The role of secondary electrons in EUV resist

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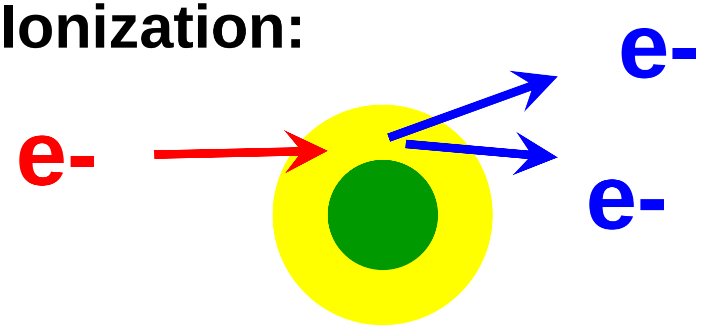
Secondary Electrons are Central to Many Current and Future Imaging Technologies:
EUV, E-Beam Multibeam

Yet, many fundamental questions remain unanswered:

Ionization:



How many are made?

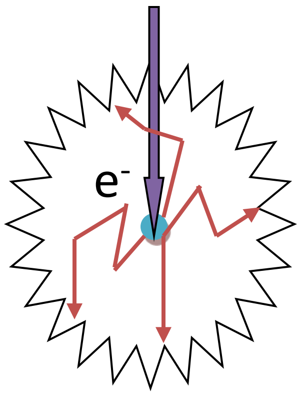
How far do they travel?

What energy are they?

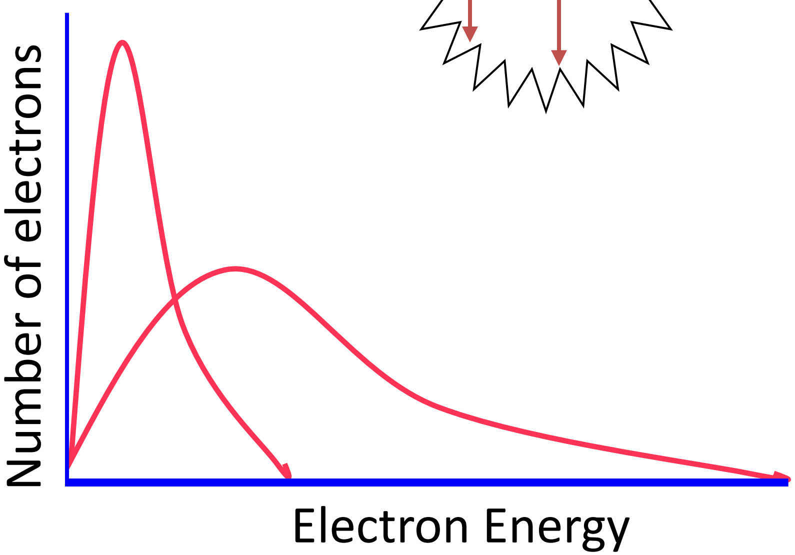
How do they react? (By which mechanisms?)

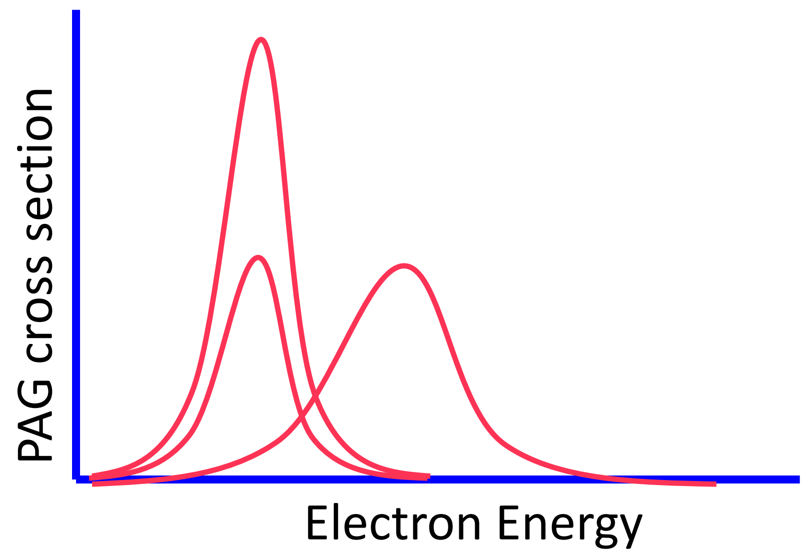
EUV Resist exposures are fundamentally secondary electron chemistry, not photon chemistry

EUV
hν = 92 eV



Need to know the number and energy of electrons present in polymer
Need to know the cross section of the PAG to electrons
Larger overlap of electrons with PAG reactivity will be higher efficiency resists





