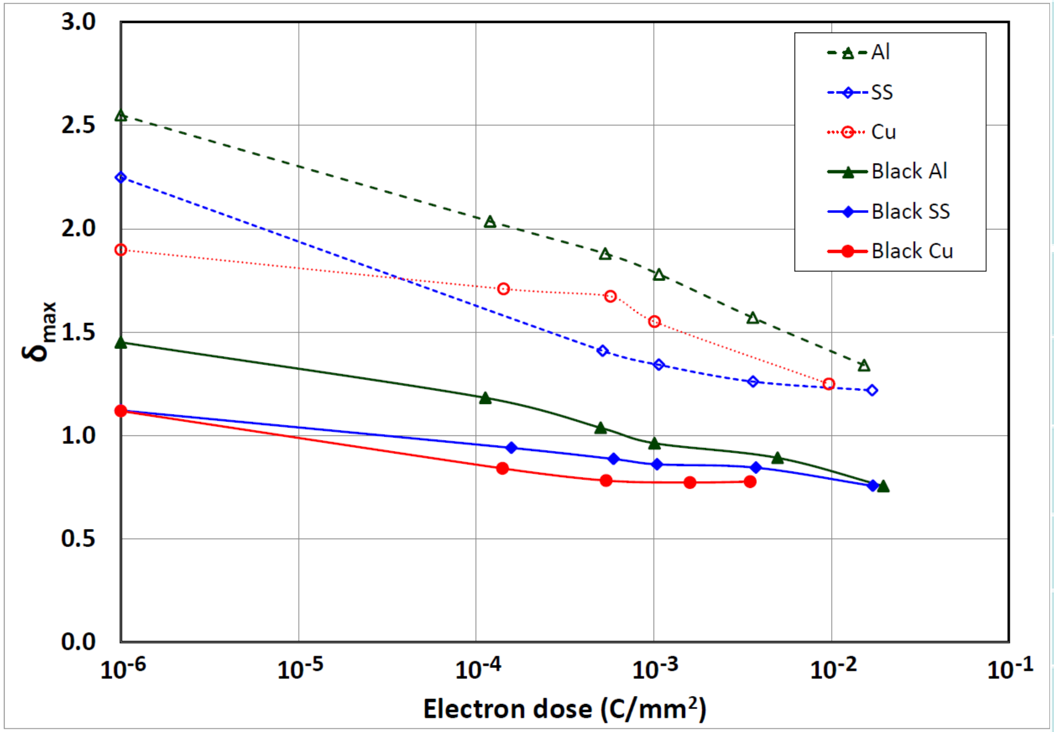
Applied Physics Letters
12/2014; 105(23): 231605

