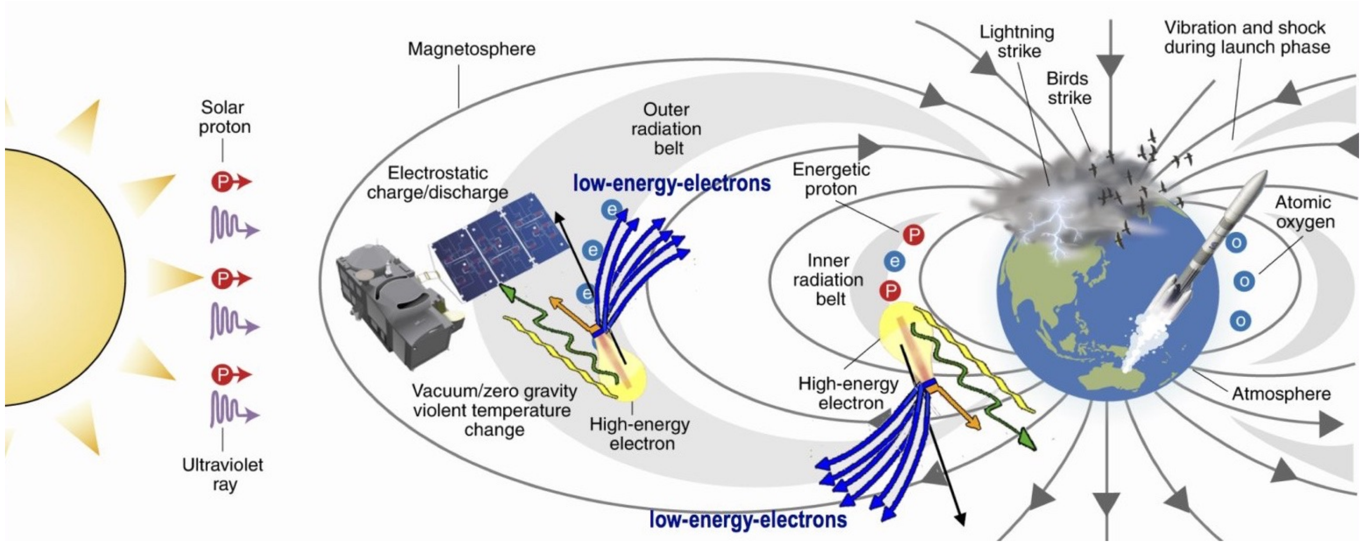
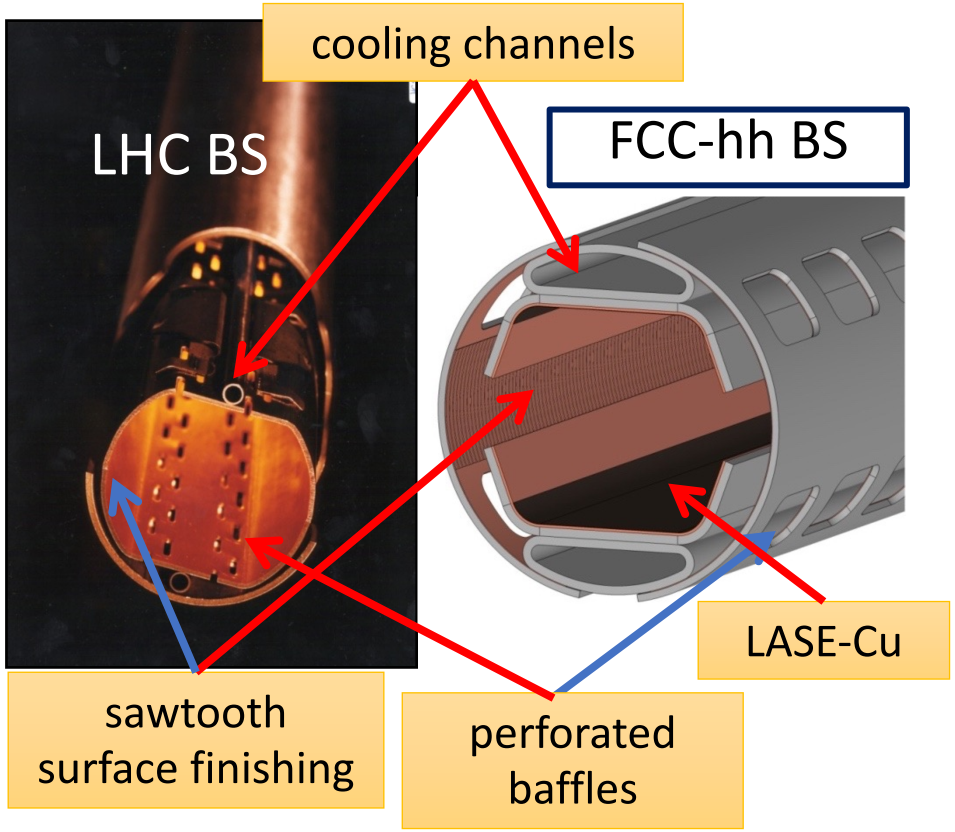
Low Energy Electrons relevance in accelerator technology

Marco Angelucci, Luisa Spallino, Roberto Cimino



LEE2022
A brainstorming meeting on relevance of Low Energy Electrons in aerospace
(Tuesday, November 15th 2022)
Organized by *Stefano Iacobucci* & *Giovanni Stefani* (ISM-CNR)

Introduction



- **Low temperature**
  (LHC beam screen T~5-20 K)
- **UHV (P <10^{-11} mbar)**
- **Different Surface characteristics**

Introduction

Residual Gas ionization

Phoelectrons from synchrotron radiation

Desorption from losses on the wall

Generation of electrons inside vacuum chamber

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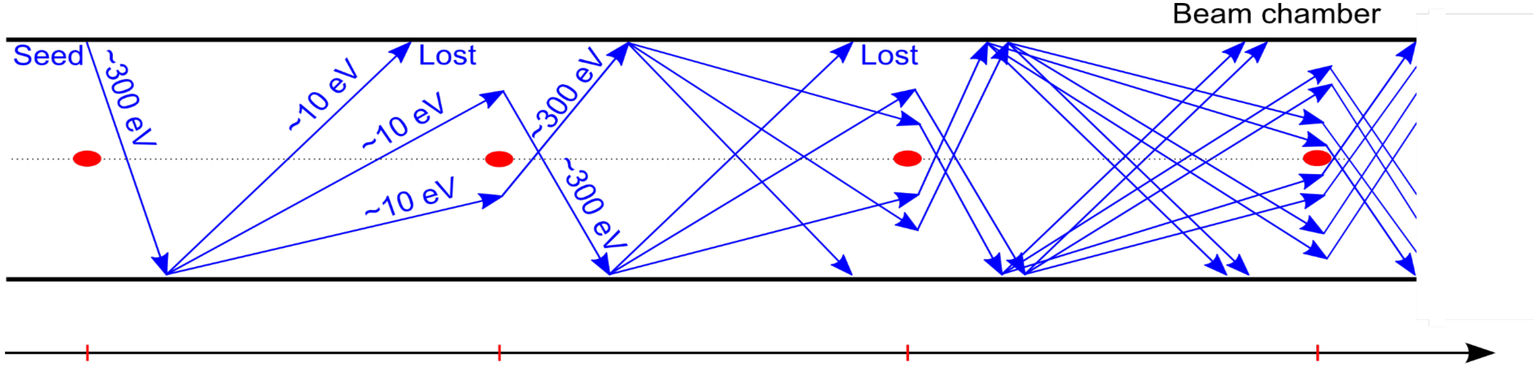
Desorption from losses on the wall

Generation of electrons inside vacuum chamber

1. Interaction of primary electrons with the beam
2. Acceleration of primary electrons
3. Production of Secondary electrons when hit the wall



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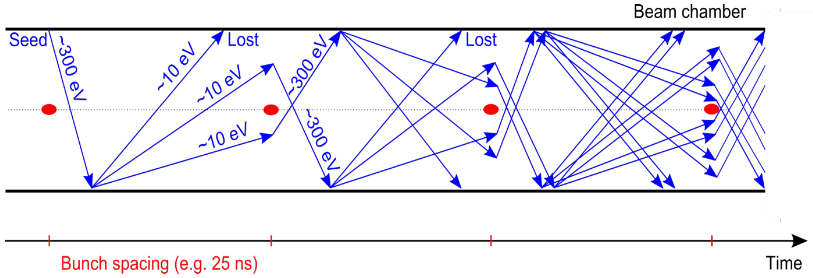
Desorption from losses on the wall



Generation of electrons inside vacuum chamber

1. Interaction of primary electrons with the beam
2. Acceleration of primary electrons
3. Production of Secondary electrons when hit the wall

Electrons multiplication

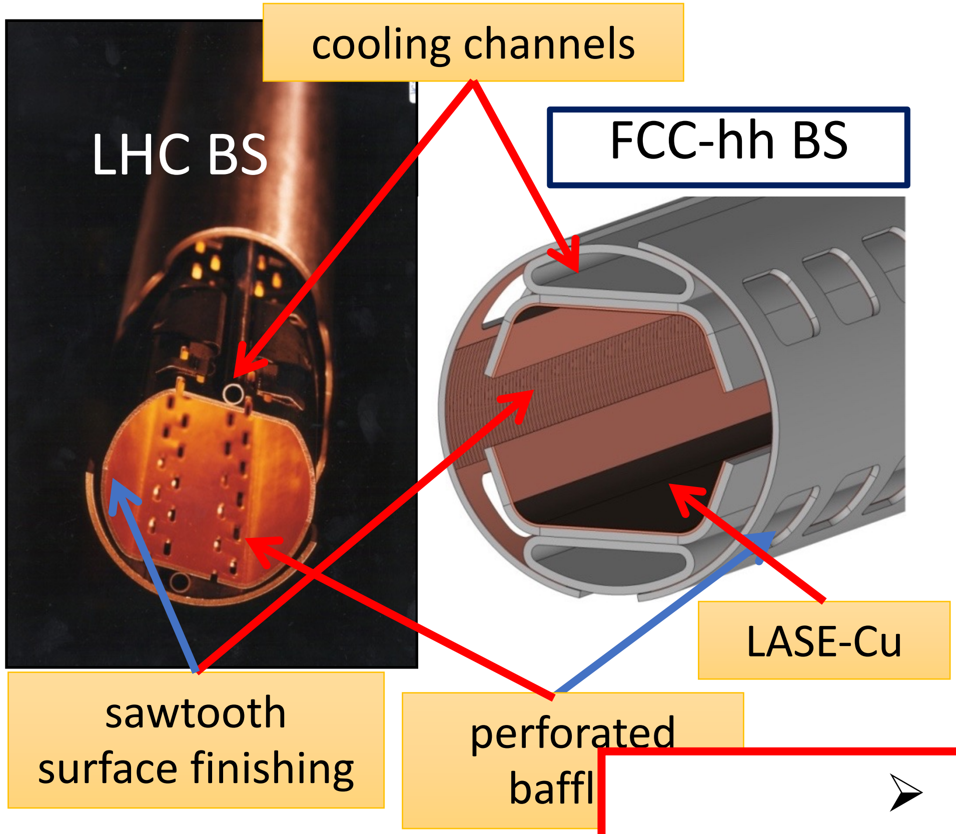
Electron Cloud

Introduction

The presence of an e-cloud inside an accelerator ring is revealed by several **typical signatures**

- ✓ Fast pressure rise, outgassing
- ✓ Additional heat load (LHC has cold Dipoles)
- ✓ Baseline shift of the pick-up electrode signal
- ✓ Tune shift along the bunch train
- ✓ Coherent instability
  - Single bunch effect affecting the last bunches of a train
  - Coupled bunch effect
- ✓ Beam size blow-up and emittance growth
- ✓ Luminosity loss in colliders
- ✓ Energy loss measured through the synchronous phase shift
- ✓ Active monitoring: signal on dedicated electron detectors (e.g. strip monitors) and retarding field analyzers

Introduction



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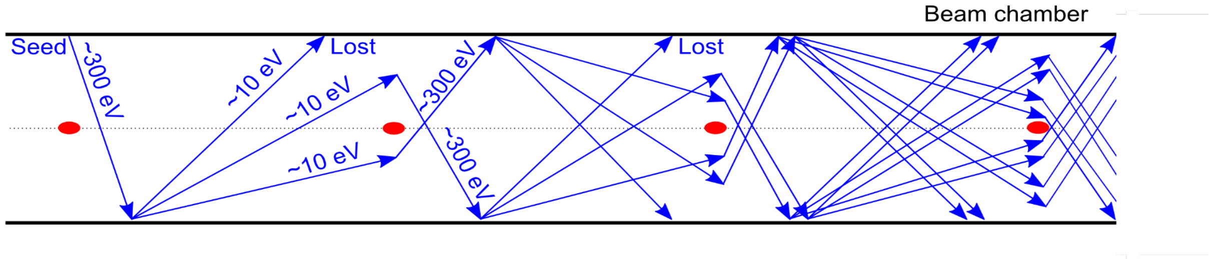
- **UHV (P <10^{-11} mbar)**
- **Different Surface characteristics**

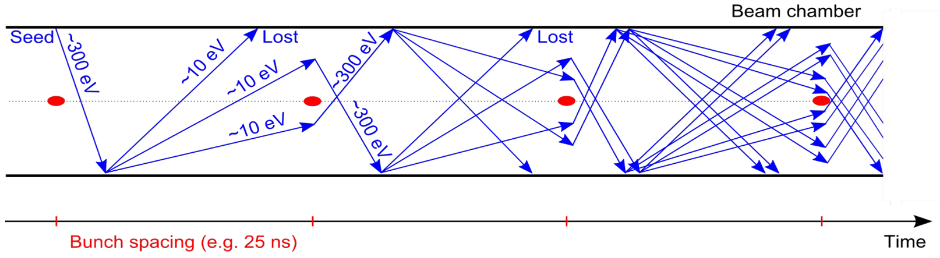


- **Mitigation of electron emission from surface (SEY<1)**
- **Understanding the variation of electron emission under extreme condition**
- **Accurate prediction of SEY to simulate the operate conditions**

Introduction

- Mitigation of electron emission from surface (SEY<1)
- Understanding the variation of electron emission under extreme condition
- Accurate prediction of SEY to simulate the operate conditions

- Engineering new materials/surface
- Accurate studies of SEY and its correlation with surface properties
- Develop more accurate analytical method



Outline

SEY of Metal surfaces

- Difference between “As Received” and atomically Clean Metals

SEY variation induced by Surface modifications

- Morphology
- Defects
- Chemical state variations (interactions with photons and electrons)

SEY variation induced by Overlayers

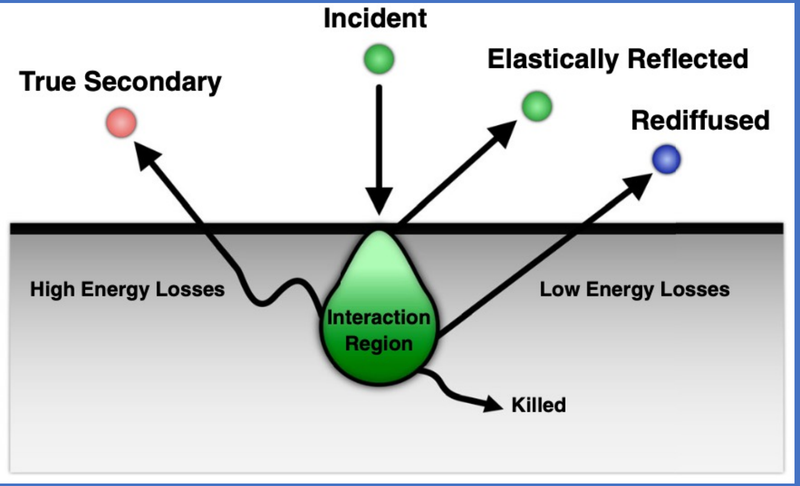
- Coatings
- Contaminants (Low Temperature)

SEY and EDC

- Correlation between SEY and surface properties

Introduction

Secondary Electron Emission

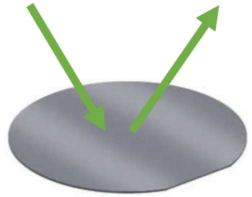


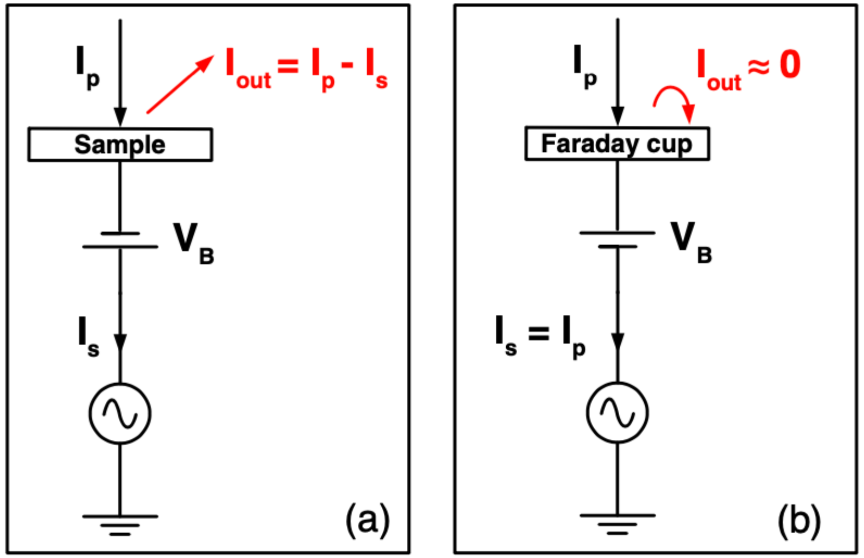
Three-step process:

- Production of SE at a depth *z*
- Transport of the SE toward the surface
- Emission of SE across the surface barrier

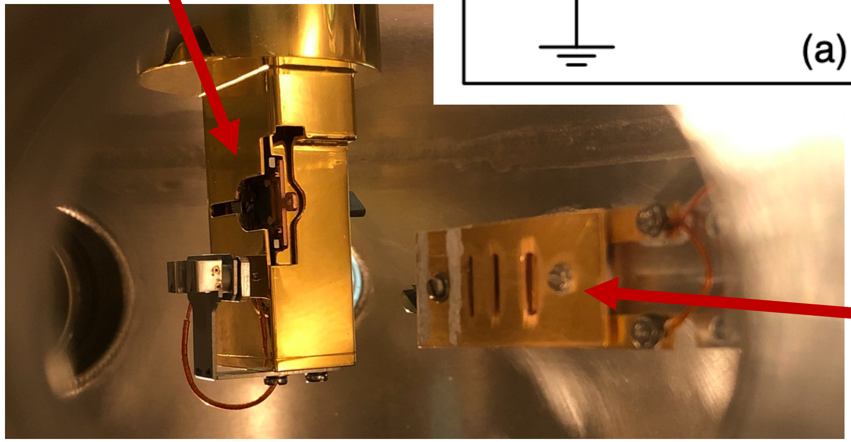
Incident electrons current (I_p)

Emitted electrons current (I_{out})