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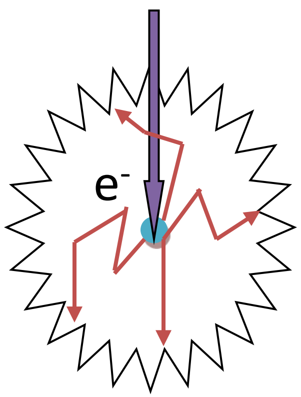
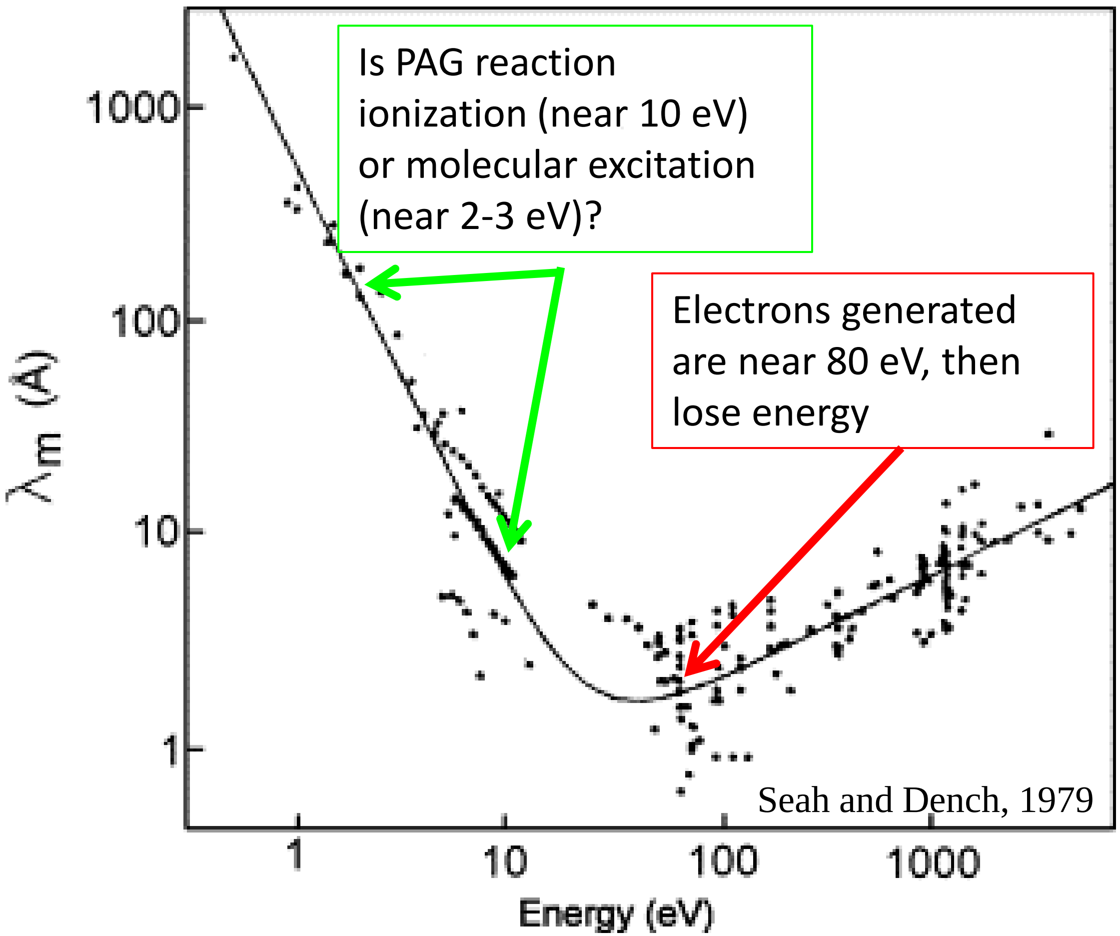
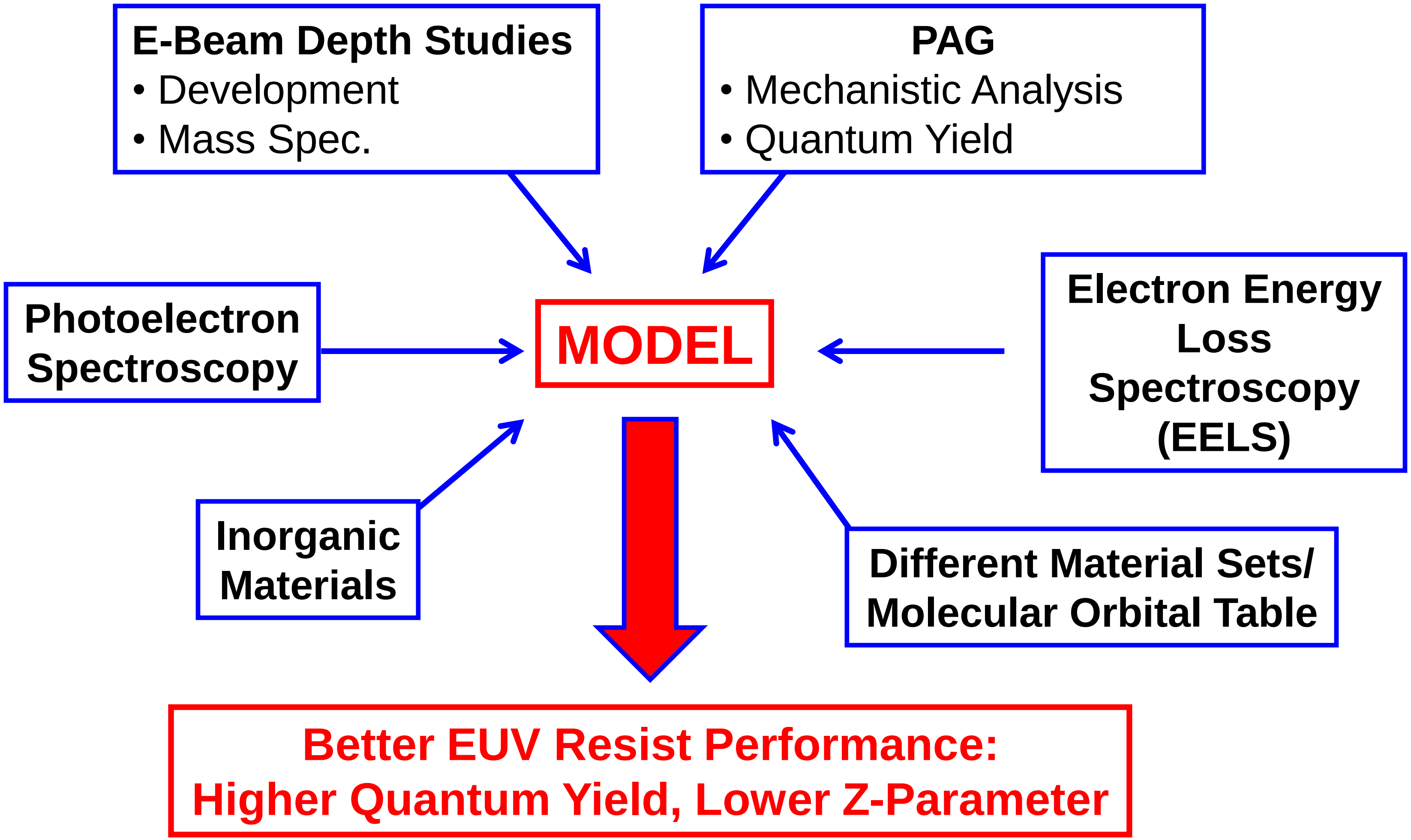
Why we care about electrons for EUV exposures