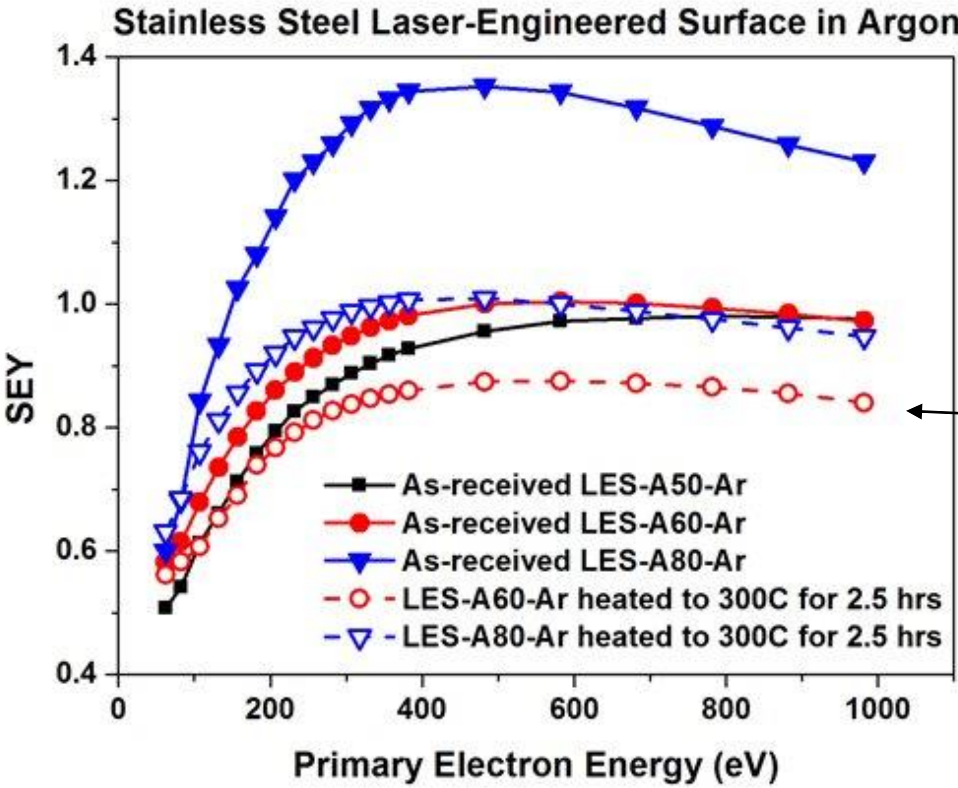
Original Data
June 2014

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



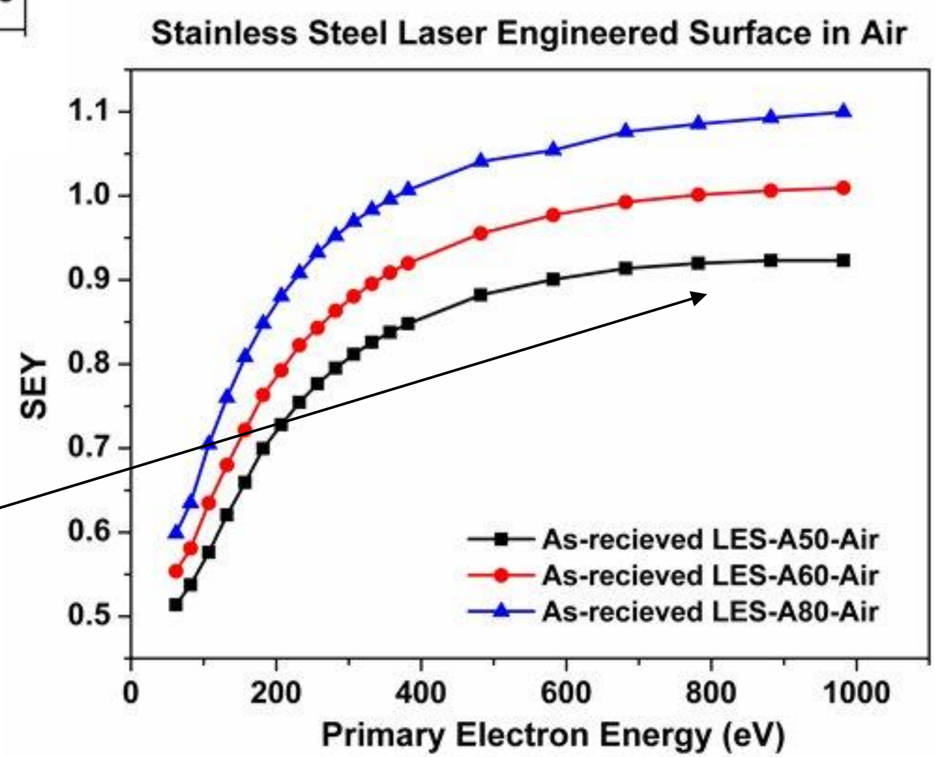
Sample	Initial		After conditioning to Q_{max}		
	δ_{max}	E_{max} (eV)	δ_{max}	E_{max} (eV)	Q_{max} ($C\cdot mm^{-2}$)
Black Cu	1.12	600	0.78	600	3.5×10^{-3}
Black SS	1.12	900	0.76	900	1.7×10^{-2}
Black Al	1.45	900	0.76	600	2.0×10^{-2}
Cu	1.90	300	1.25	200	1.0×10^{-2}
SS	2.25	300	1.22	200	1.7×10^{-2}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