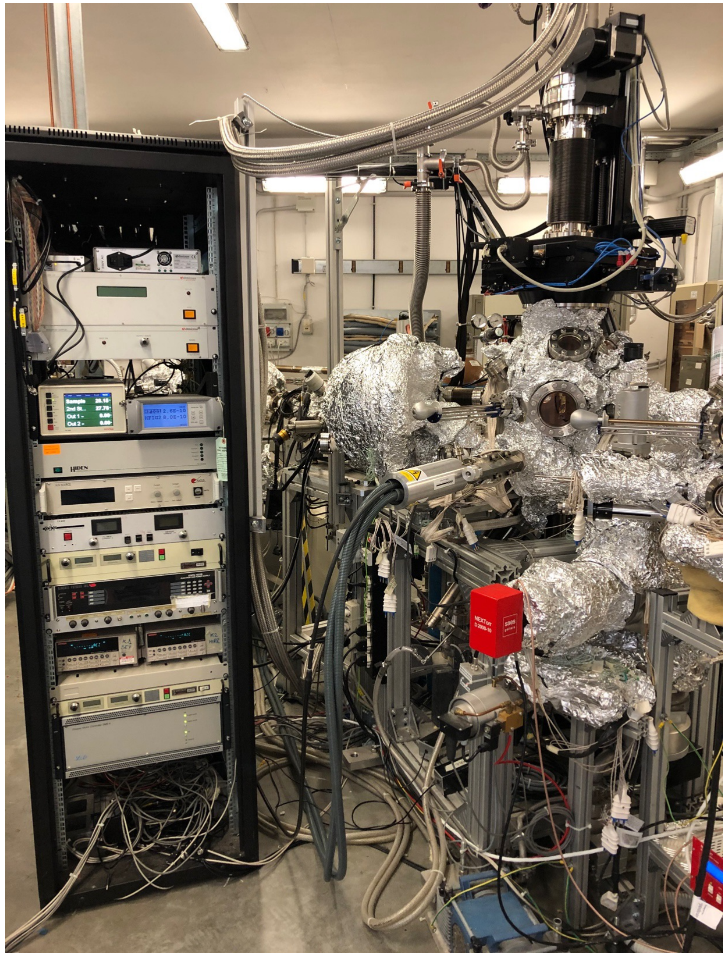


Sample



Faraday cup

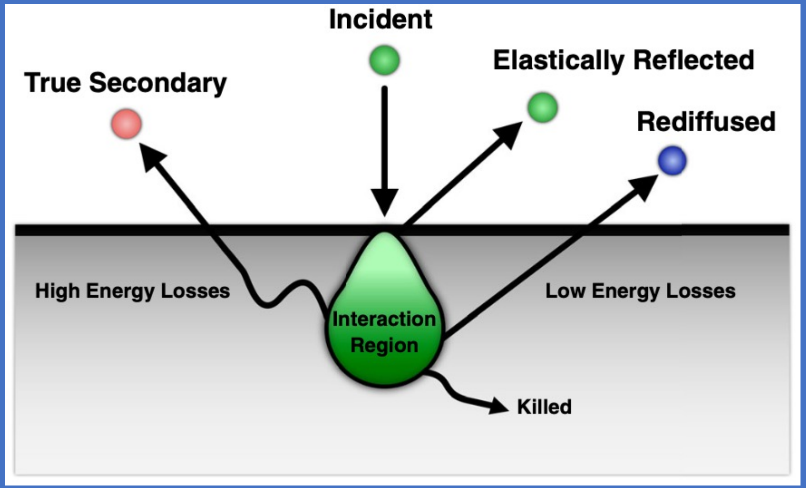
Experimental stations at XUV MaSSLab - INFN



- **HE Chamber:**
  - XPS set-up (Al and Ag monocromatic and Al and Mg nonmonocromatic sources)
  - Electron gun and flood gun
  - Quadrupole Mass Spectrometer

Introduction

Secondary Electron Emission



Three-step process:

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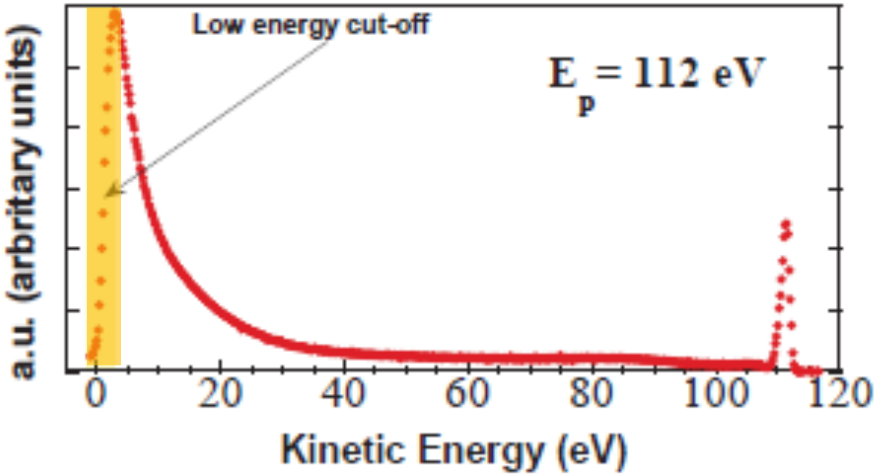
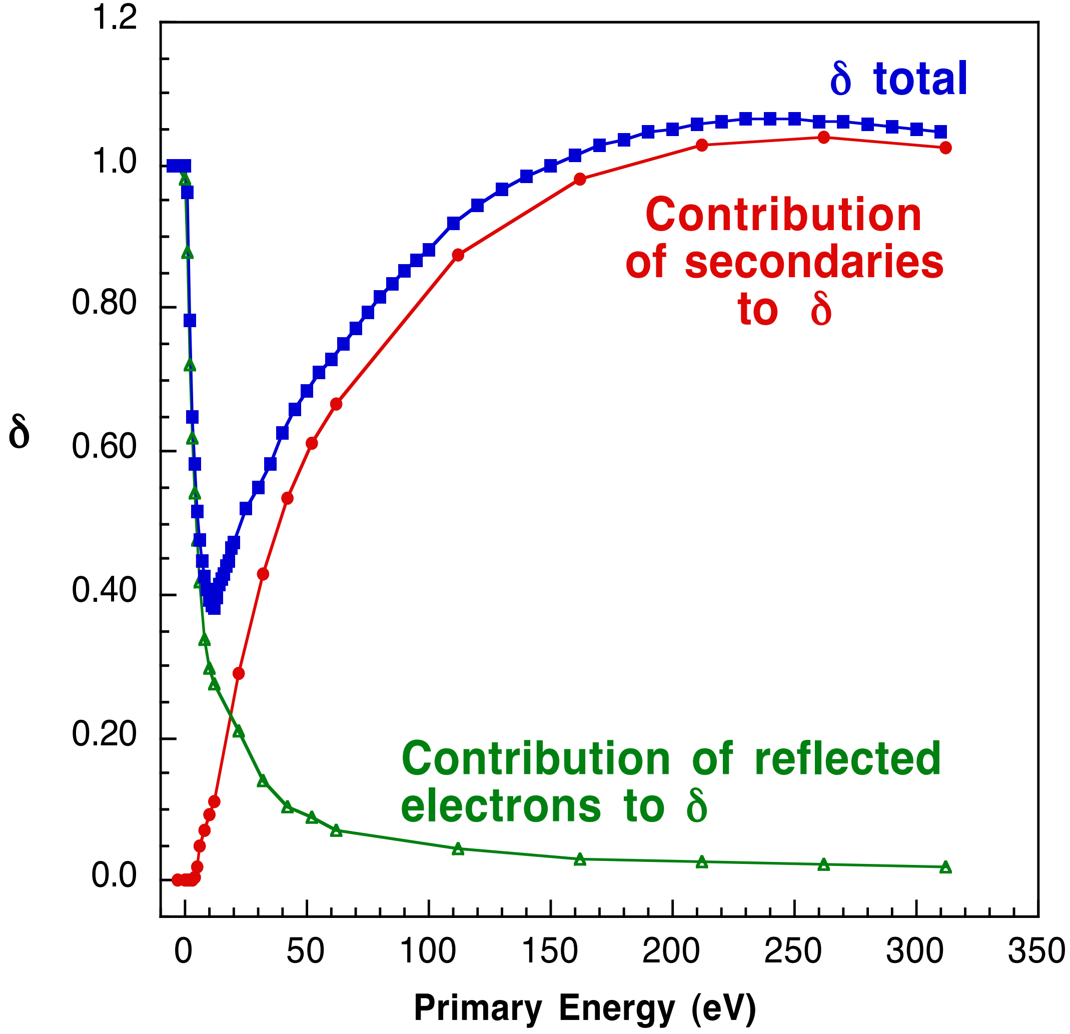
Surface conditions influence SEY measurements



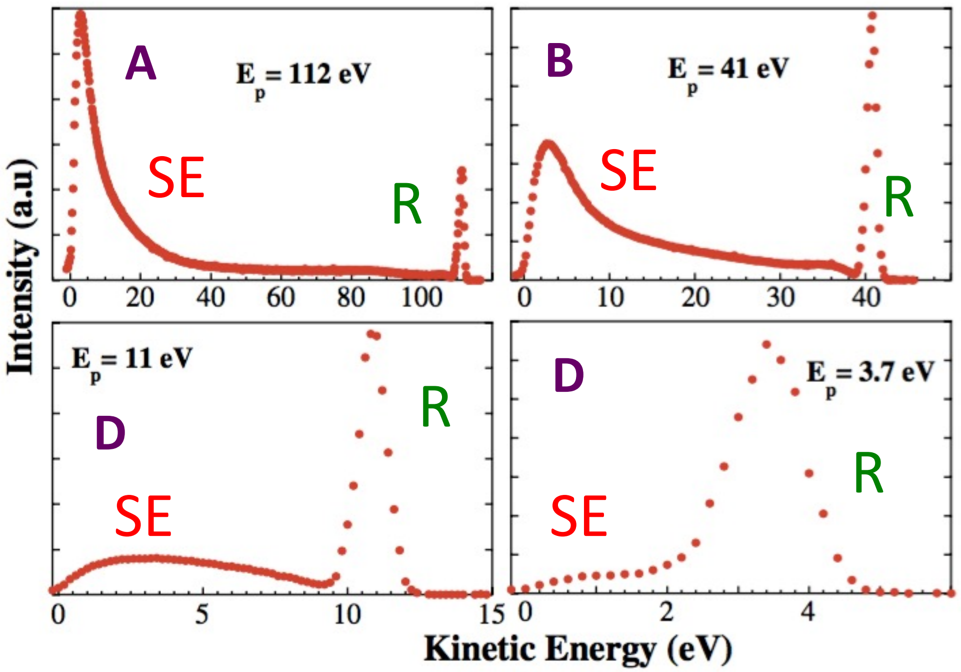
R. Cimino & T. Demma, Int. J. Mod. Phys. A (2014)

Energy Distribution Curve (EDC) of the electrons produced by a 112 eV primary energy electron beam impinging on a Cu technical surface

SEY OF MATERIALS



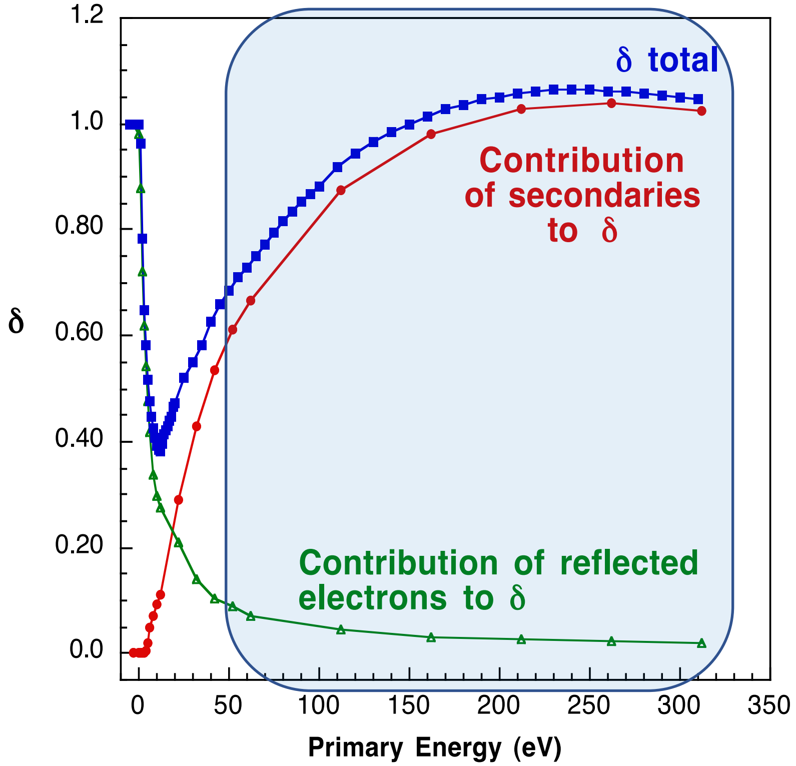
Energy Distribution Curves at different Primary Energy



Cimino et al., PRL 93 (2004)

SEY OF MATERIALS

Cimino et al., PRL 93 (2004)



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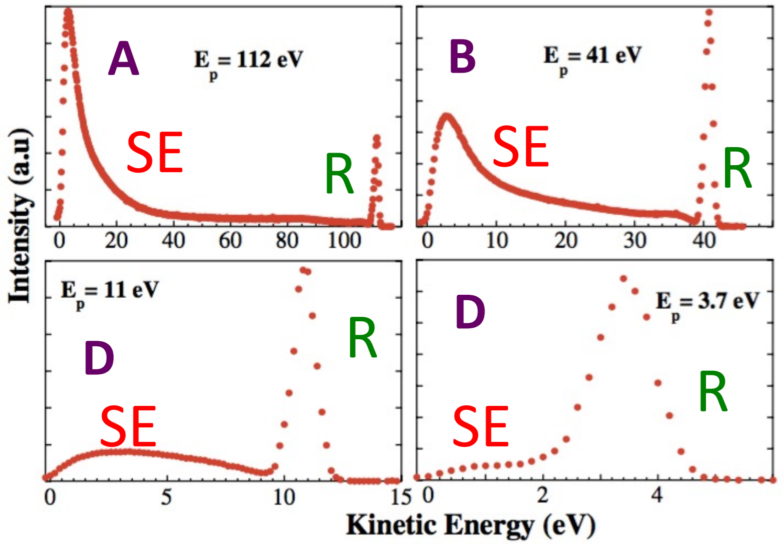
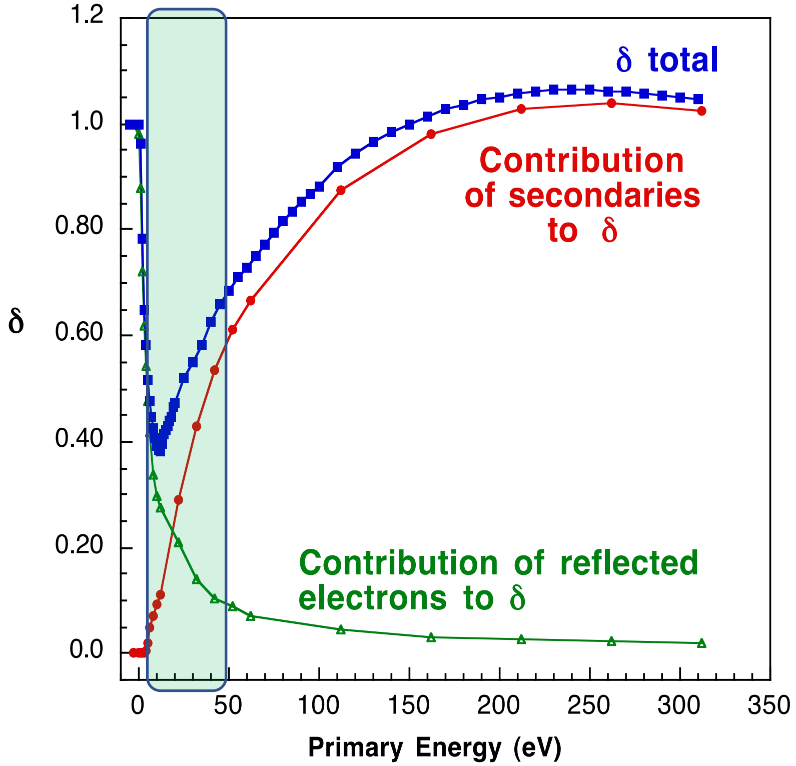


High-Energy Range → Total amount of emitted secondary electrons → Sensitive to thick layer

SEY OF MATERIALS

Cimino et al., PRL 93 (2004)



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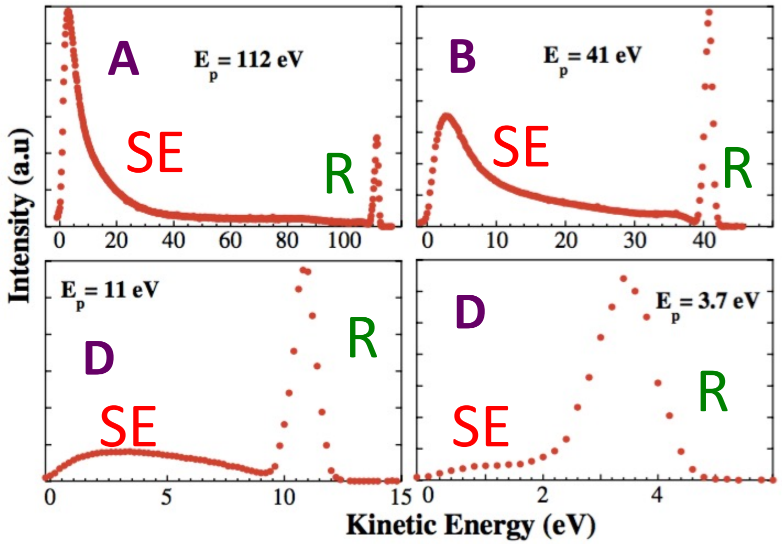

Low-Energy Range → Reflected electron component → Sensitive to surface variation

Outline

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- Coatings
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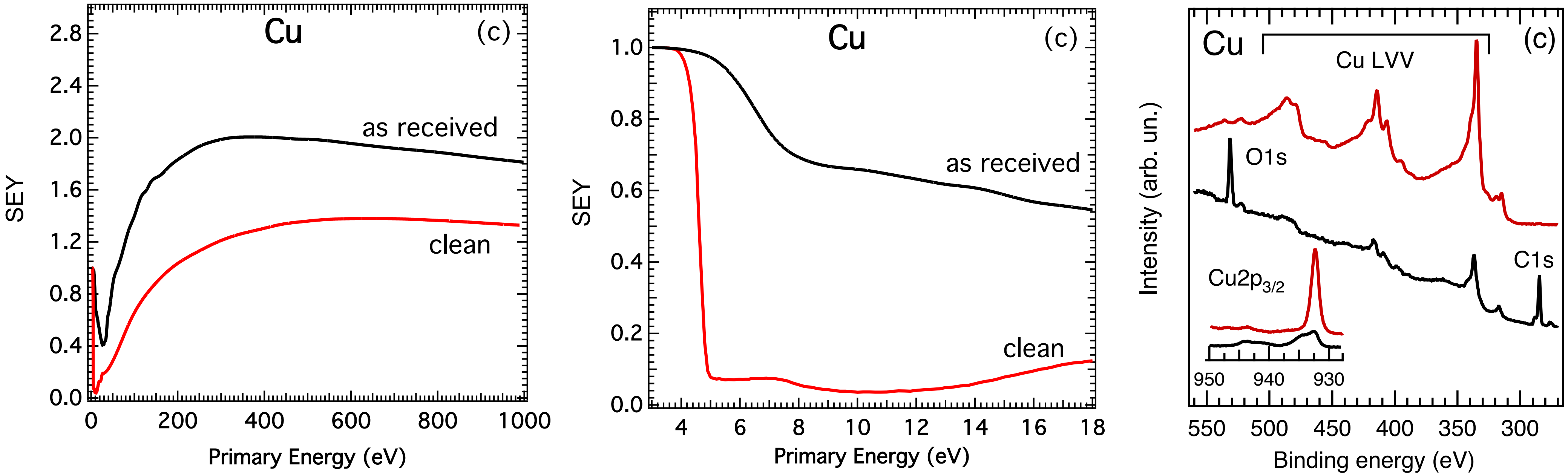
SEY and EDC

- Correlation between SEY and surface properties

SEY OF METAL SURFACES

Differences between “As Received” and Atomically Clean Metals



AIP Advances 7, 115203 (2017)

