Science & Technology
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Efficient electron cloud mitigation with novel low SEY laser-engineered surface structures (LESS)

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ASTeC

UNIVERSITY OF DUNDEE

26 Feb 2015

A&T seminar, CERN

Part II. Evaluation of LESS for particle accelerator application

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

STFC

UK Astronomy Technology Centre
Edinburgh, Scotland

Polaris House
Swindon, Wiltshire

Chilbolton Observatory
Stockbridge, Hampshire

Daresbury Laboratory
Daresbury Science and Innovation Campus
Warrington, Cheshire

Rutherford Appleton Laboratory
Harwell Science and Innovation Campus
Didcot, Oxfordshire

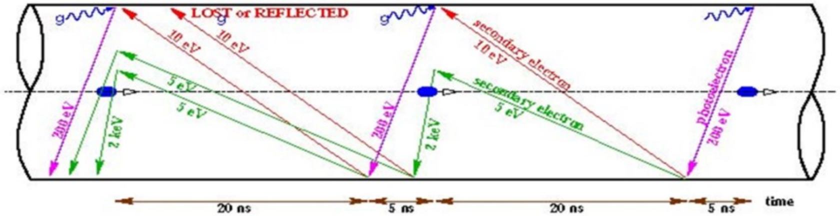
STFC Daresbury Laboratory

- 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
  - Experience in studies related to and design of particle accelerator vacuum system with an e-cloud problem such as SSC, LHC, ILC, etc.

- STFC grant for Proof of Concept (PoC) work

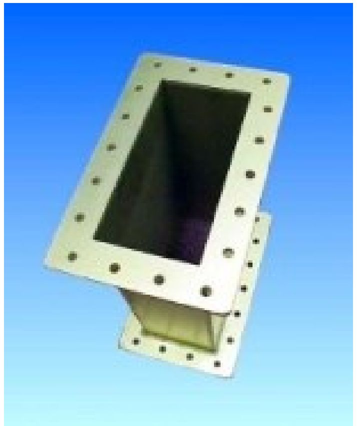
Main Goal

1. Mitigation of beam-induced electron multipacting and electron cloud built-up in a particle accelerator beam chamber due to photo- and secondary electron emission
    - to reduce beam instability, beam losses, emittance growth, reduction in beam life time, or heat loads on cryogenic vacuum chamber



Curtesy to
F. Ruggero

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



3. Reducing PEY and SEY in other instruments and devices, where necessary

Existing Mitigation method

By active means:

- Weak solenoid field (10-20 G) 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 a space for them)
- Beam parameters have some flexibility

Disadvantages:

- Requires:
  - Controllers
  - Power supplies
  - Cables
  - Vacuum compatible electric feedthroughs

I.e. should be avoided if possible

By passive means:

- Low SEY material
- Low SEY coating
- Grooved surface
- Special shape of vacuum chamber
  - An antechamber allows reducing PEY

Advantages:

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

Disadvantages:

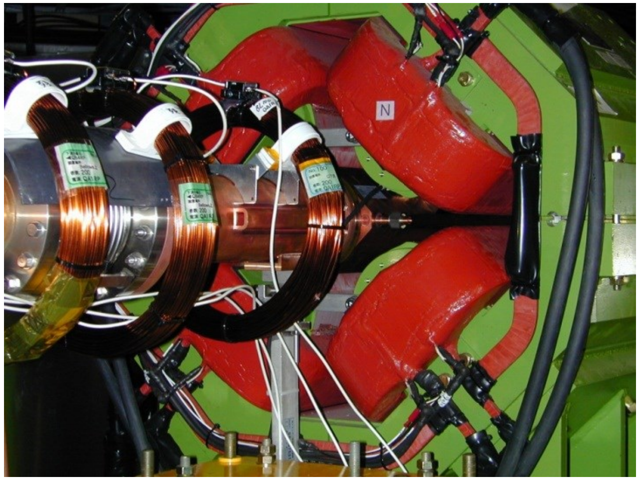
- In-vacuum deposition
- Difficult to apply on existing facilities
- Durations of surface treatments
- Cost

Existing Mitigation method

By active means:

- Weak solenoid field along the vacuum chamber
- Biased electrodes

Solenoids at KEKB, Japan



Advantages:

- Solenoids can be installed on existing facilities (if there is a space for them)

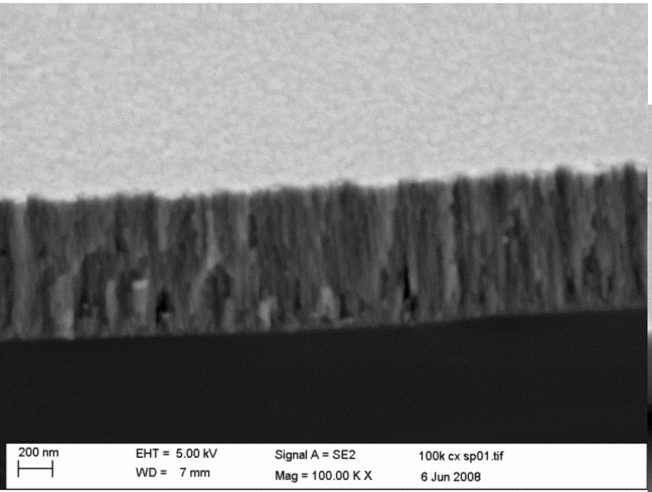
Biased electrodes at DAΦNE, Italy

Down side:

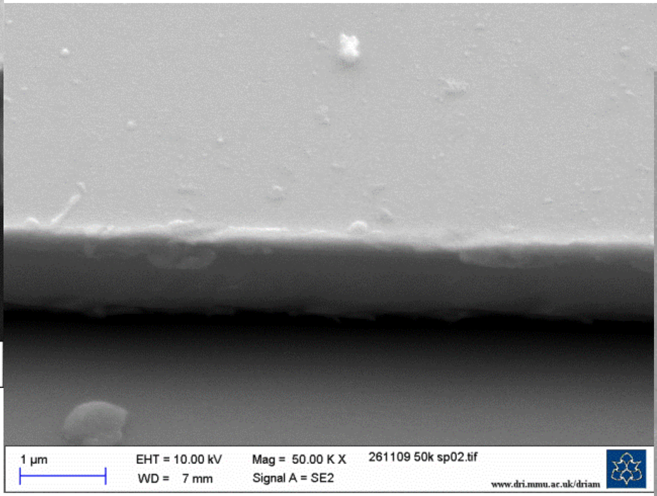
- It requires
  - Controllers
  - power supplies
  - cables
  - Vacuum compatible electric feedthroughs
  - i.e. should be avoided if possible:

Existing Mitigation methods

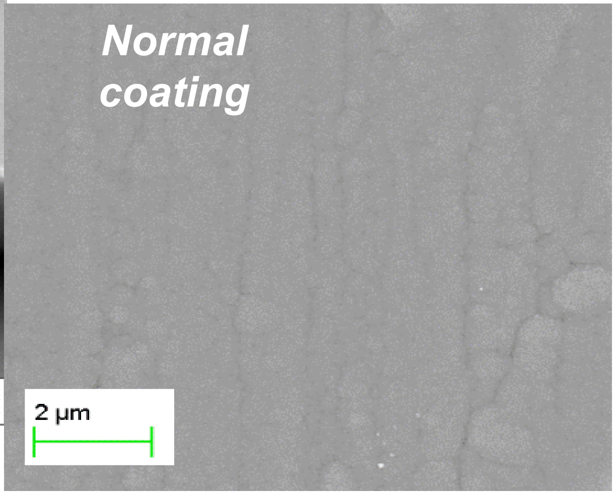
- Coating with Low SEY Material



Ti-Zr-V-Hf



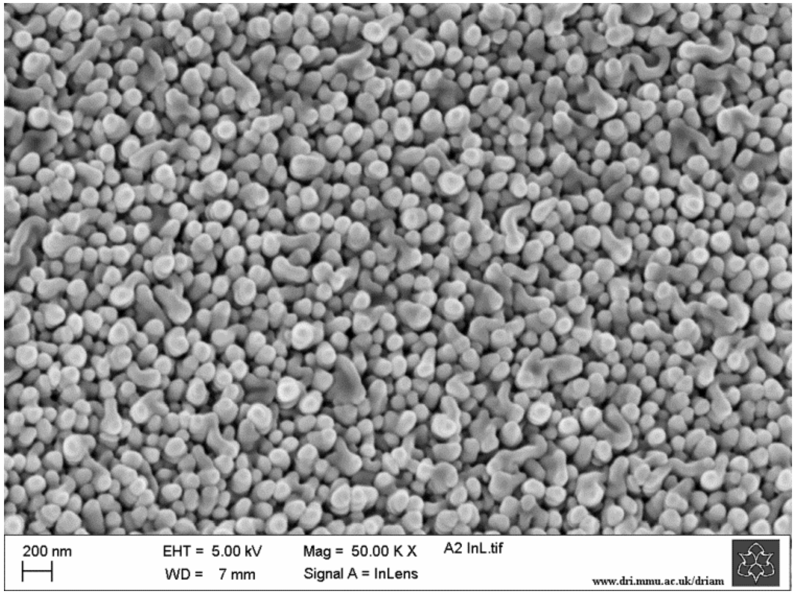
Ti-Zr-Hf-V-N



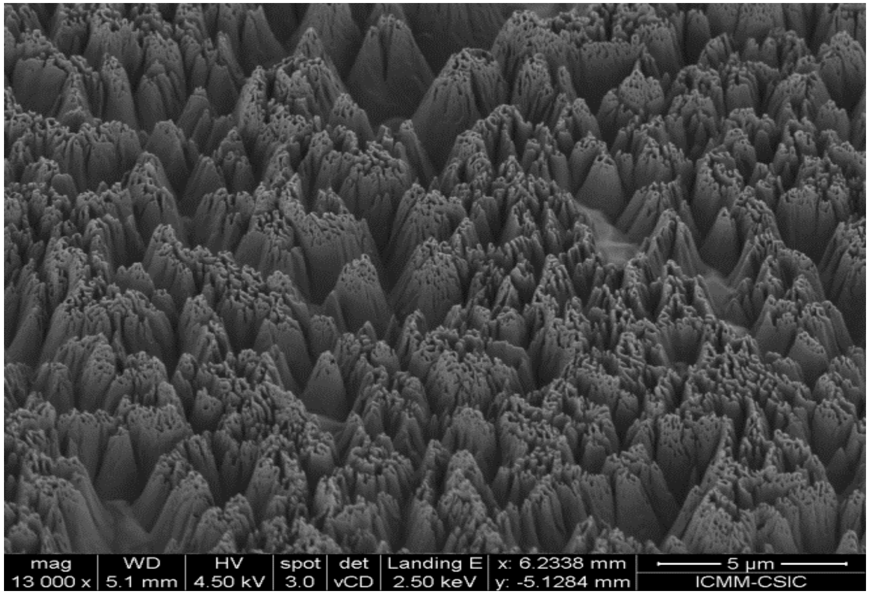
a-C at CERN

Existing Mitigation methods

- Coating with a low SEY material with submicron size structure



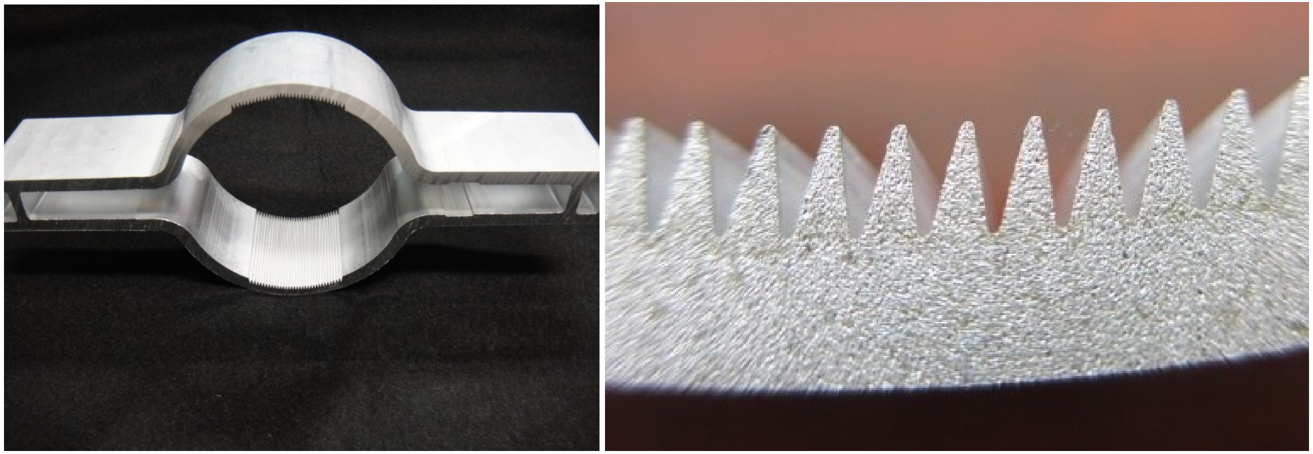
Ti-Zr-V black



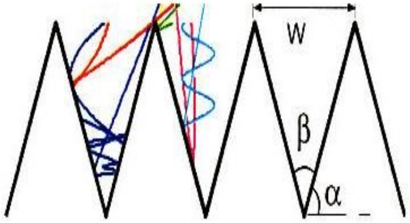
Ag plating, ion etched with Mo Mask
I. Montero et.al, Proc. e-Cloud12