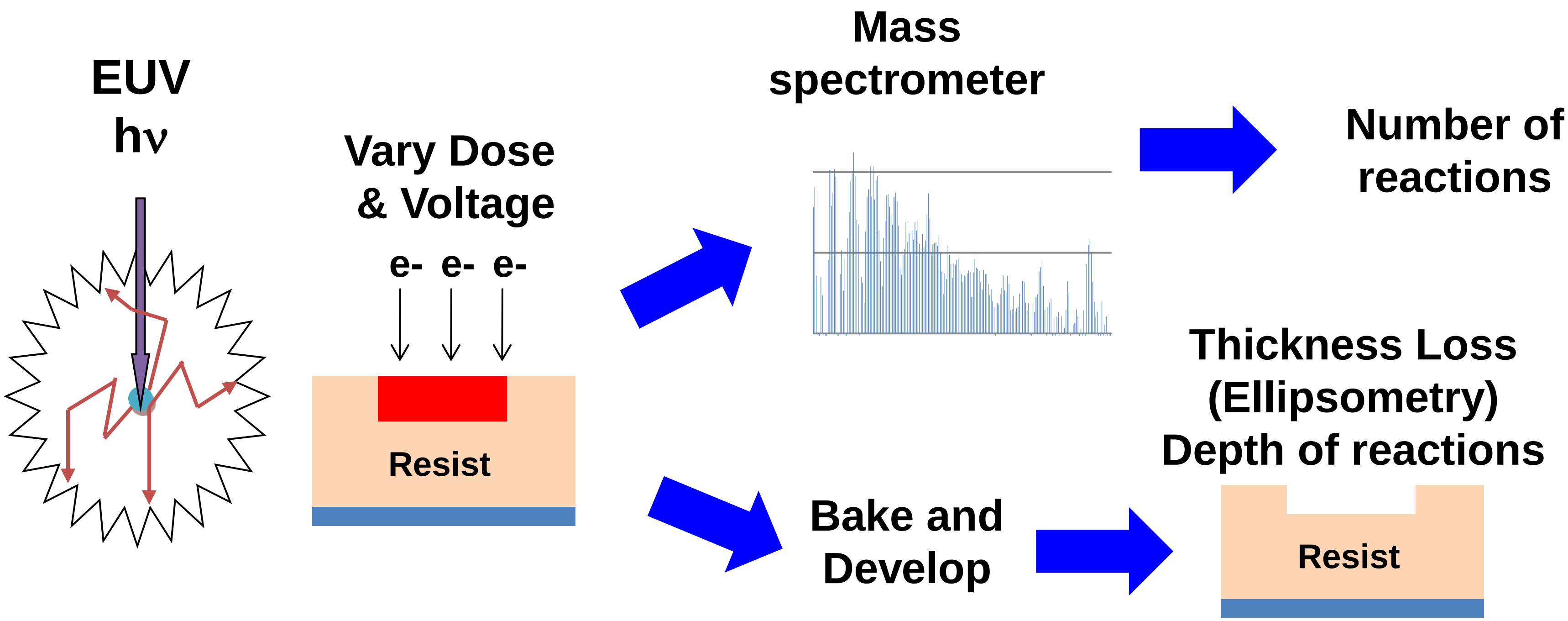
“Universal” curve for electron inelastic mean free path (IMFP)