Stainless steel data

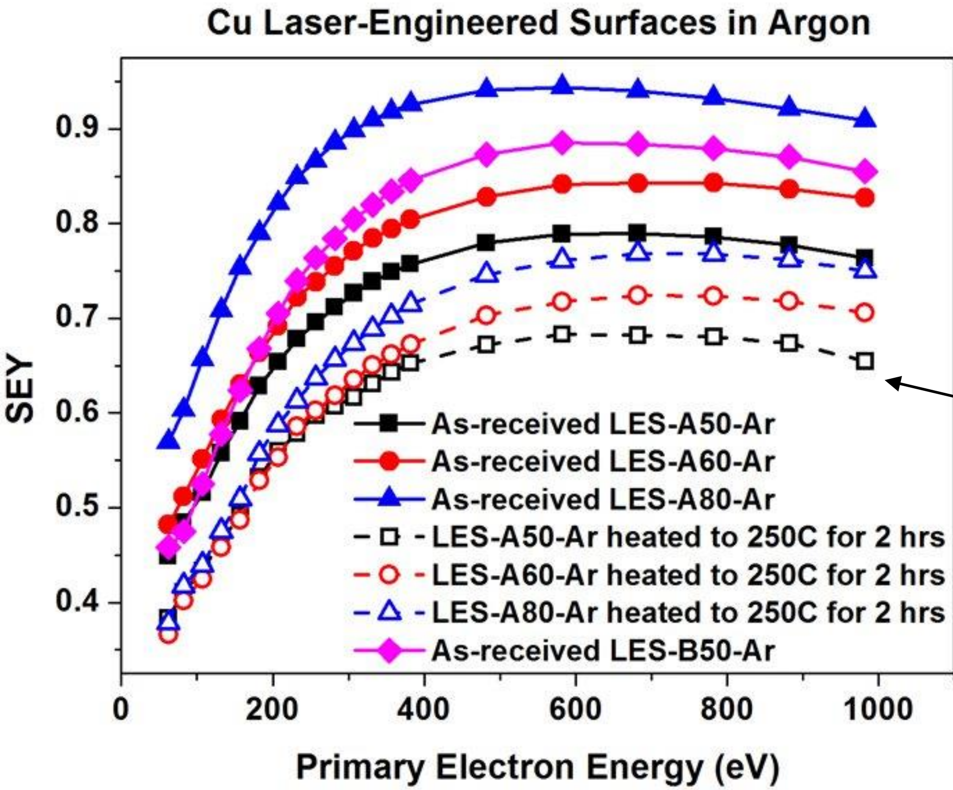
Note δ < 0.85



Recent Data
Nov-Dec 2014

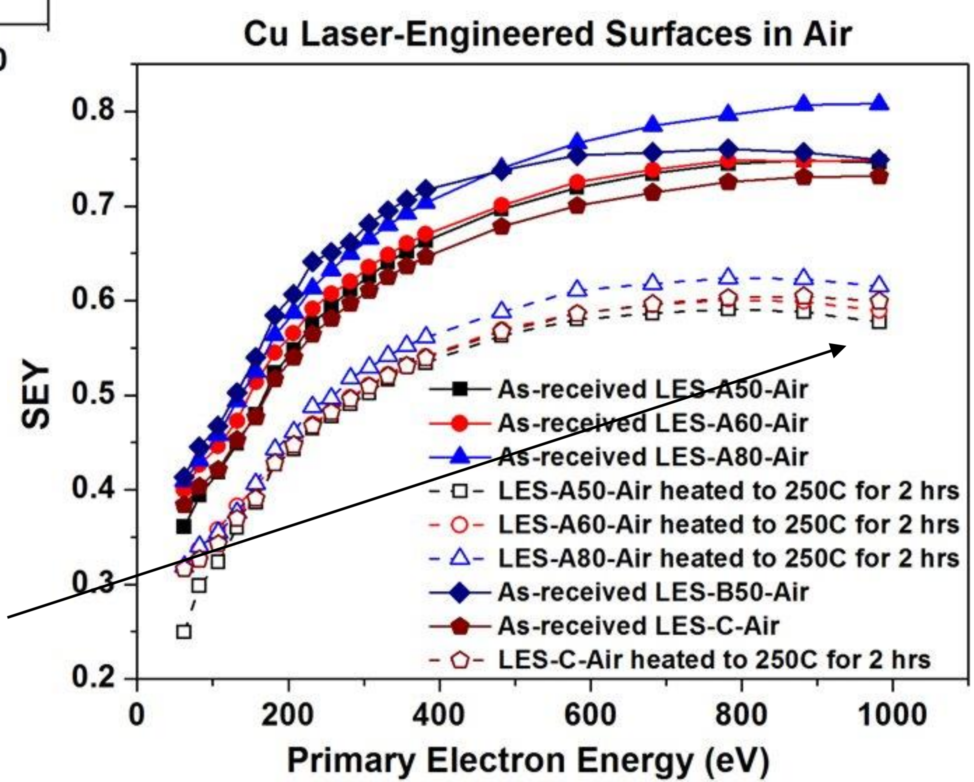
Note δ < 0.9

.. and reduces to < 0.8



Copper data

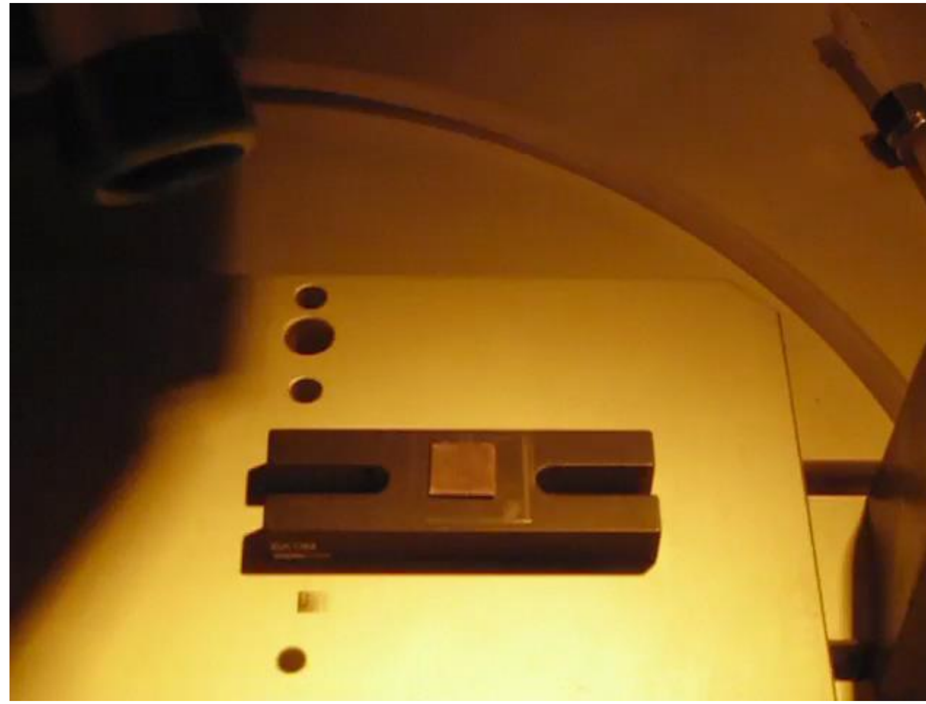
Note $\delta < 0.65$



Recent Data
Nov-Dec 2014

Note $\delta < 0.55$

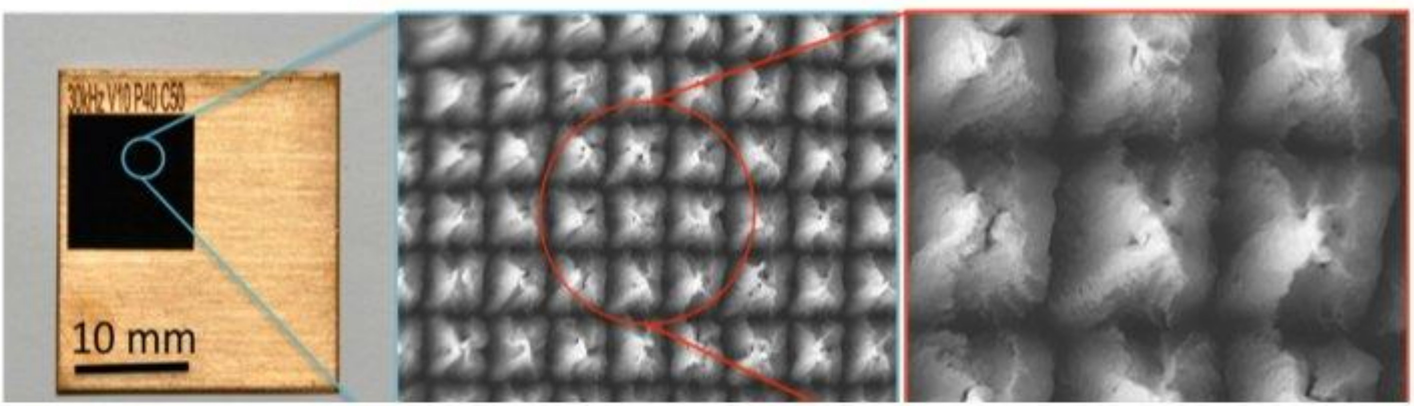
How do we do this?