Existing Mitigation methods

- Modifying the surface geometry
  - making mechanical grooves

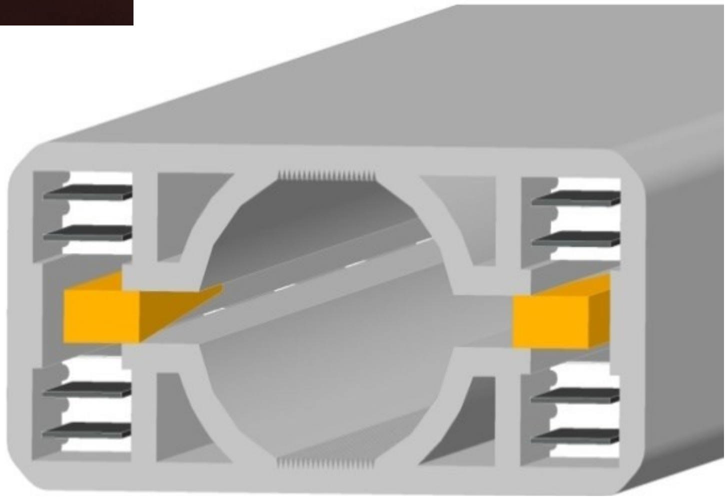


KEKB vacuum chamber (by courtesy of Y. Suetsugu)



By A. Krasnov and
By L Wang et.al

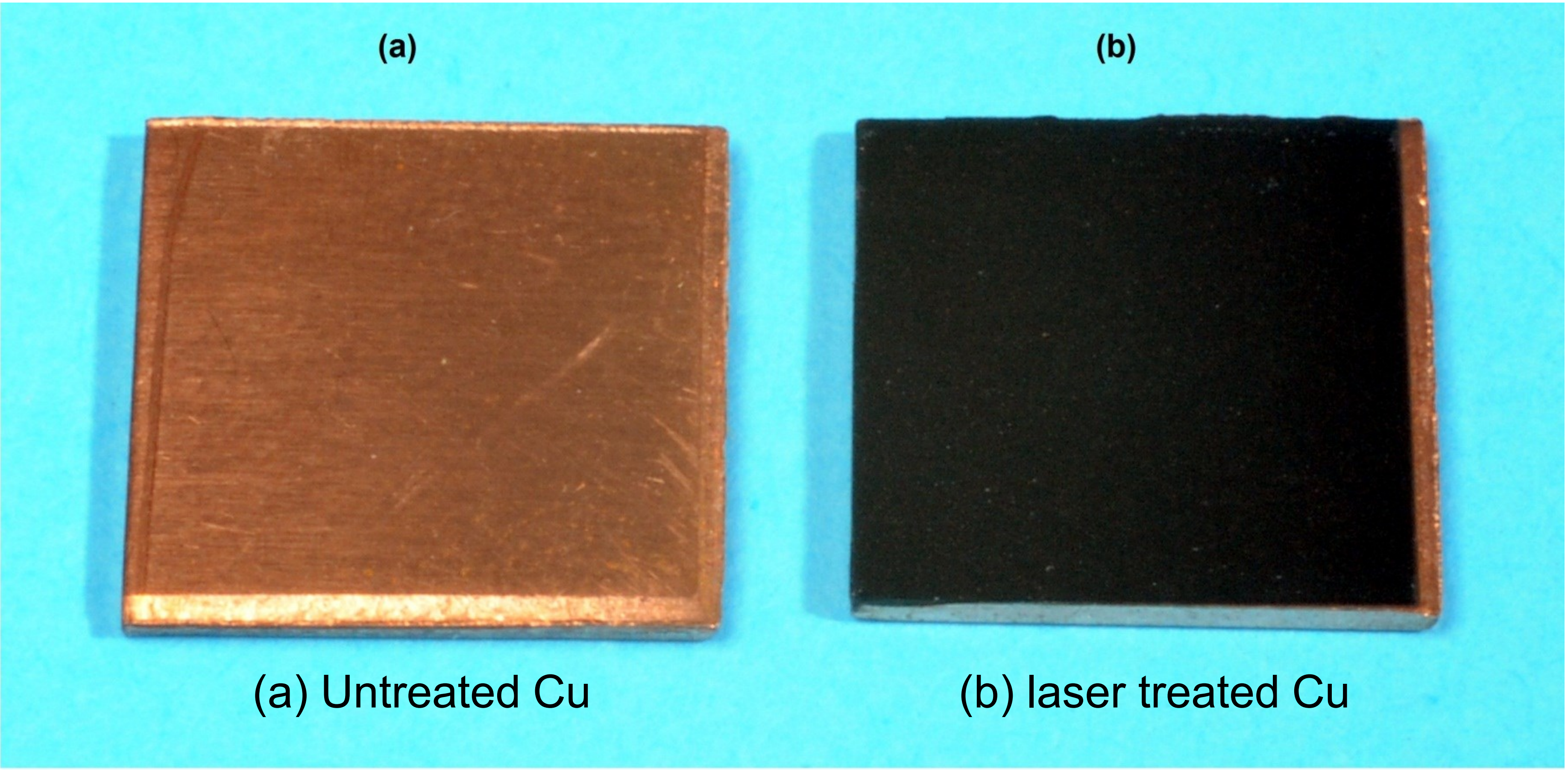
- Modifying the vacuum chamber geometry
  - making an antechamber



ILC wiggler vacuum chamber

Introducing new technology

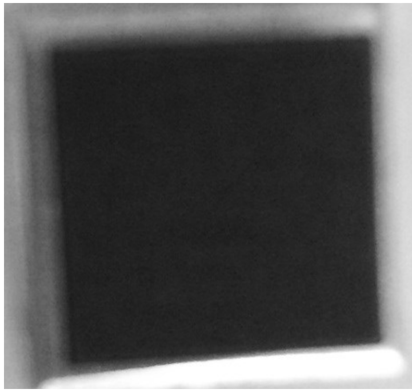
- Laser treatment in air or noble gas atmosphere



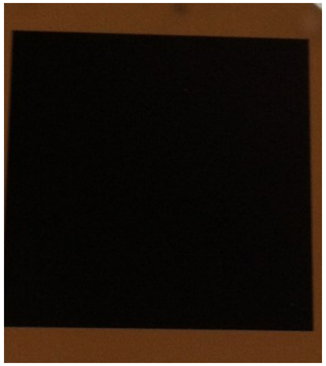
(a) Untreated Cu

(b) laser treated Cu

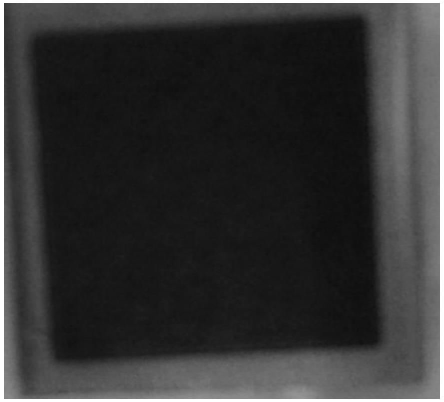
Laser Treated Metal Surface



Aluminium



Copper

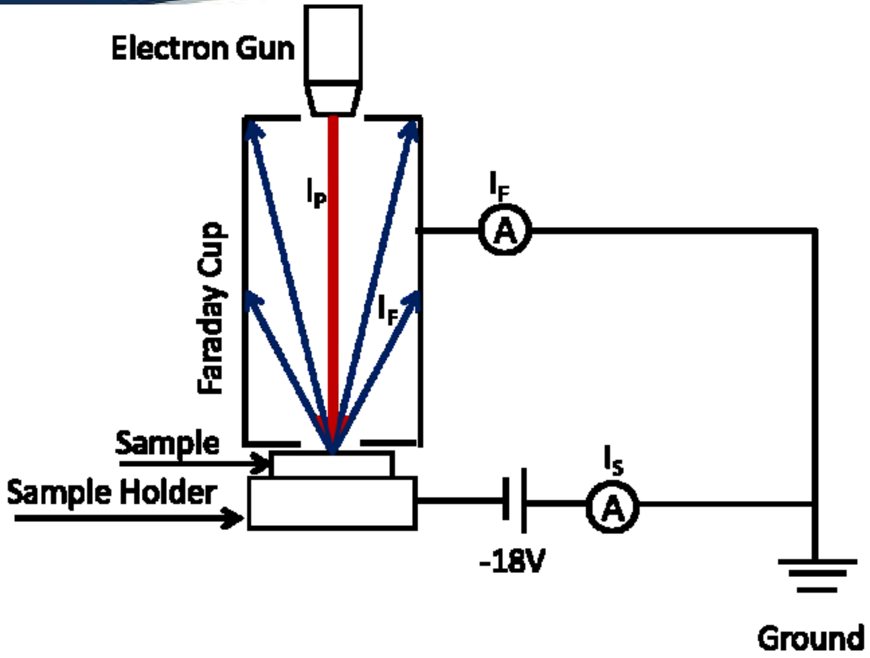


Stainless Steel

Nd:YVO4 Laser

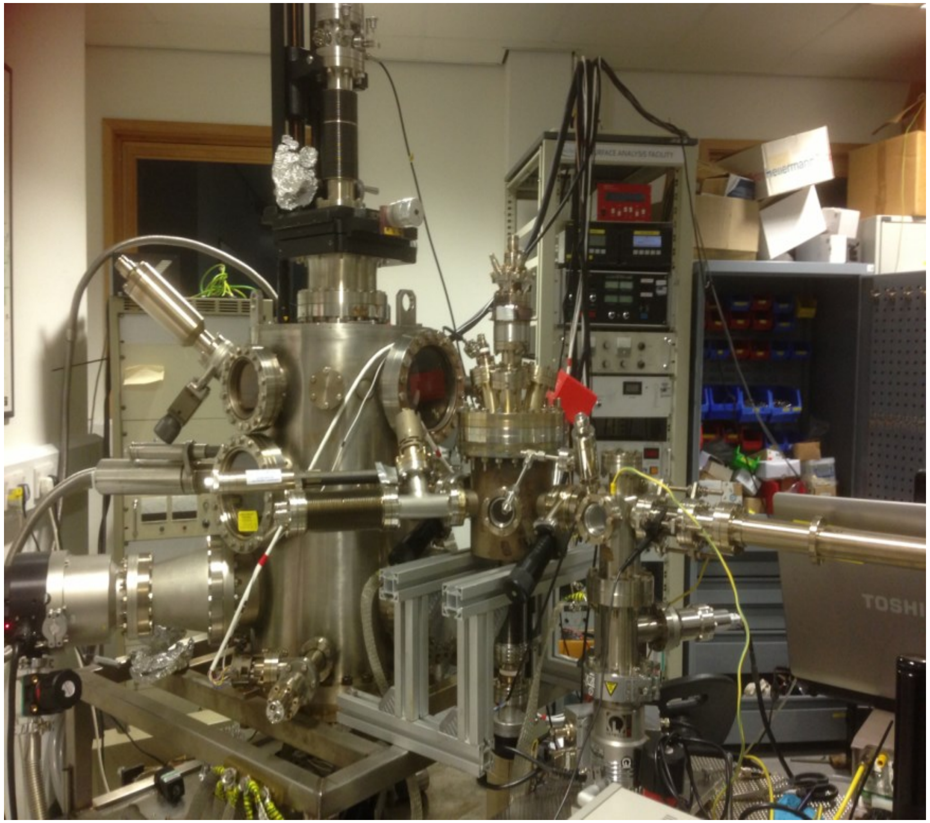
- Pulse length =12 ns at Repetition Rate = 30 kHz
  - For Aluminium
    - Max Average Power = 20 W at λ =1064 nm
  - For Copper
    - Max Average Power = 10 W at λ = 532 nm
- Argon or air atmosphere
- Beam Raster scanned in both horizontal and vertical direction
- With an average laser energy fluence of just above the ablation threshold of the metal.