- What energy electrons are generated
- How far do they travel
- What energies are present at which distances
- What energies cause PAG decomposition

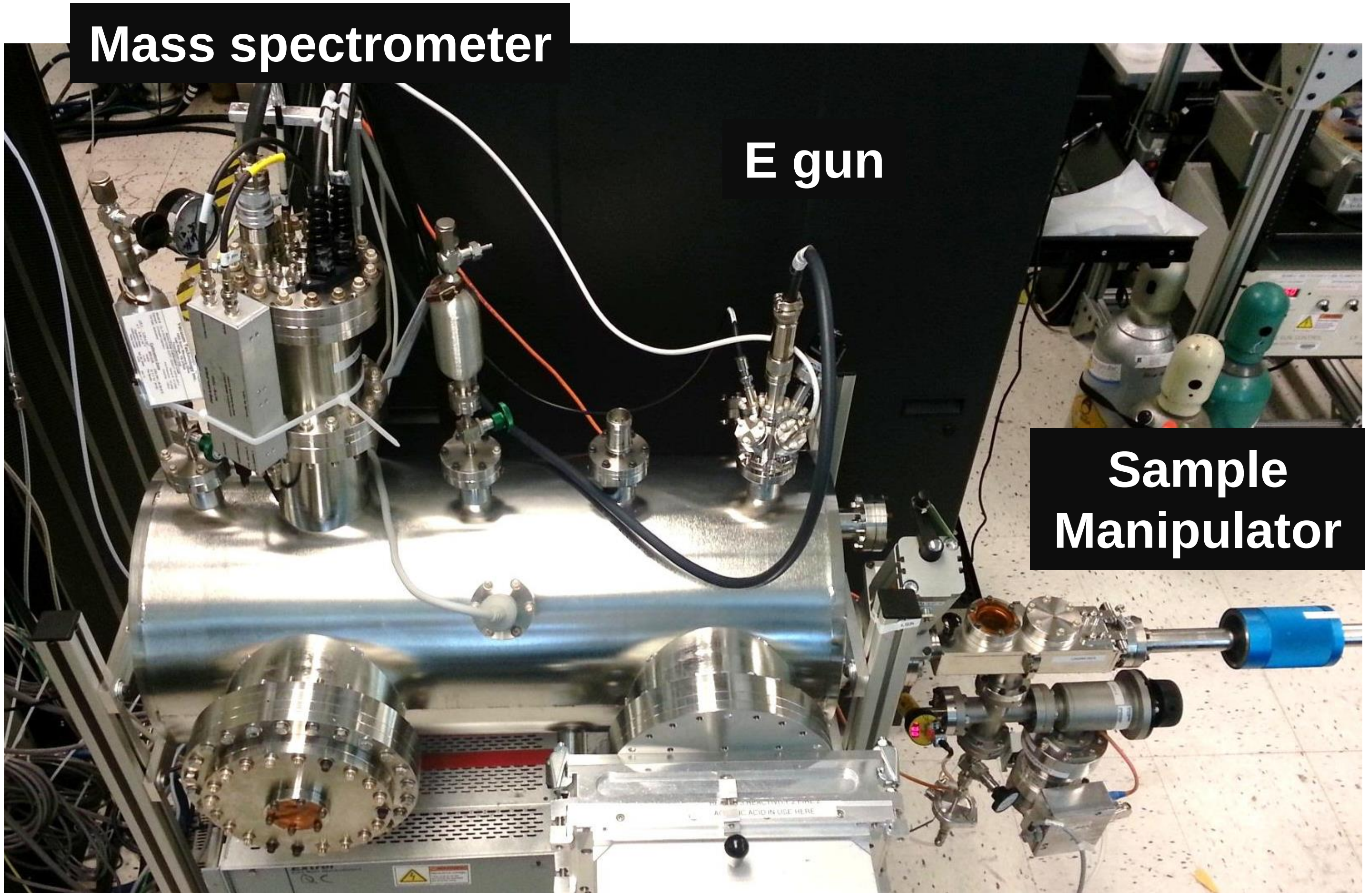

E-Beam Depth Studies
• Development
• Mass Spec.
PAG
• Mechanistic Analysis
• Quantum Yield
Photoelectron Spectroscopy
MODEL
Electron Energy Loss Spectroscopy (EELS)
Inorganic Materials
Different Material Sets/ Molecular Orbital Table
Better EUV Resist Performance:
Higher Quantum Yield, Lower Z-Parameter

E-beam Reaction rate and depth studies



- From the central absorption event, there will be a maximum range of e- movement.
- We measure the range by top down exposures and measure the depth to represent the lateral electron travel away from the EUV absorption site.
- We measure number of reactions by mass spectrometry