Laser processing of Copper

beam is raster-scanned in both horizontal and vertical directions

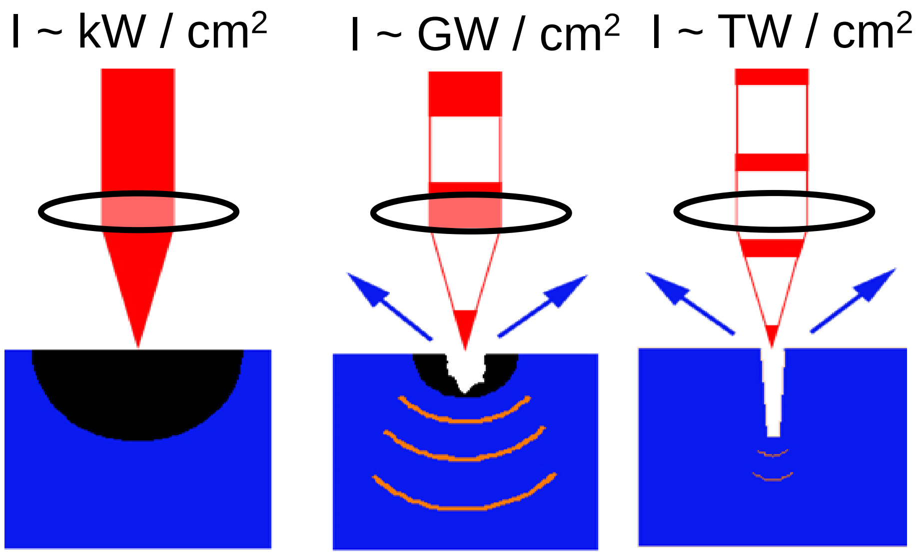
with average laser energy fluence just above ablation threshold of the metal



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

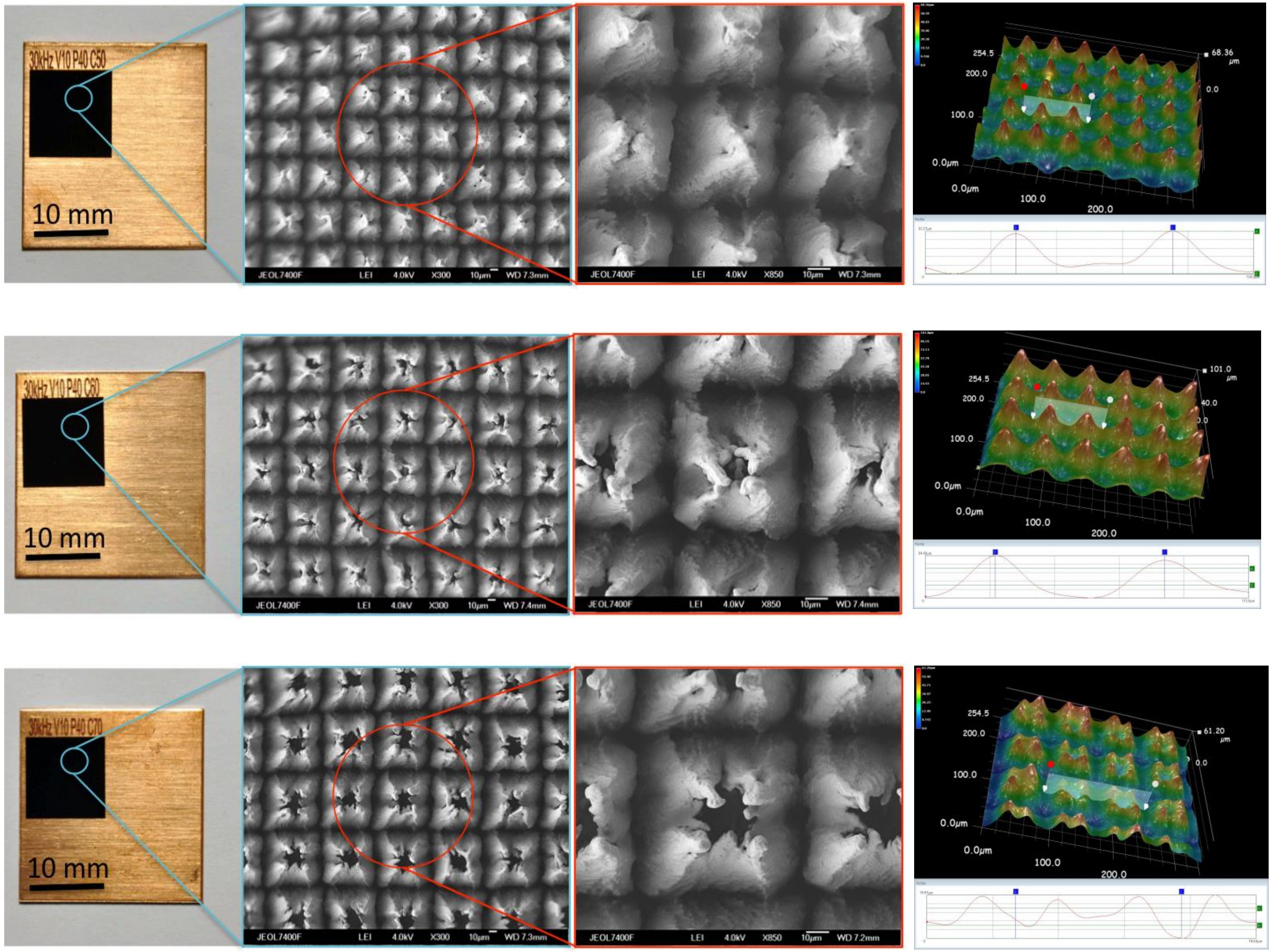
a) *Conducted into the bulk of the material*

b) *Converted into directed kinetic energy by thermal expansion of the heated layer.*

Two separate regimes are identifiable at high irradiances:

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

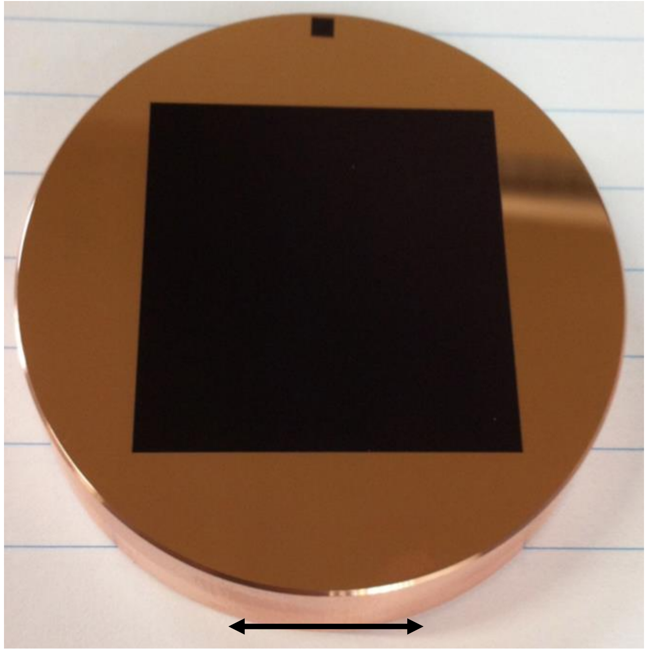
Material: Copper



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

Metals treated so far

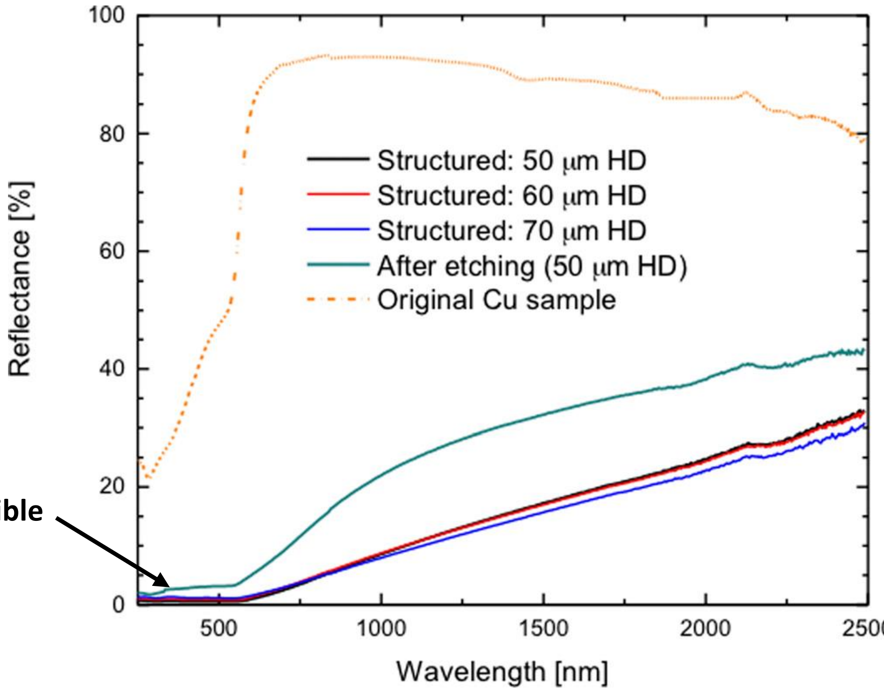
Copper; Aluminium; Titanium; S.Steel



A practical example:

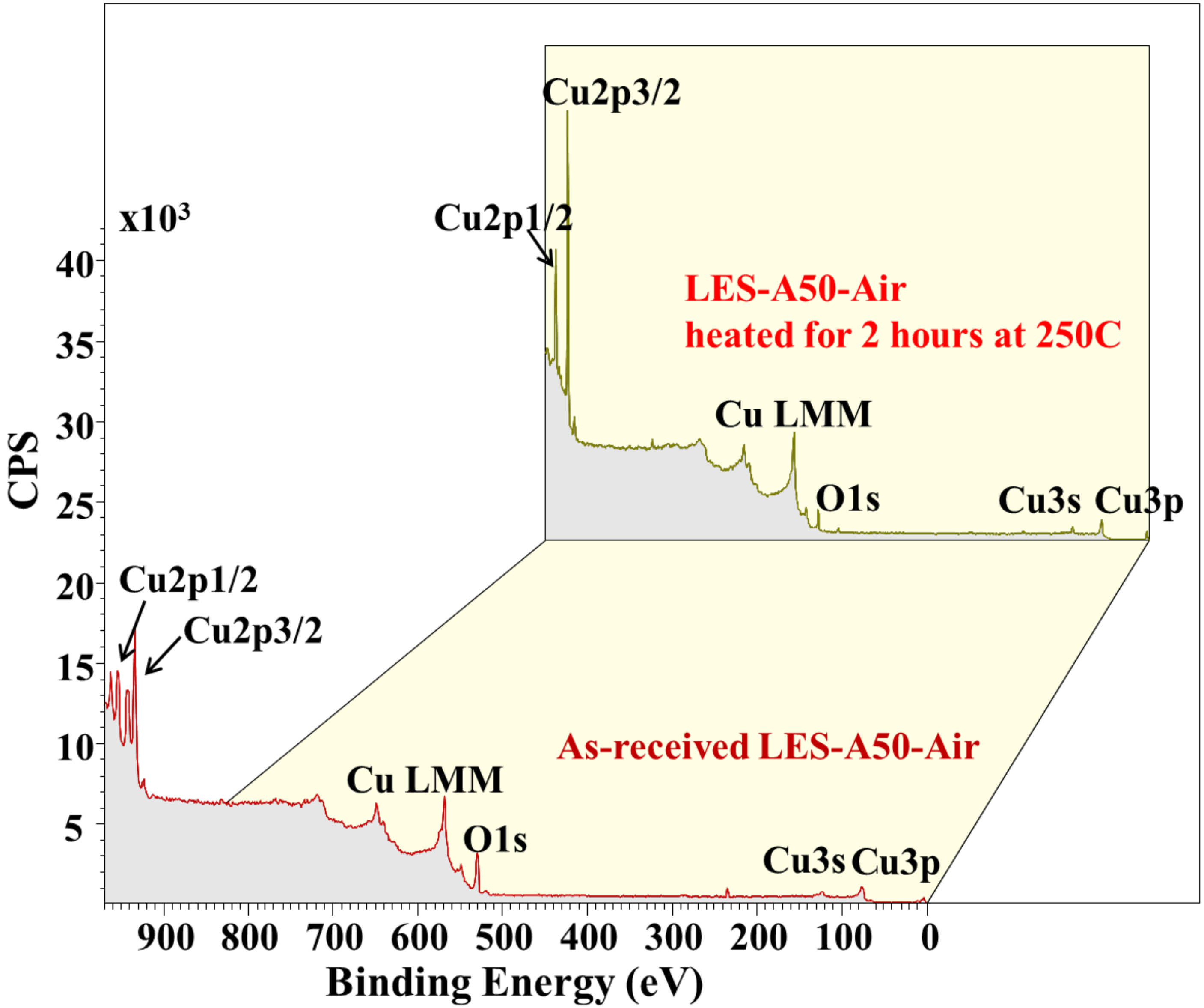
Laser micro-structured copper mirror **(an optical / THz separator)** Fabricated for the Beam Diagnostics Group at ASTeC, Daresbury Laboratory.