SEY Measurements



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

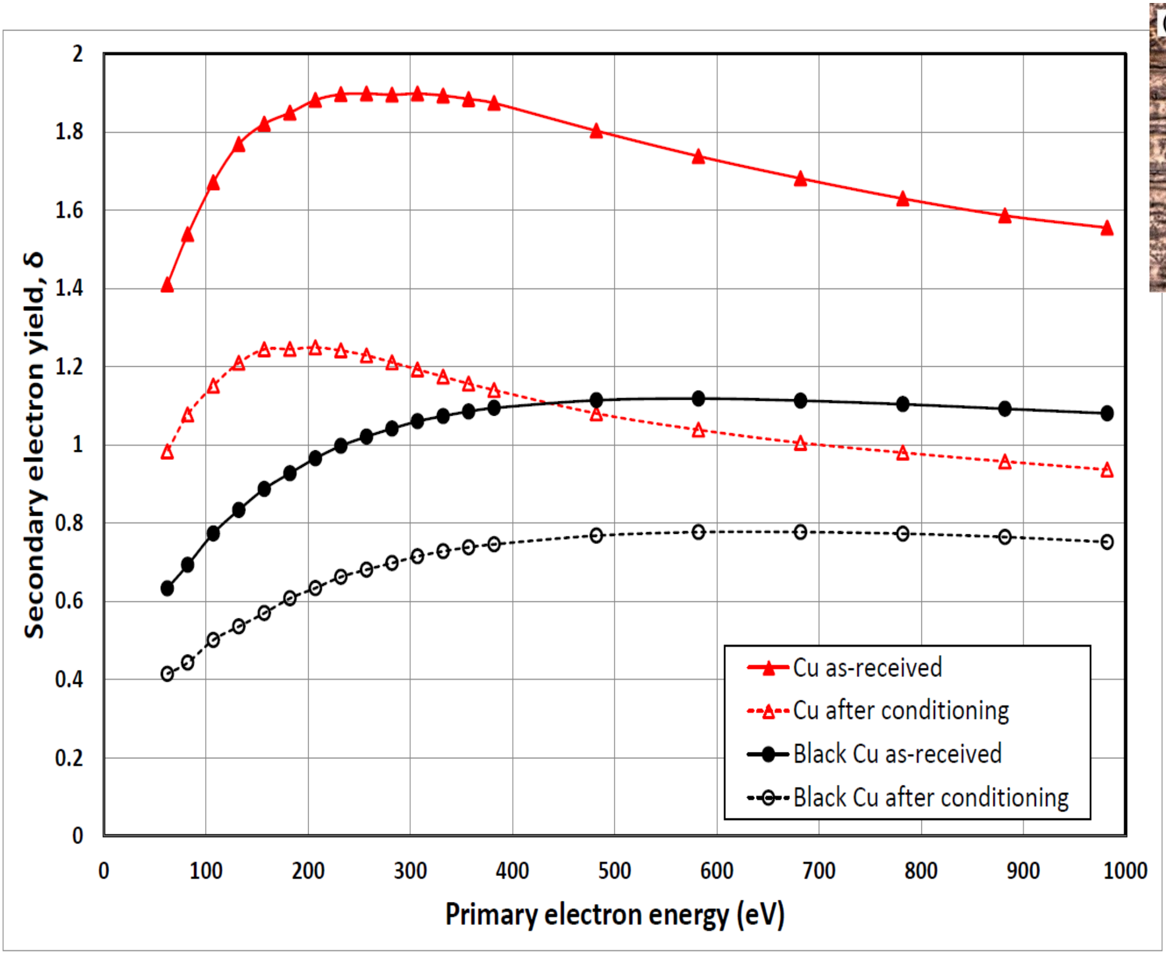
I_P is the primary beam current
I_F is the secondary electron current including elastic and inelastic processes, measured on the Faraday cup
I_S is the currents on the sample

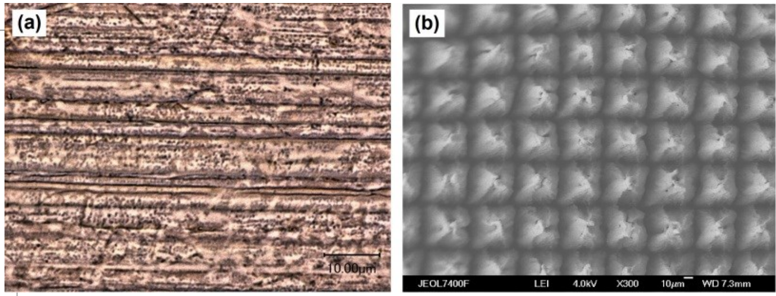


Analysis chamber with

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

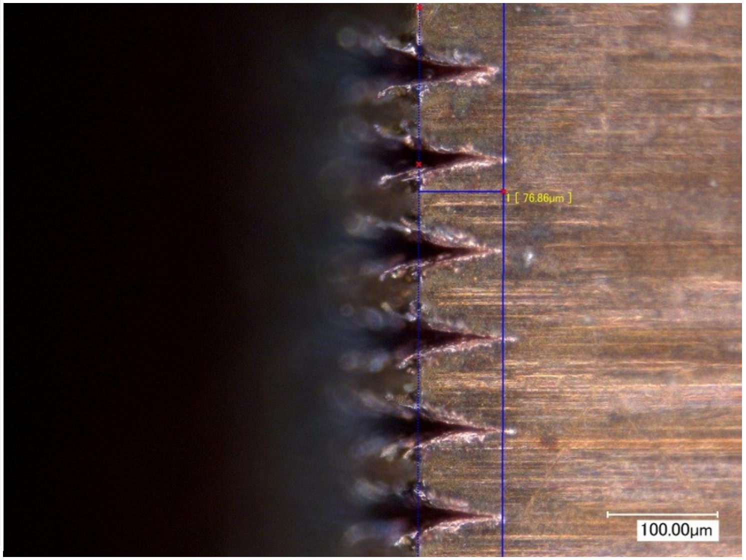
First results on SEY of Cu as a function of incident electron energy





Untreated

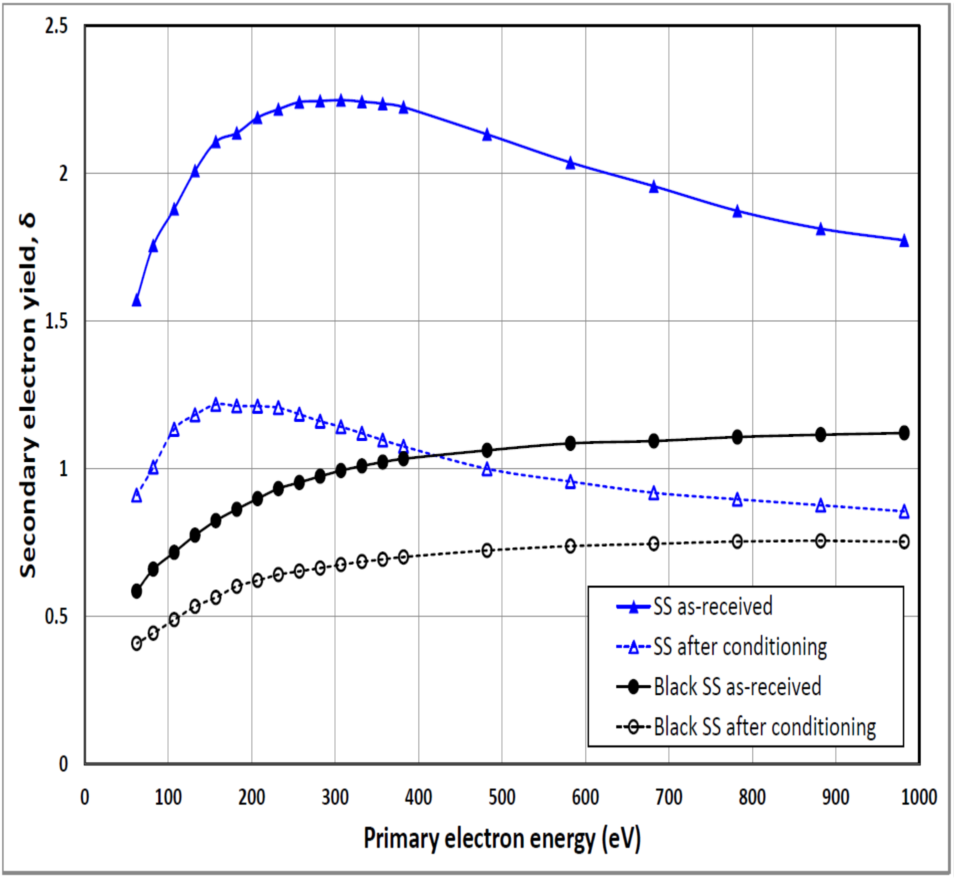
Laser treated

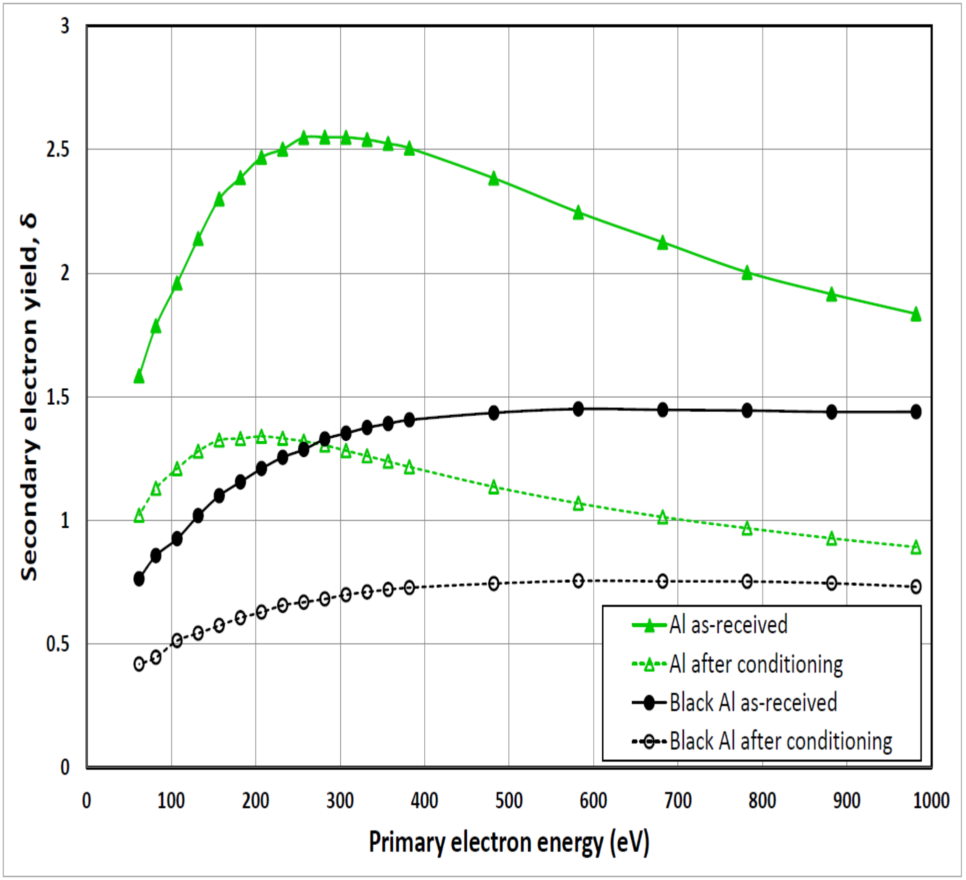


Original data June 2014

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

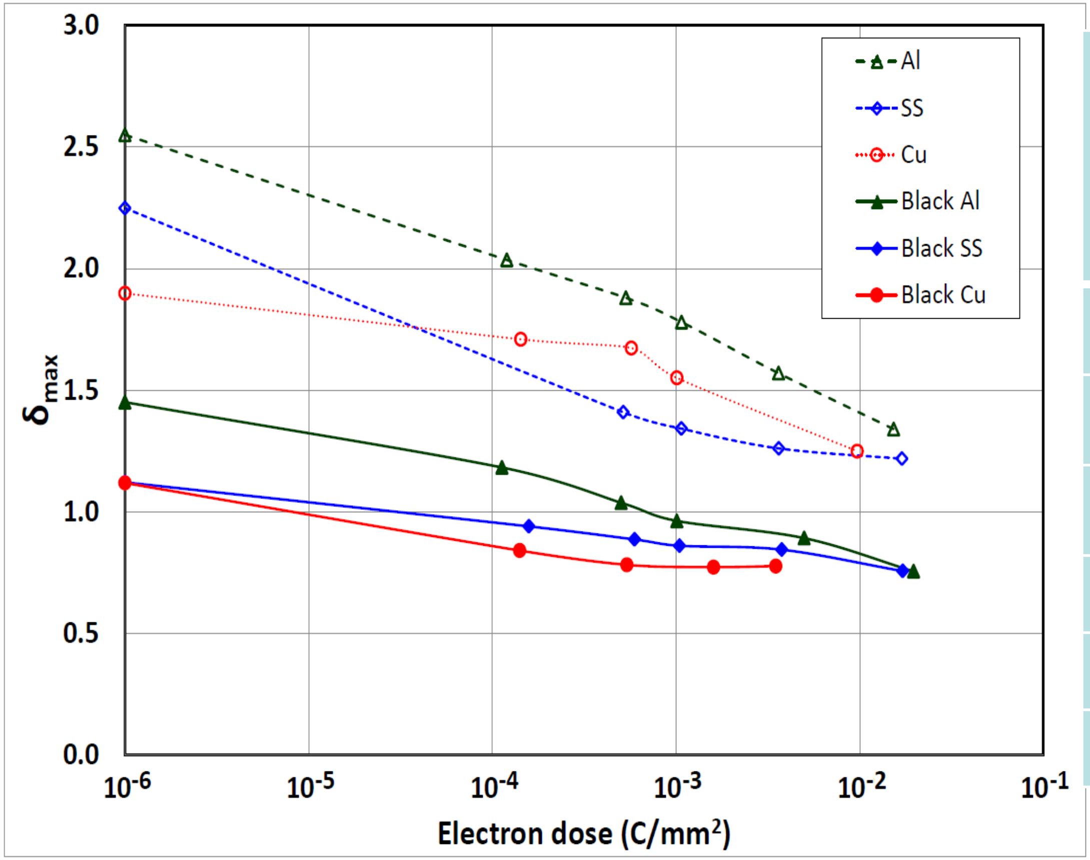
First results on SEY of SS and Al as a function of incident electron energy