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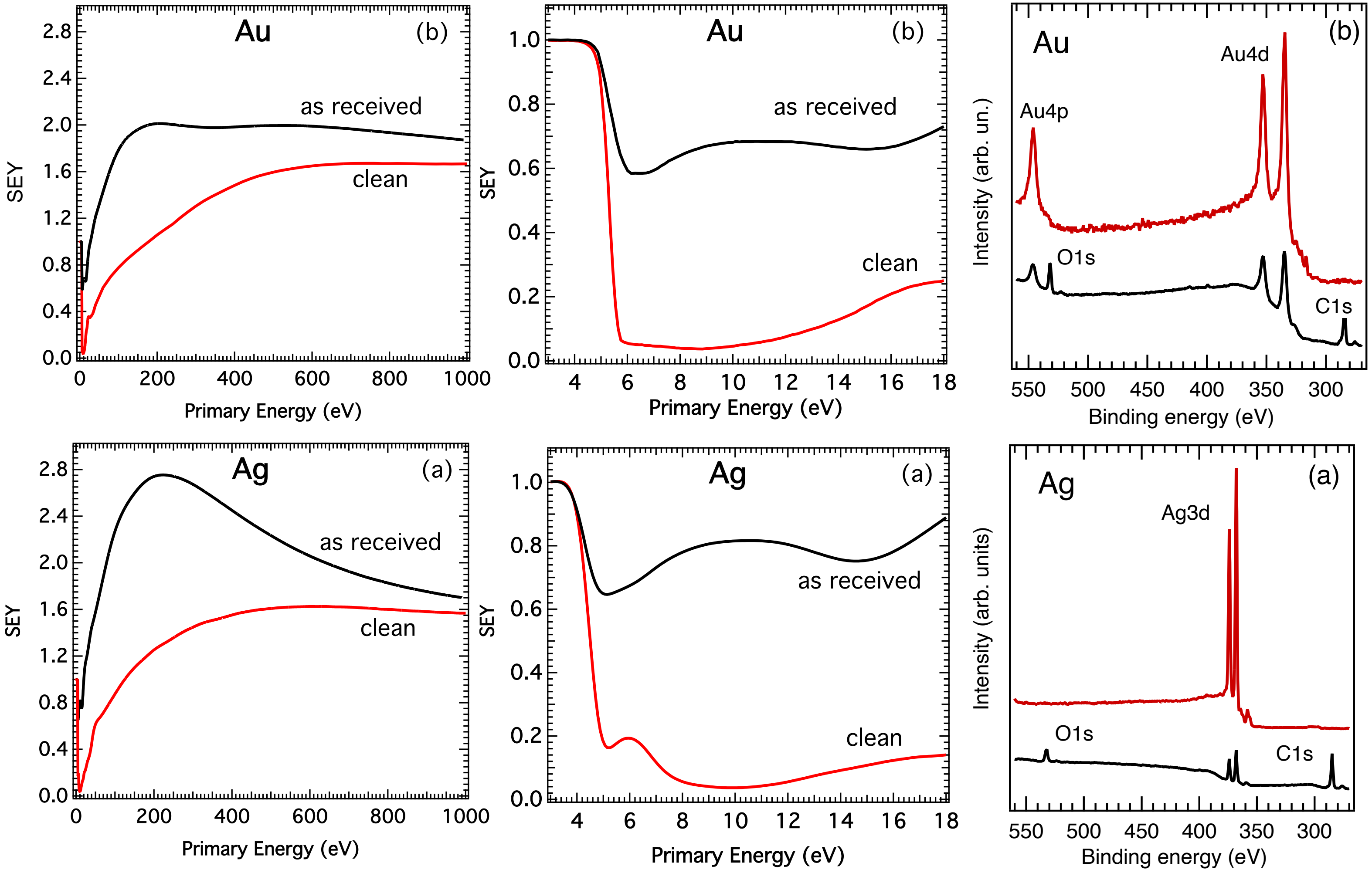

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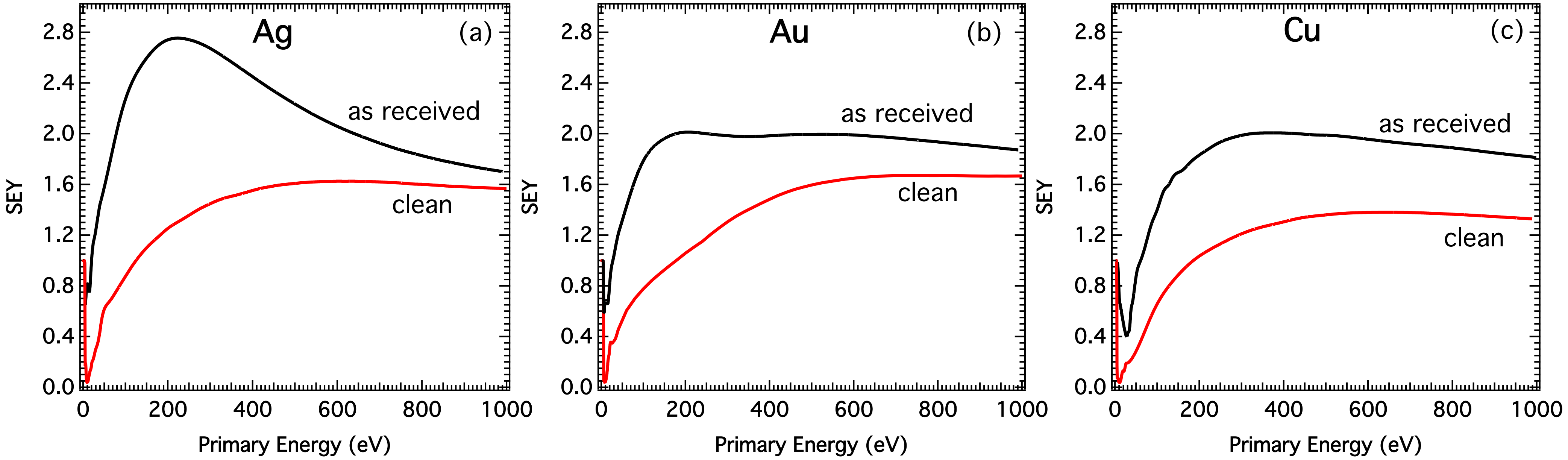


AIP Advances 7, 115203 (2017)

High-Energy SEY dependence

Contaminants (as received)

General High SEY

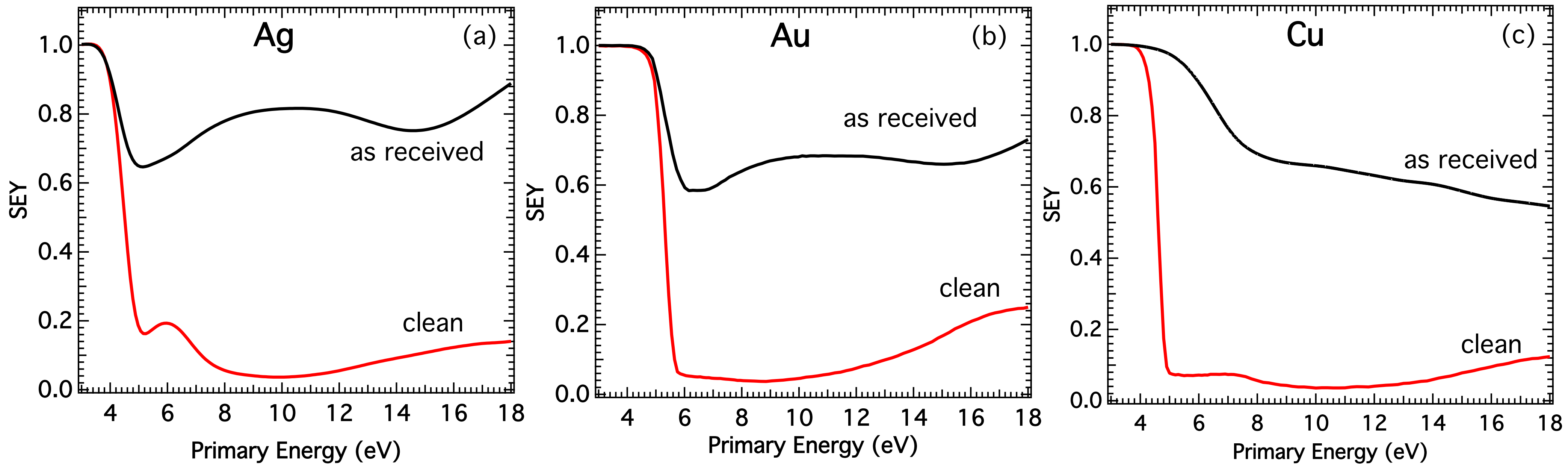
Materials (clean)

- Lower SEY
- Characteristic Curves

SEY OF METAL SURFACES

Differences between “As Received” and Atomically Clean Metals in the Low-Energy range

AIP Advances 7, 115203 (2017)



General Behaviour in all clean metals

Evaluation of Work Function

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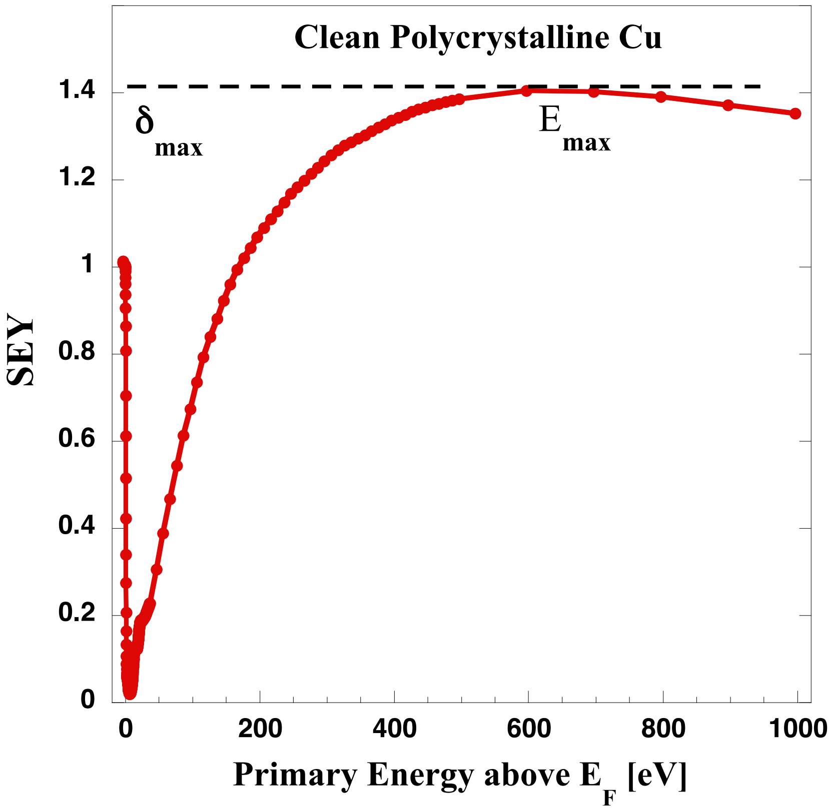
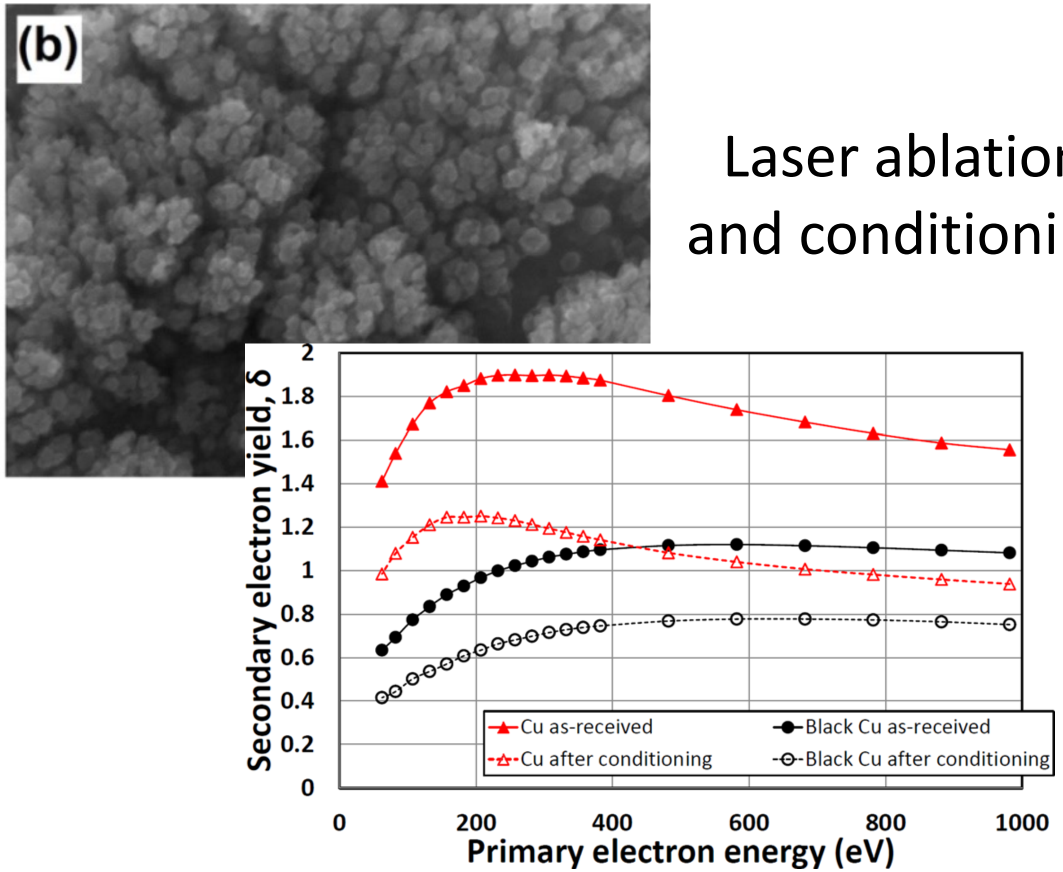
SEY VARIATION INDUCED BY SURFACE MODIFICATIONS (MORPHOLOGY)

Engineering the surface morphology



R. Cimino et al. PR ST (2015)

Morphological Changes



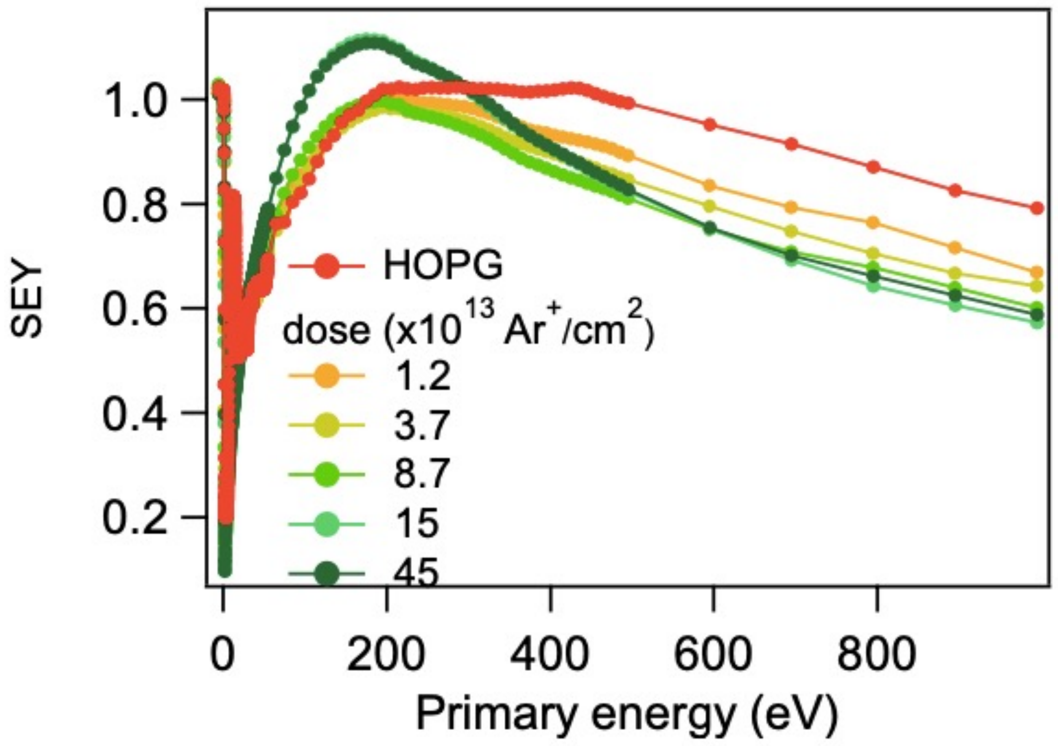
Laser ablation and conditioning

R. Valizadeh et al. , Appl. Phys. Lett. (2014)

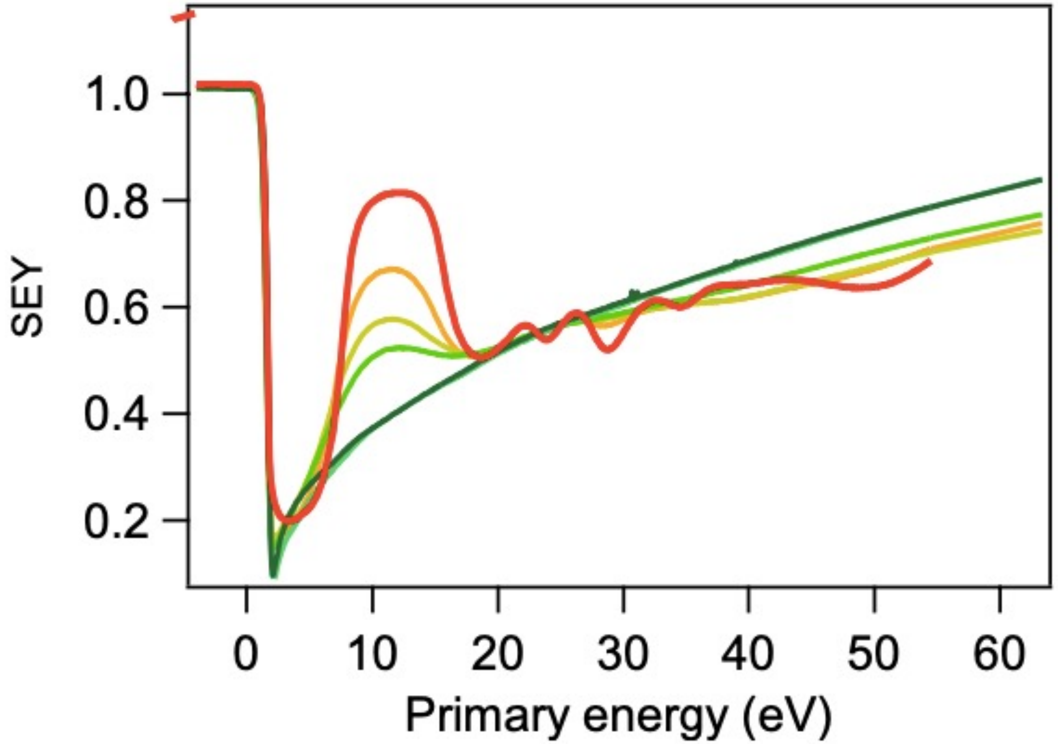
SEY VARIATION INDUCED BY SURFACE MODIFICATIONS (DEFECTS)

Modification of surface

Structural modification



Ar^{+} Sputtering

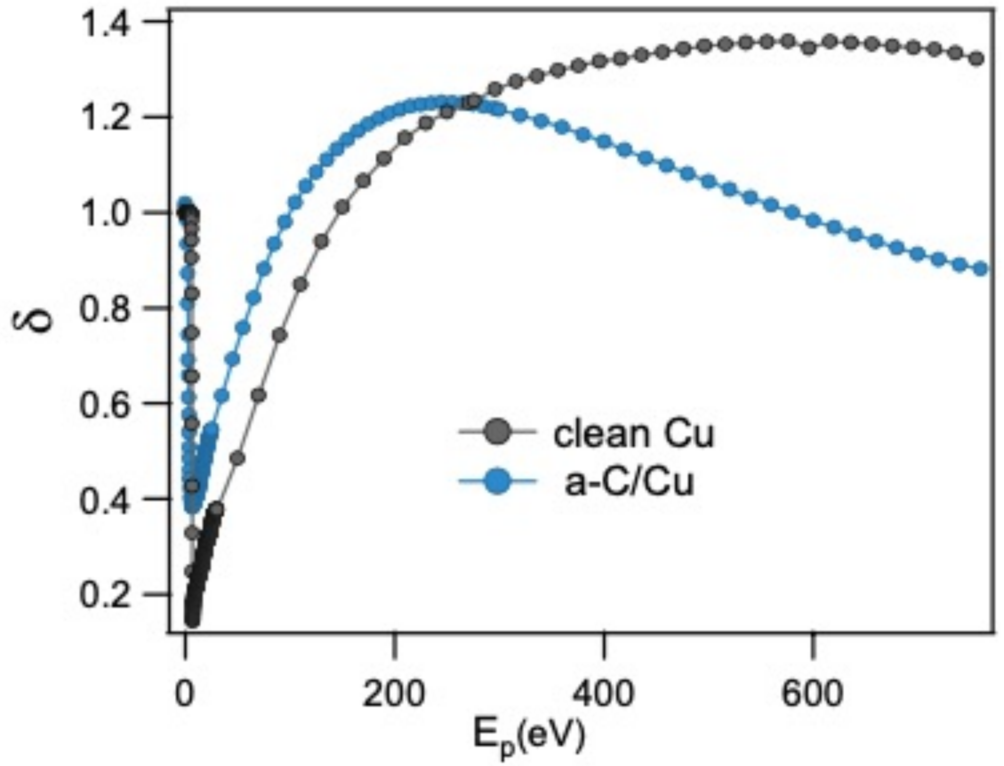


L.A. Gonzalez et al., AIP Adv. 6 (2016) 095117

SEY VARIATION INDUCED BY SURFACE MODIFICATIONS (CHEMICAL MODIFICATION)

