Electron cloud mitigation with laser-engineered surface structures (LESS) with SEY < 1

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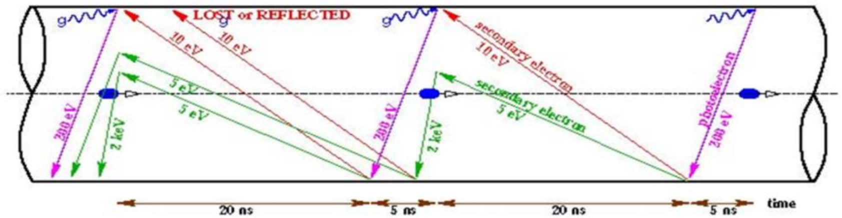
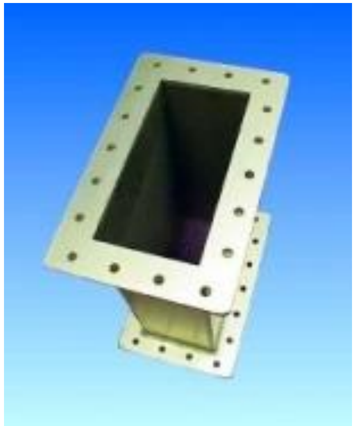
Main Goal



Curtesy to
F. Ruggero

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

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 along the vacuum chamber
- Biased electrodes
- Charged particle beam train parameters
  - Bunch charge and sizes
  - Distance between bunches

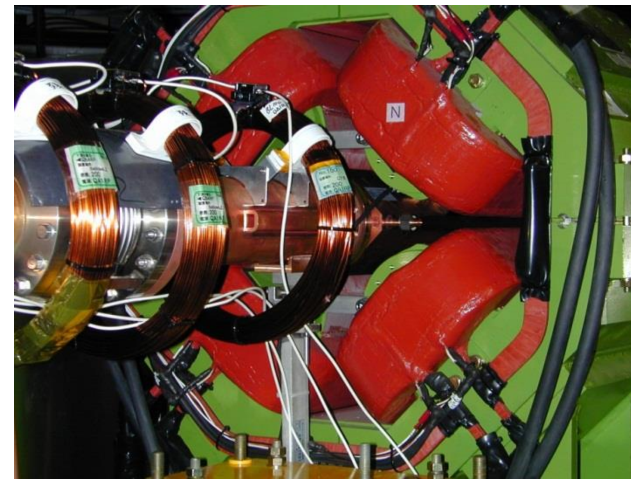
Advantages:

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

Down side:

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

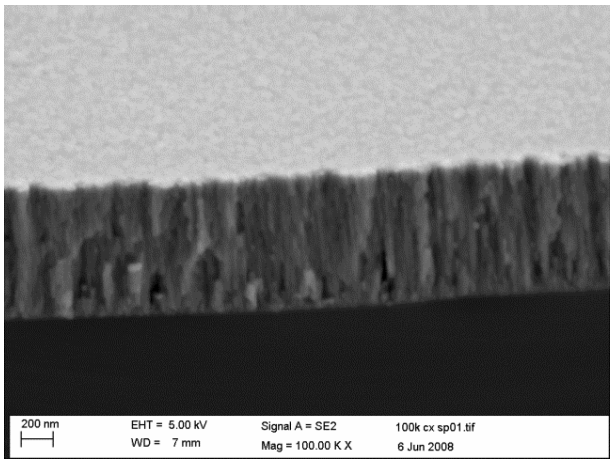
Solenoids at KEKB, Japan



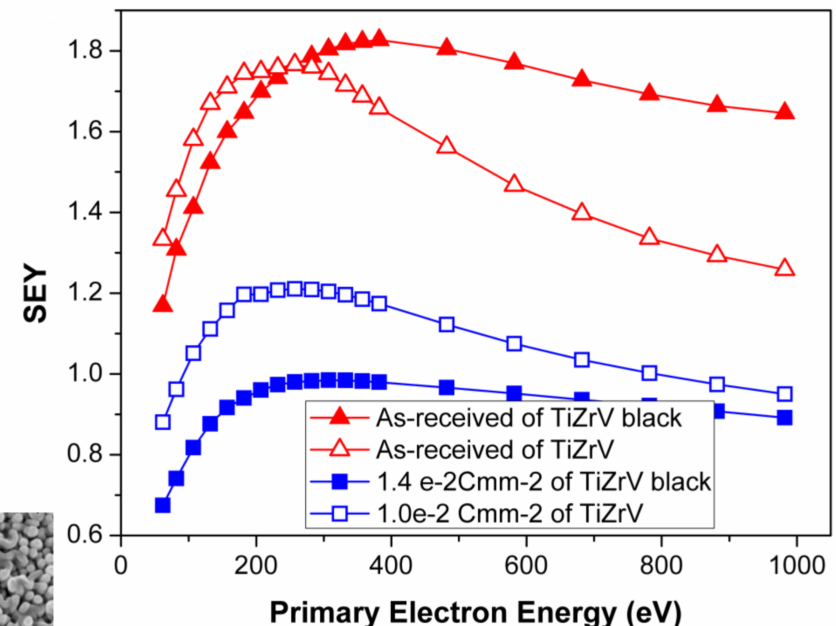
Biased electrodes at DAΦNE, Italy

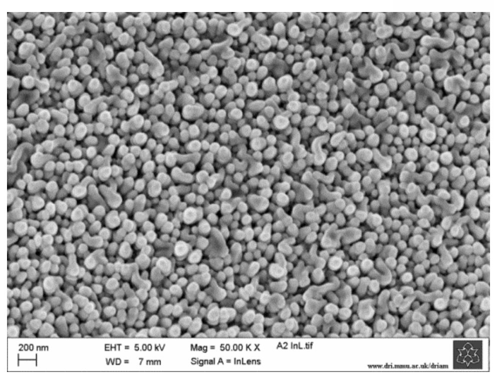
Existing Passive Mitigation methods

- Coating with Low SEY Material



•TiZrV NEG Coating

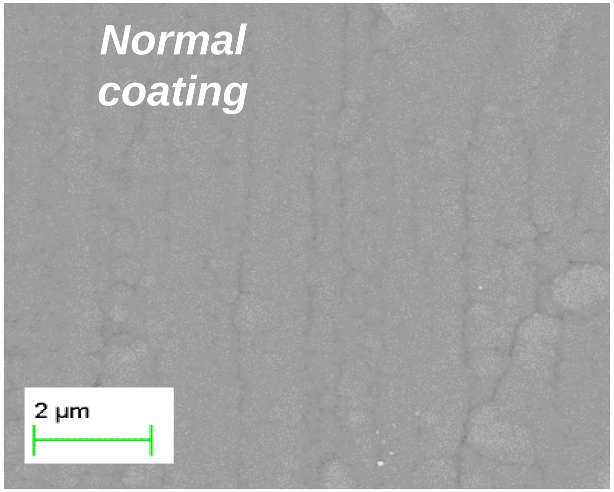


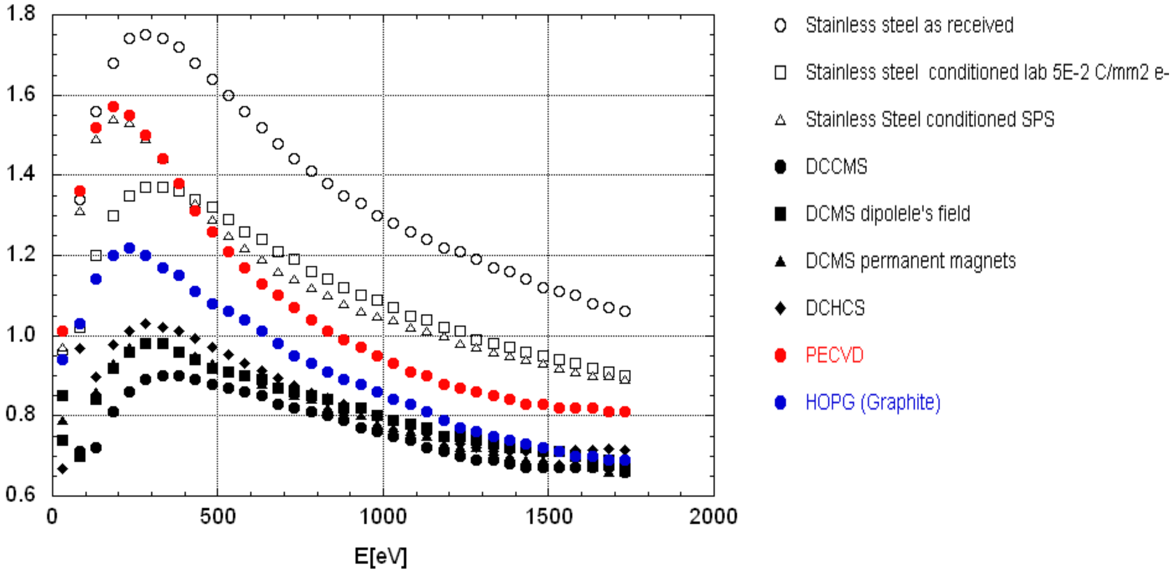


•TiZrV NEG Black

Existing Passive Mitigation methods

- Coating with Low SEY Material

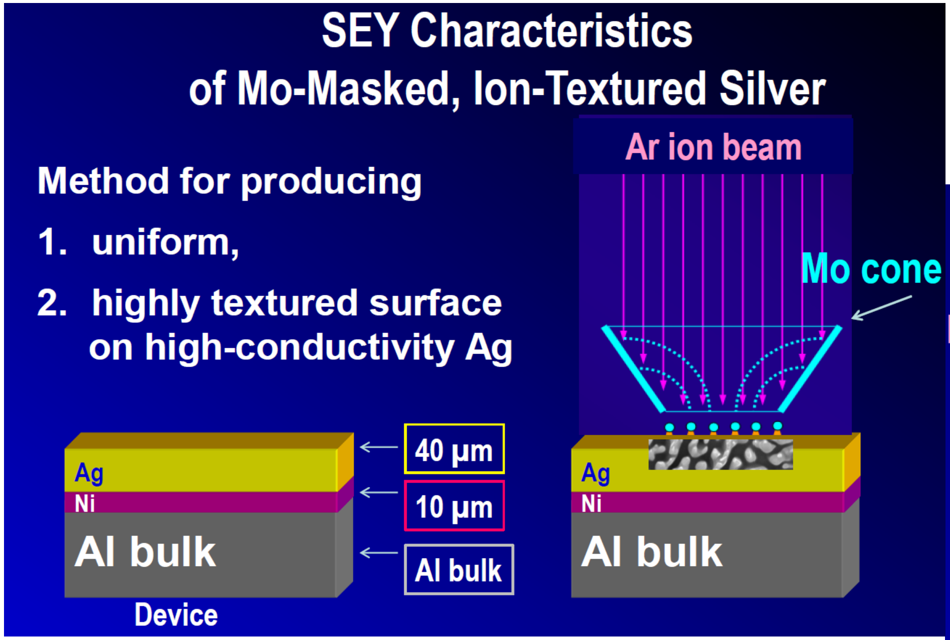




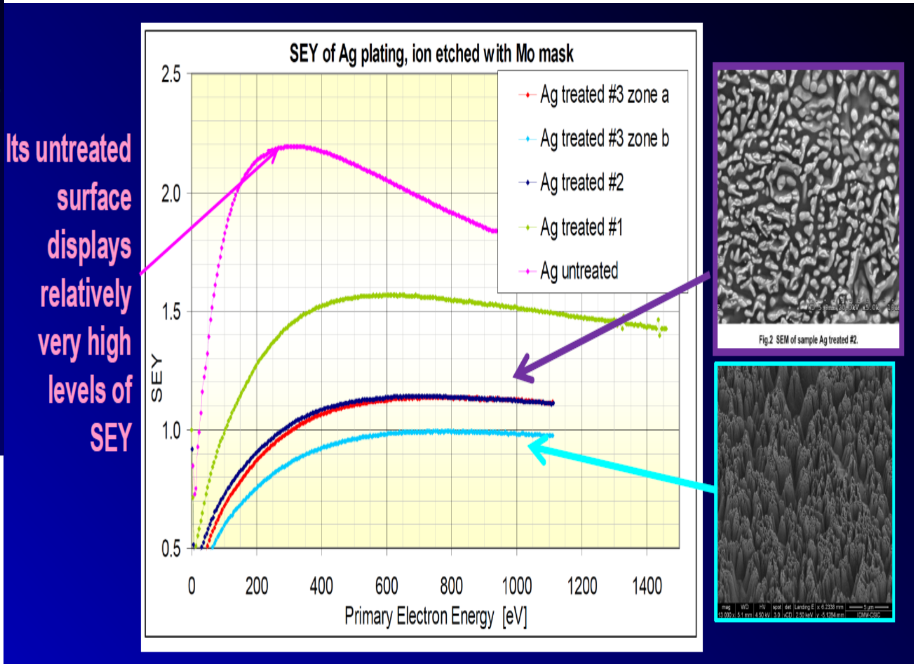
CERN a-Carbon

Existing Passive Mitigation methods

- SEY of Ag treated coating

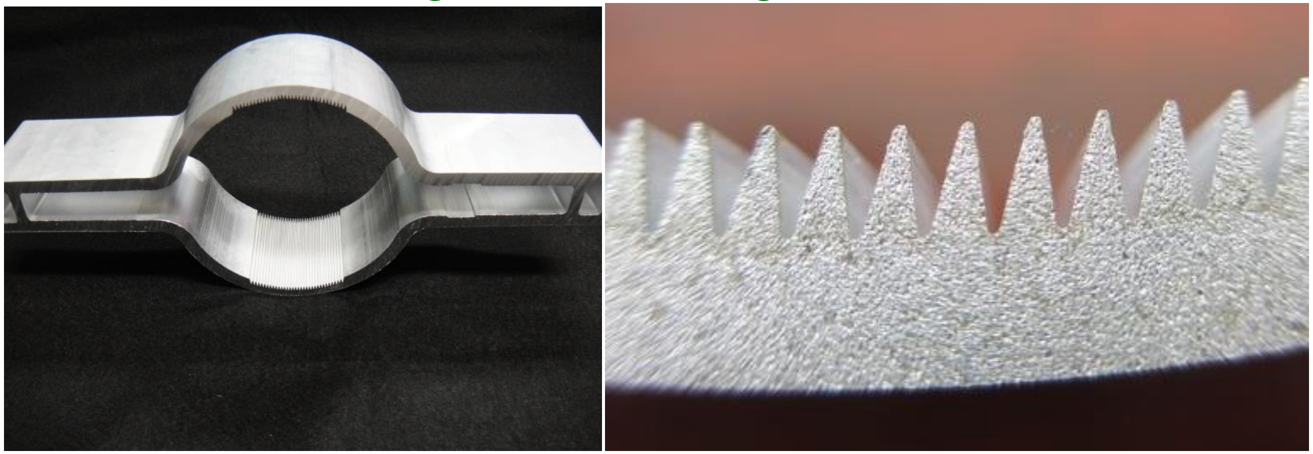


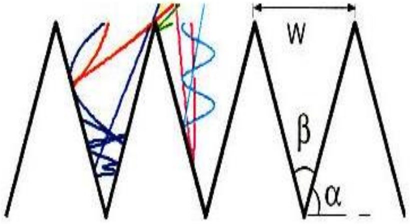
Isabel Montero, ICMM-CSIC



Existing Passive Mitigation methods

- Modifying the surface geometry
  - making mechanical grooves

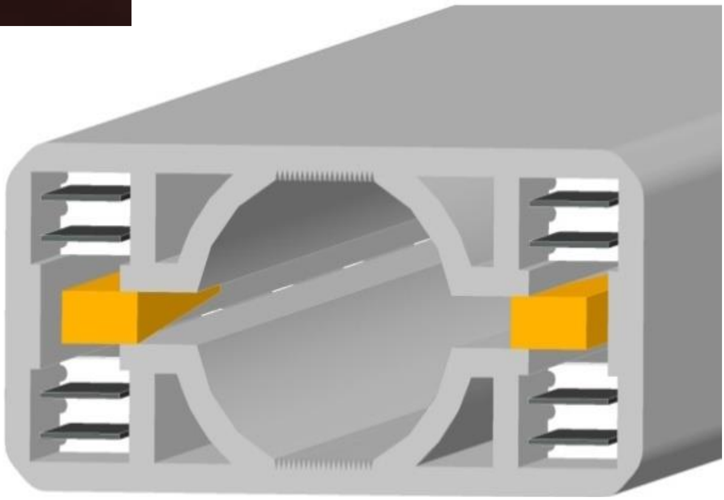




By A. Krasnov and
By L Wang et.al

KEKB vacuum chamber (by courtesy of Y. Suetsugu)

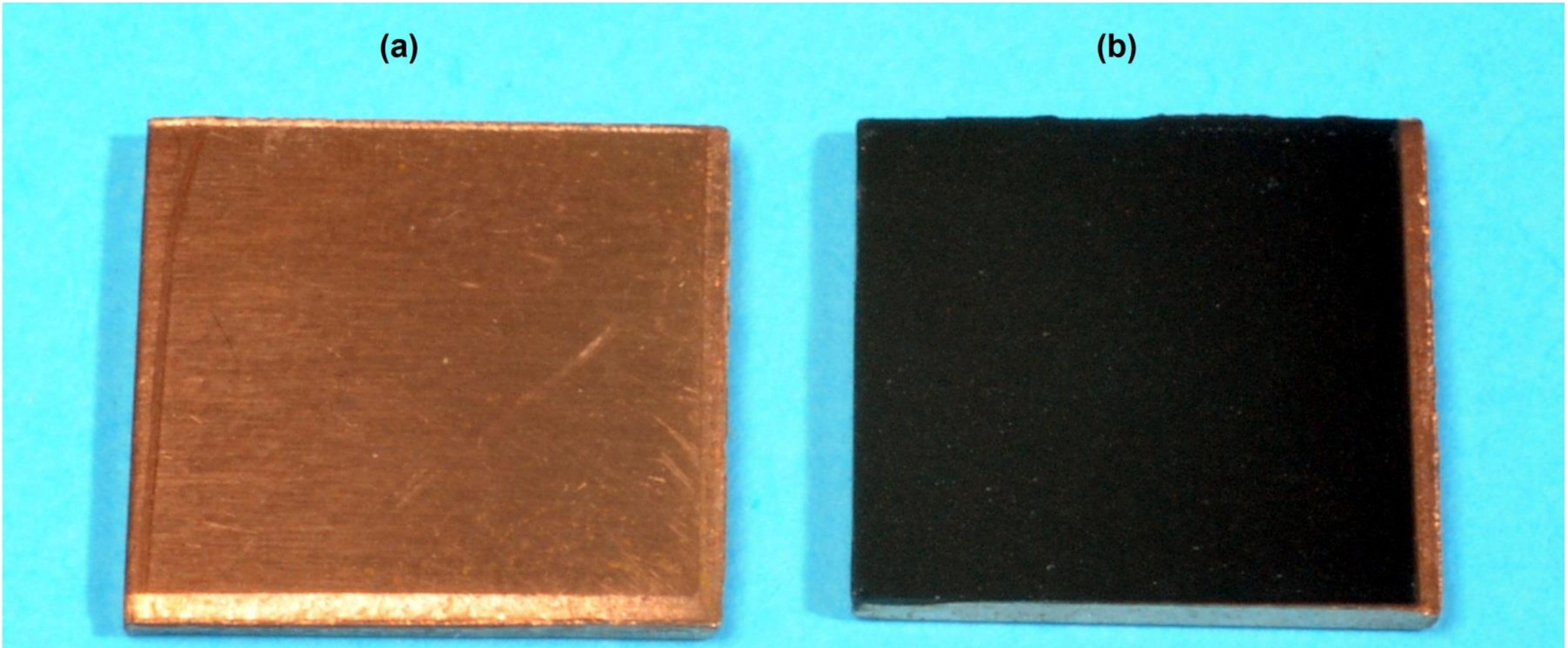
- Modifying the vacuum chamber geometry
  - making an antechamber