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

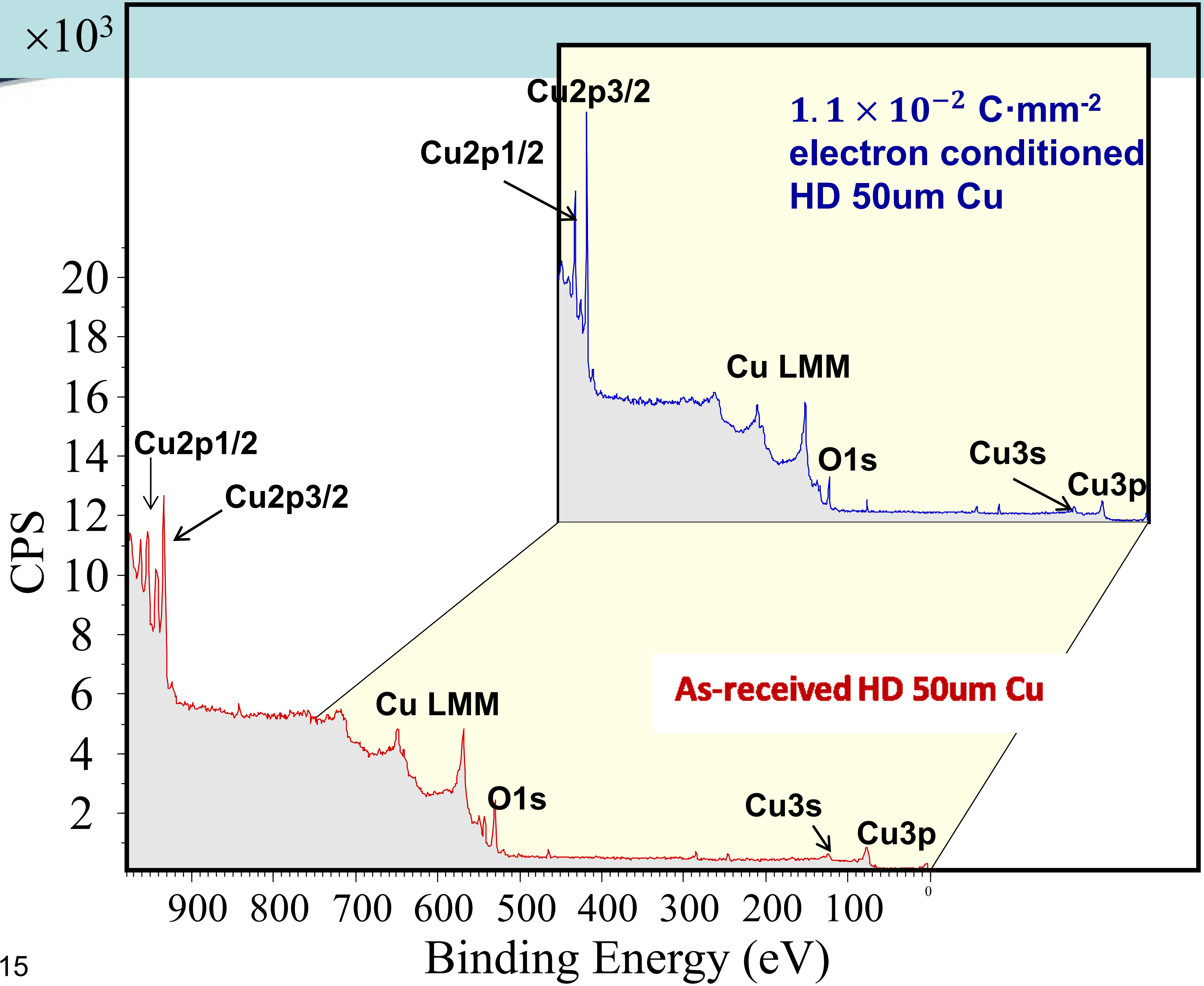
δ_{max} as a function of electron dose for Al, 306L SS and Cu



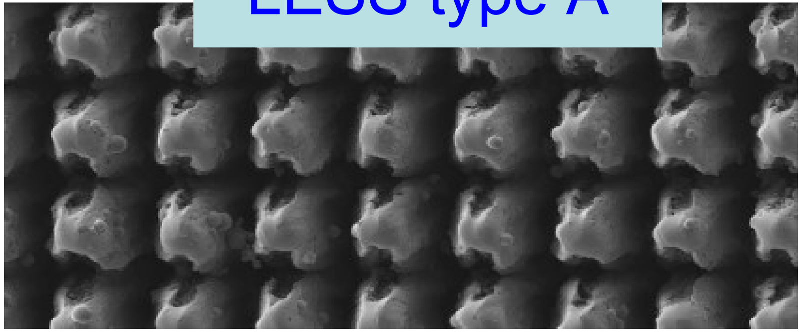
Sample	Initial		After conditioning to Q_{max}		
	δ_{max}	E_{max} (eV)	δ_{max}	E_{max} (eV)	Q_{max} ($C{\cdot}mm^{-2}$)
Black Cu	1.12	600	0.78	600	3.5×10^{-3}
Black SS	1.12	900	0.76	900	1.7×10^{-2}
Black Al	1.45	900	0.76	600	2.0×10^{-2}
Cu	1.90	300	1.25	200	1.0×10^{-2}
SS	2.25	300	1.22	200	1.7×10^{-2}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

XPS results of electron dose for Cu

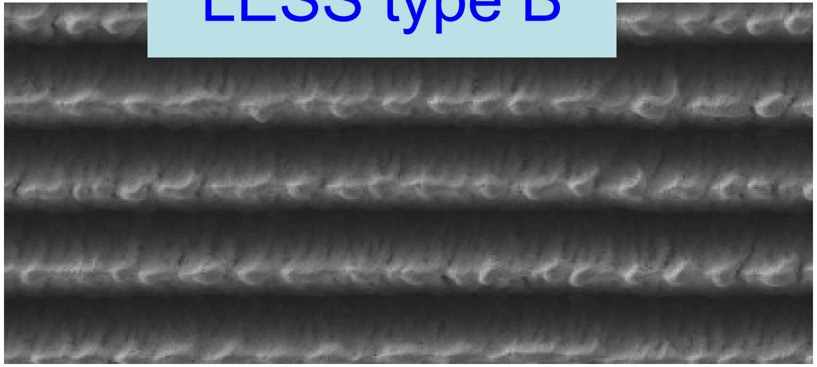


More laser treated surfaces

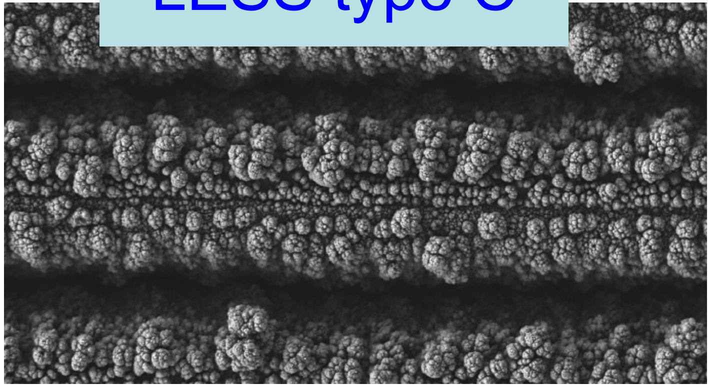


LESS type A

- Surfaces treated in air or Ar
- Studied
  - As received (after 12-hour pumping)
  - After 2-hour bakeout to 250ºC