Modification of surface

Chemical modification



R. Larciprete et al., Appl. Surf. Sci. (2015)

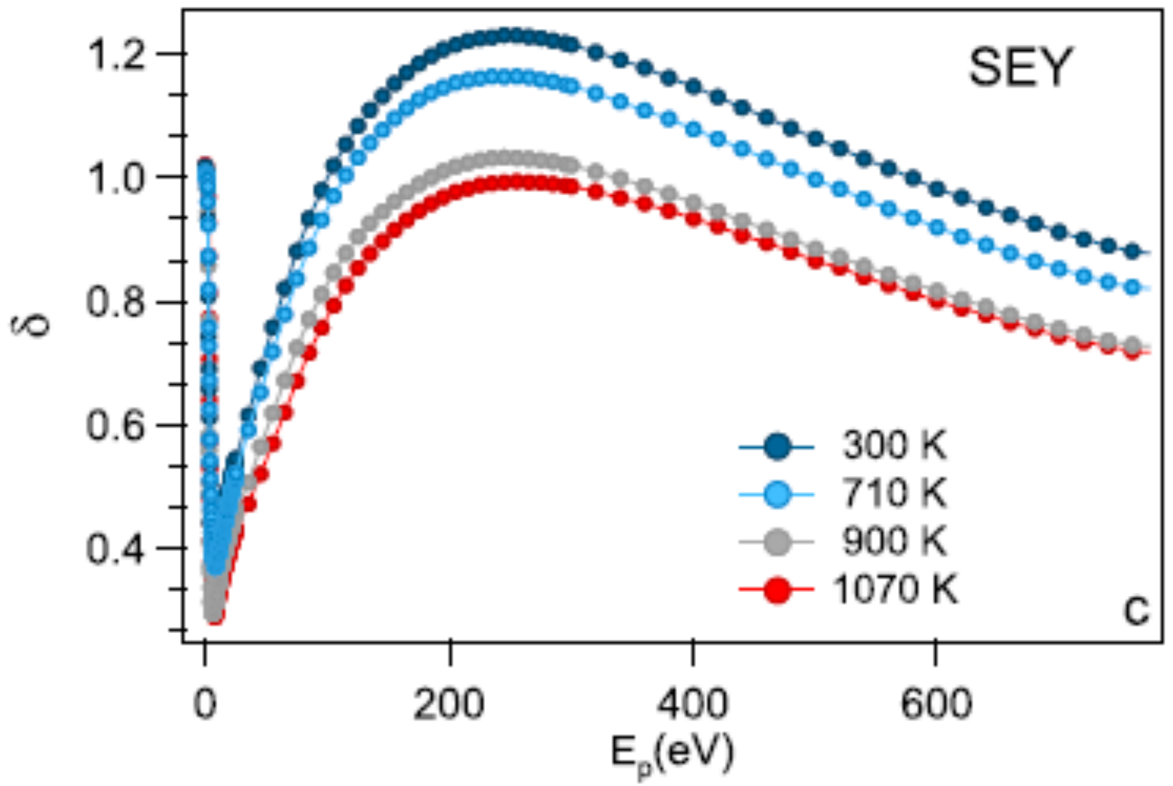
Amorphous C-coating

ultra high vacuum
RF magnetron sputtering 50W p(Ar) $6x10^{-2}$ mbar
a-C (~ 20 nm)/poly Cu

SEY VARIATION INDUCED BY SURFACE MODIFICATIONS (CHEMICAL MODIFICATION)

Modification of surface

Chemical modification



R. Larciprete et al., Appl. Surf. Sci. (2015)

Amorphous C-coating

Thermal graphitization of thin amorphous C layers deposited by magnetron sputtering on Cu substrates

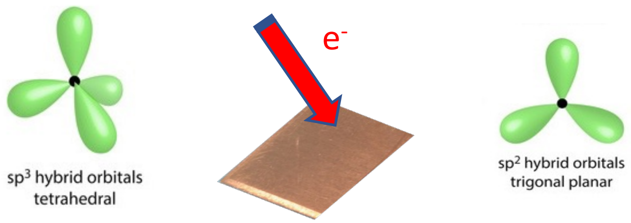
SEY VARIATION INDUCED BY SURFACE MODIFICATIONS

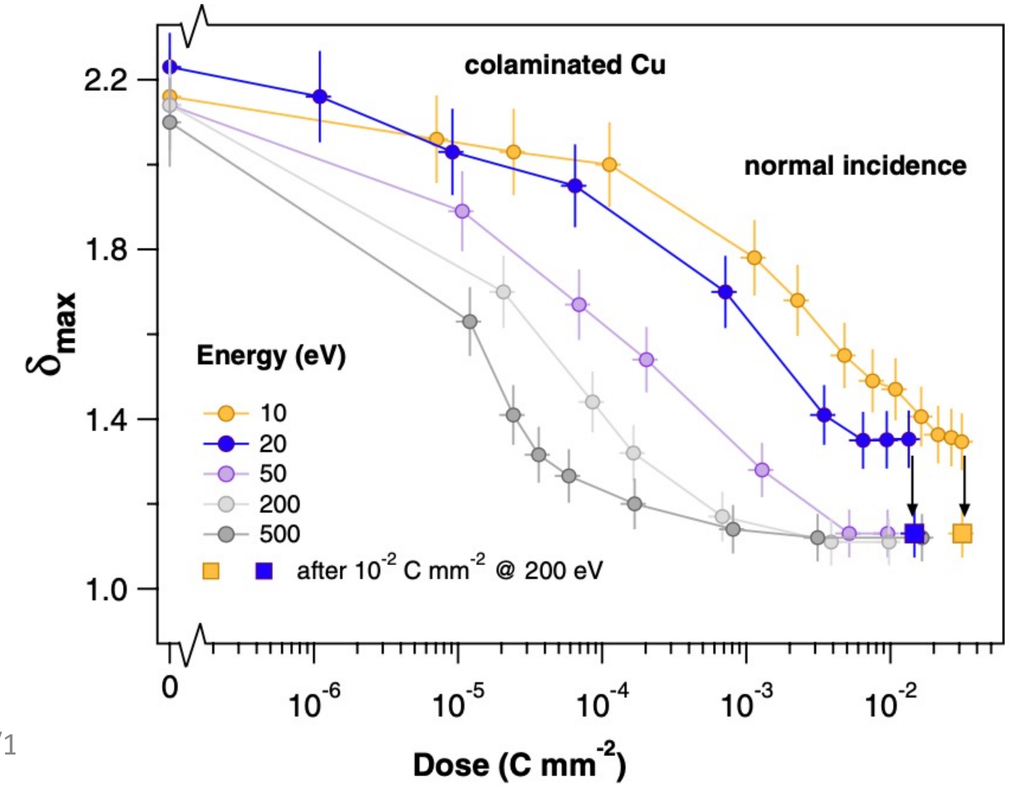
Chemical variation induced by electron irradiation

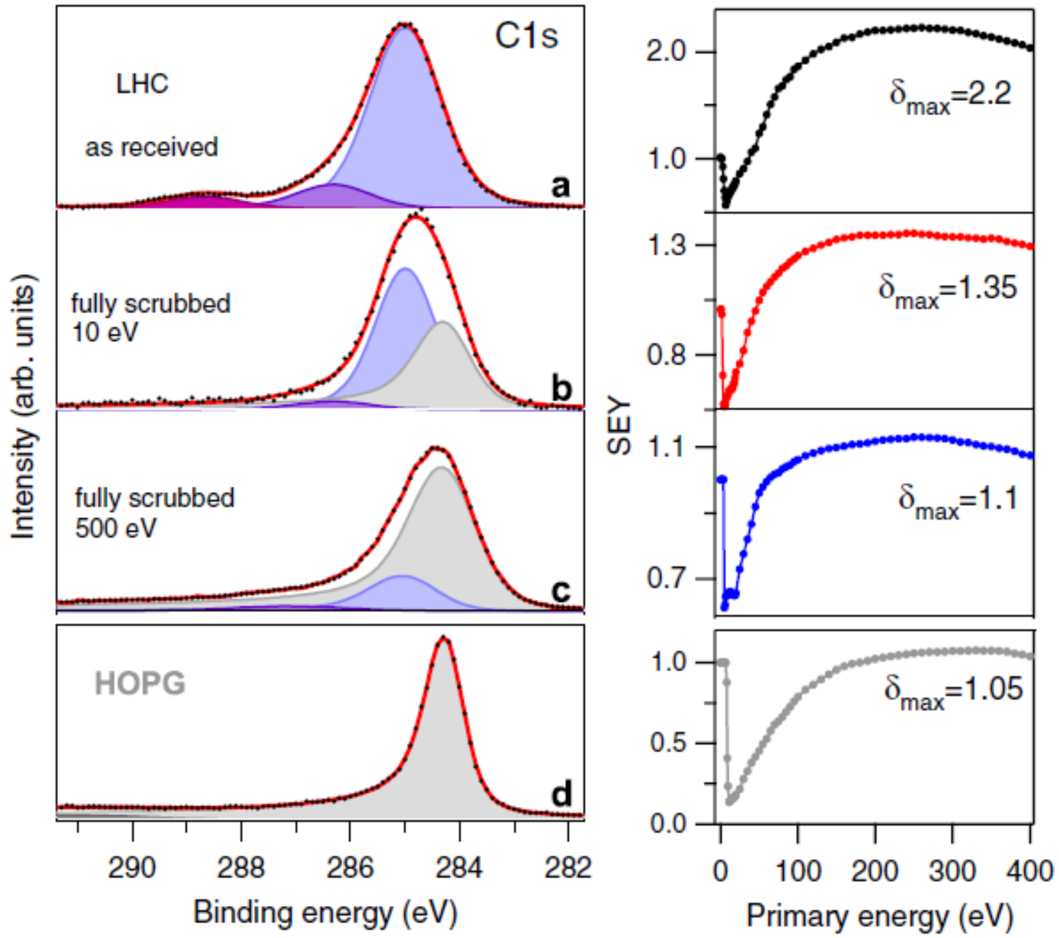
Copper

$sp^3 \rightarrow sp^2$ carbon surface contamination conversion

- **SEY depends on the surface chemical state**







R. Cimino et al., Phys. Rev. Lett. (2012)

SEY VARIATION INDUCED BY SURFACE MODIFICATIONS

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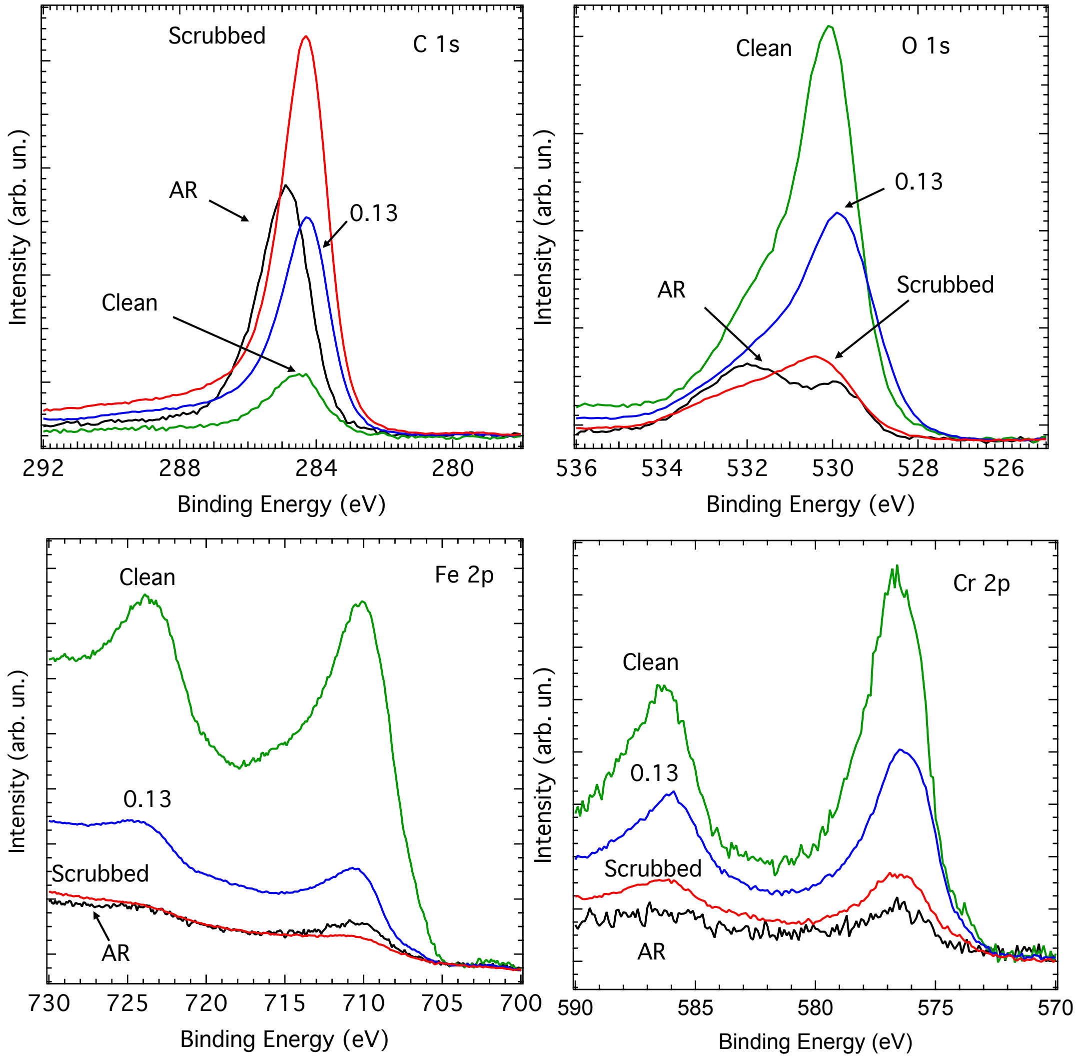
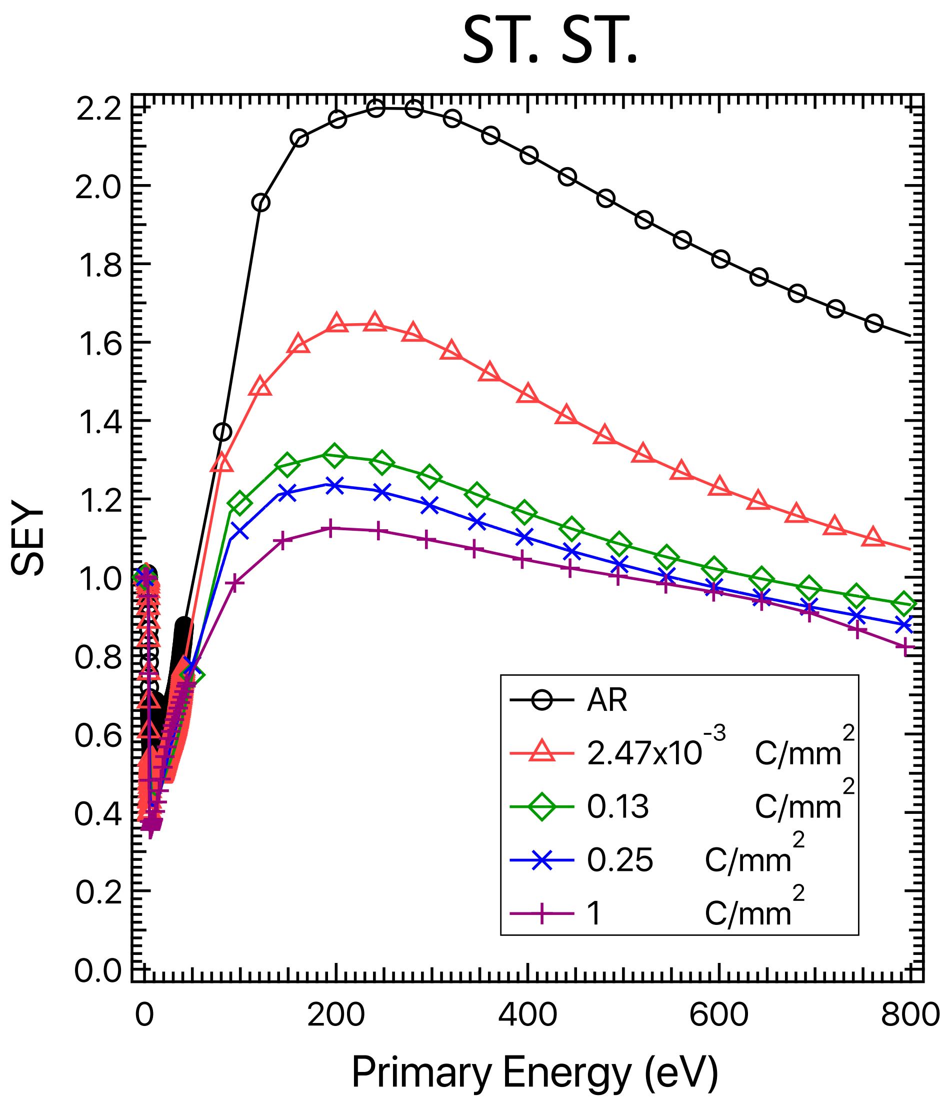




SEY VARIATION INDUCED BY SURFACE MODIFICATIONS

Chemical variation induced by electron irradiation

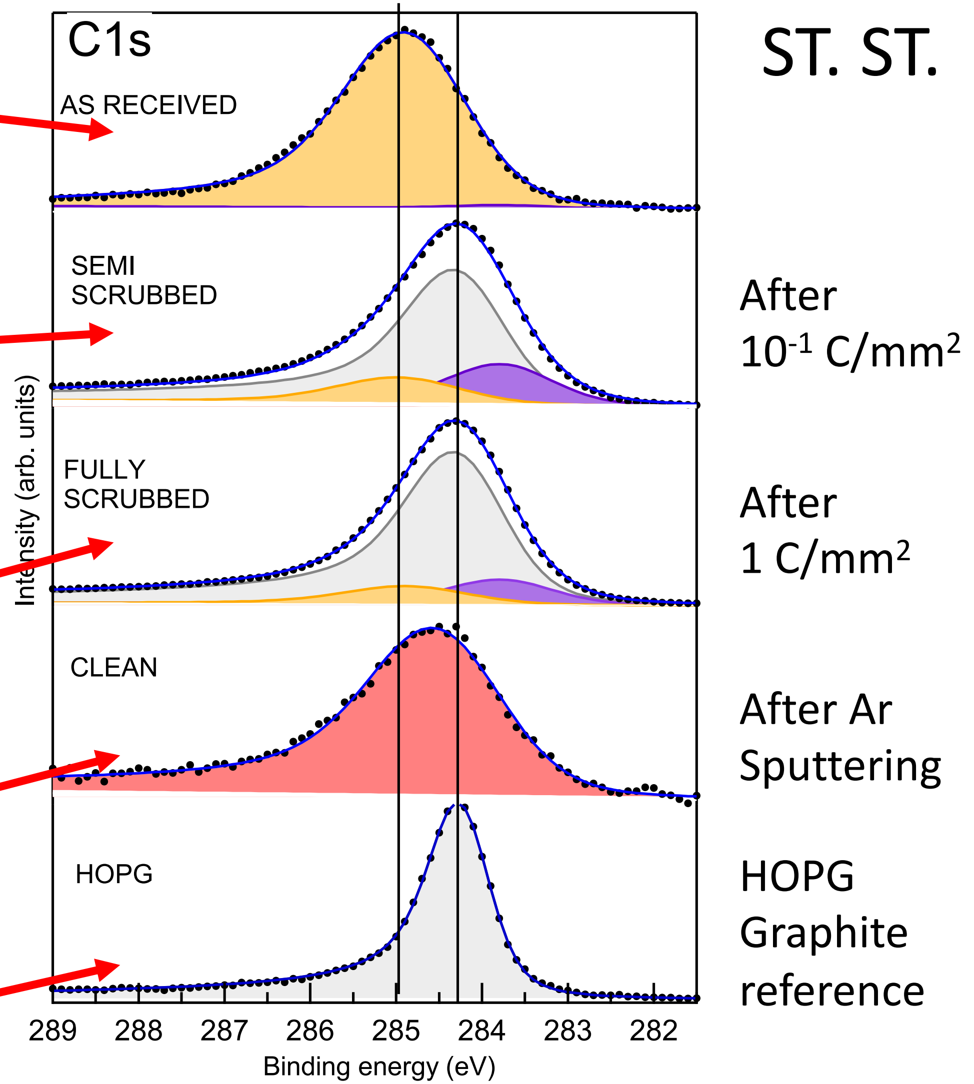
- The **As received** St. St. shows some C in the Bulk + The typical C in sp^3 form.