ILC wiggler vacuum chamber

Introducing a new technology

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



(a) Untreated Cu

(b) laser treated Cu

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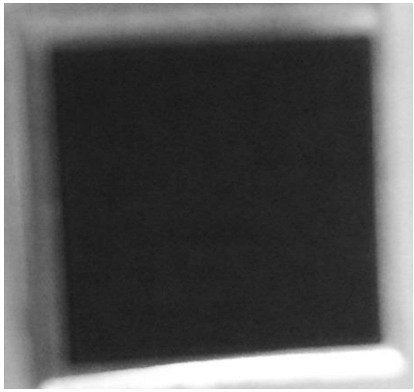
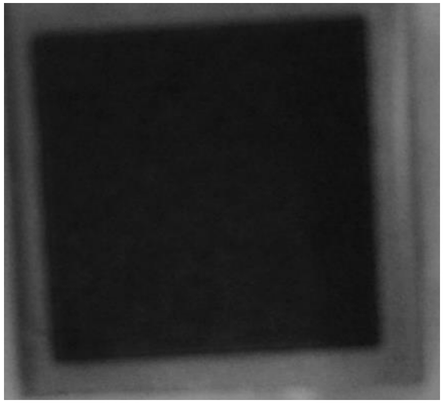
Laser Treated Metal Surface