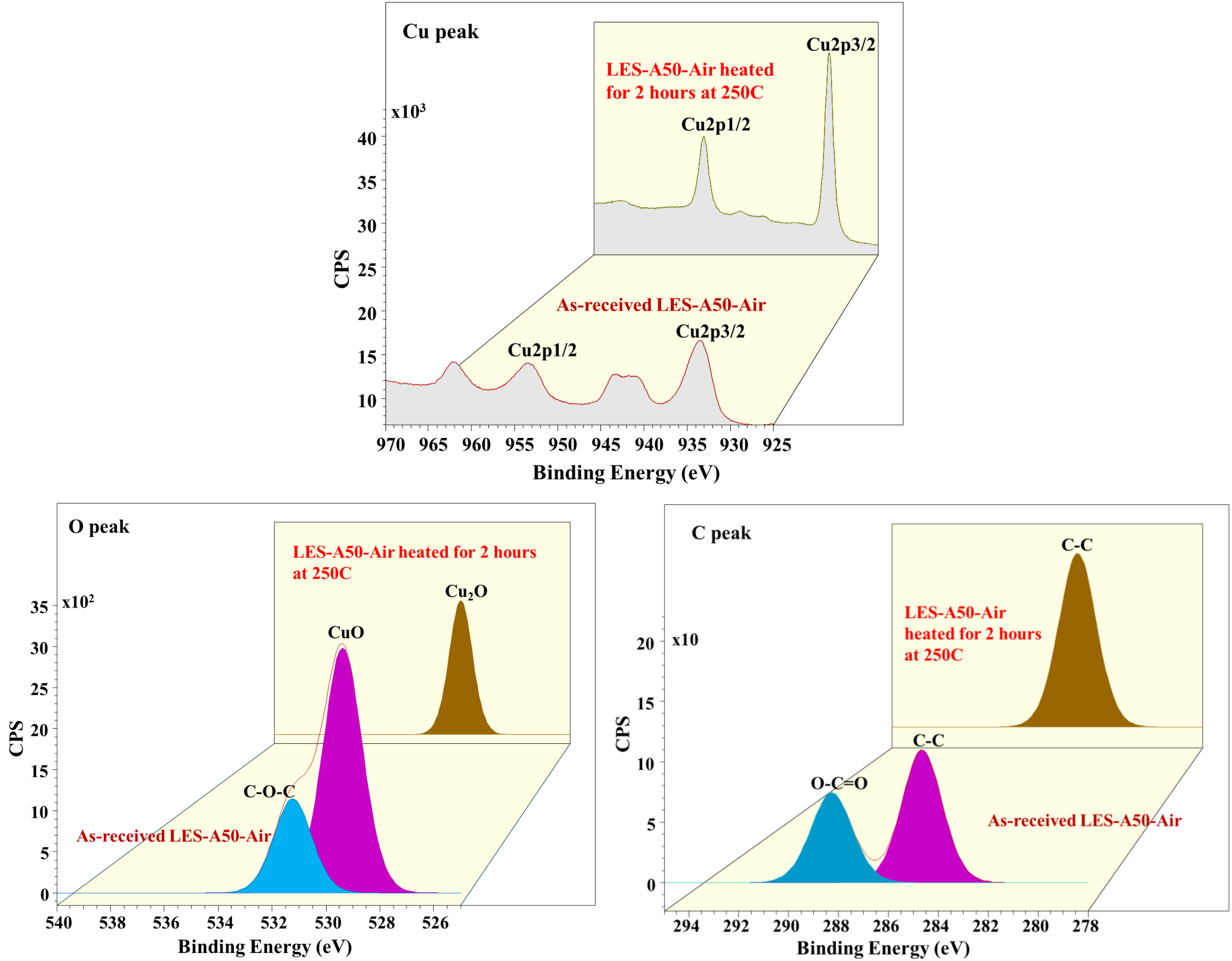
Reflectance of "black copper"