- The Semi scrubbed St. St. shows some C in the bulk + most C already in sp^2 form.

- The fully scrubbed St. St. shows some C in the bulk+ most C already in sp^2 form. **Identical to the Semi scrubbed**

- The St. St. shows that C is in the Bulk.

- The HOPG Graphite shows the C in sp^2 form as a reference.



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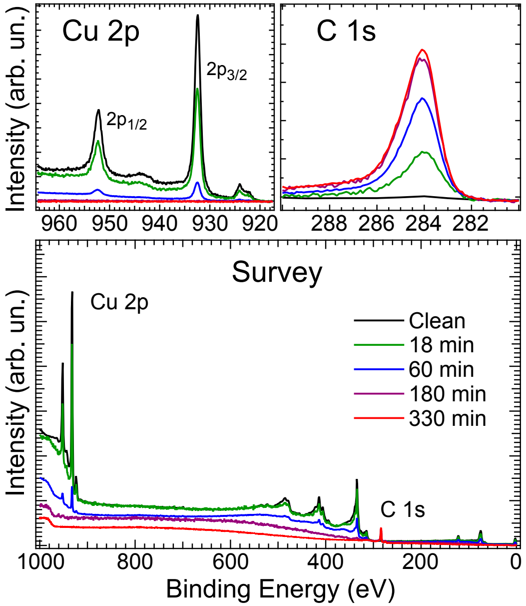
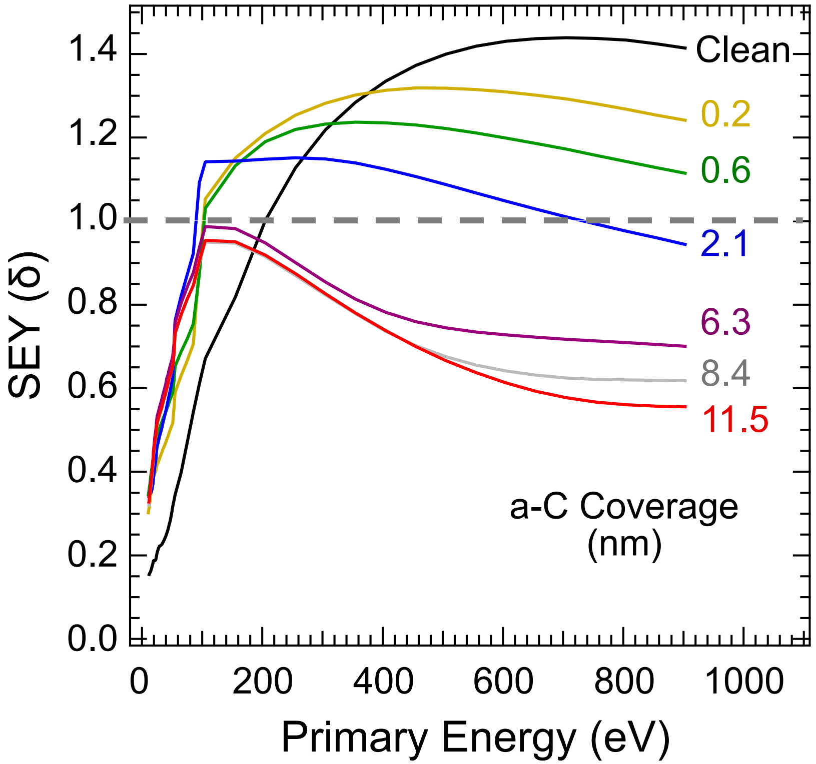
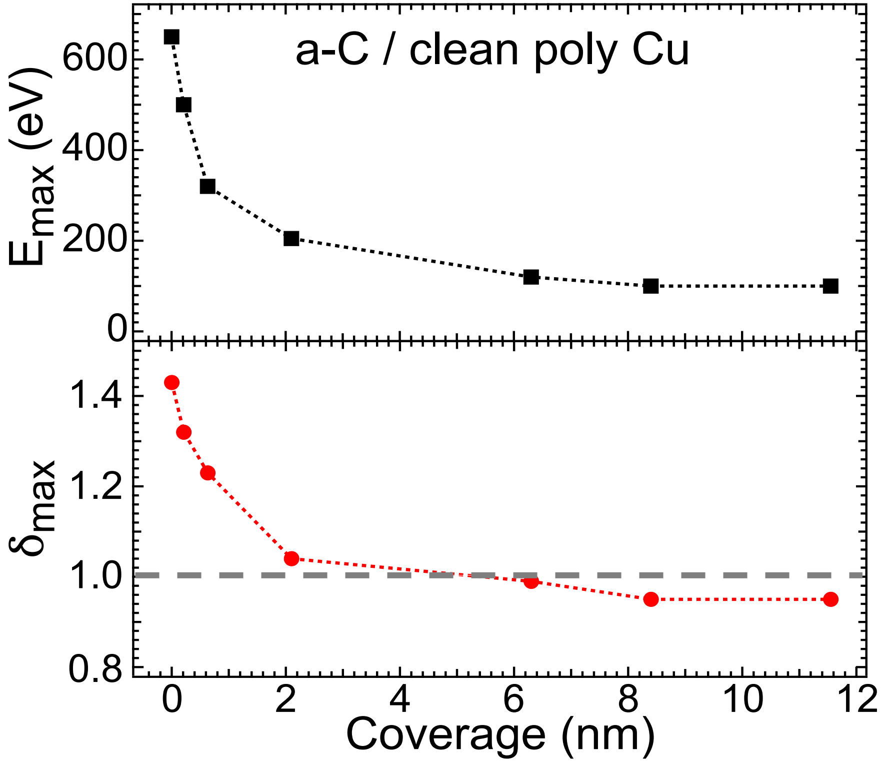
Secondary Electron Yield Reduction

e-beam evaporation from graphite rod



Carbon minimum thickness



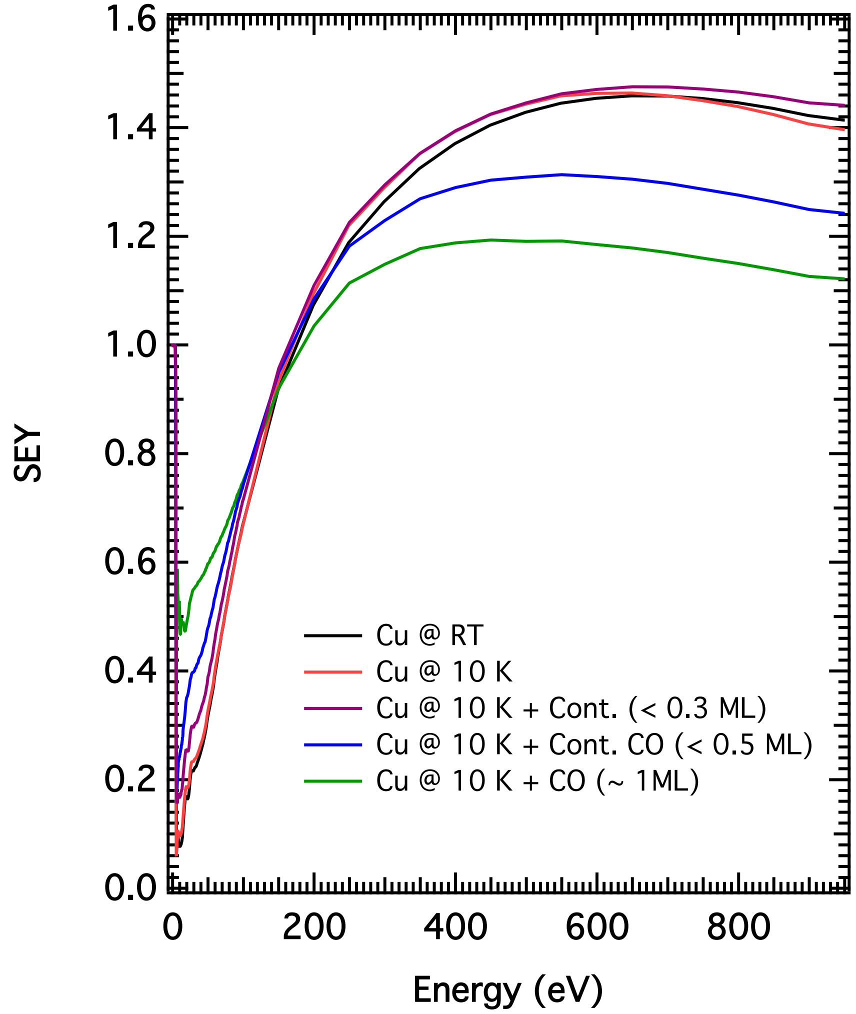


Fundamental information for coating engineering

M. Angelucci et. al; Phys. Rev. Research Rapid Comm. 2, 032030(R) (2020)

Secondary Electron Yield Variations at Cryogenic Temperatures

Induced SEY variation by external contaminants



Sub-Monolayer Contaminations

High-Energy Range

- Low Variations

(SEY Max from 1.4 to 1.3)

- Variation Dependence on Gas contaminant

Low-Energy Range

- Strong Variations

(SEY @10eV from 0.05 to 0.25)

- New characteristic structures

AIP Advances 7, 115203 (2017)

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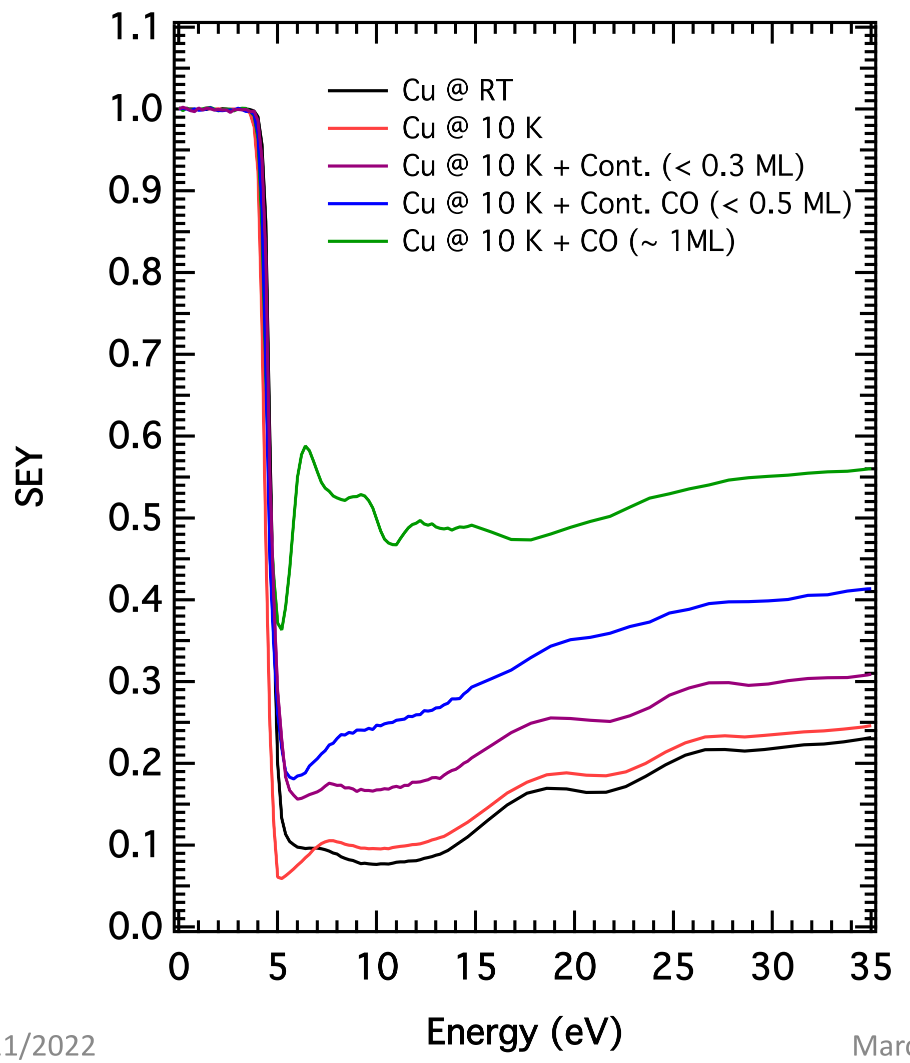

Sub-Monolayer Contaminations

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(SEY Max from 1.4 to 1.3)

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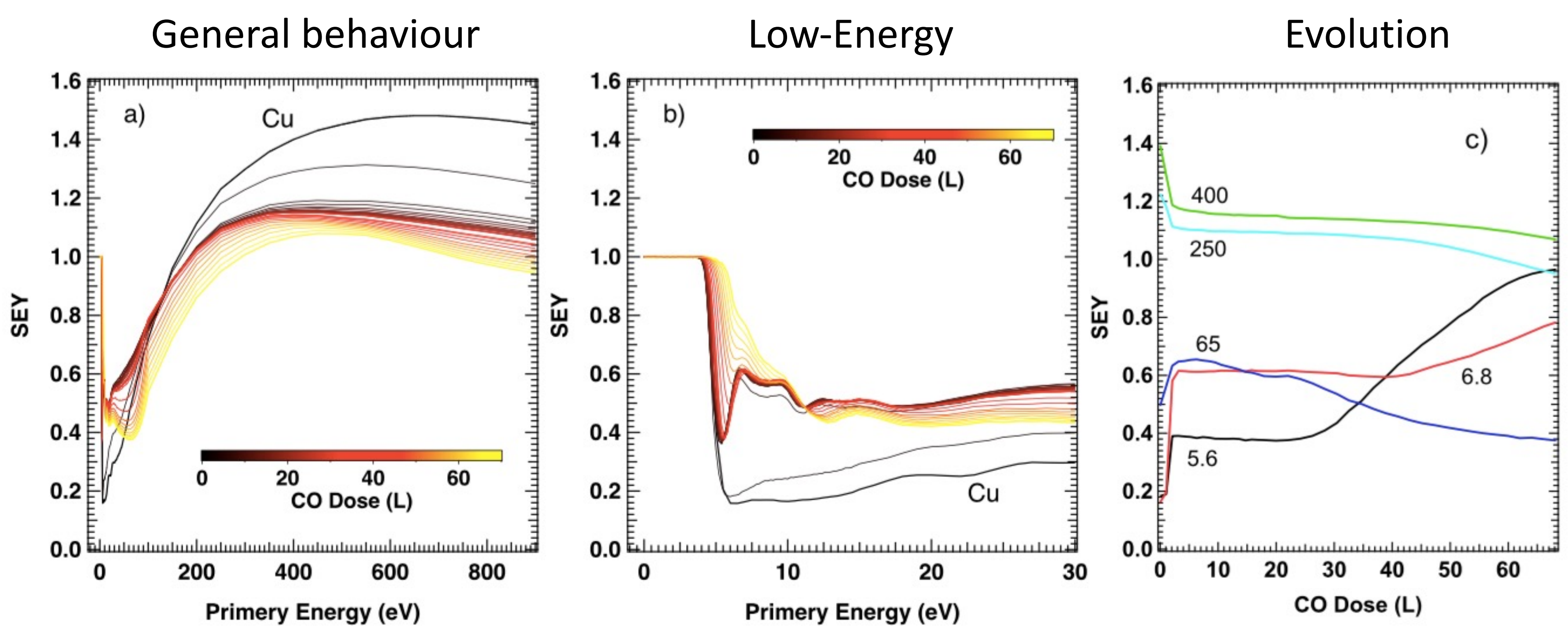
(SEY @10eV from 0.05 to 0.25)

- New characteristic structures

AIP Advances 7, 115203 (2017)

Secondary Electron Yield Variations at Cryogenic Temperatures

Adsorption process of Carbon Monoxide on Cu sample at 10K



- SEY @ 900 eV decreases during adsorption from 1.4 to 1.1
- Formation of CO Thick Film (TF)
- Characteristic peak of TF at 65 eV

- Characteristic peaks at different low energies
- Formation of CO Single Layer (SL)

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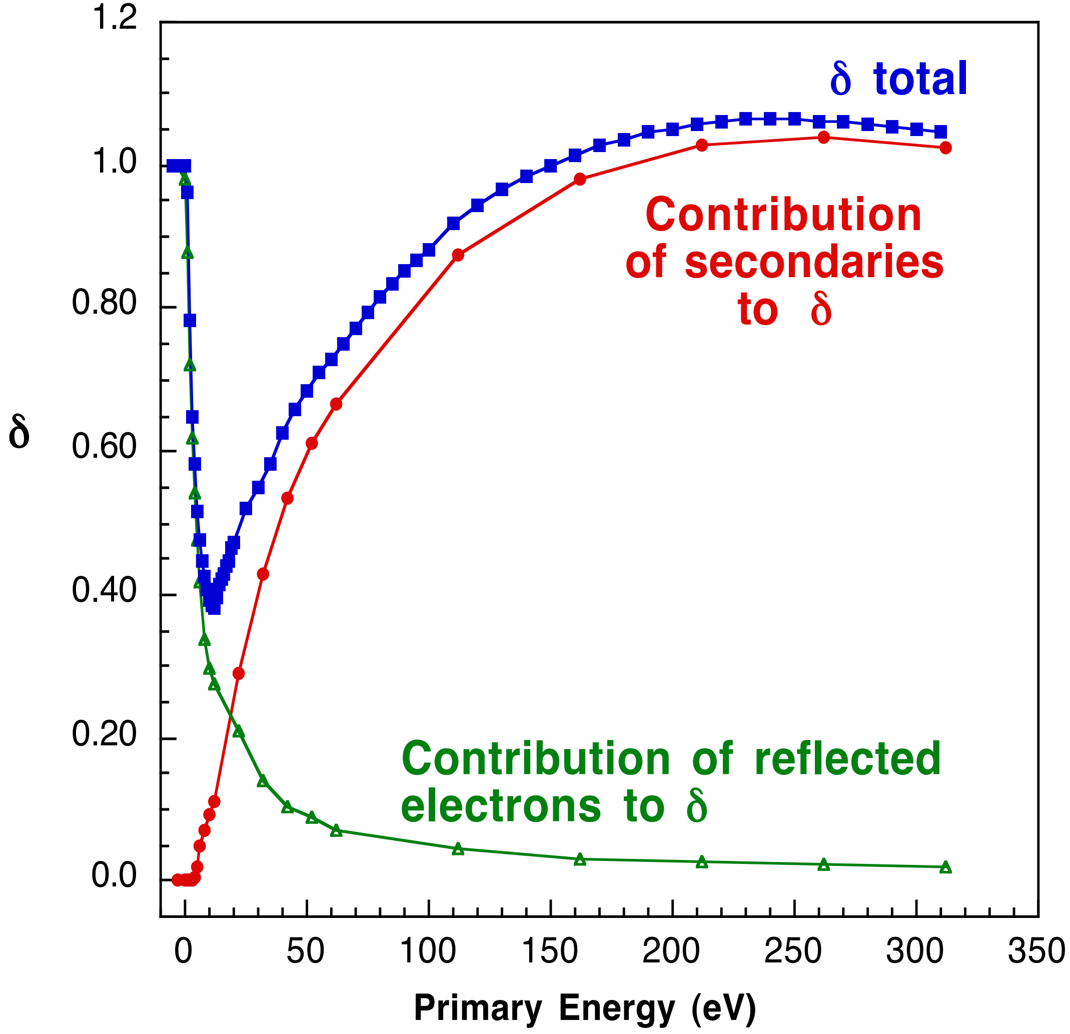
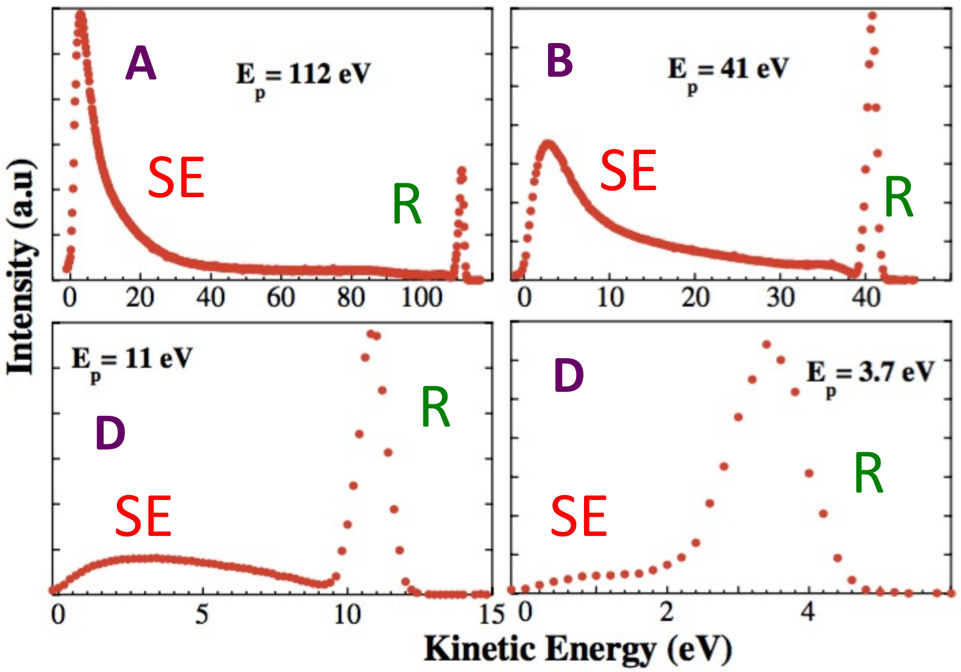
SEY OF MATERIALS