Aluminium

Copper

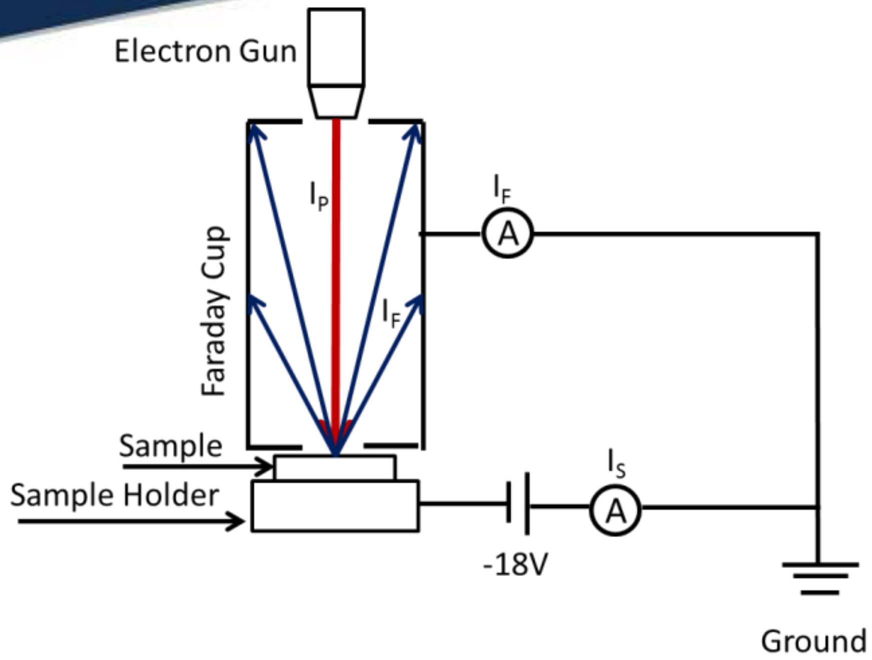


Stainless Steel

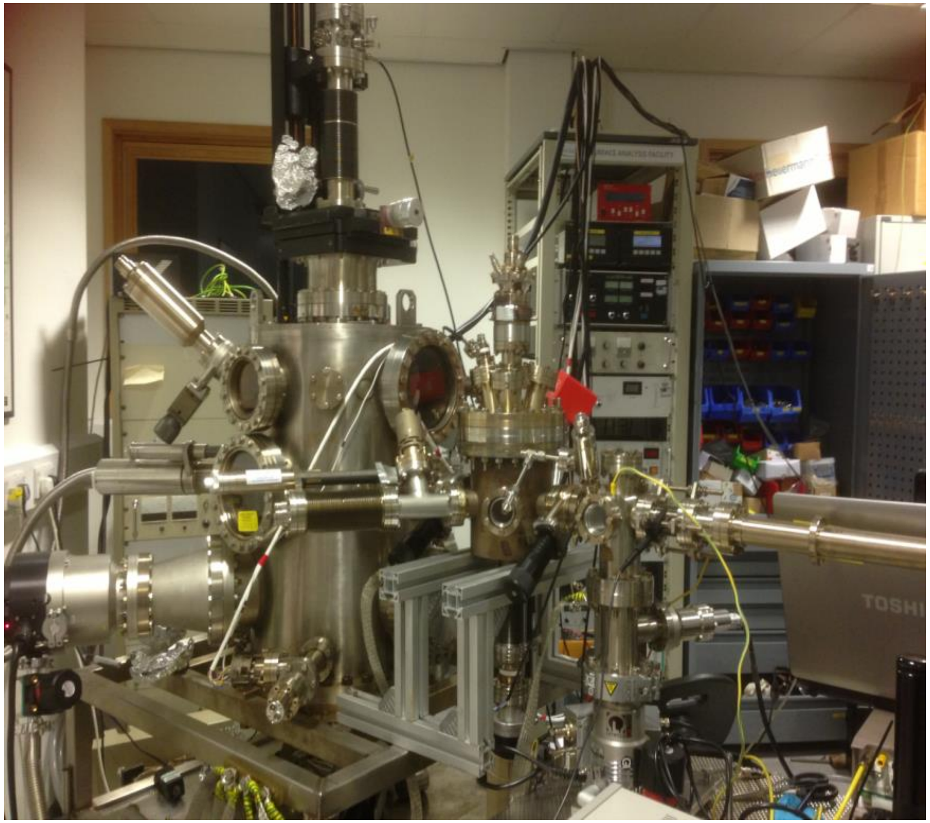
Nd:YVO4 Laser

- 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



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

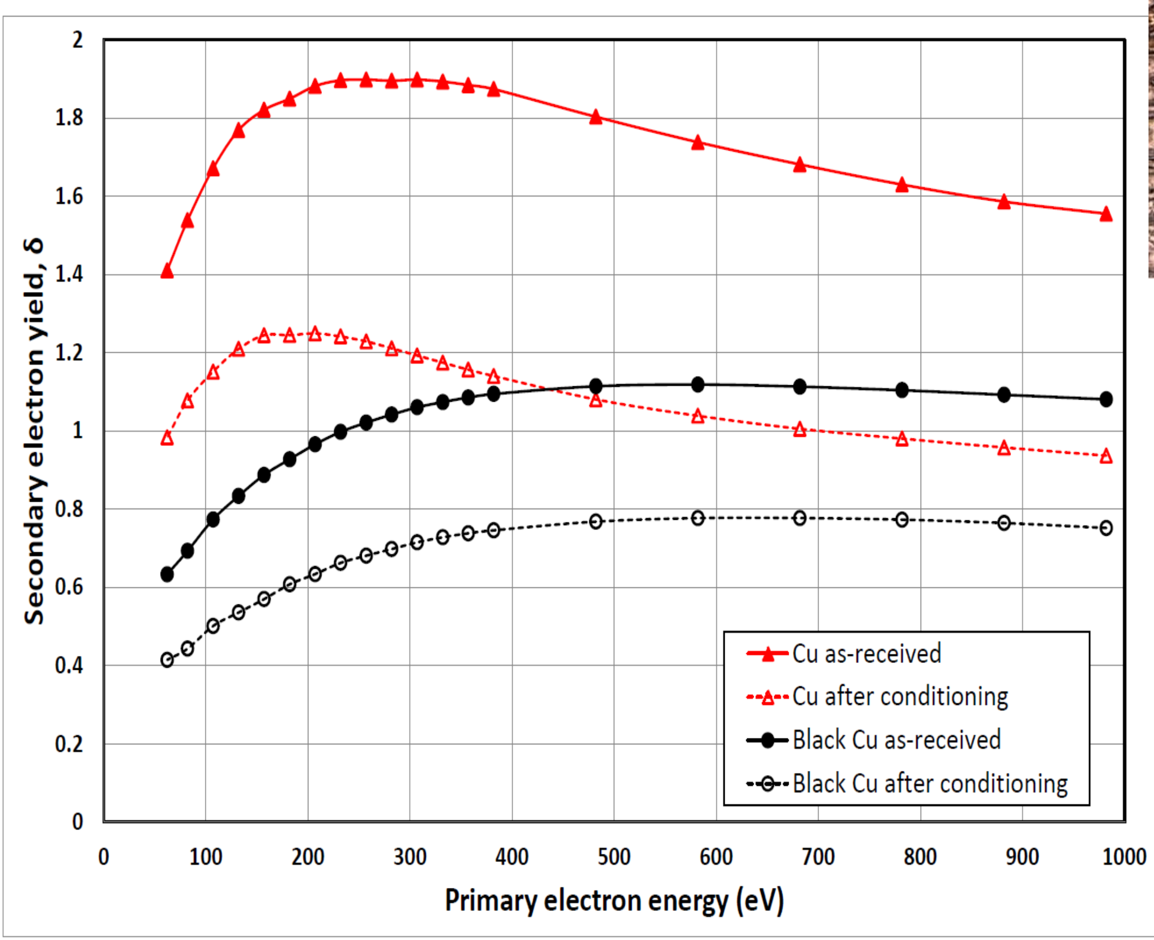


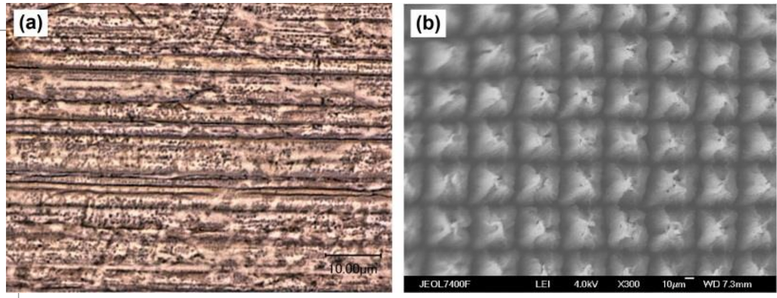
I_P is the primary beam current
I_F is the secondary electron current including elastic and inelastic processes, measured on the Faraday cup
I_S is the currents on the sample

Analysis chamber with

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

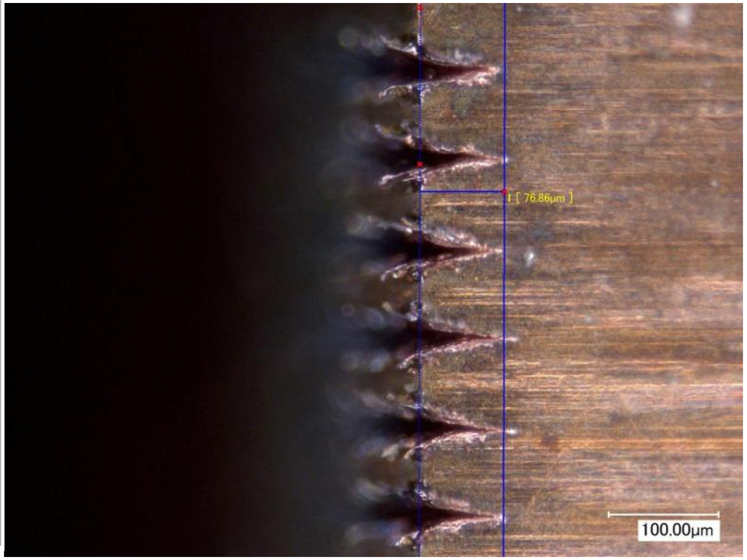
First results on SEY of Cu as a function of incident electron energy