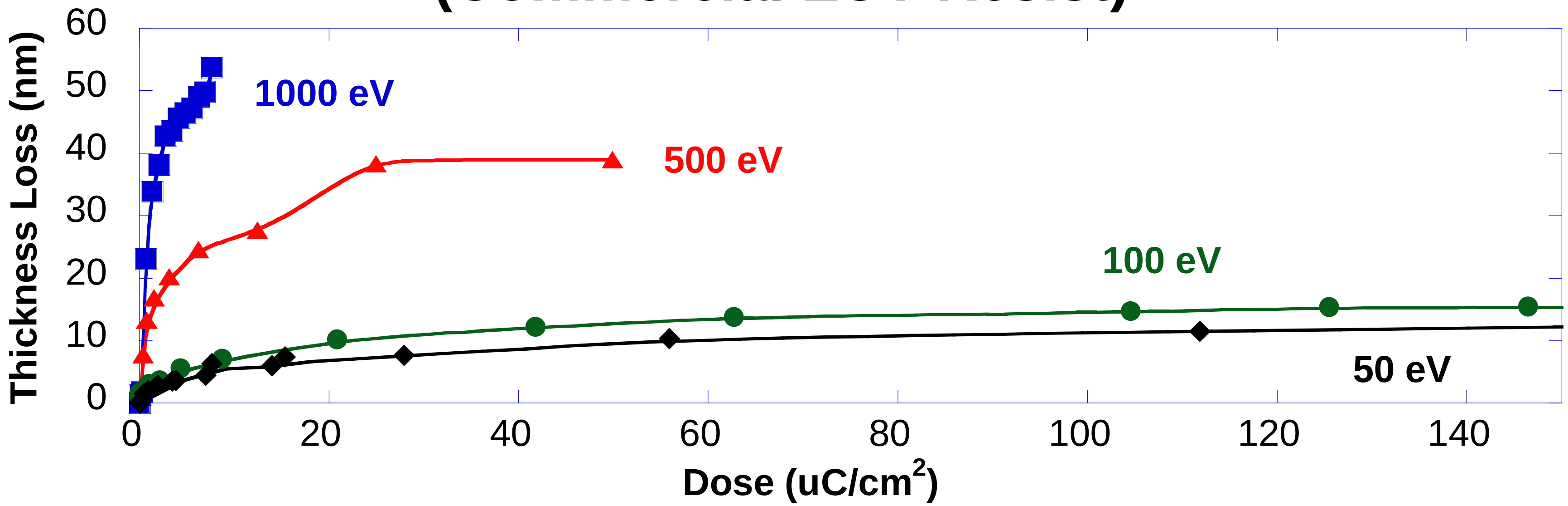
Electron Resist Interaction Chamber (ERIC)

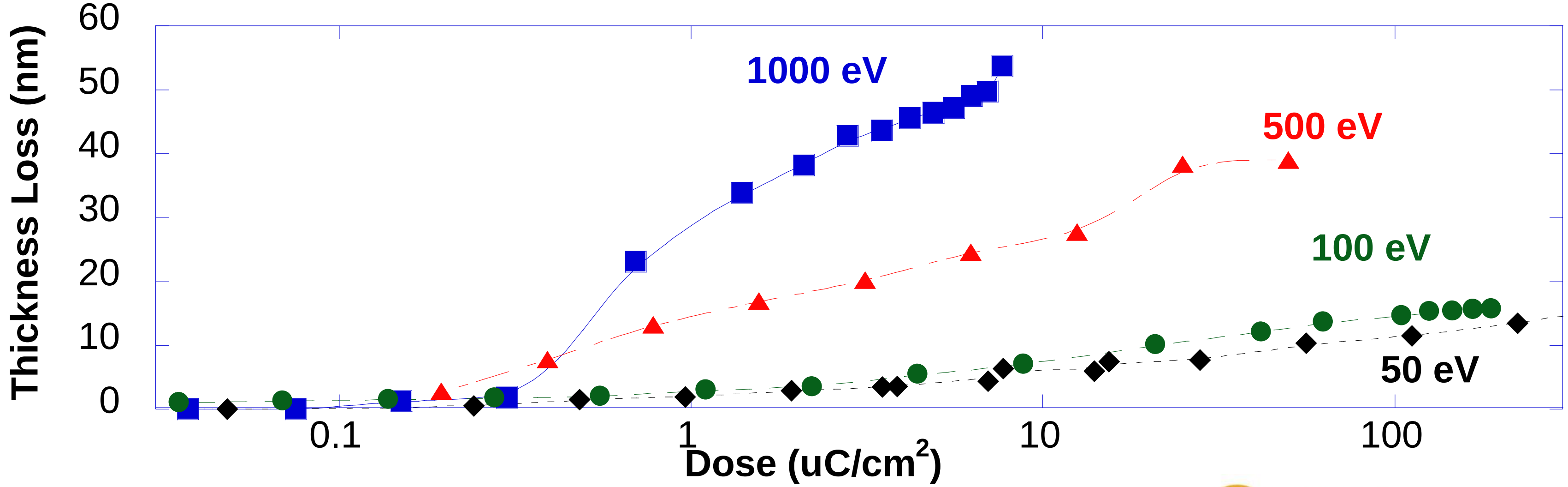


- Expose EUV resist from 80-2000 eV across a wide range of doses and collect real-time outgassing information using mass spectrometry
- Bake and Develop, then measure the thickness lost with ellipsometry

Previous Experimental Results: Thickness Loss vs. Dose

(Commercial EUV Resist)



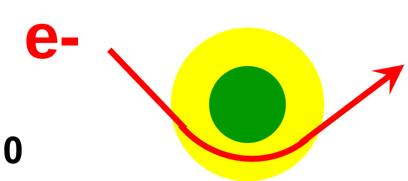


Low Energy Electron Scattering in Solids (LESiS) Monte Carlo Modeling Program

LESiS can start with photons or electrons and map photoelectrons and secondary electrons as they are created and destroyed in a solid film.