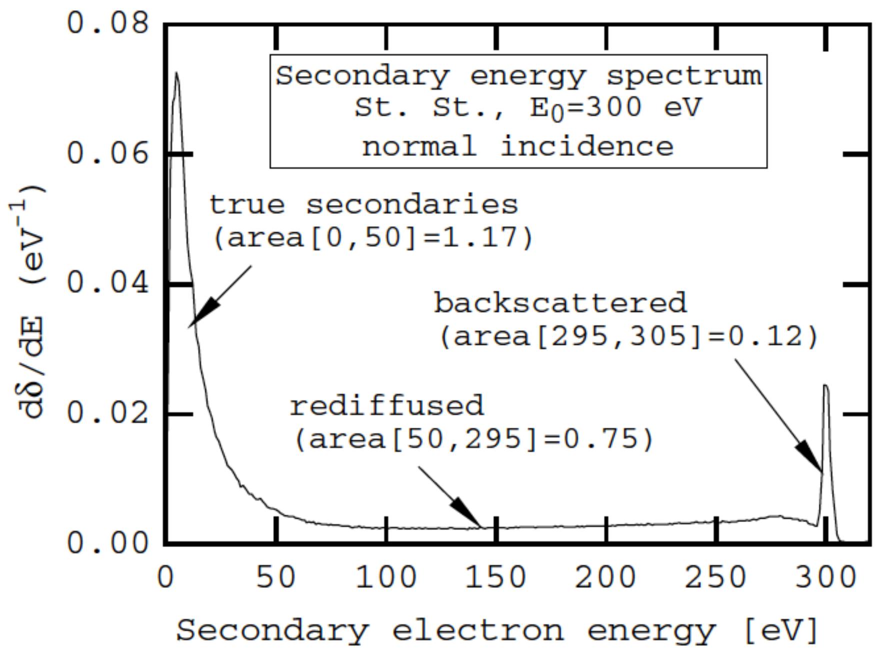
Energy Distribution Curves at different Primary Energy



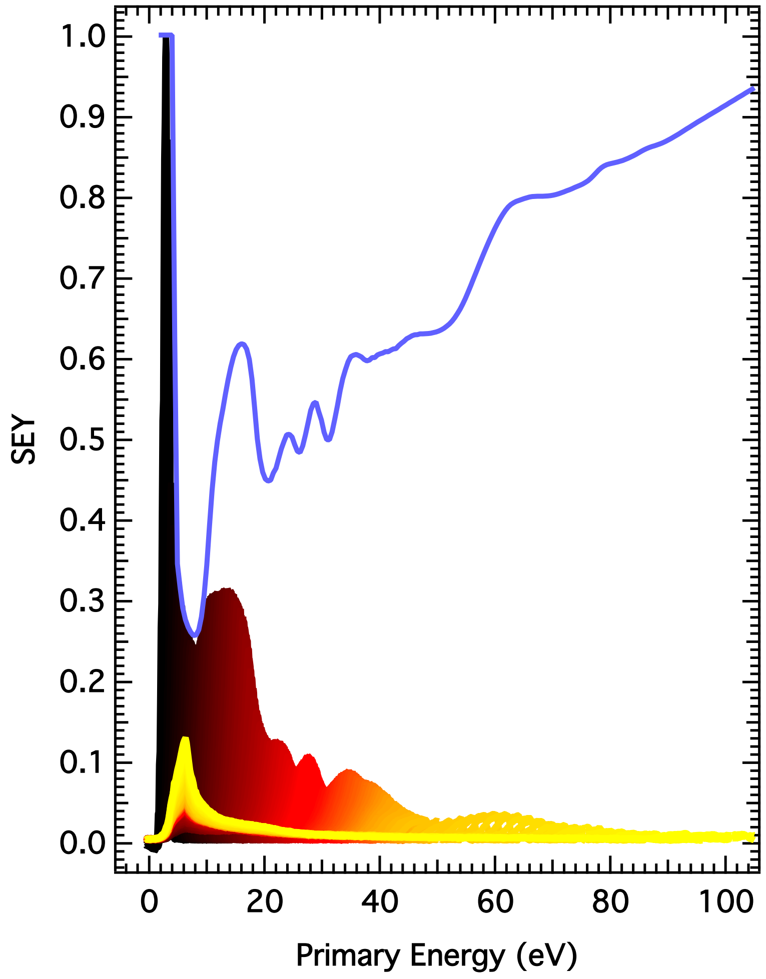
Cimino et al., PRL 93 (2004)

SEY OF MATERIALS

- By normalizing to 1 spectra taken with $E_p - E_{bias} < W_f$ and than plotting together all EDC of clean oriented HOPG



HOPG



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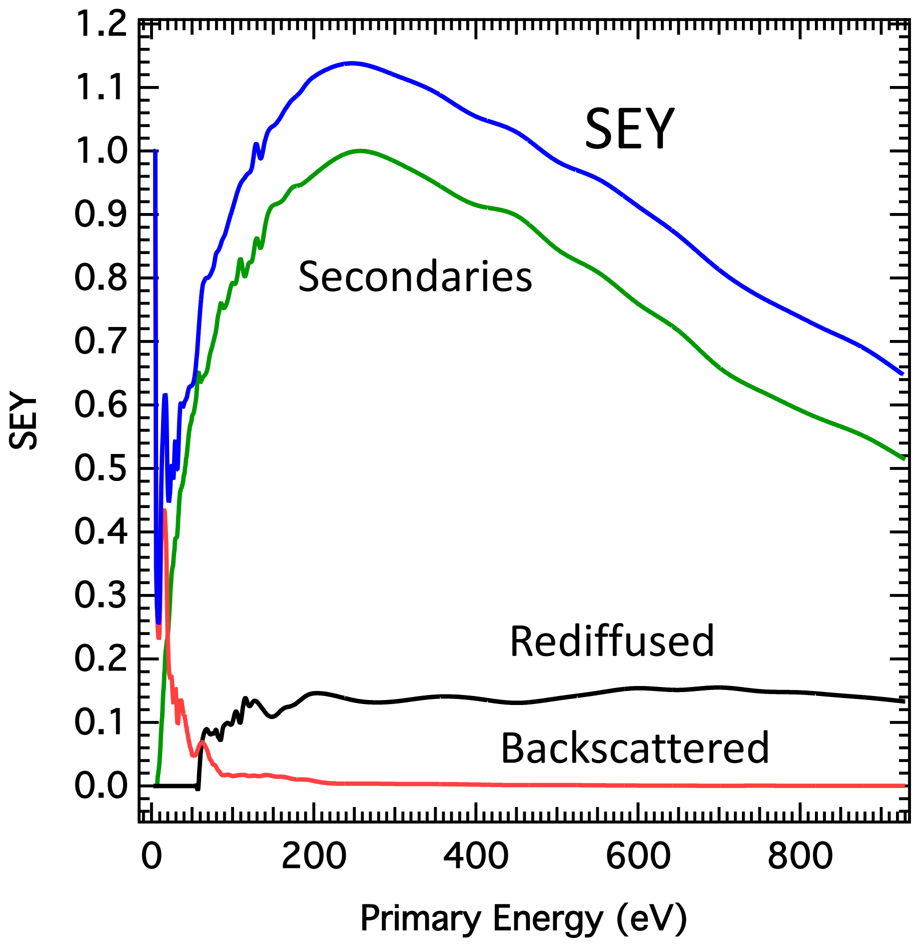

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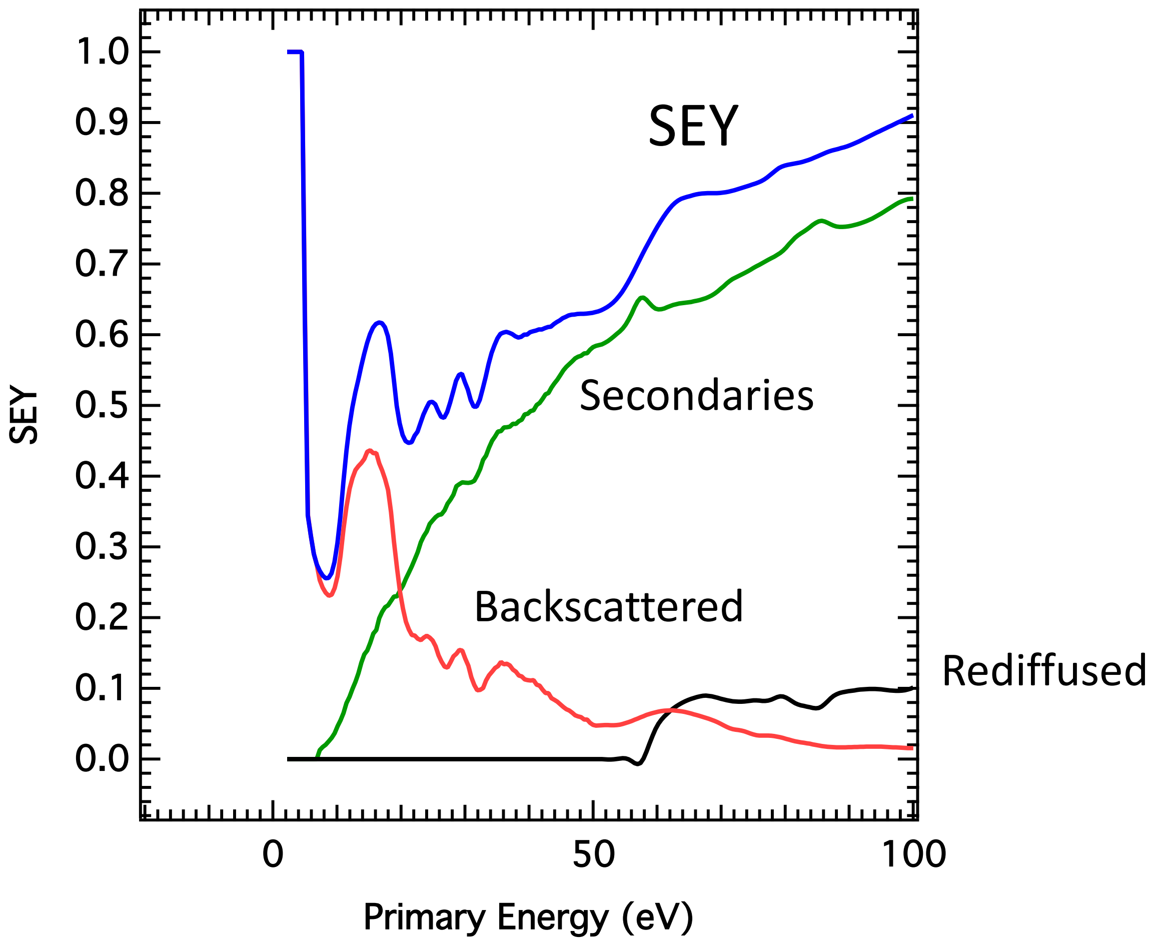

Conclusions

- Each system has a different SEY depending on the chemistry and morphology
- Overlayers plays a crucial role
- The overlayer thickness can induce significant variation in SEY

- Contaminant Layer thickness could be responsible of the different sectors behaviour in accelerators

Conclusions

- Studies of different systems and material
- Studies of chemistry on the surface
- Evaluation of physical properties
- Important input for computational methods

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ELSEVIER

Modelling the impact on the secondary electron yield of carbon layers of various thicknesses on copper substrate

C. Inguimbert [a,*], Q. Gibaru [a,b,c], P. Caron [a], M. Angelucci [d], L. Spallino [d], R. Cimino [d]

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[c] CNES, 18 Avenue Edouard Belin, 31401 Toulouse, France
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Secondary electron emission and yield spectra of metals from Monte Carlo simulations and experiments

Martina Azzolini[1,2], Marco Angelucci[3], Roberto Cimino[3], Rosanna Larciprete[3,4], Nicola M Pugno[2,5,6], Simone Taioli[1,7] and Maurizio Dapor[1]

Thank you for your attention

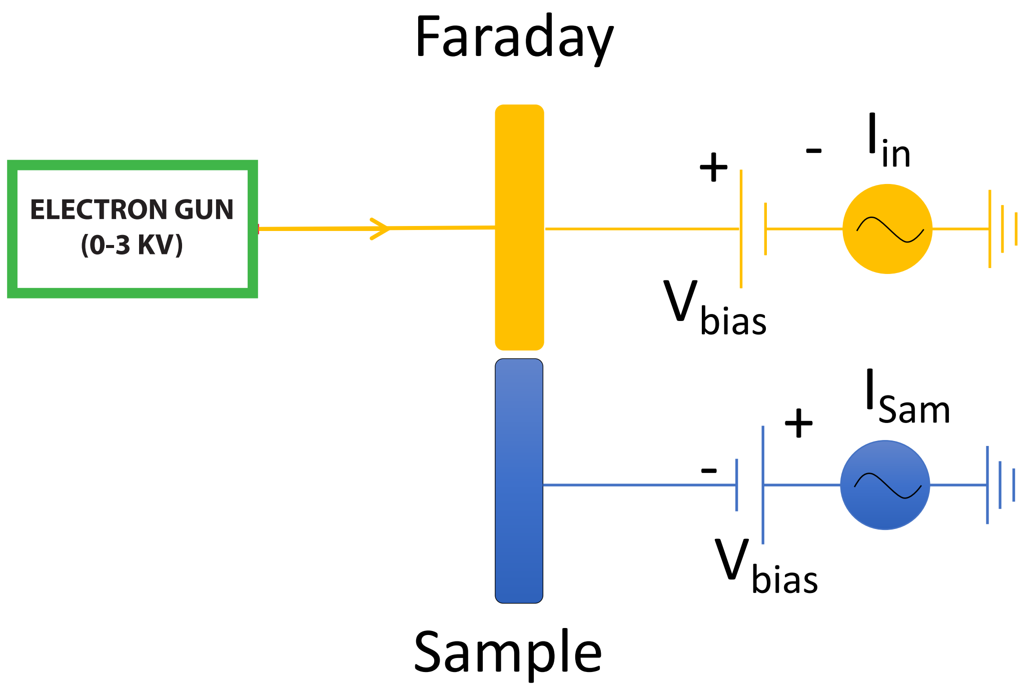
BK

Measure of Secondary Electron Yield

Method 2

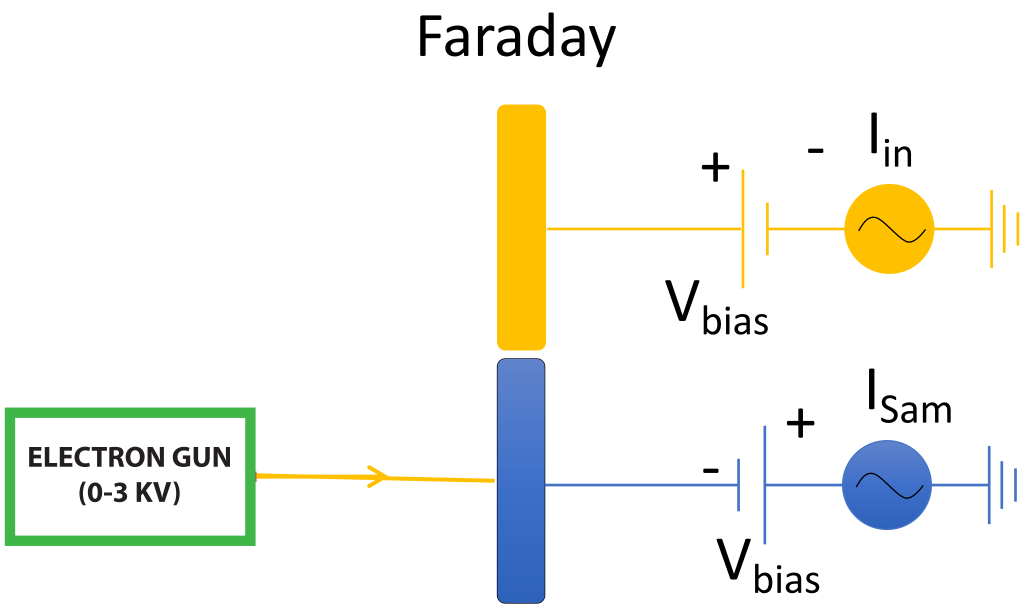
Direct measure of I_{in}

$$SEY = \delta = \frac{I_{out}}{I_{in}}$$



Measure of Secondary Electron Yield

$$SEY = \delta = \frac{I_{out}}{I_{in}} = \frac{I_{in} - I_{Sam}}{I_{in}}$$



Method 2

Direct measure of I_{out}

I_{Sample} and I_{in}

Advantages:

- Gun close to sample.
- **Reduce noise for low current measurements (i.e. insulators)**
- **LE-SEY accessible**