Untreated

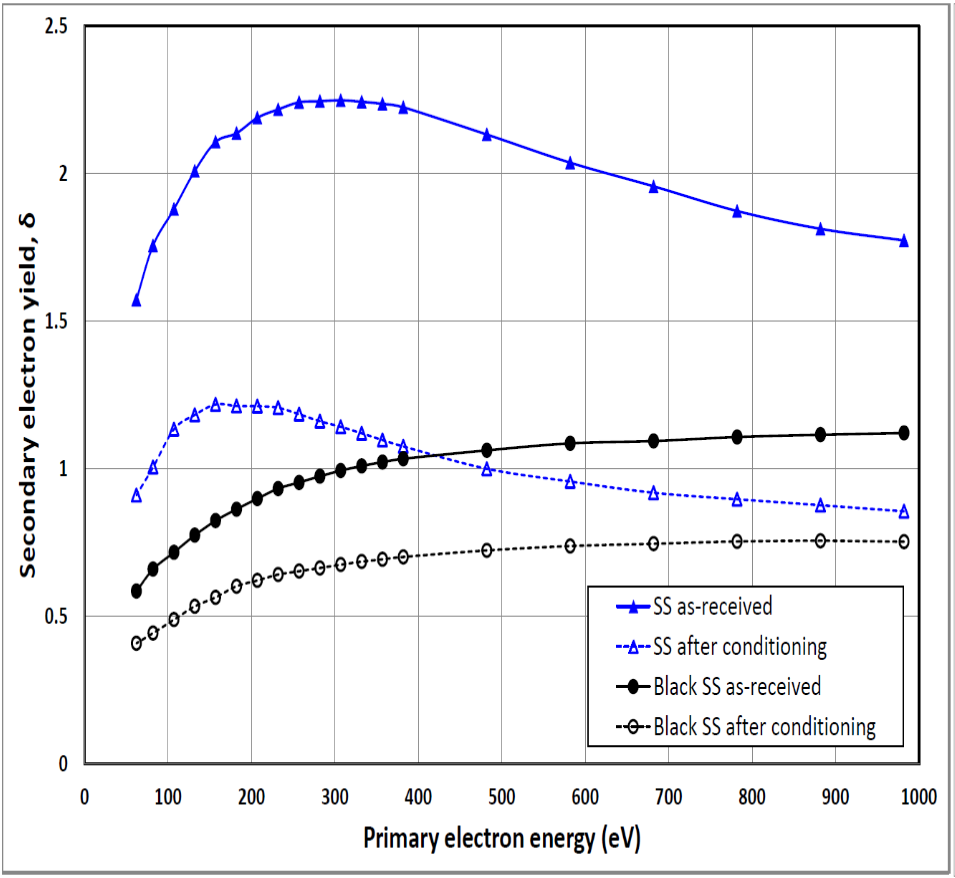
Laser treated

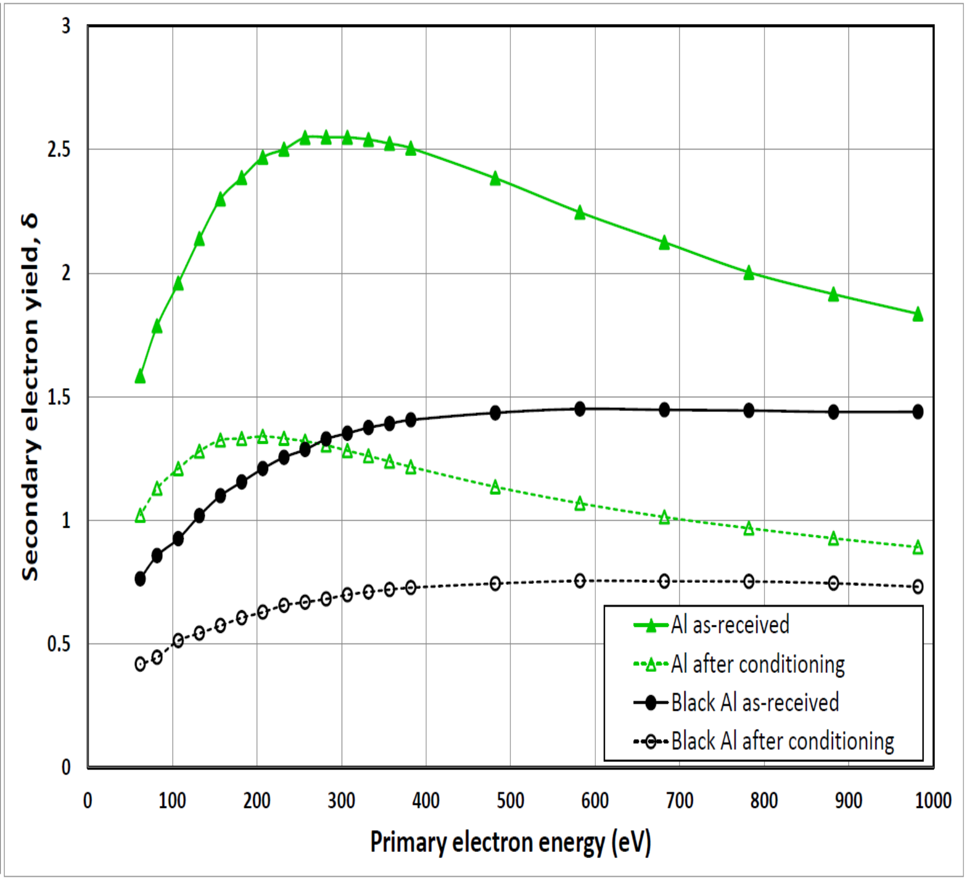


Original data June 2014

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

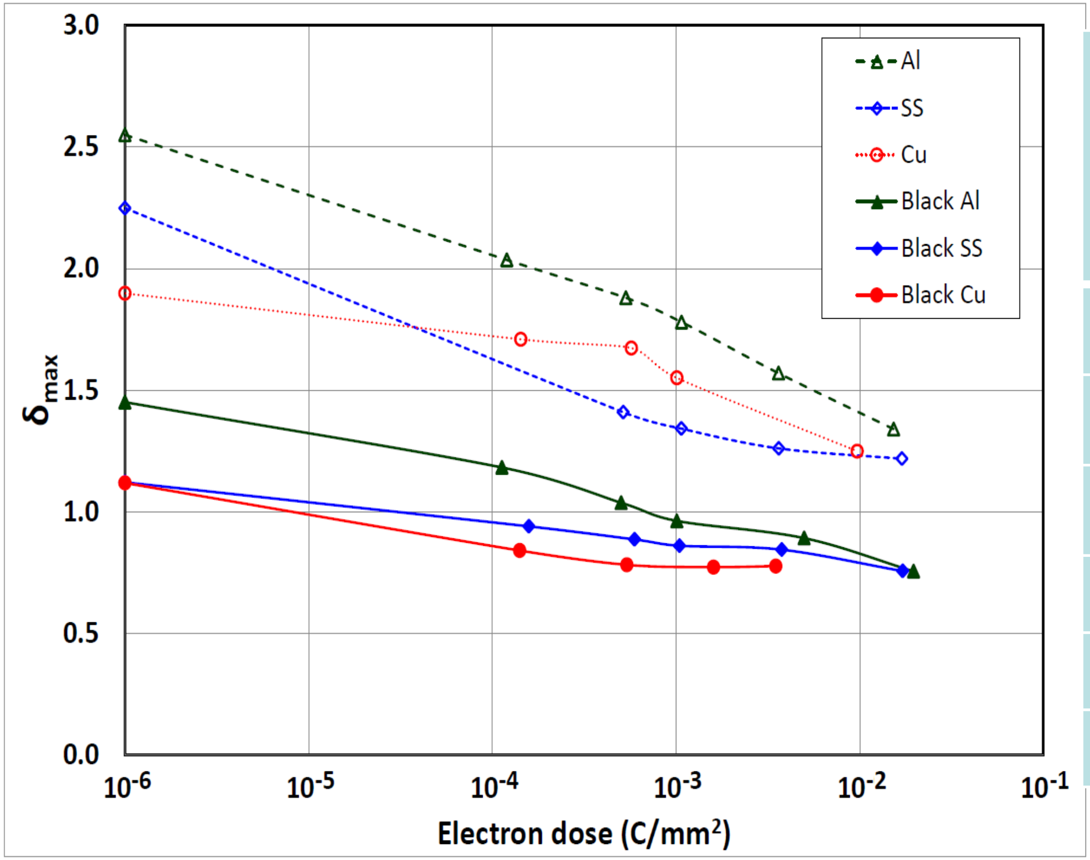
First results on SEY of SS and Al as a function of incident electron energy





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

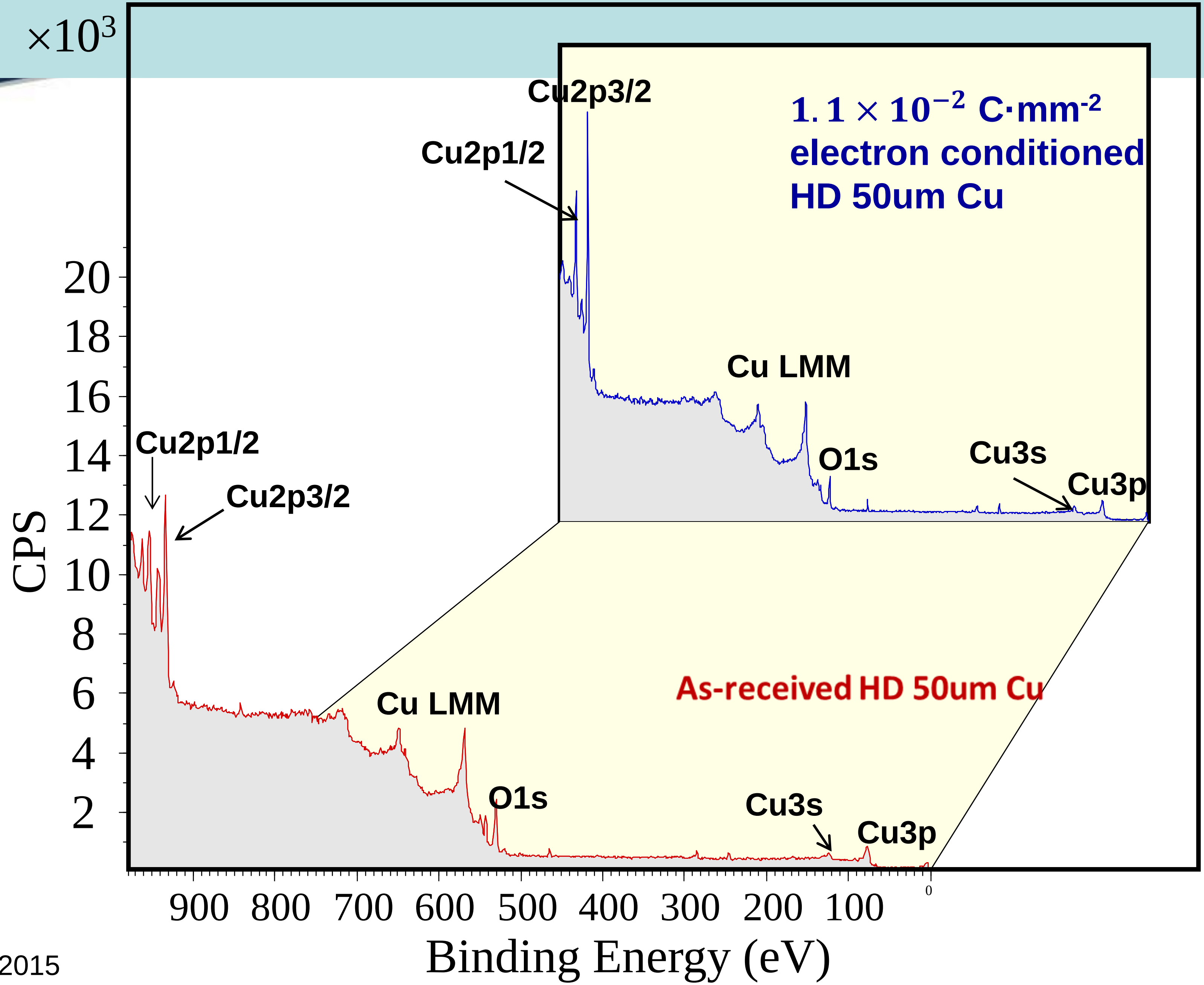
δ_{max} as a function of electron dose for Al, 306L SS and Cu



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.