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

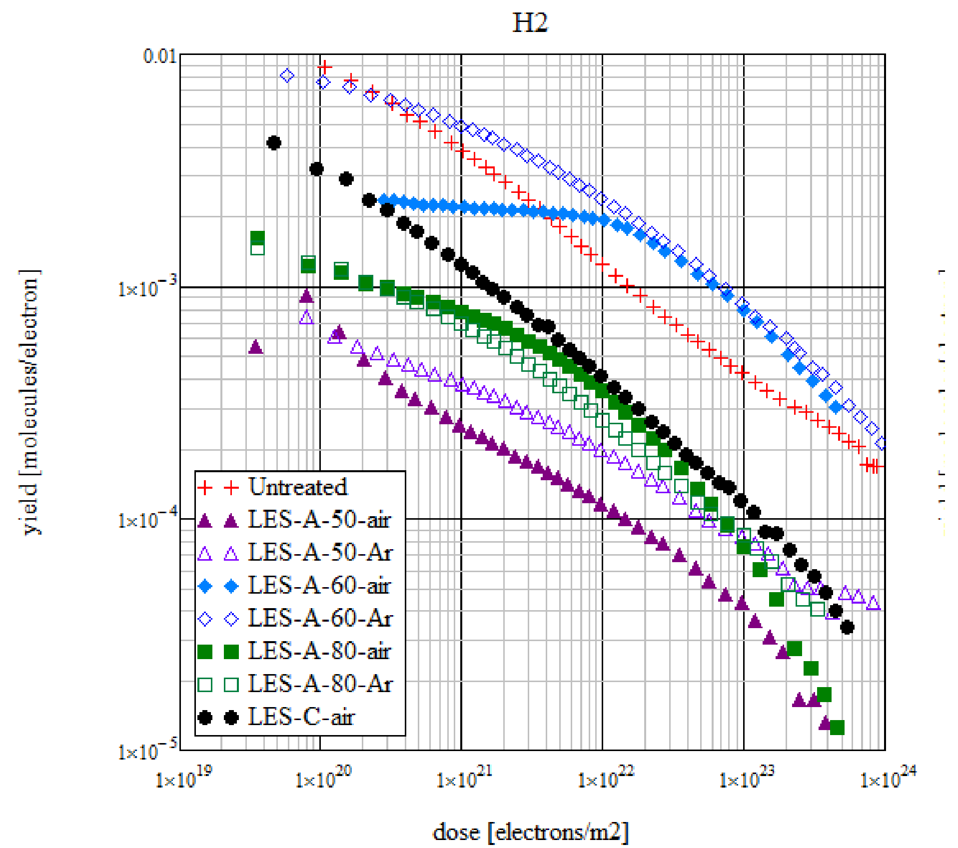
XPS analysis of Cu sample before & after conditioning




Cu peak
LES-A50-Air heated
for 2 hours at 250C
Cu2p3/2
Cu2p1/2
As-received LES-A50-Air
Cu2p1/2
Cu2p3/2
x10^3
40
35
30
25
20
15
10
CPS
970 965 960 955 950 945 940 935 930 925
Binding Energy (eV)
O peak
LES-A50-Air heated for 2 hours
at 250C
Cu$_2$O
CuO
C-O-C
As-received LES-A50-Air
x10^2
35
30
25
20
15
10
5
0
CPS
540 538 536 534 532 530 528 526
Binding Energy (eV)
C peak
C-C
LES-A50-Air
heated for 2 hours
at 250C
C-C
O-C=O
As-received LES-A50-Air
x10
20
15
10
5
0
CPS
294 292 290 288 286 284 282 280 278
Binding Energy (eV)

Electron Stimulated Desorption (ESD)

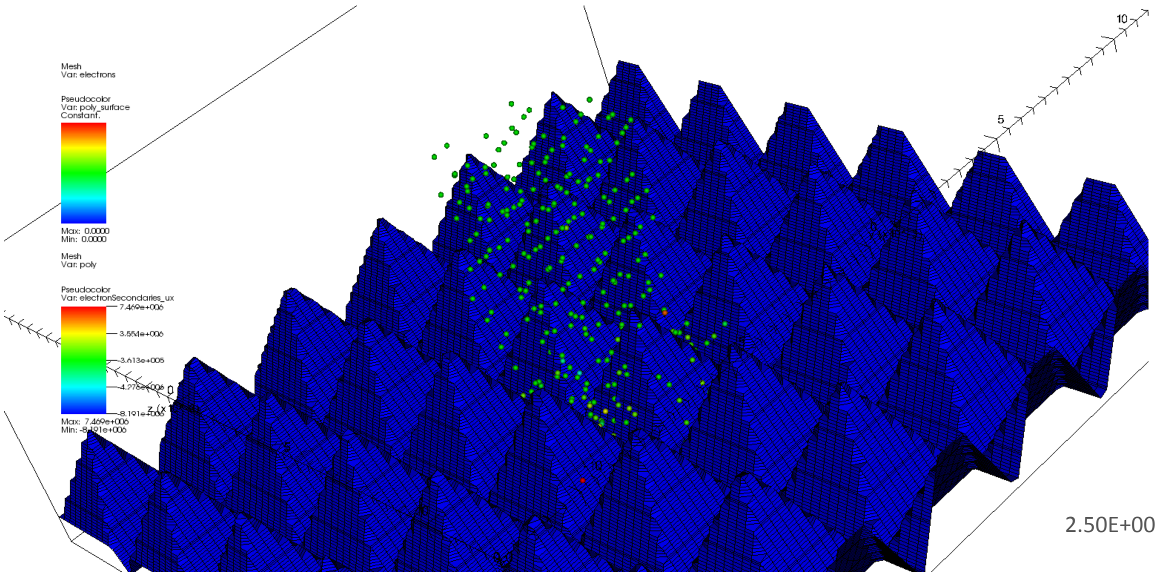
- 9 samples were tested:
  - Cu blank gaskets ∅48 mm
    - Untreated (2 samples)
    - LES-A type treated in air or Ar atmosphere
    - LES-C type treated in air
  - E_{e-} = 500 eV