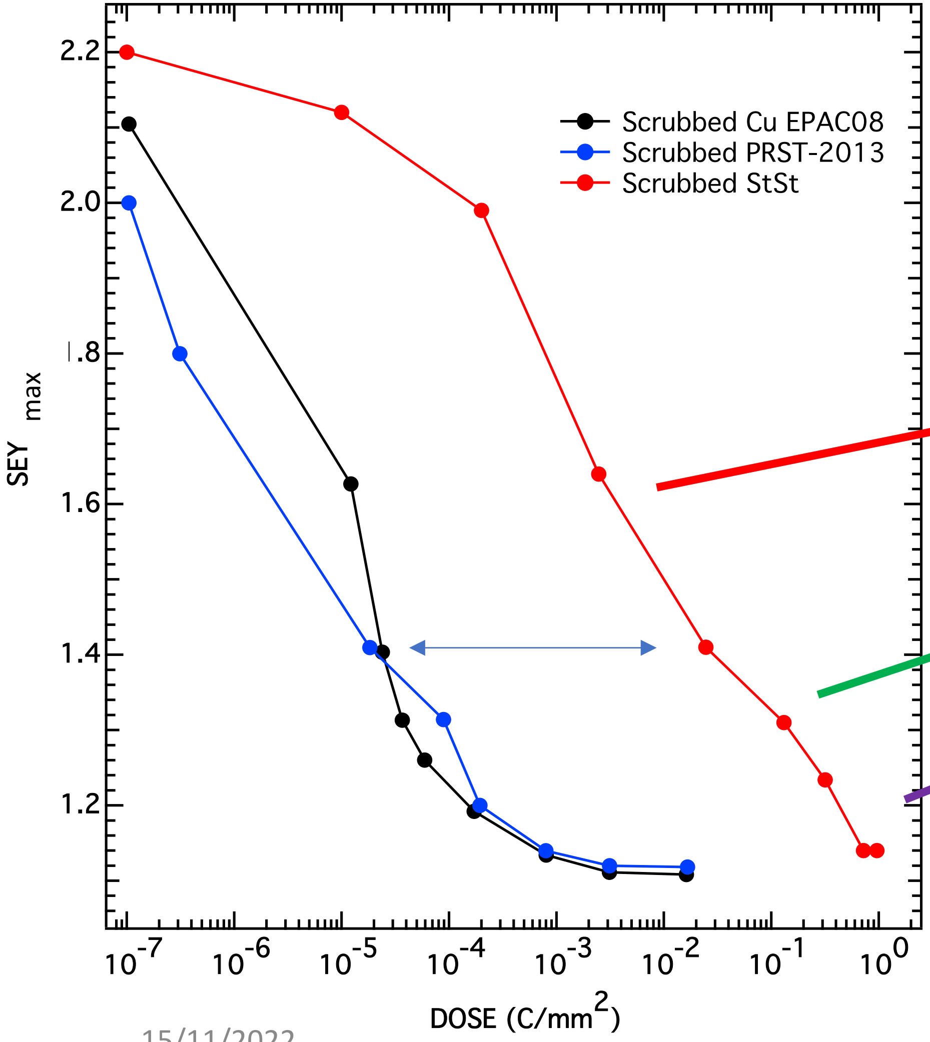
Disadvantages

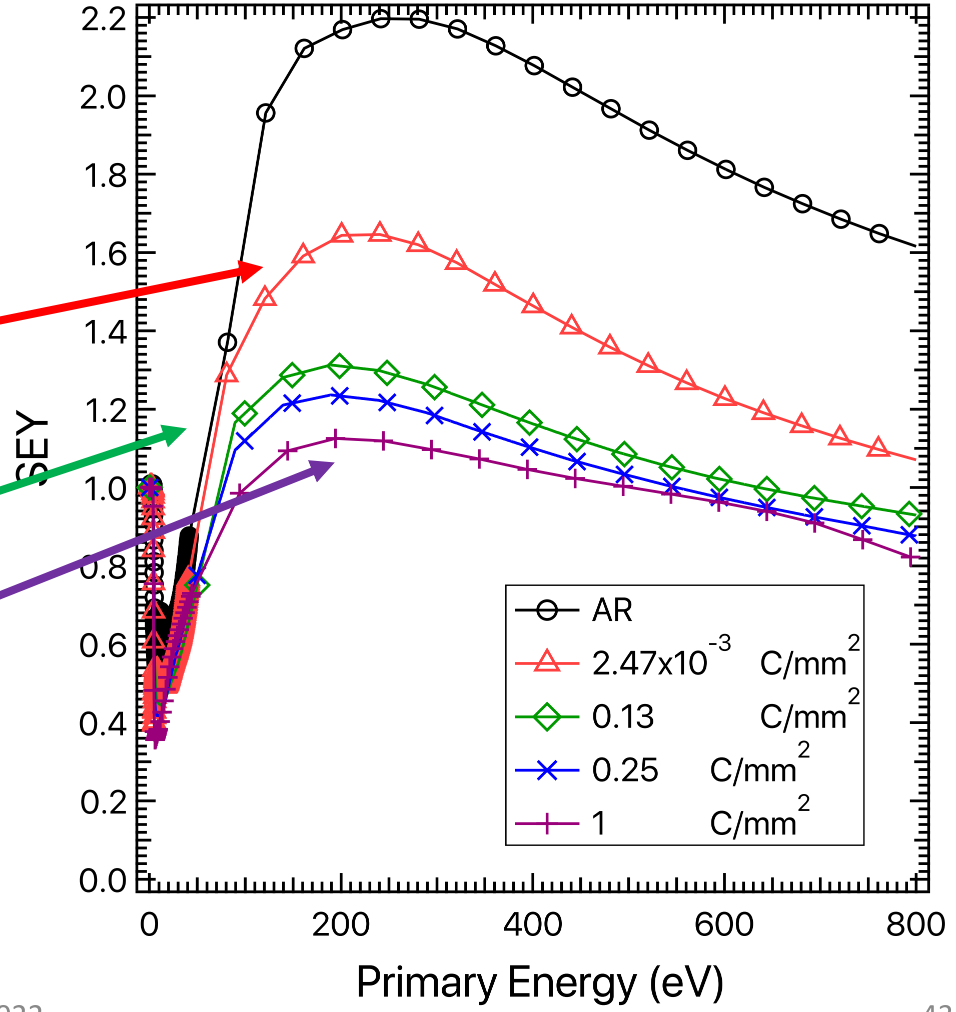
- Gun need to be very stable (takes time)
- More work (2 separate runs)

SEY Variation

Chemical variation induced by electron irradiation

ST. ST.

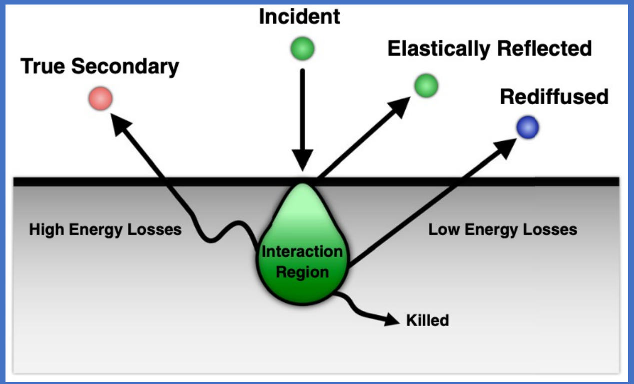




SEY Variation

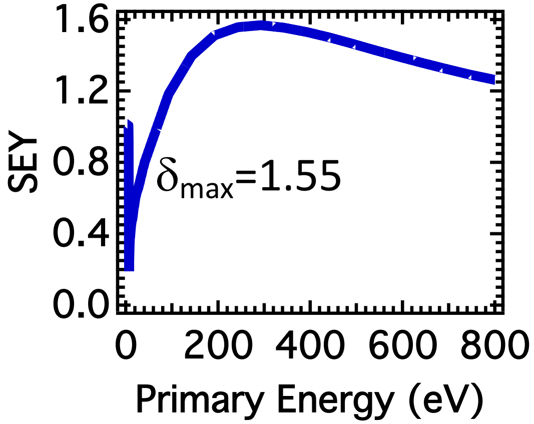
Chemical variation induced by electron irradiation **St. St.**

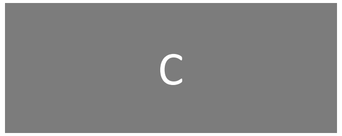
Secondary Electron emission

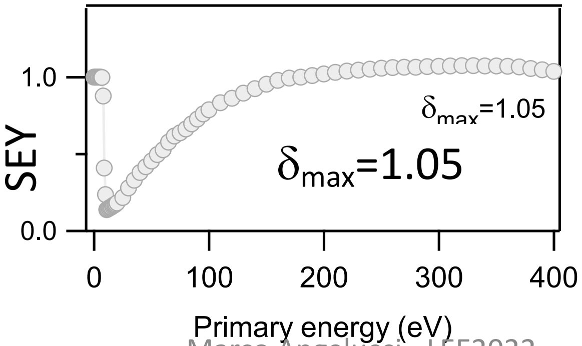


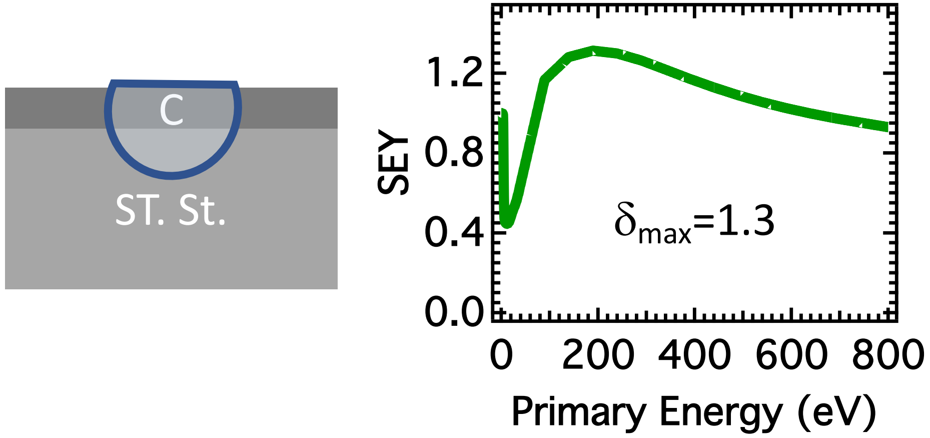
Three-step process:

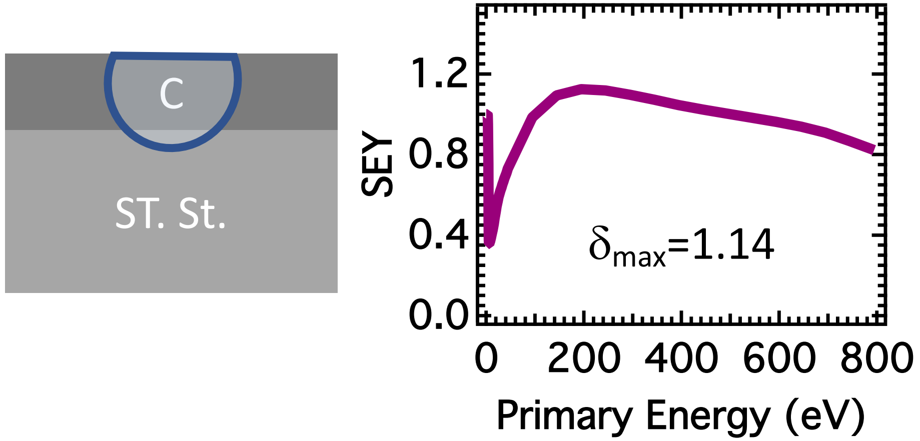
- Production of SE at a depth z
- Transport of the SE toward the surface
- Emission of SE across the surface barrier
- SEY electrons are produced within a semi-sphere of about few nm radius









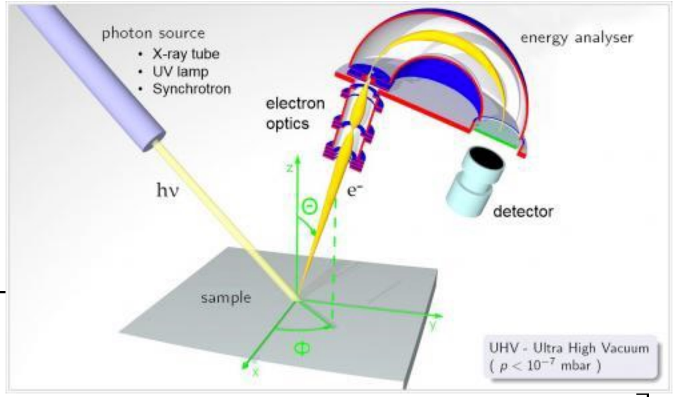


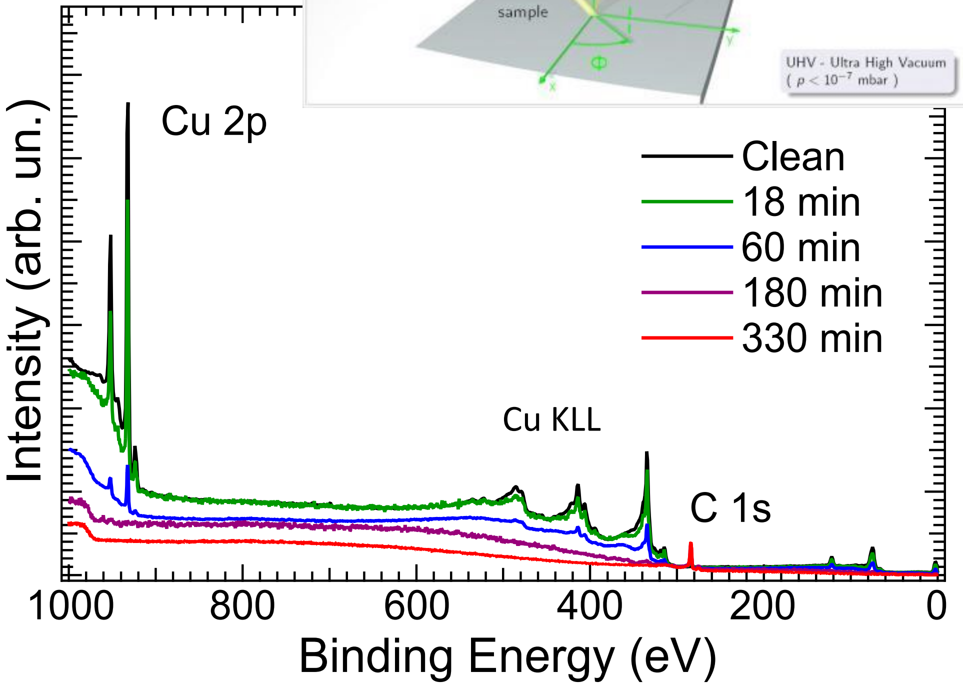
Secondary Electron Yield Reduction

Carbon minimum thickness

e-beam evaporation from graphite rod

XPS analysis
(Coverage Estimation)





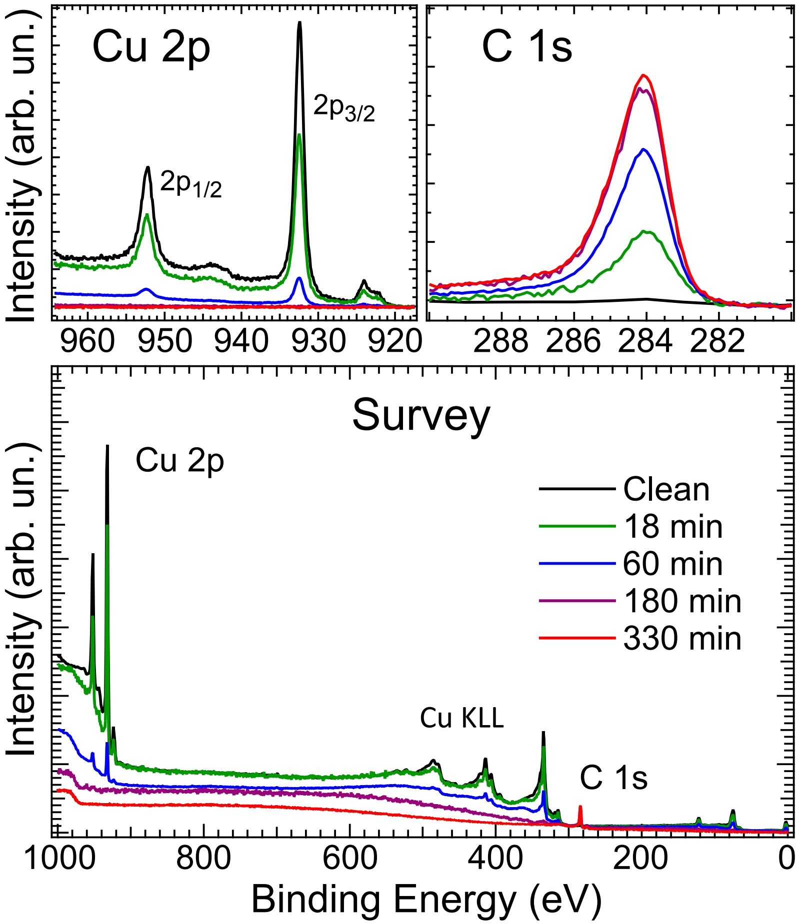
SEY measurements

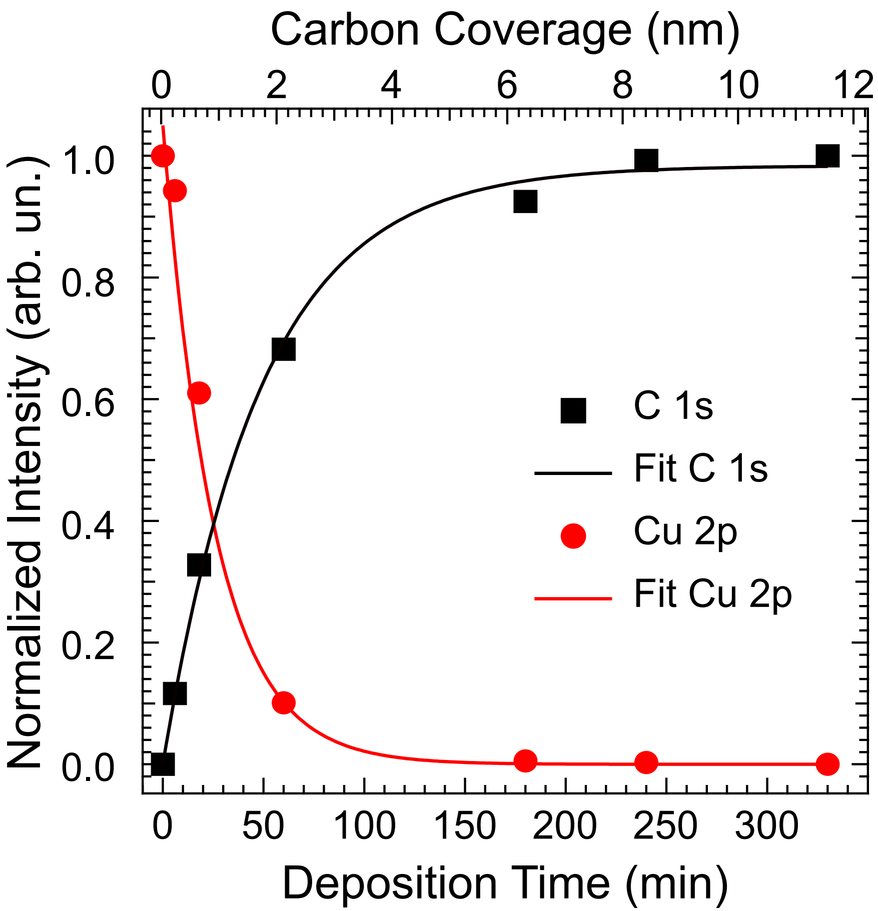
Minimum thickness evaluation

M. Angelucci et. al; Phys. Rev. Research Rapid comm. 2, 032030(R) (2020)

Secondary Electron Yield Reduction

Carbon minimum thickness

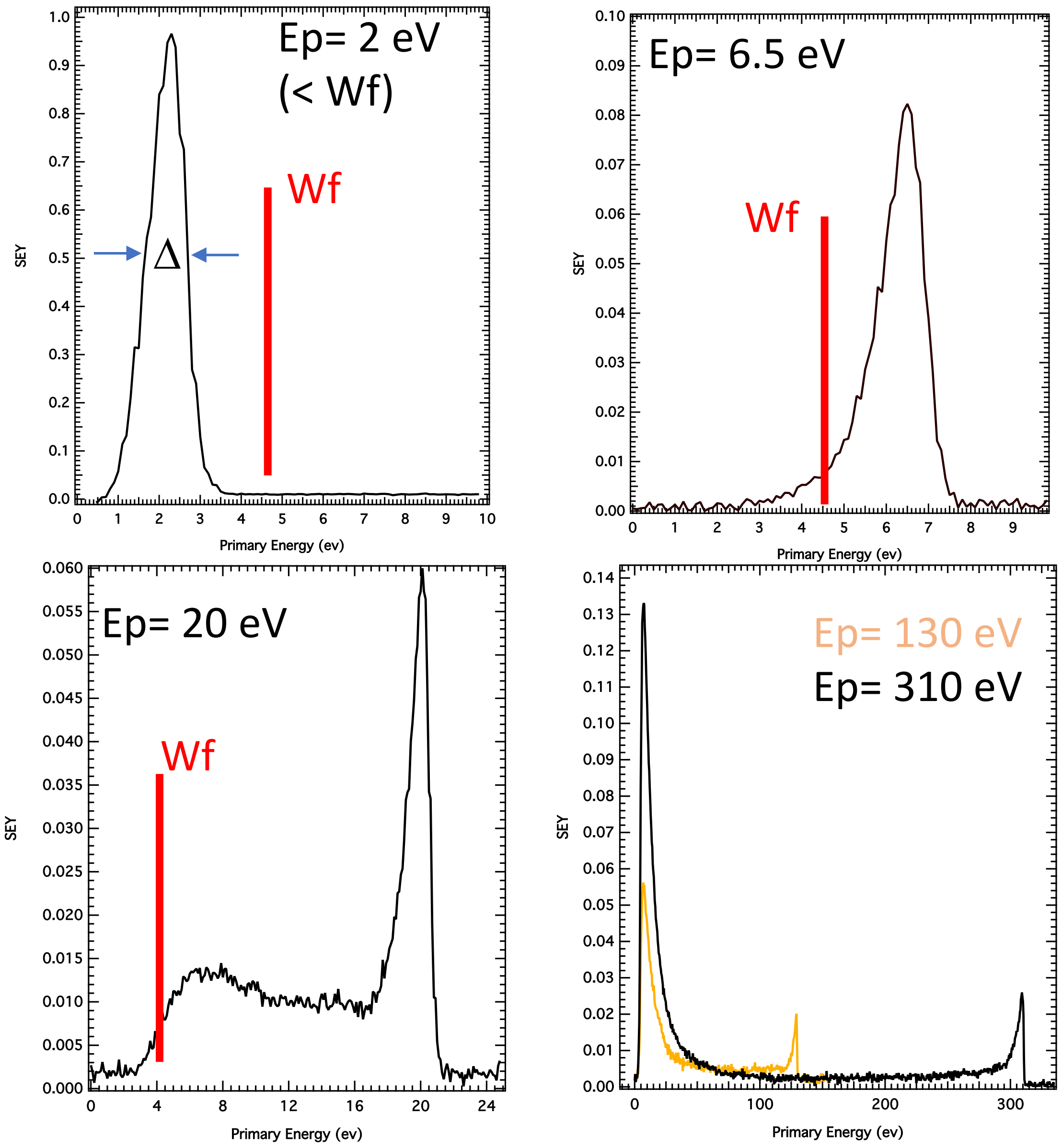




Conversion of deposition time to Carbon Coverage (nm)

M. Angelucci et. al; Phys. Rev. Research Rapid Comm. 2, 032030(R) (2020)

REMAINING QUESTION: Such Surface sensitivity depends on a reduced MFP than known so far?