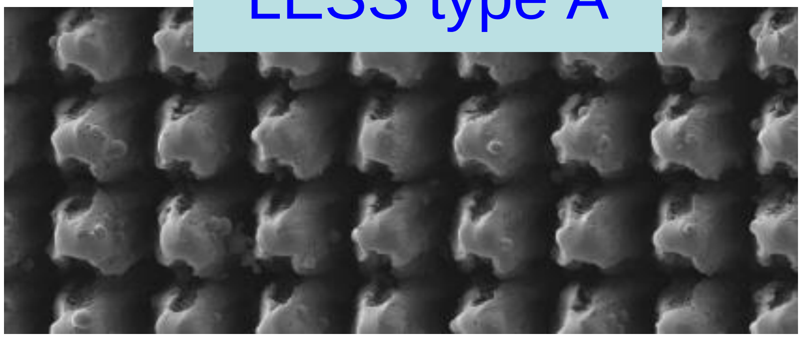
XPS results of electron dose for Cu



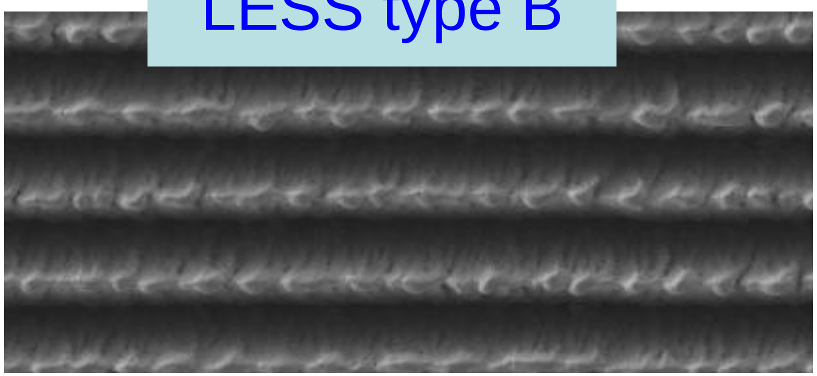
More laser treated surfaces

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

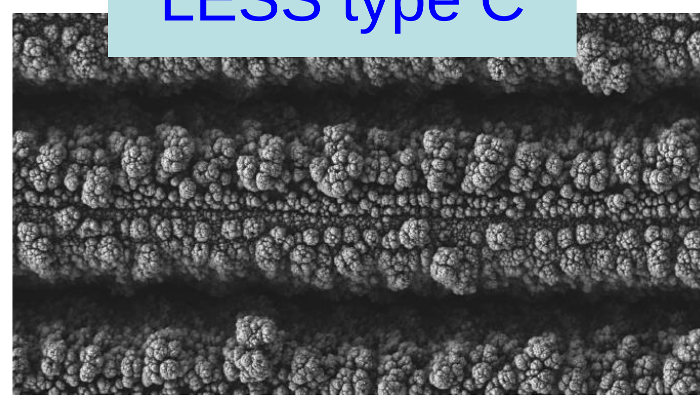
LESS type A



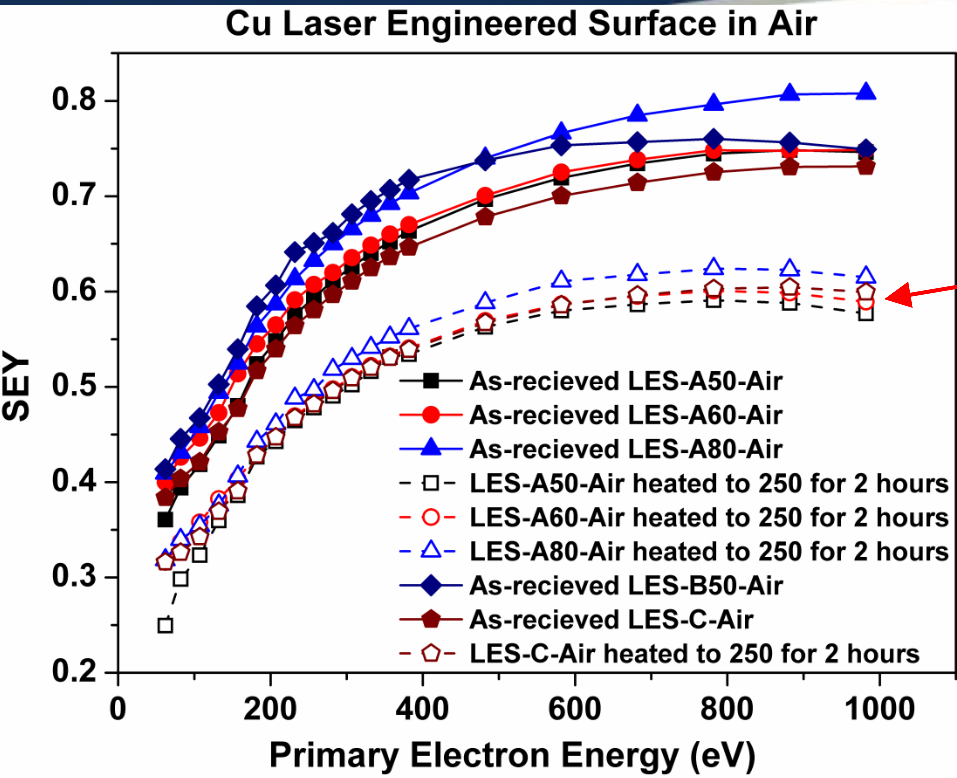
LESS type B



LESS type C

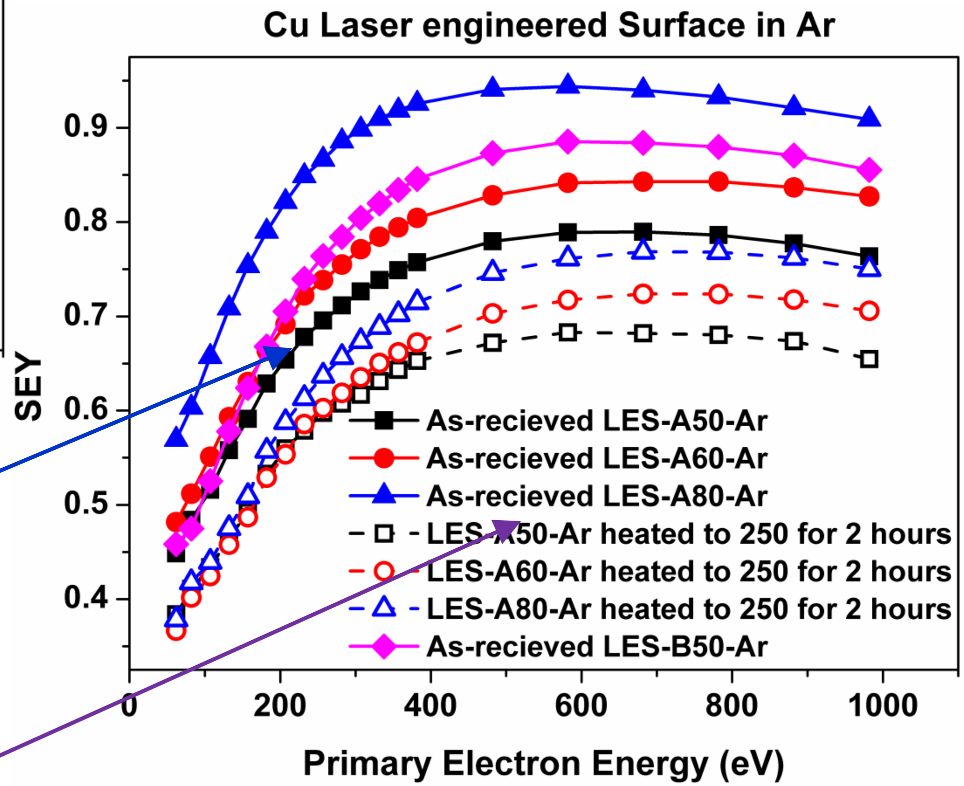


The latest results: Cu



$\delta < 0.82$ as-received