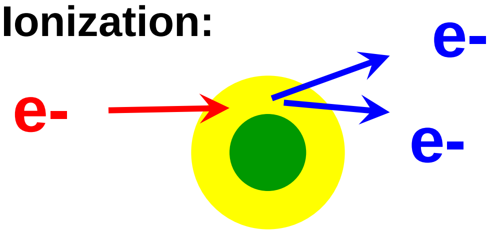
Atomic Interactions Currently Part of the Model:

Elastic Scattering:



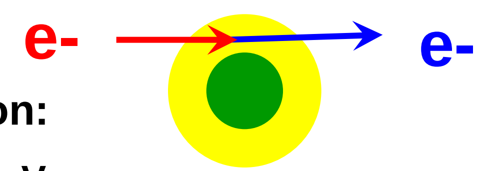
ΔE ≈ 0

Ionization:



ΔE = 10-12 eV
Ionization Energy

Plasmon Generation:



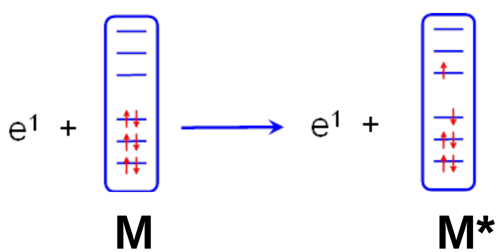
ΔE ≈ 3-12 eV

A plasmon is a wave of bound valence electrons in a solid

= Core Electrons
= Valence Electrons

Currently Not being Included:

Internal Excitation
(Similar to Photolysis)