Measure Angle integrated EDC (Δ~ 1.3 eV) with LEED Optics (Omicron) in Auger Mode with a modified electronics allowing to maintain the e-gun in LEED condition.
(necessary to go to LE)

Plotting all the data normalizing to UNITY the intensity of the EDC @ Ep< Wf

or

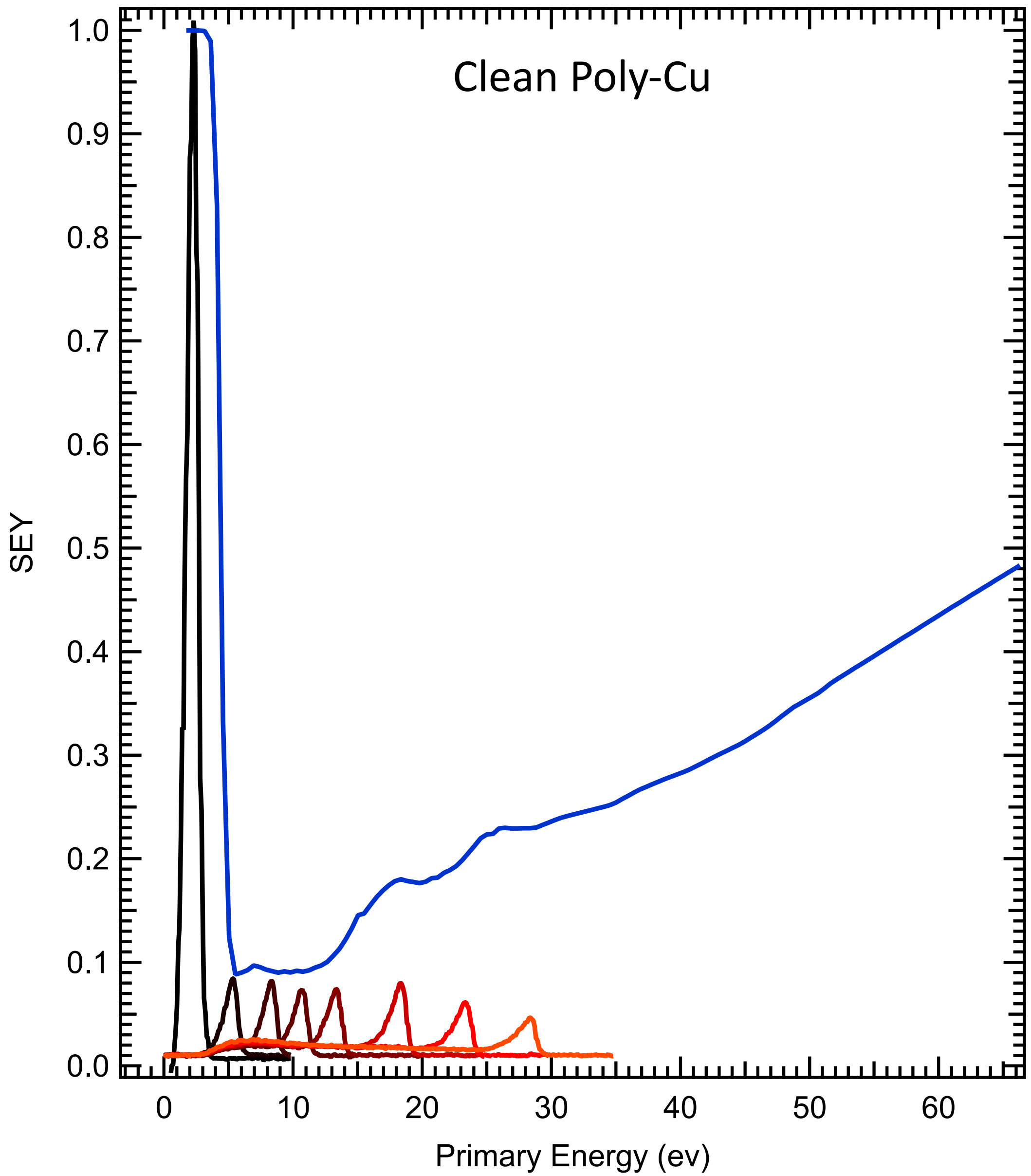
Integrating the curves:
(when Ep <50 eV)

- 0 to $E_P - \Delta$ (True Secondary)
- $E_P - \Delta$ to $E_P + \Delta$ (Elastically Back.)

(when Ep > 50 eV)

- 0 to 50 eV (True Secondary)
- 50 eV to $E_P - \Delta$ (Rediffused)
- $E_P - \Delta$ to $E_P + \Delta$ (Elastically Back.)

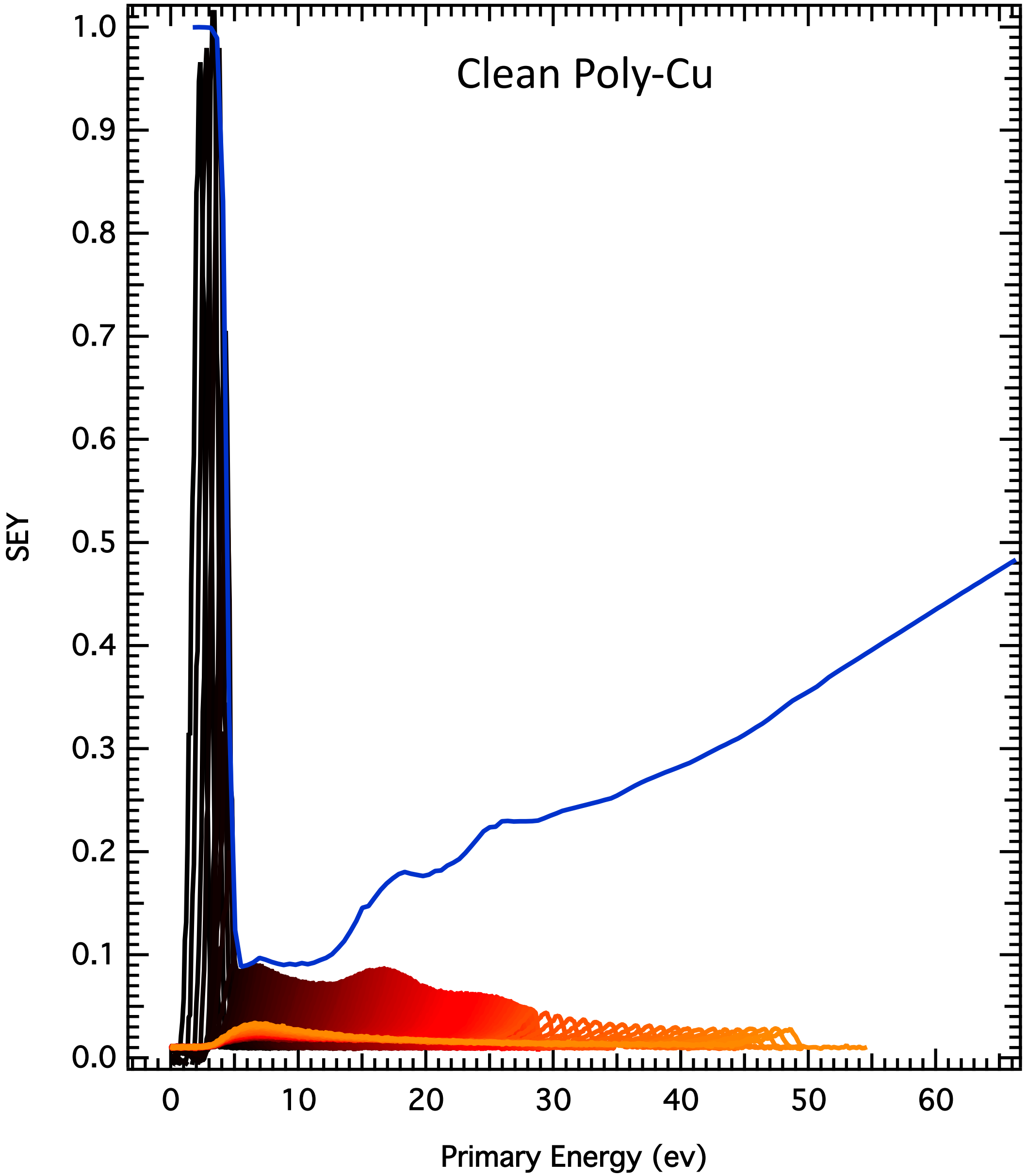
REMAINING QUESTION: Such Surface sensitivity depends on a reduced MFP than known so far?



Plotting all the data normalizing to UNITY the intensity of the EDC
@ Ep – E_{BIAS}< Wf:

It is clear that the SEY structures are oscillations in the elastically backscattered components

REMAINING QUESTION: Such Surface sensitivity depends on a reduced MFP than known so far?



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REMAINING QUESTION: Such Surface sensitivity depends on a reduced MFP than known so far?

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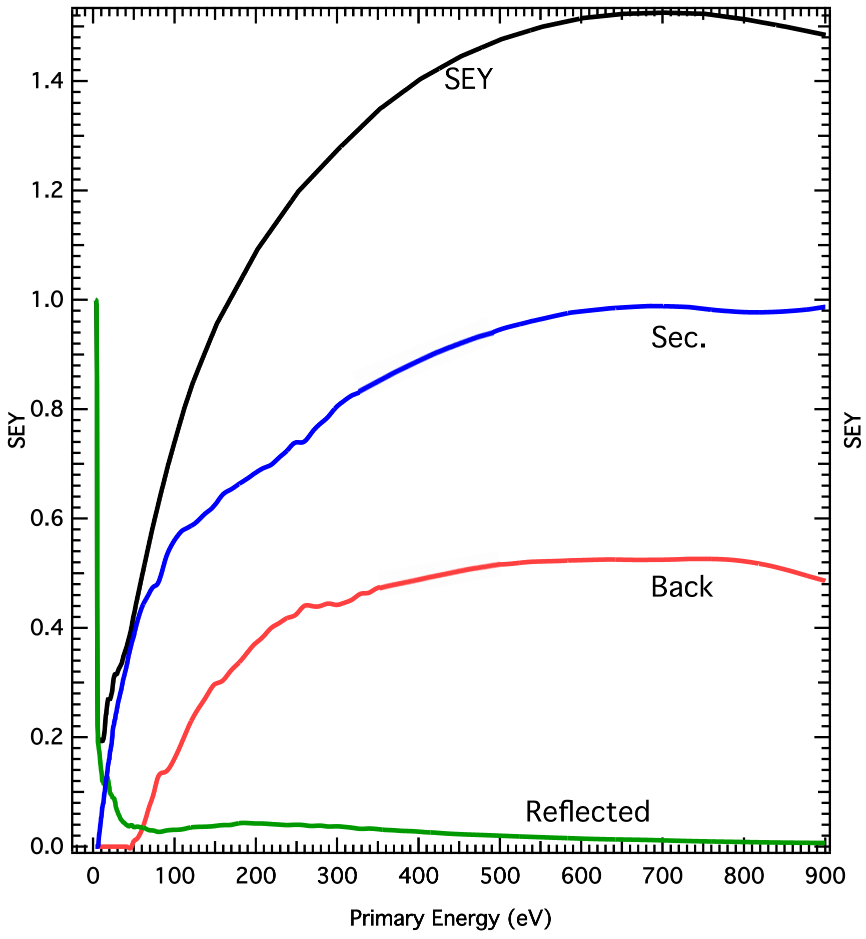
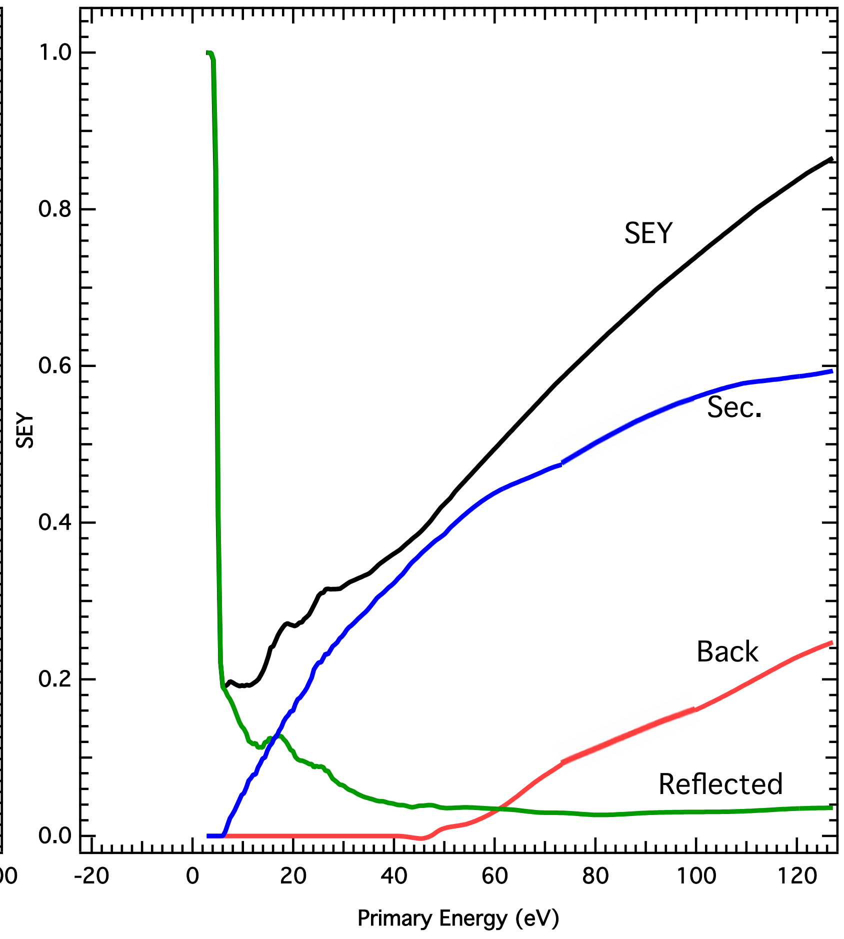
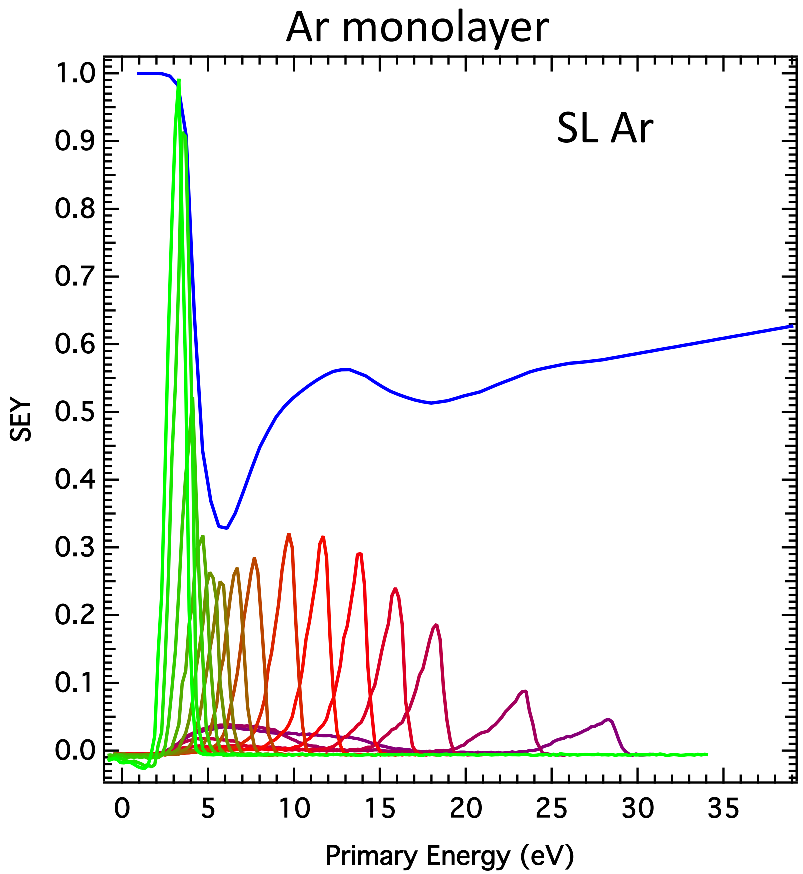


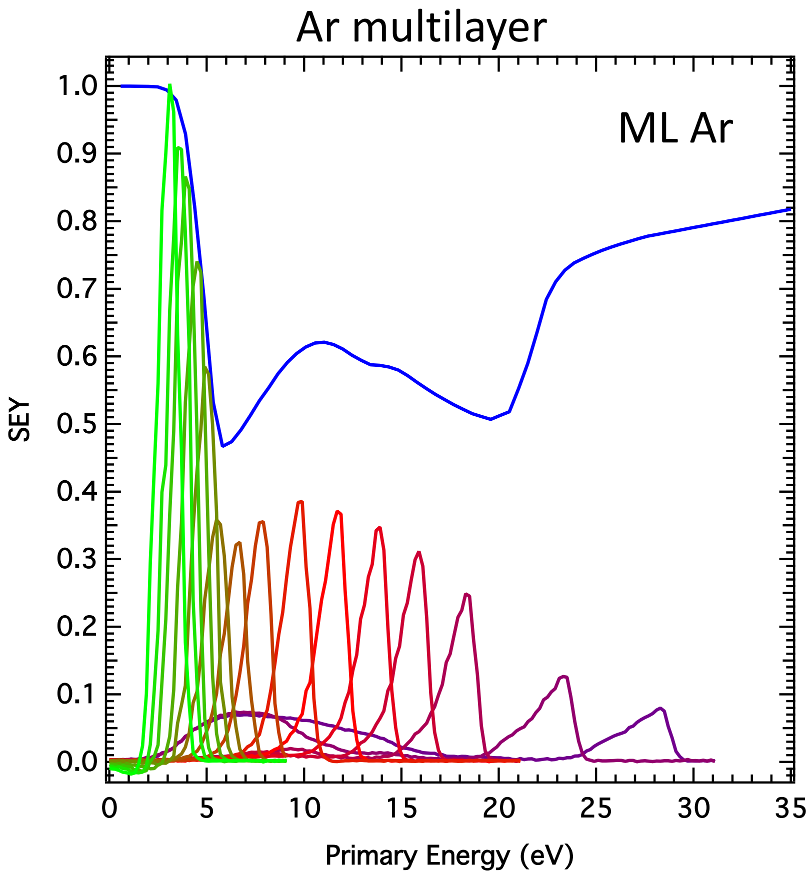
(when Ep > 50 eV)

- 0 to 50 eV (True Secondary)
- 50 eV to $E_P - \Delta$ (Rediffused)
- $E_P - \Delta$ to $E_P + \Delta$ (Elastically Back.)



General Trend: Ar on poly-Cu





Wf Difference!