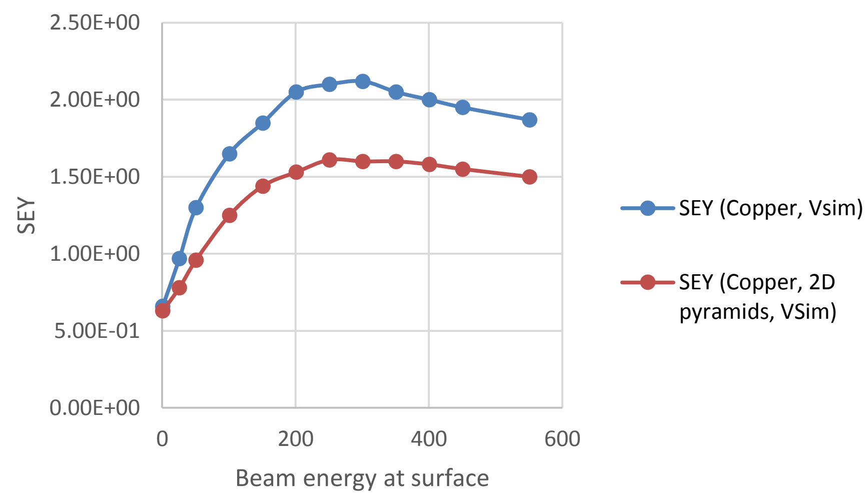


- Main results:
  - LES-A-50, LES-A-50 and LES-C demonstrated lower ESD yields than untreated samples
  - LES-A-50 treated in air yielded the best results

Simulations

Very preliminary studies of e-cloud mitigation are being carried out (using 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.

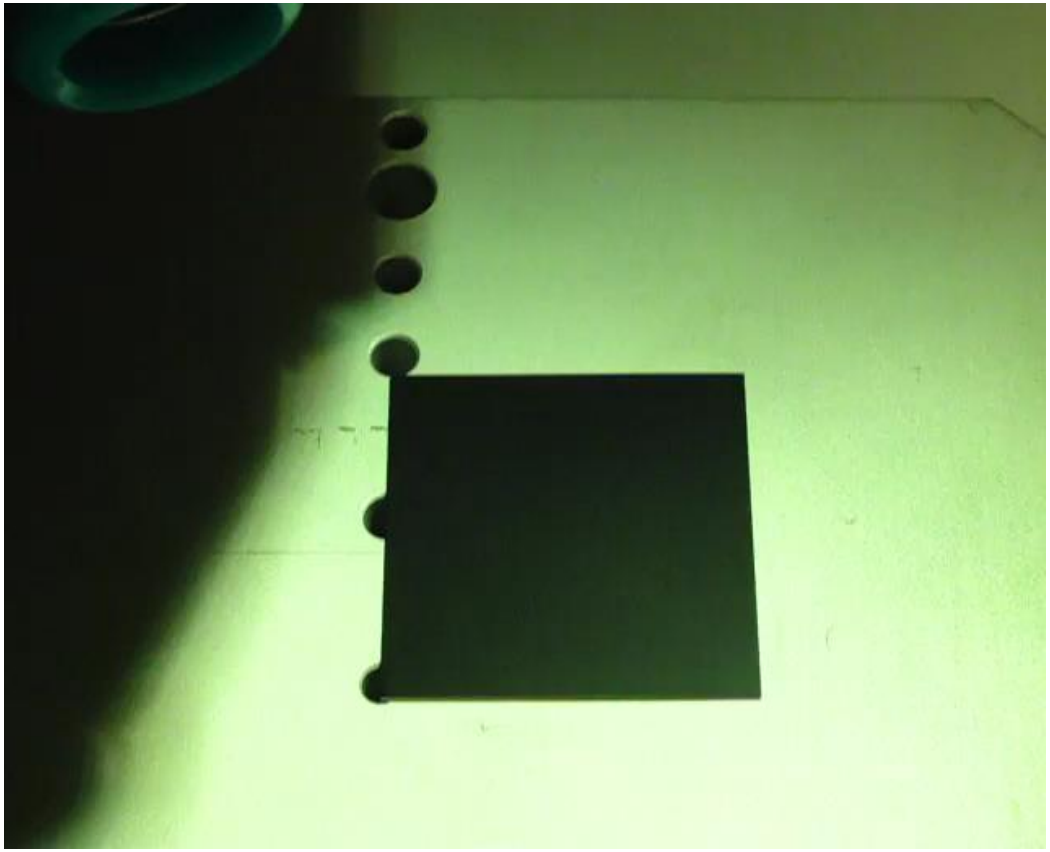
- The blackening process can be carried out in air at atmospheric pressure; the actual cost of the mitigation is therefore considerably lower, a fraction of existing mitigation processes. The process is also readily scalable to large areas.

- 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.

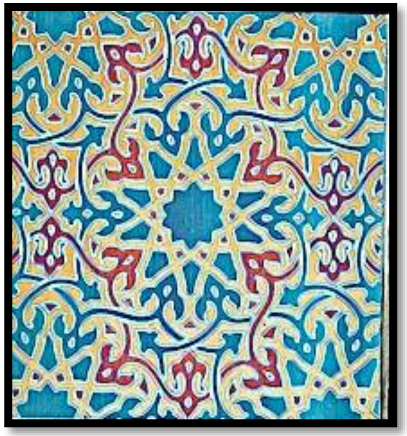
- The treated surface remains the same material, therefore it is unlikely to have a significant effect on the surface impedance – recent measurements verify this.

nanosecond processing of Al

Material: Anodised aluminium
Wavelength: 1064 nm
Pulse length: 10 ns
Focal spot diameter: 60 μm
Processing speed: 1200 mm/s



Laser Refractive Index Engineering of Metals



1 cm

Examples

Materials: Titanium & Steel
Wavelength: 1064 nm
Pulse length: < 50 ns
Processing speed: 100 mm/s

Thank you for your attention