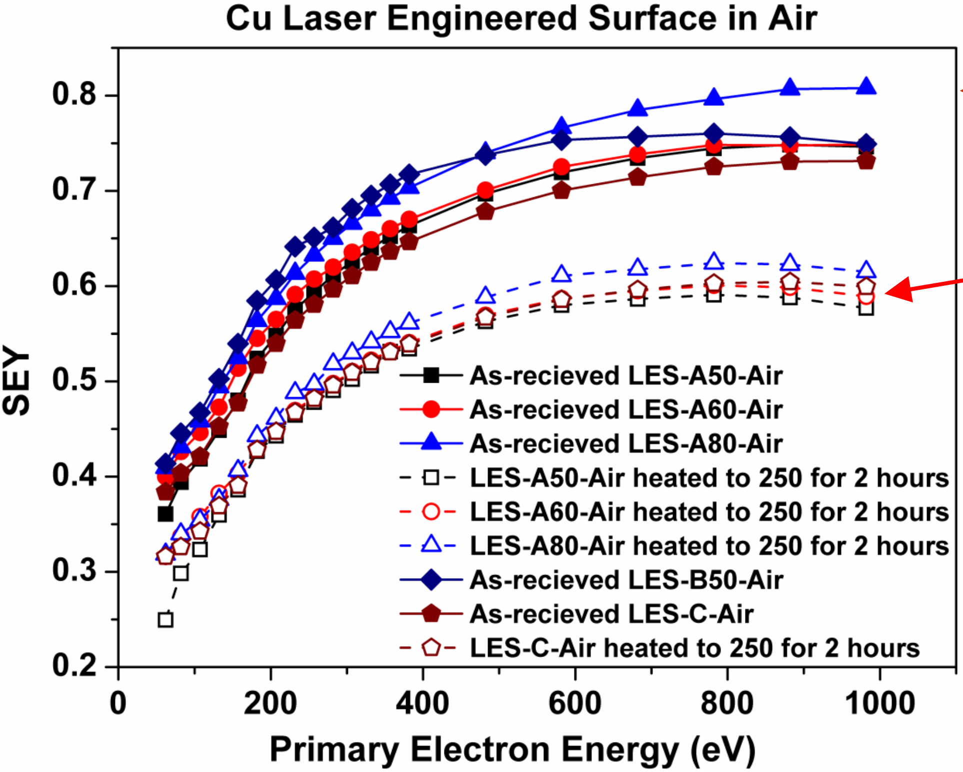


LESS type B



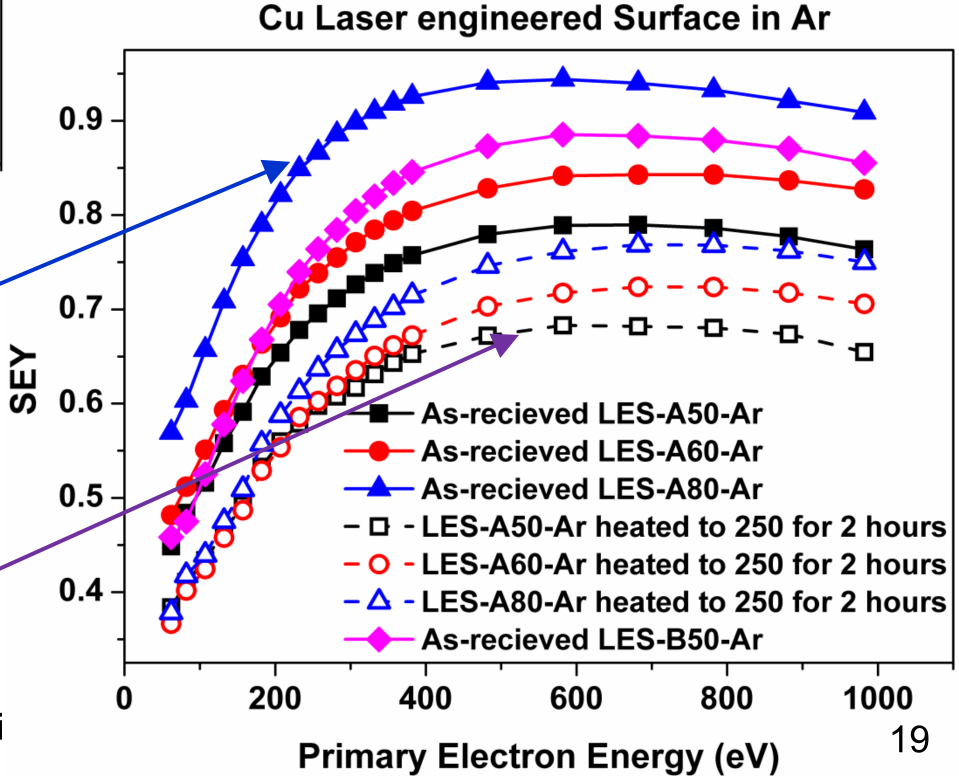
LESS type C

The latest results: Cu



δ < 0.82 as-received

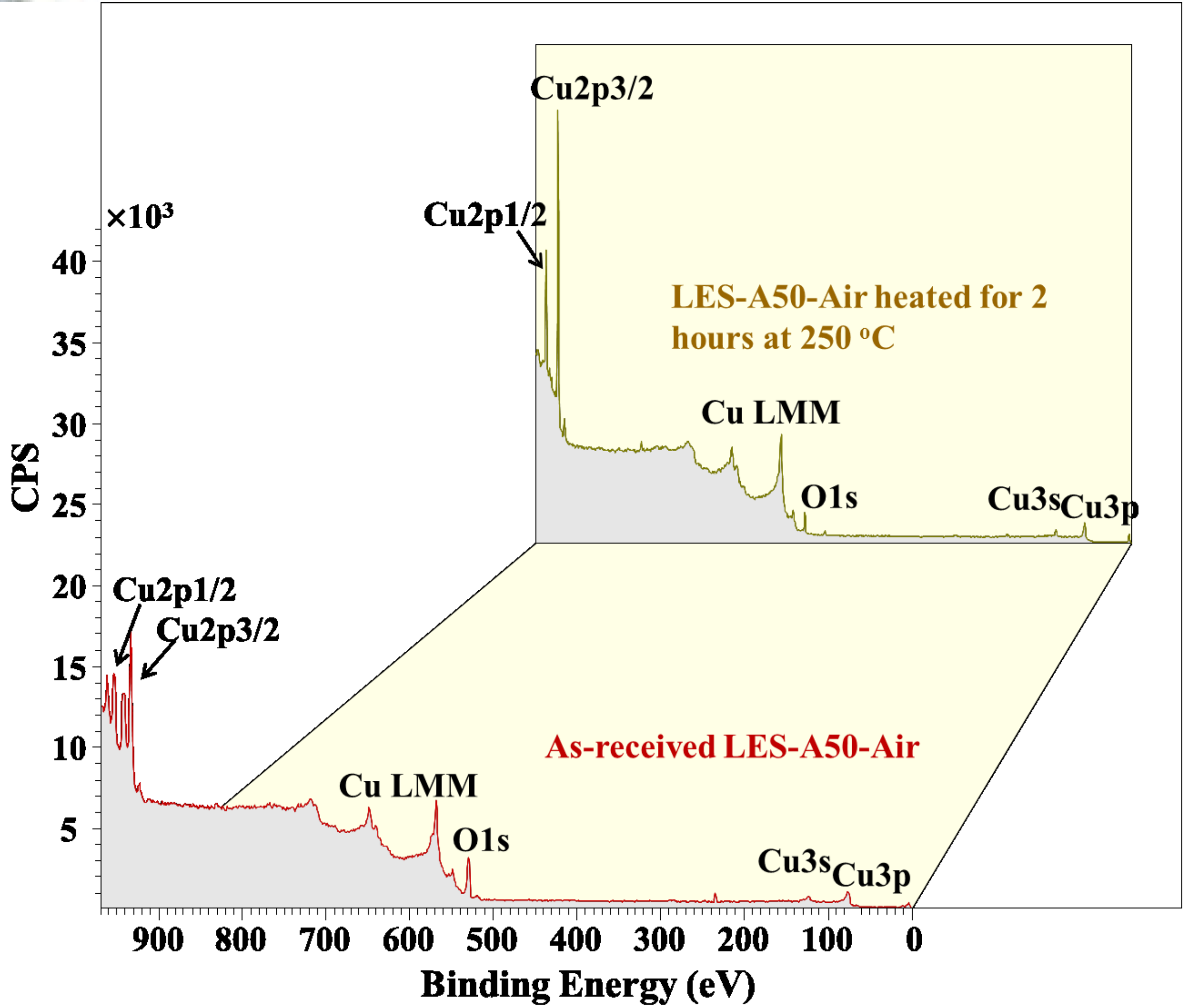
δ < 0.55 after 2h bake

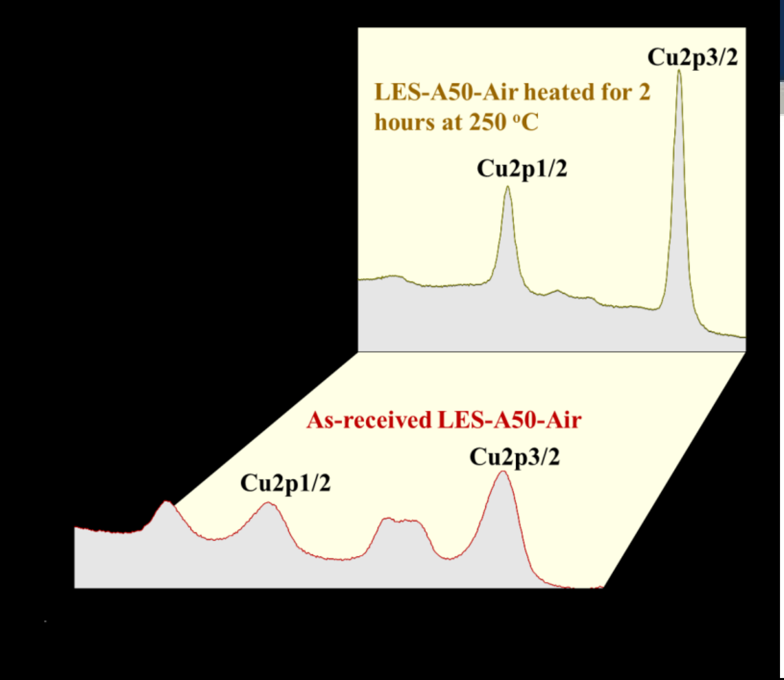


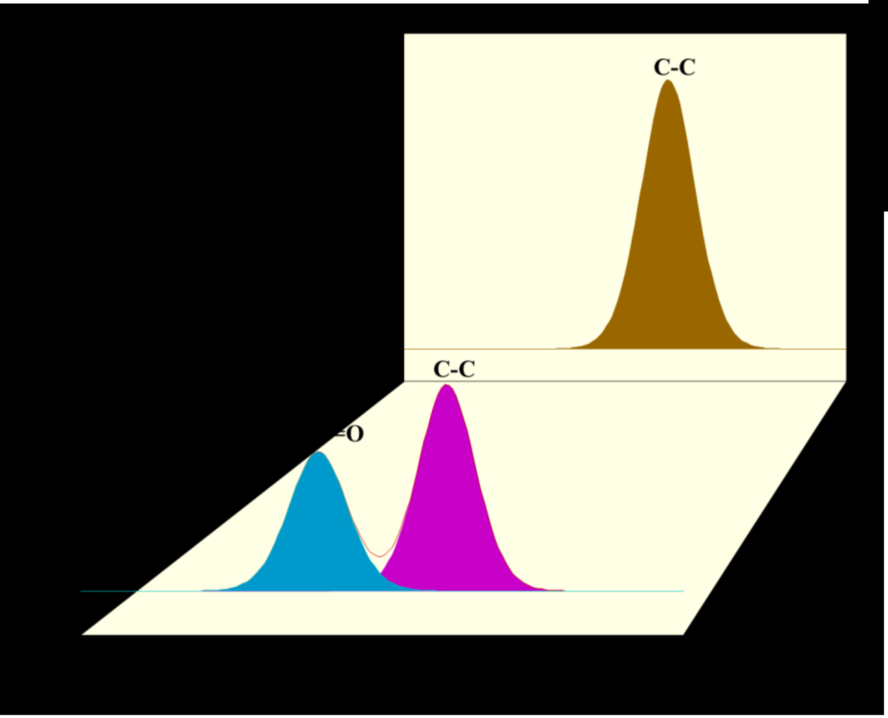
δ < 0.82 as-received

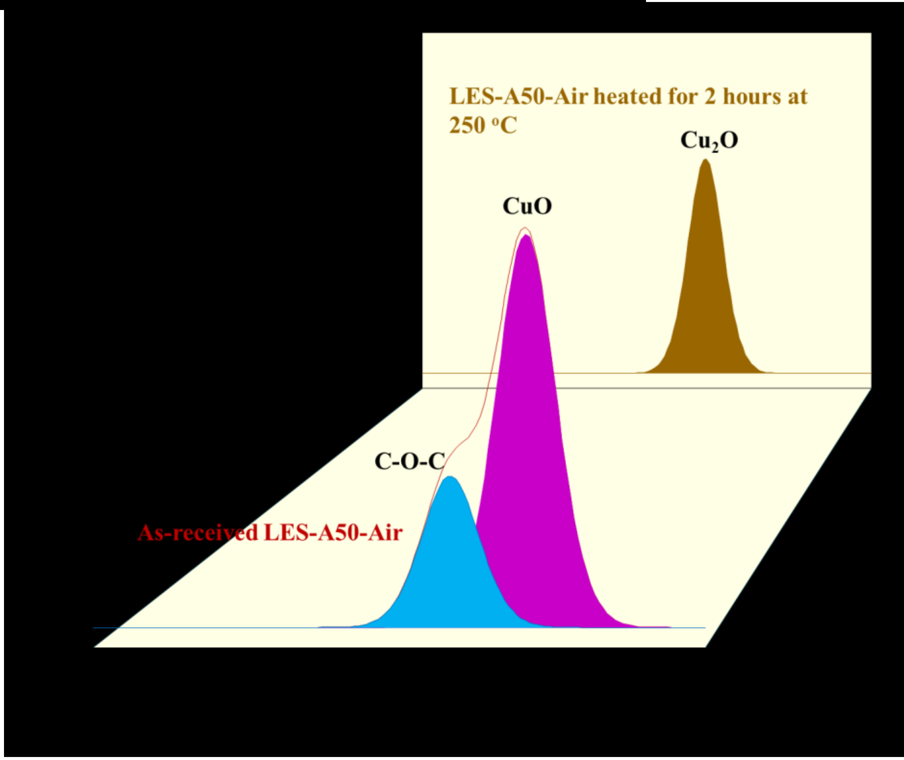
δ < 0.65 after 2h bake

XPS analysis of Cu sample before and after heating




Cu2p3/2
LES-A50-Air heated for 2 hours at 250 °C
Cu2p1/2
As-received LES-A50-Air
Cu2p1/2
Cu2p3/2