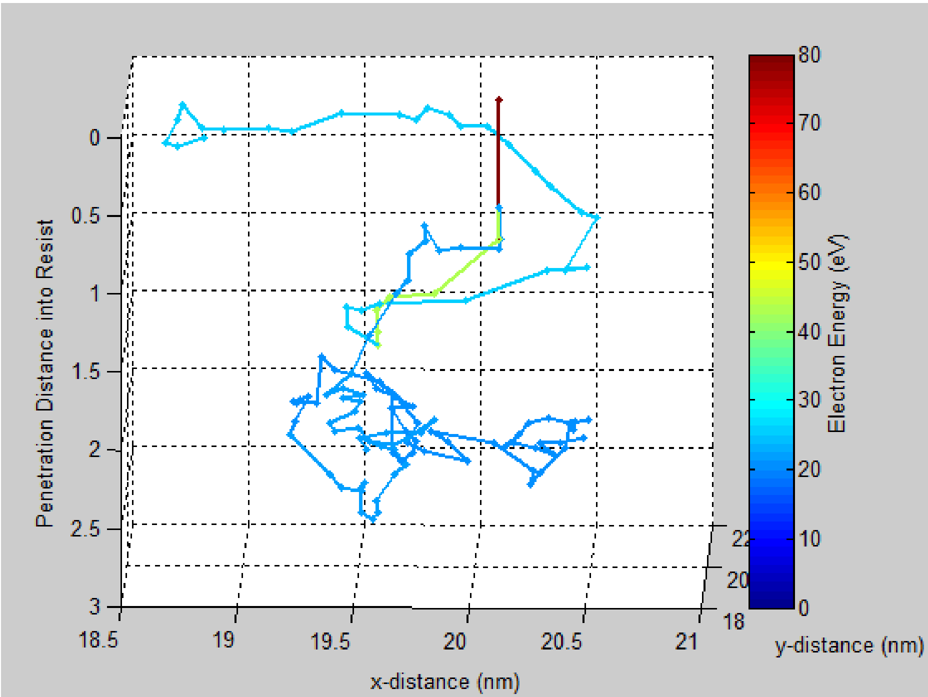


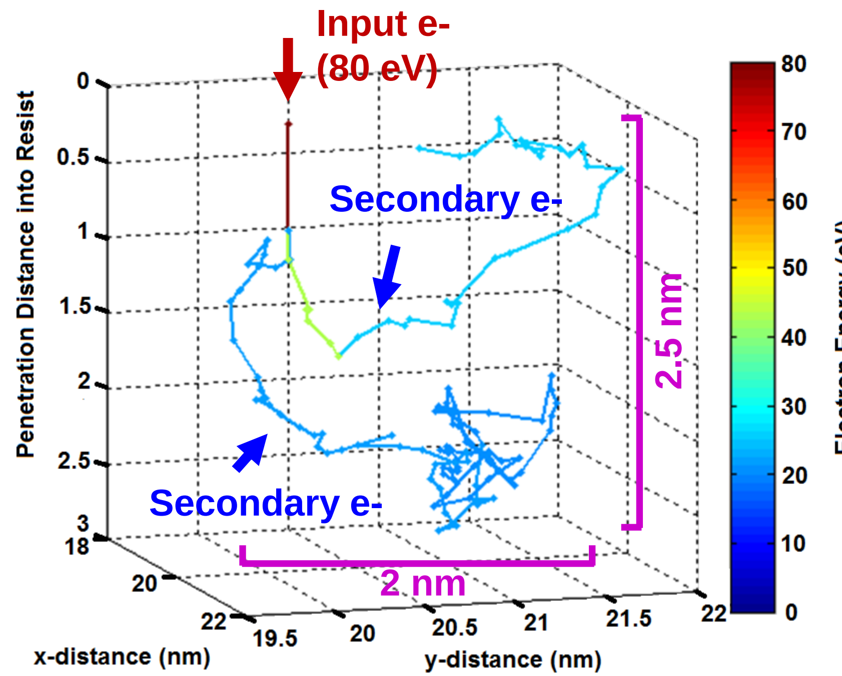
ΔE ≈ 2-3 eV

Also not yet included:

- Molecular interactions
- Creation of Phonons
- Energy lost as heat.

Electron Trajectory Simulations in a Commercial Resist



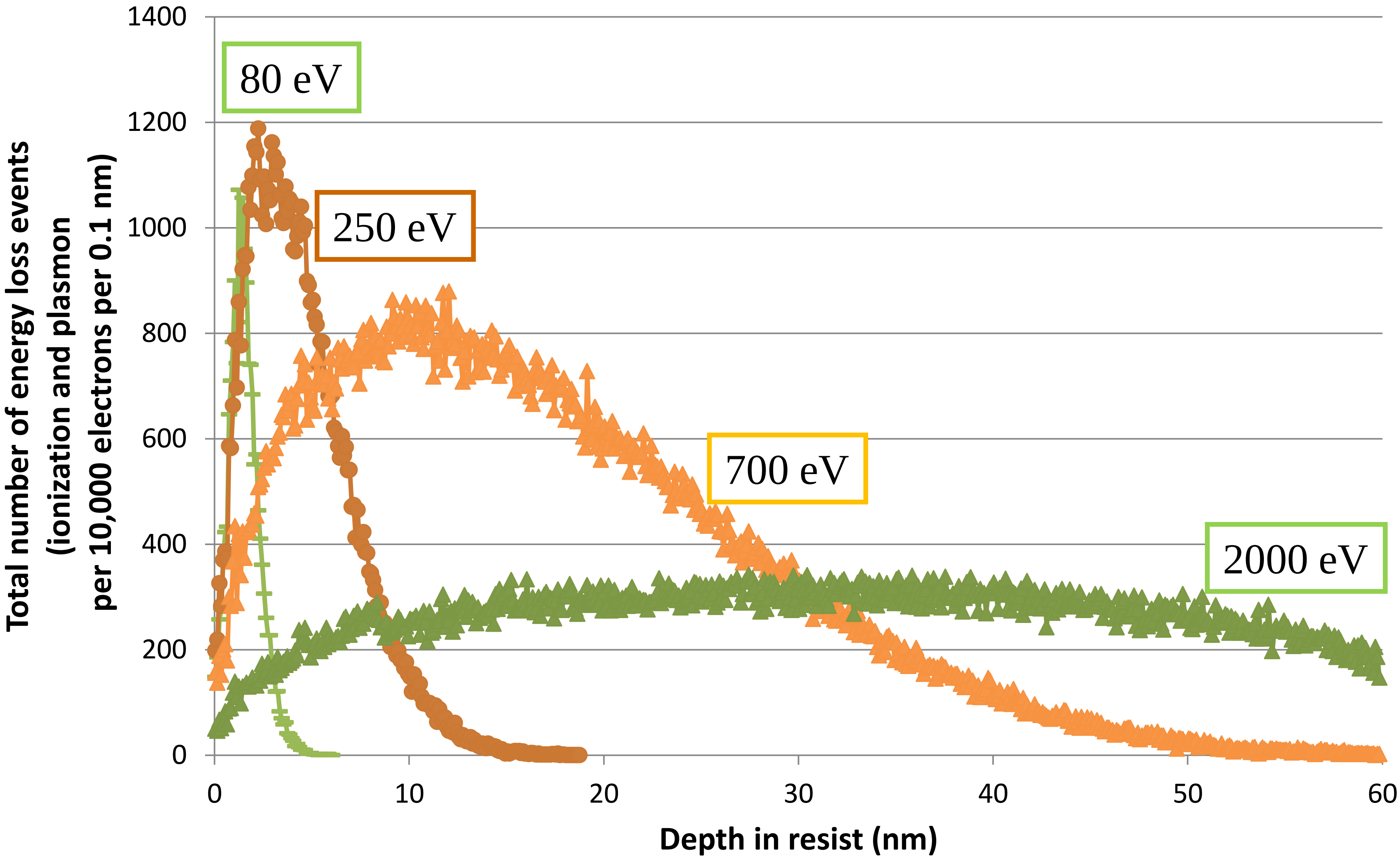


One Secondary is Made:
Two total electrons

e_1^- → e_1^-, e_2^-

Only two electrons are available to react with PAG!