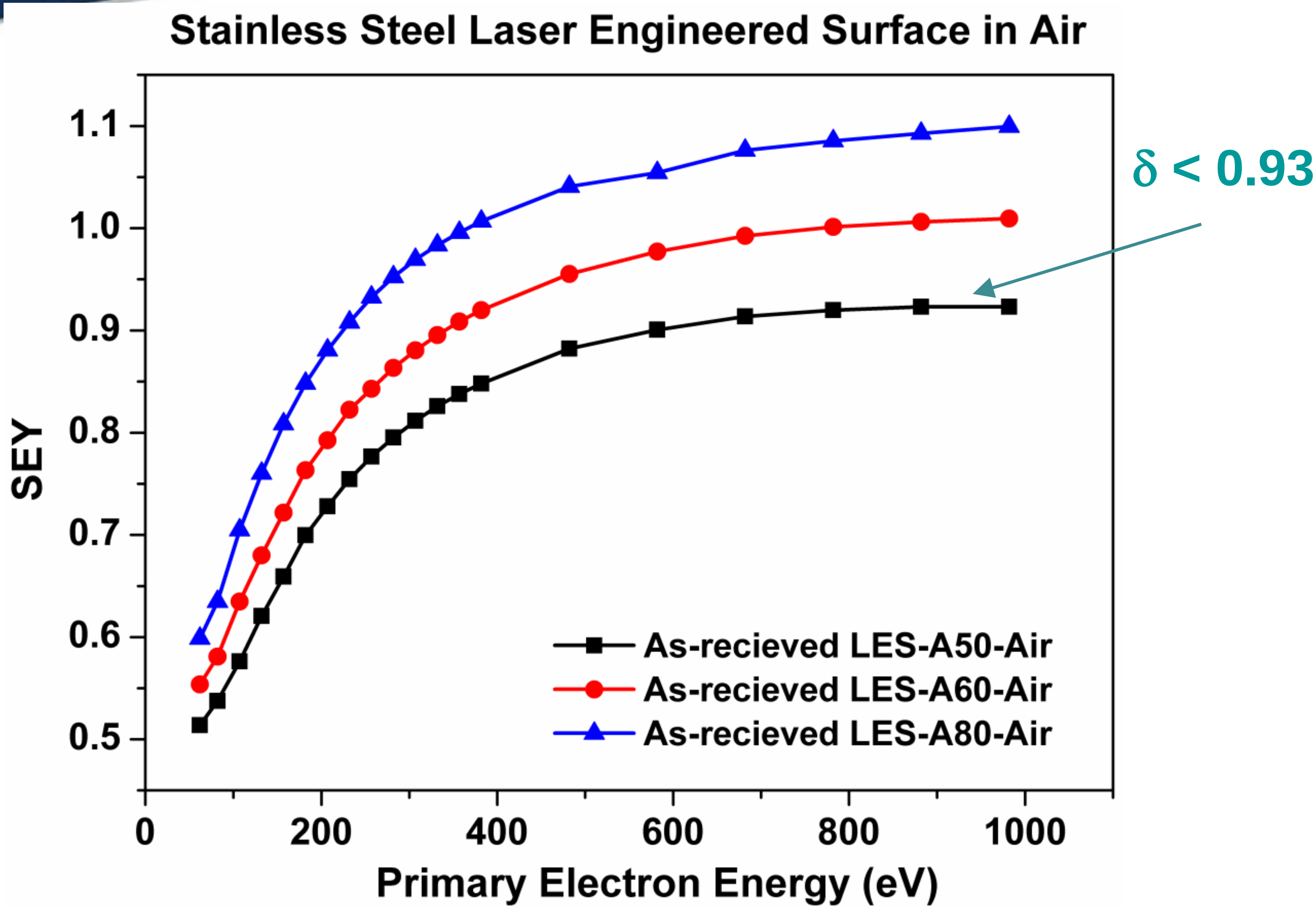
$\delta < 0.55$ after 2h bake



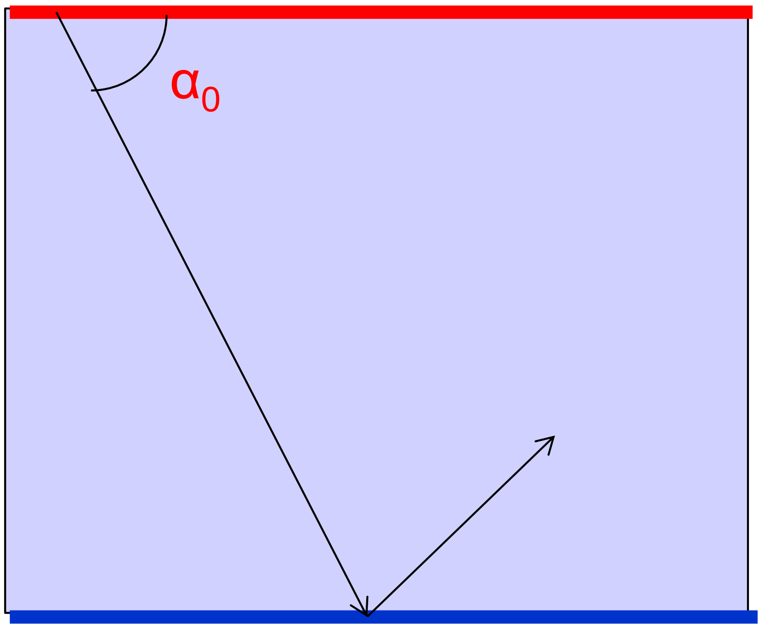
$\delta < 0.82$ as-received

$\delta < 0.65$ after 2h bake

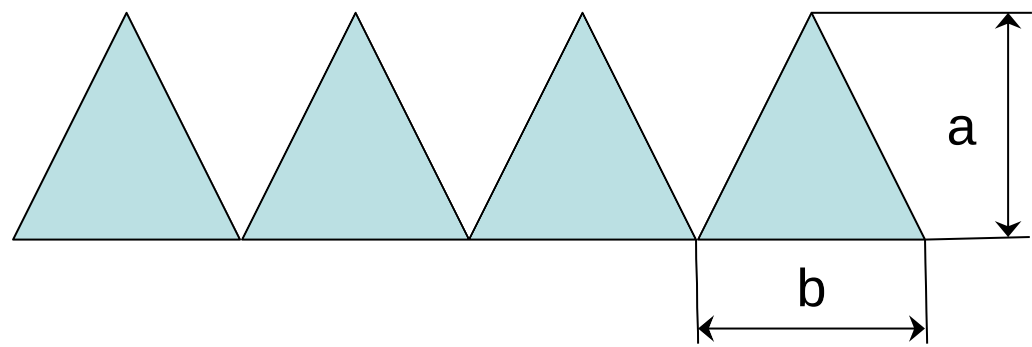
The latest results: 304L



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 α_0 = 90° and α_0 = 45°



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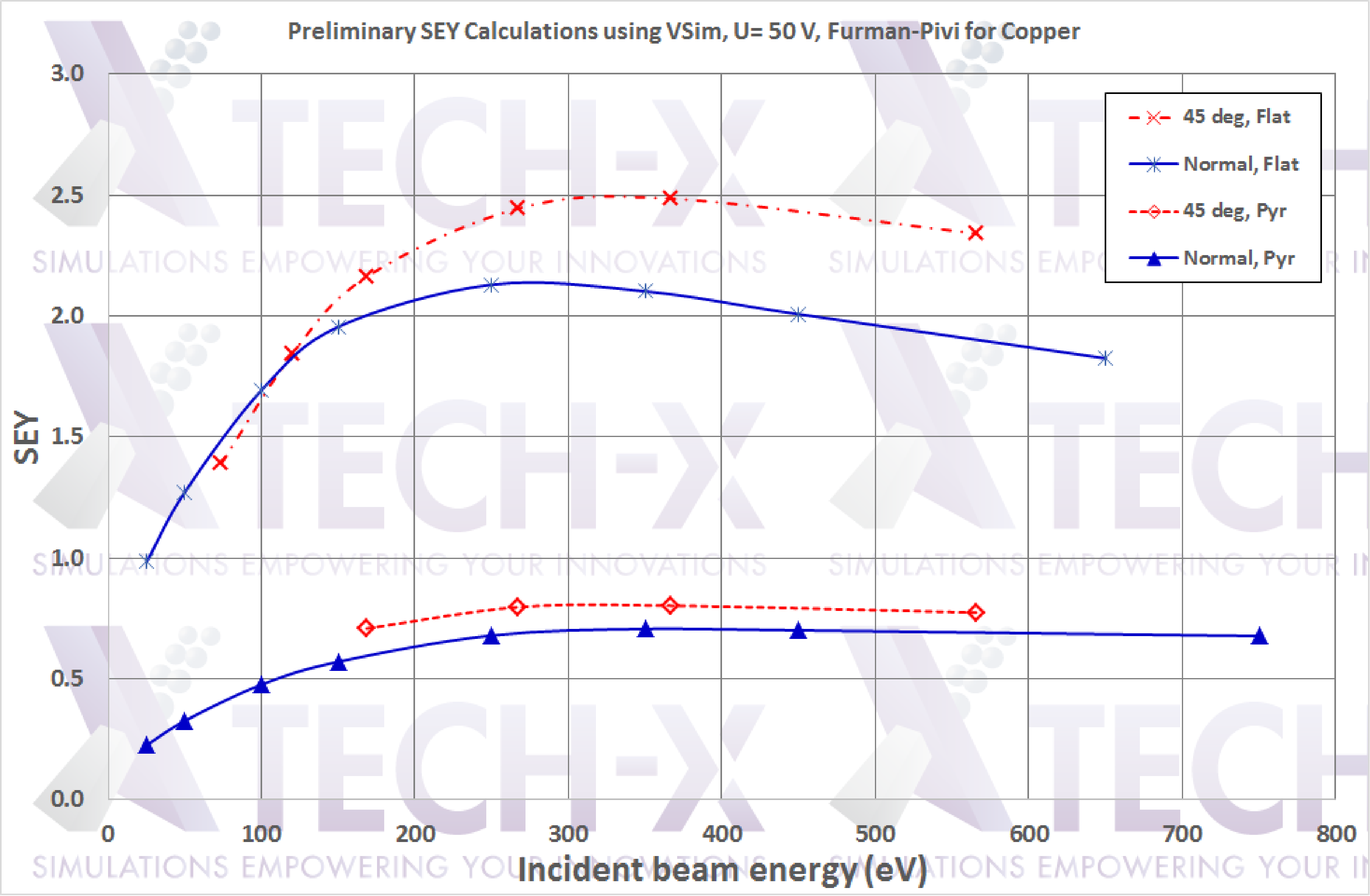
Modelling: Effect of initial angle α_0