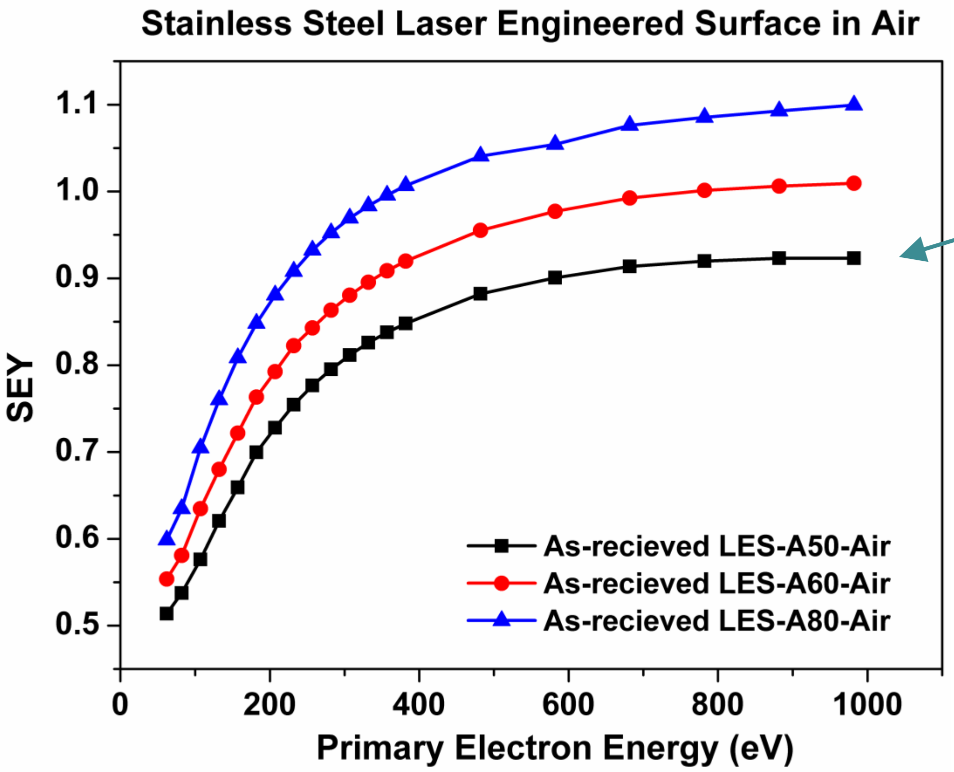

C-C
C-C
-O


LES-A50-Air heated for 2 hours at 250 °C
Cu₂O
CuO
C-O-C
As-received LES-A50-Air

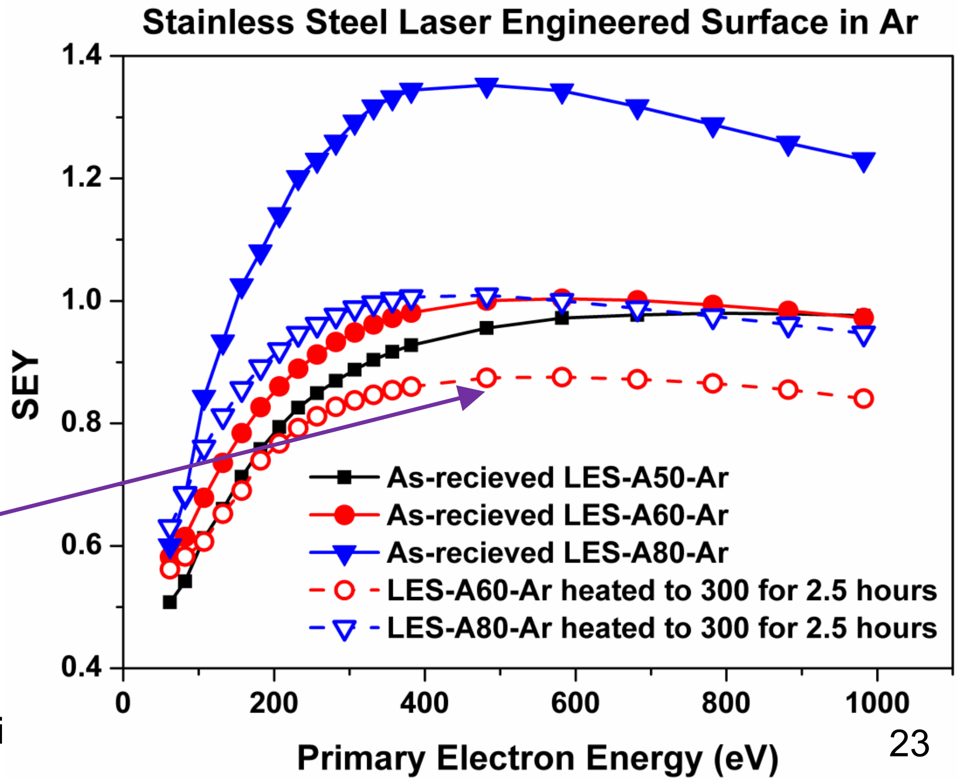
XPS results of surface composition

Sample	Cu2p 933 eV	Cu2p 943 eV	C 285 eV	C 288 eV	O1s 531 eV	O1s 529 eV
	Peak area ratios (electron bombarded)/(as-received)					
Cu	2.72	0	1.09	0.41	0.44	
LESS-A50	2.04	0	1.23	0.60	0.44	
	Peak area ratios (heated)/(as-received)					
LESS-A50	1.60	0	2.32	0.92	0.28	0.44
LESS-A60	1.40	0	2.40	0.92	0.35	0.47
LESS-A80	1.77	0	2.36	0	0.15	0.58

The latest results: 304L



δ < 0.93

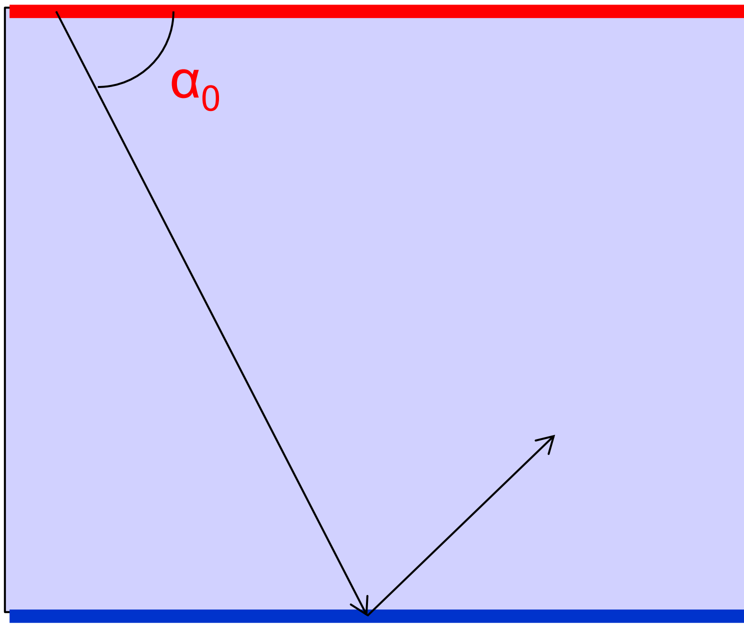


δ < 0.84

Modelling an effect of surface geometry

- A 3D modelling of the structure was made by Dr. J. Smith with use of Vsim code
- The code allows modelling of:
  - Electron generated with initial energy E_0 and angle: $0 < \alpha_0 \leq 90°$,
  - Electric field dE/dz (or bias U),
  - Bombarded surface:
    - flat or structured.
  - Generating of secondary electron energy and spatial distribution based on the Furman-Pivi model (SLAC-PUB-9912)

- Electron generation: E_0, α_0
- Bias U
- Collection of electrons

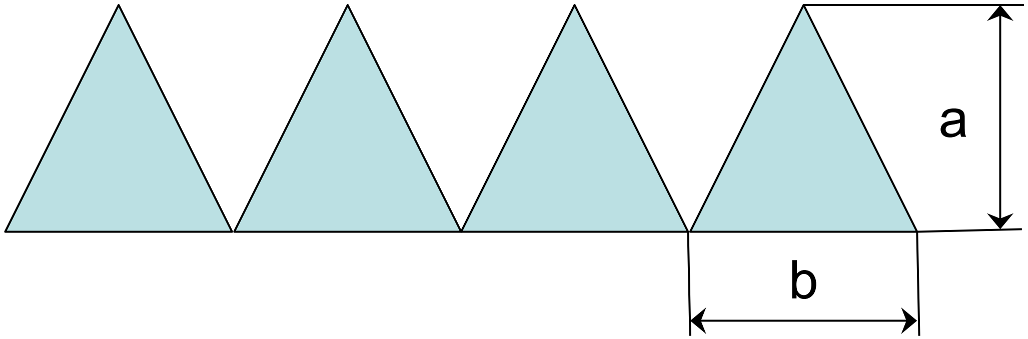


- Bombarded surface,
- U=0,
- Secondary electrons

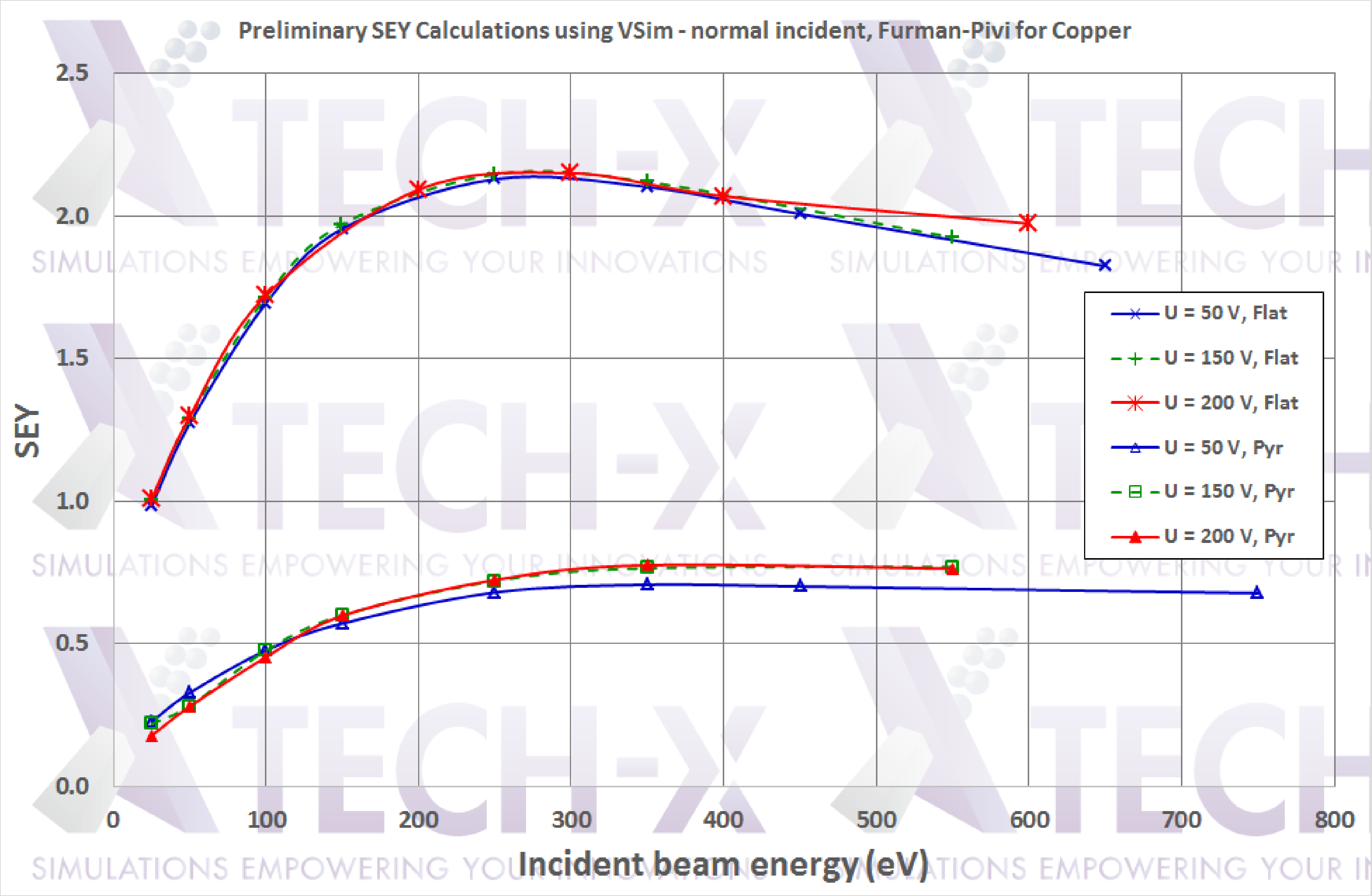
Vsim is being used in 3D to predict geometric factors

- Flat surface was compared to
- Pyramidal structure with high-to-base ratio **a/b= 1**
- for $\alpha_0 = 90°$ and $\alpha_0 = 45°$