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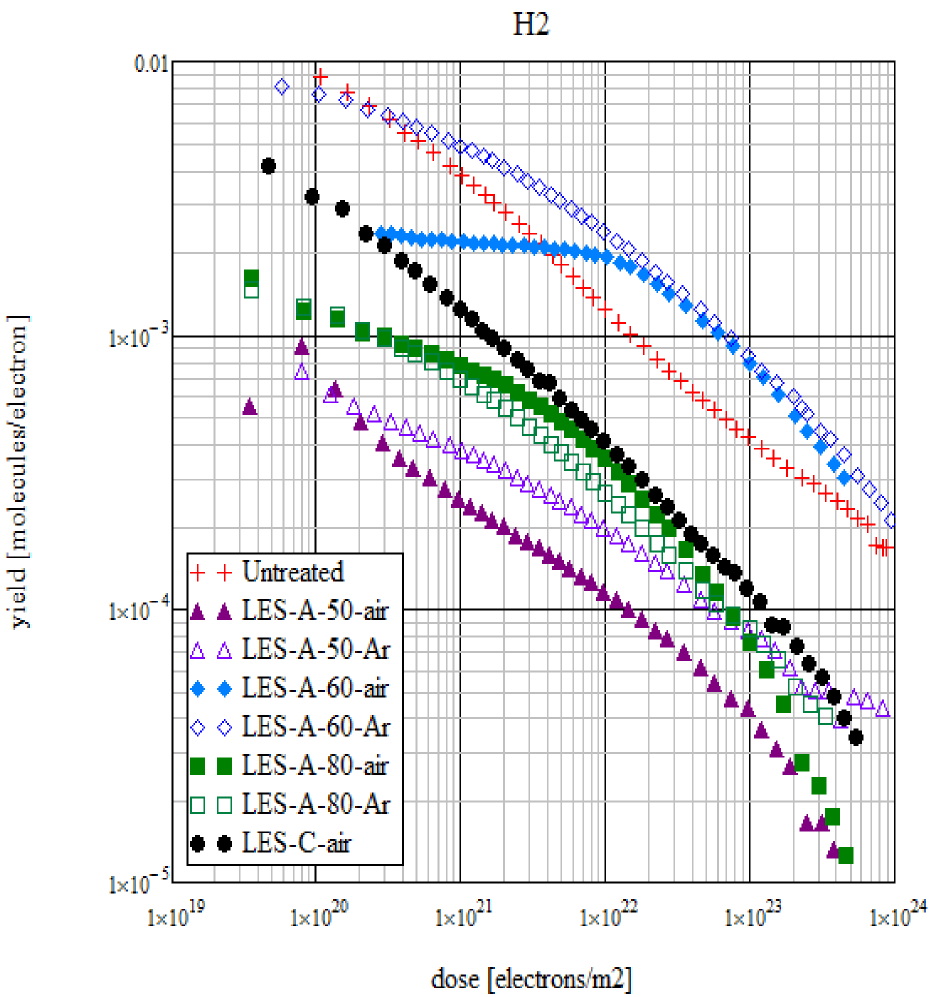
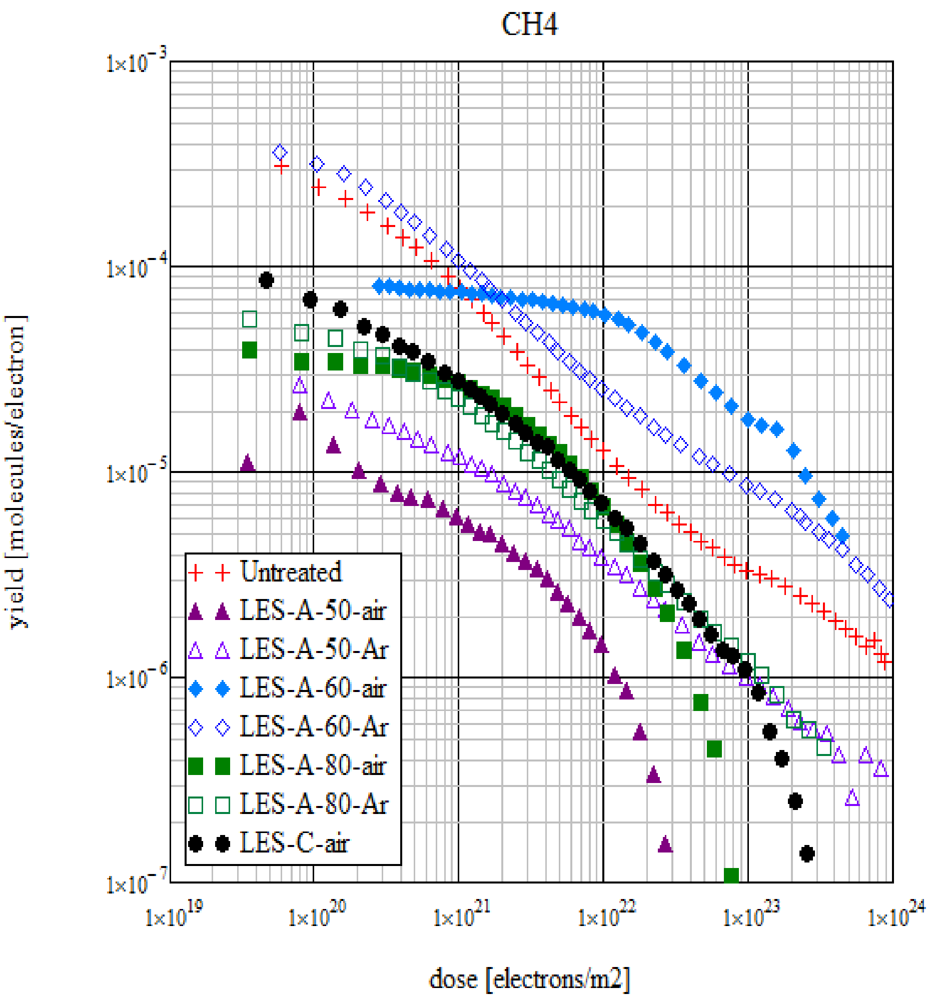
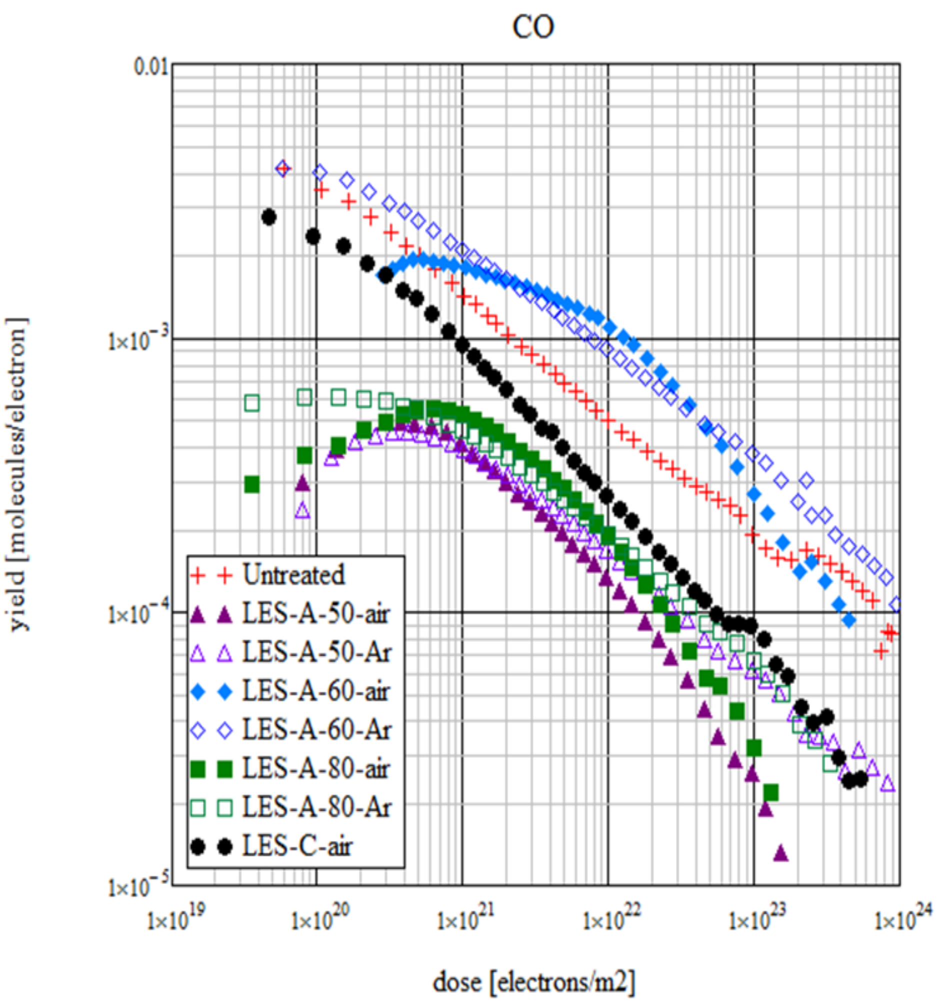
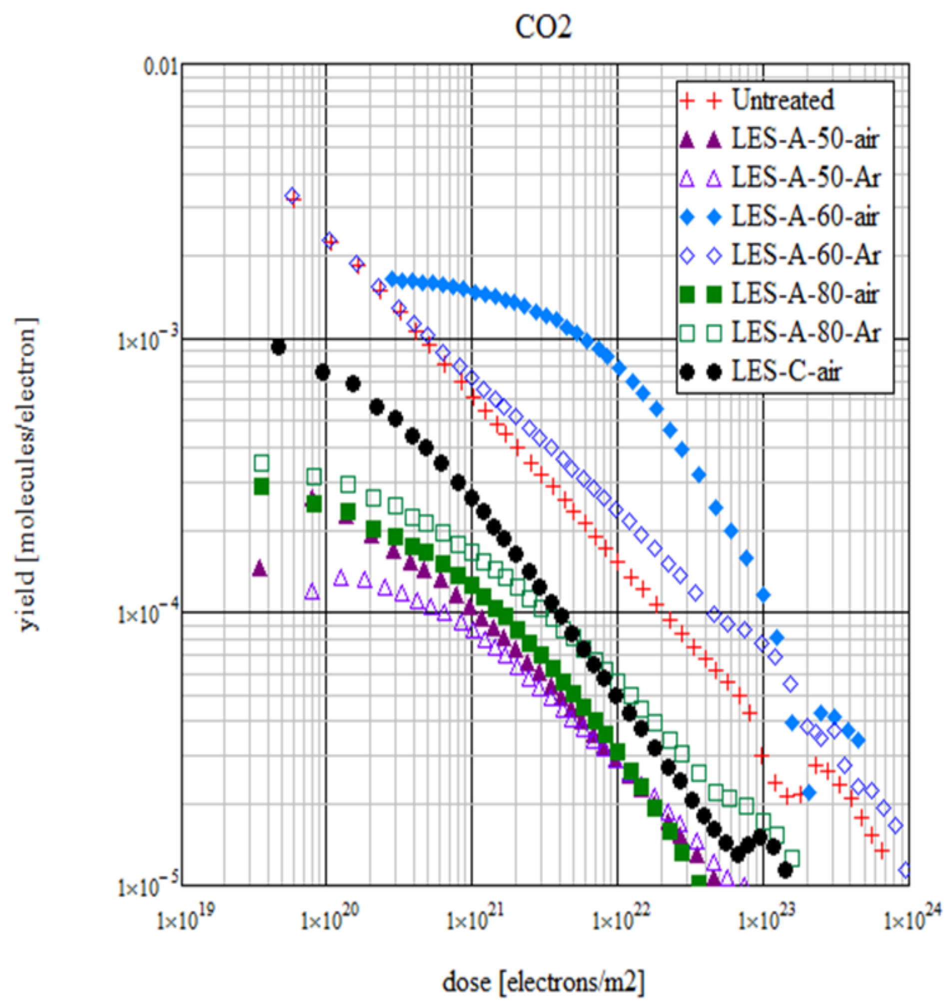
ESD: H_2 and CH_4





ESD: CO and CO_2





Electron Stimulated and Thermal Desorption

- Main results:
  - ESD results demonstrate that LESS does not compromise dinamic vacuum
  - Also, no difference was observed in thermal outgassing

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
- SEY in a strong magnetic field B = 1 T
- SEY at cryogenic temperatures

- Photo-electron emission yield (PEY)
  - PEY in a magnetic field
  - PEY at cryogenic temperatures
    - 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
  - Laser treatment in air lead to lower ESD yields and in Ar
- **Surface resistance**
  - 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 vacuum chamber.
- The blackening process can be 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

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The main conclusion

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

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