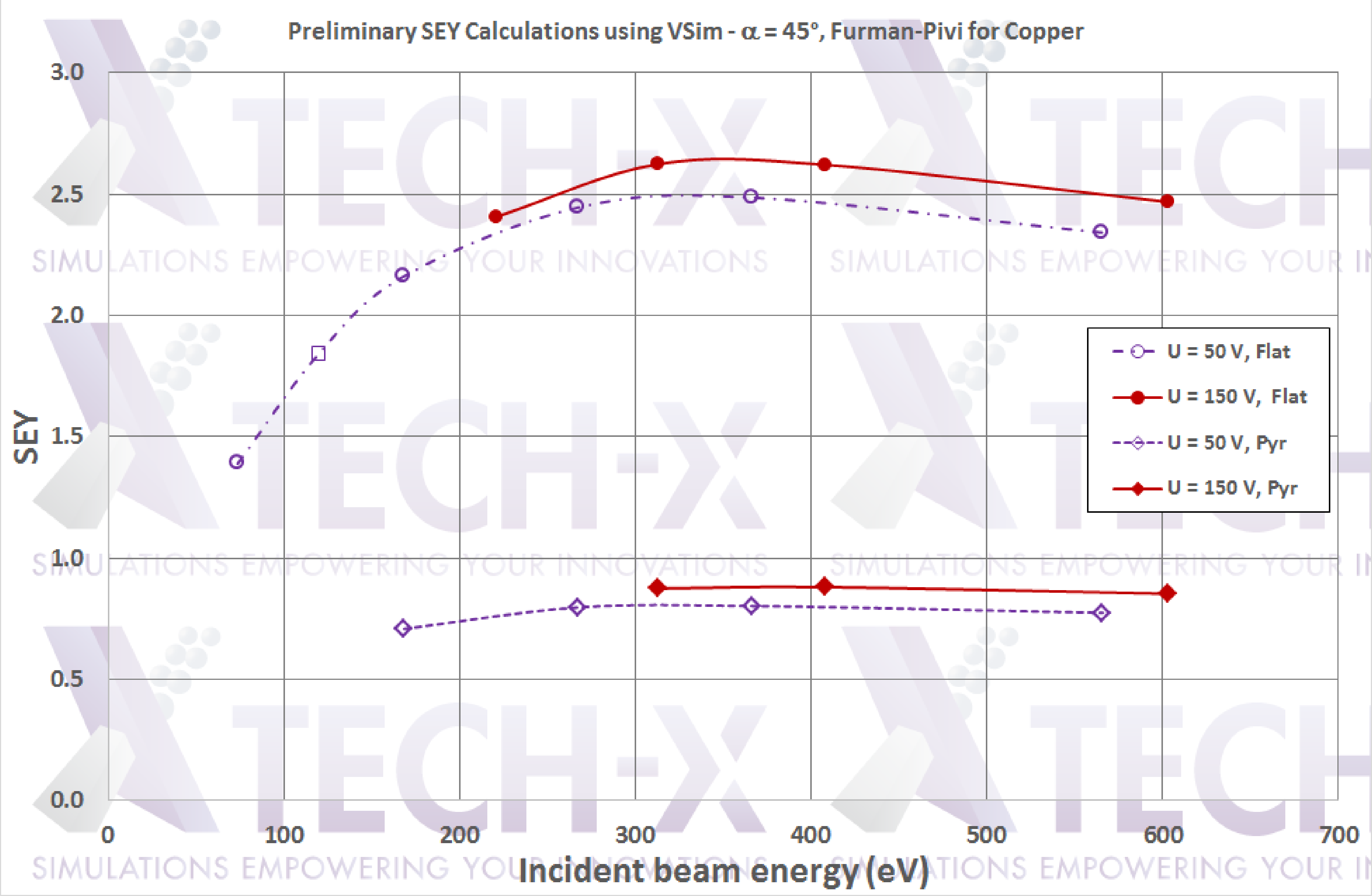
- Movie 1
- Movie 2



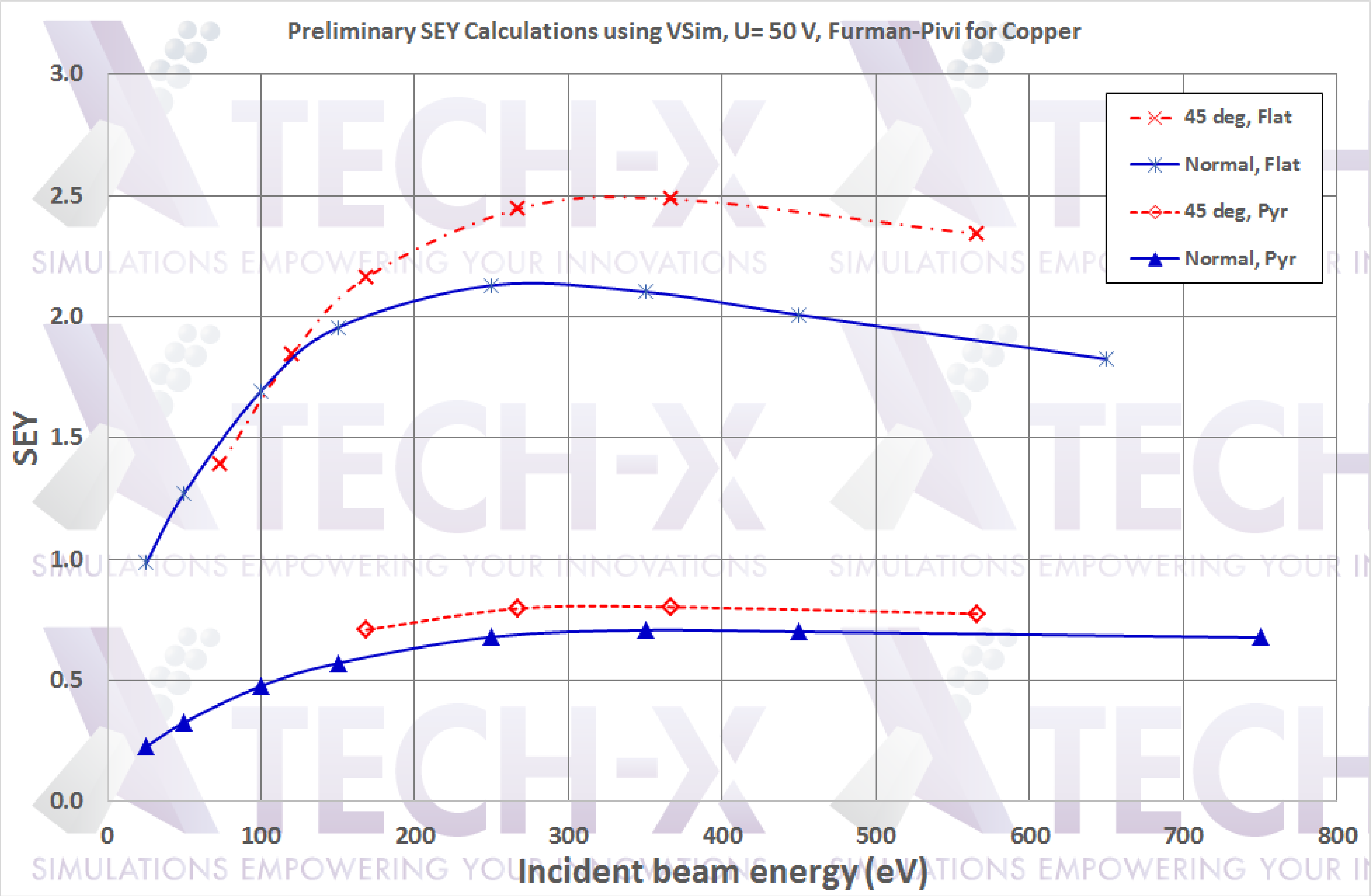
Simulations: normal incident



Simulations: $\alpha_0 = 45°$

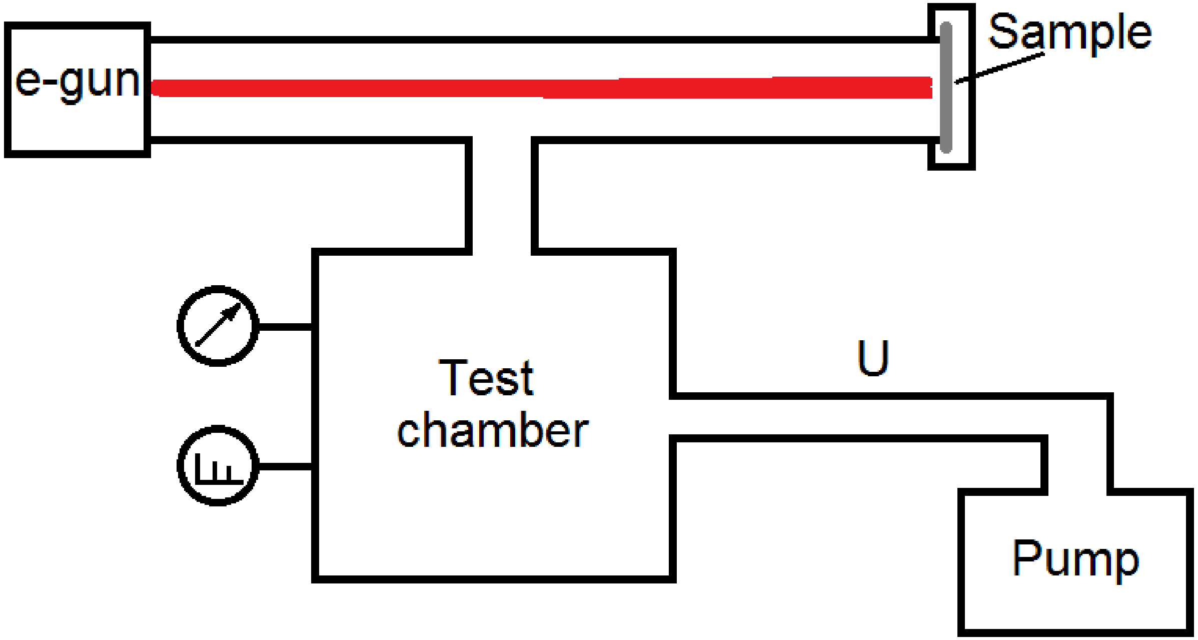


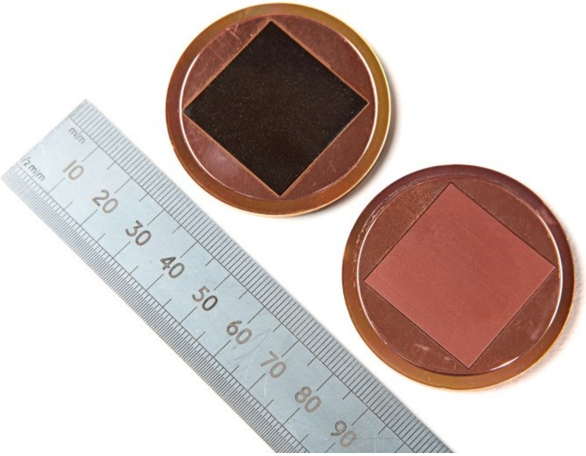
Modelling: Effect of initial angle α_0



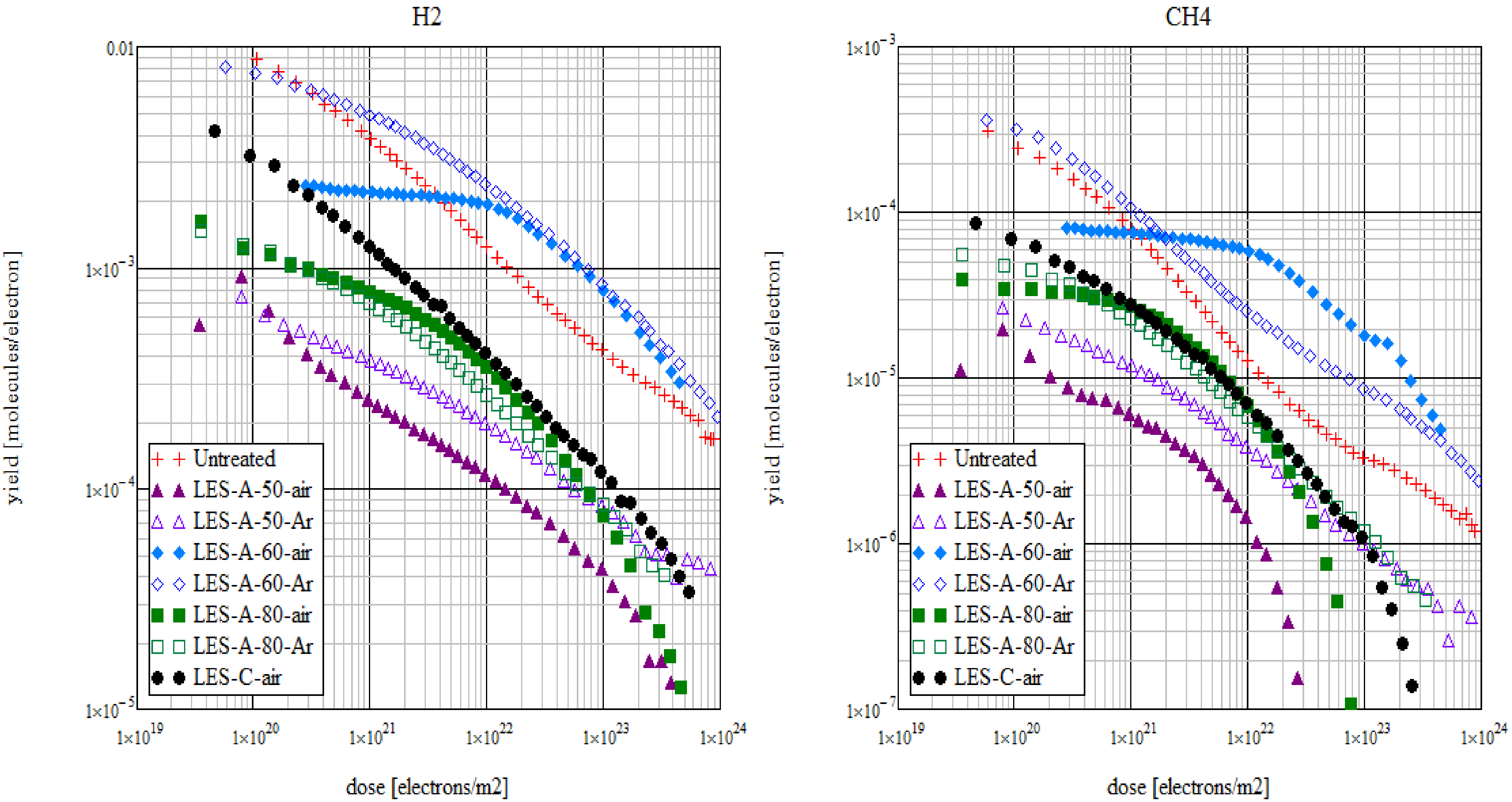
Electron Stimulated Desorption (ESD)

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





ESD: H_2 and CH_4



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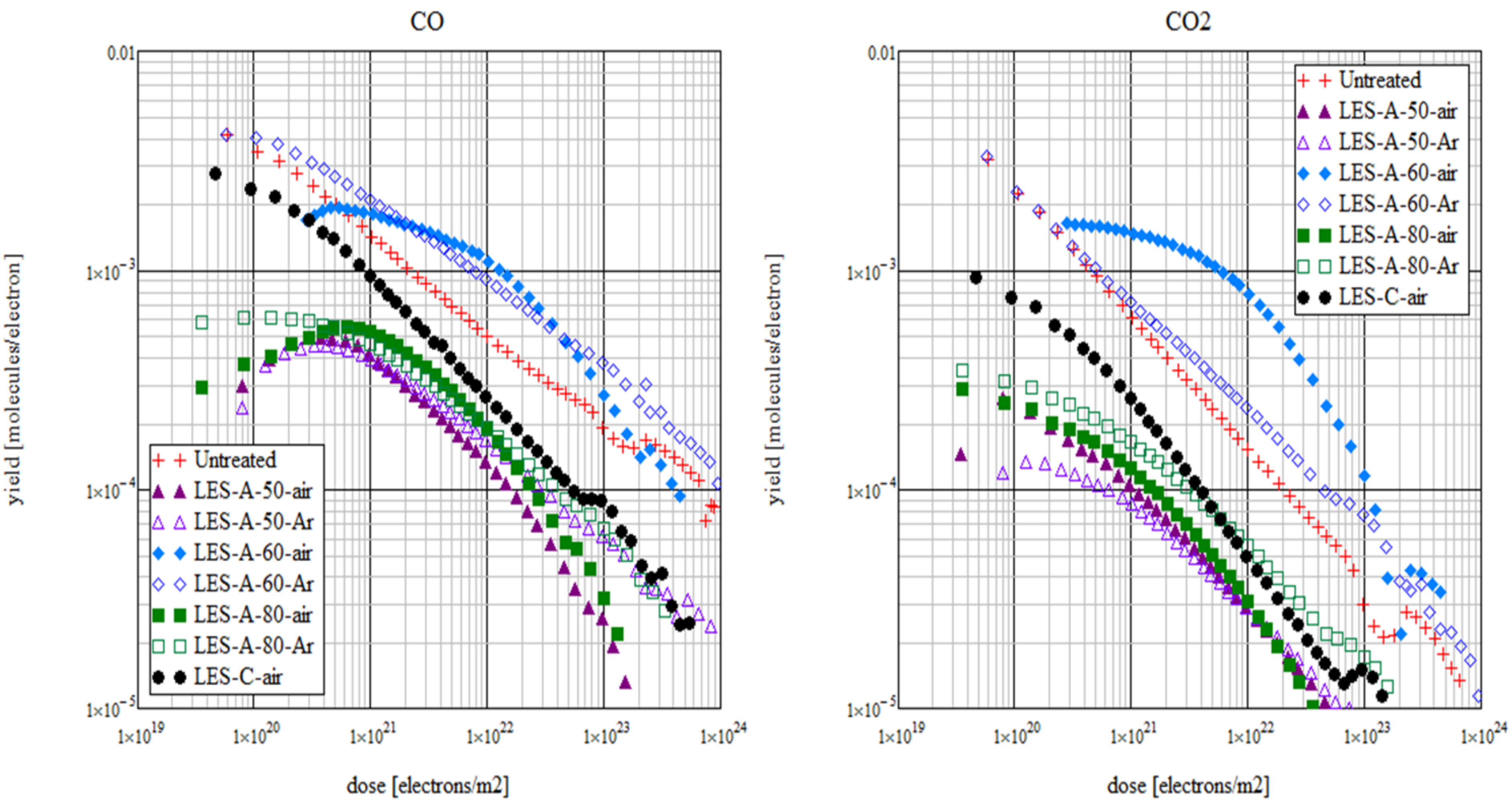
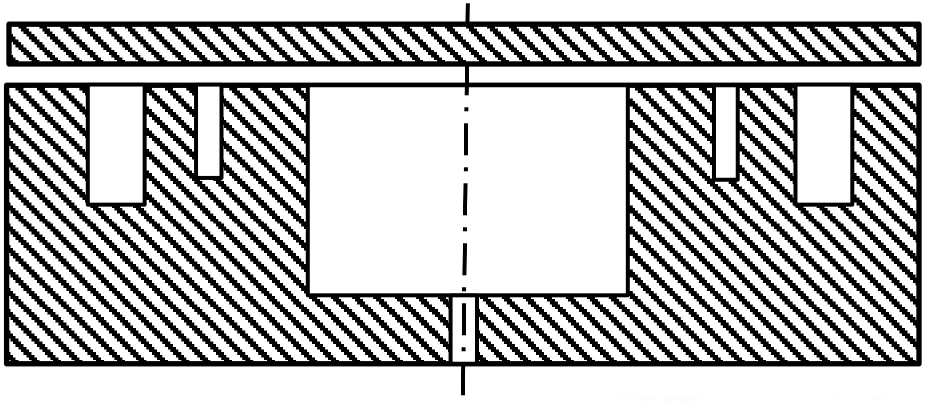
ESD: CO and CO_2



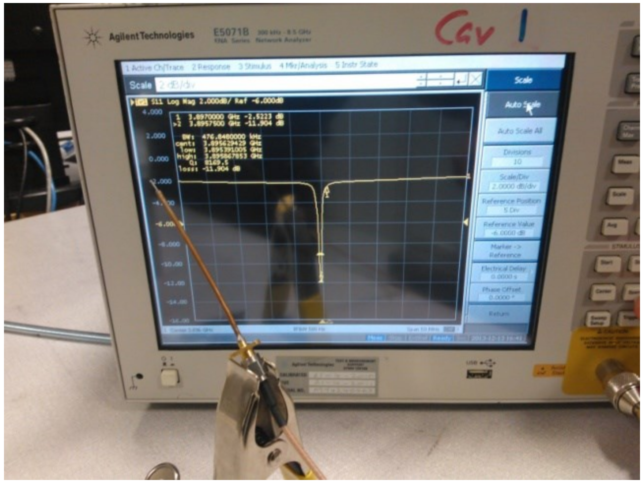
Electron Stimulated Desorption (ESD)

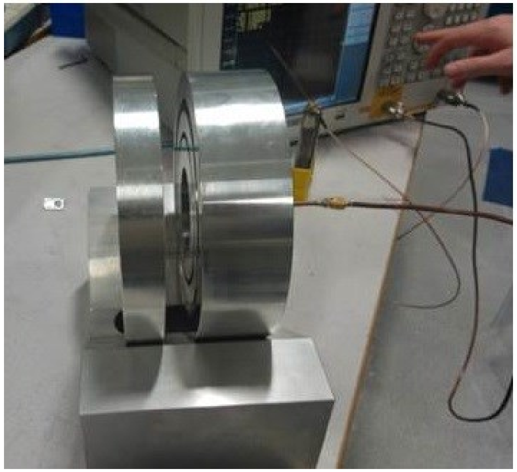
- Main results:
  - LESS-A50, LESS-A80 and LESS-C demonstrated lower ESD yields than untreated sample
  - LESS-A50 treated in air is the best results
  - LESS-A60 demonstrated the highest ESD between studied samples, but are quite comparable with an untreated sample.

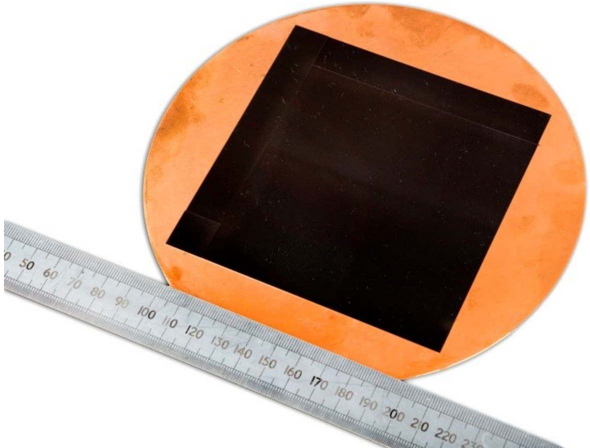
Surface resistance measurements



- Test cavities (3.9 and 7.8 GHz):
  - The simulation results obtained with Microwave Studio
  - Fabricated from Al.
- Samples:
  - a 100-mm diam. disk
  - Bulk Cu
  - 5-μm thick deposited Cu on Si wafer
  - LESS-A on copper
  - LESS-C on copper







Surface resistance measurements at 7.8 GHz

	Bulk	**Roughness**	**for 7.8 GHz**		
Sample	R (Ω·m)	r.m.s. RA (m)	R_s calc (Ω·m)	**R_s meas (Ω·m)**	Q_0
Cu bulk	1.68×10^{-8}	4.09×10^{-7}	2.86×10^{-2}	**2.70×10^{-2}**	5398
Cu(5μm)/Si	1.68×10^{-8}	9.08×10^{-9}	2.27×10^{-2}	**2.84×10^{-2}**	5333
LESS-C	**1.68×10^{-8}**	-	-	**3.4×10^{-2}**	**5079**
Al bulk	2.82×10^{-8}	4.05×10^{-7}	3.40×10^{-2}	**3.85×10^{-2}**	4787
Nb bulk	1.54×10^{-7}	(1.0×10^{-6})	8.06×10^{-2}	**6.75×10^{-2}**	3958
304-L	7.2×10^{-7}	1.44×10^{-6}	1.60×10^{-1}	**1.68×10^{-1}**	2382
LESS-A	1.68×10^{-8}	-	-	**3.66×10^{-1}**	1335

What else do we need to know about LESS?

- SEY as a function of initial angle α_0
- SEY in a weak magnetic field $B < 0.02$ T
    - requires a modification of an existing SEY measurement

- SEY at cryogenic temperatures
- SEY in a strong magnetic field $B = 1$ T
    - can be done, requires a new testing facility

- Photo-electron emission yield (PEY)
    - PEY in a magnetic field
        - requires an access to a SR beamline

Summary: LESS properties

- **SEY**:
  - LESS 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 effects
    - Initial SEY – due to the geometrical effect (confirmed by measurements and modelling)
    - Then by the surface chemistry change during a bakeout and/or bombardment with electrons, ions and (very likely) photons
- **Stimulated gas desorption**
  - ESD yields are lower than for untreated copper
    - LESS-A50 treated in air shows the best results (lowest ESD yields)
  - Laser treatment in air lead to lower ESD yields and in Ar
  - LESS-A60 with the highest ESD is comparable with an untreated sample.
- **Surface resistance** with LESS can increase
  - measured values of surface resistance at 3.9 and 7.8 GHz shows that LESS-C type is a preferable solution to minimise an effect on the surface impedance in accelerator beam pipe.

Summary: LESS 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.
- The blackening process is carried out 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

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

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