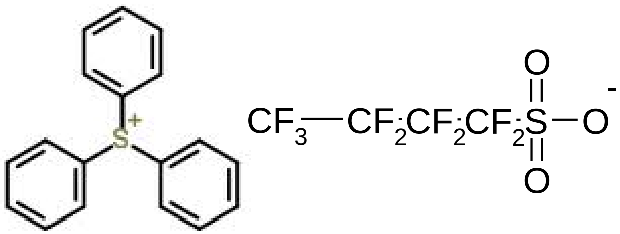
Depth of energy loss events varies with electron energy LESiS simulation



Resist Composition

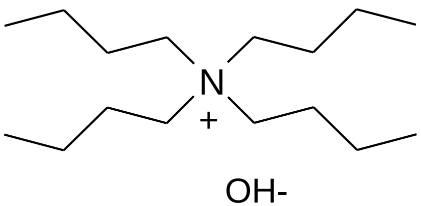
OS4

PAG (15 wt%)

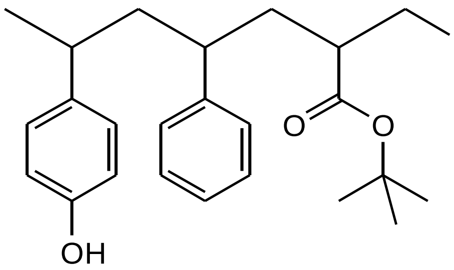


Base

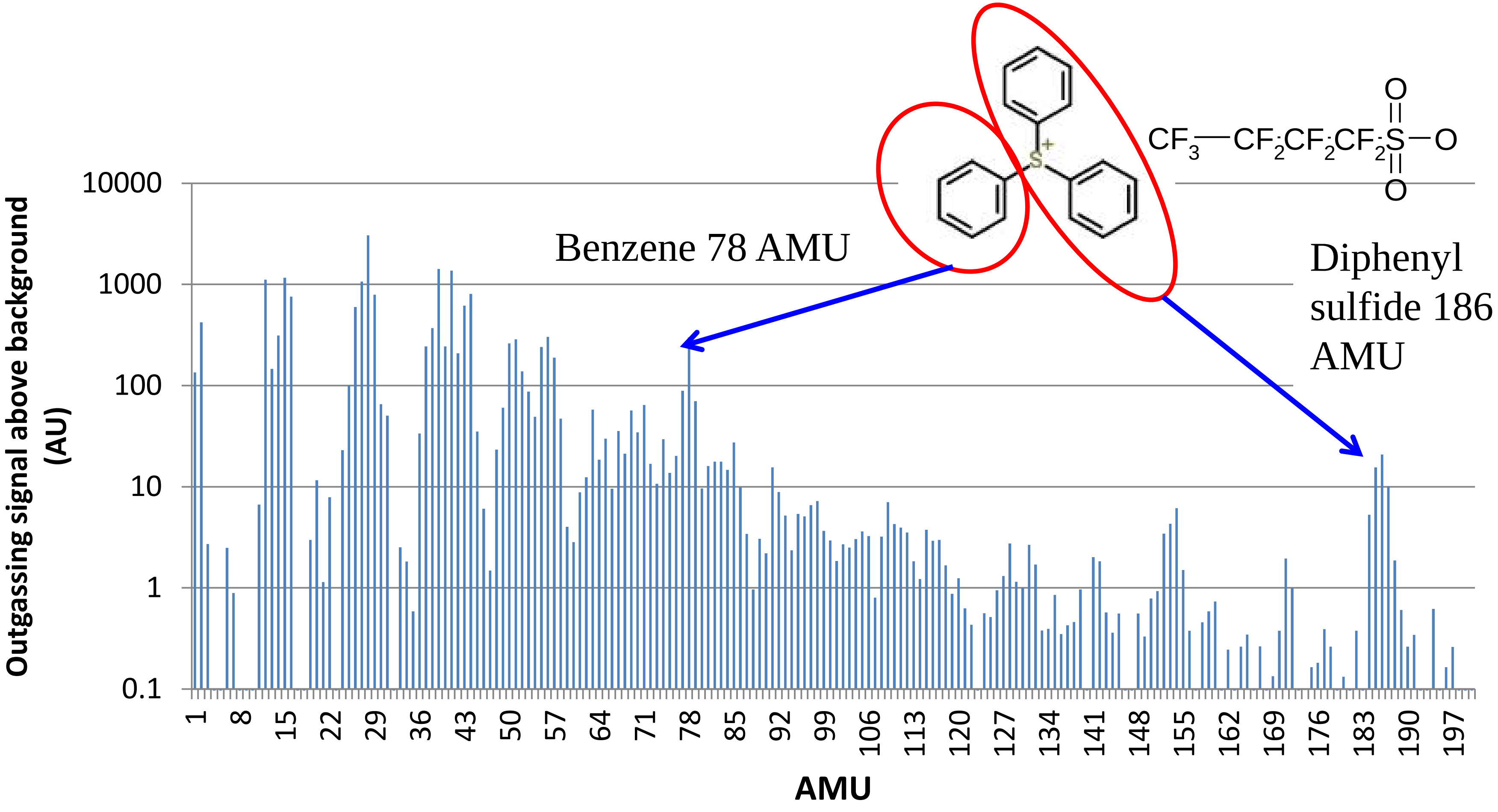
(1.5 wt%)



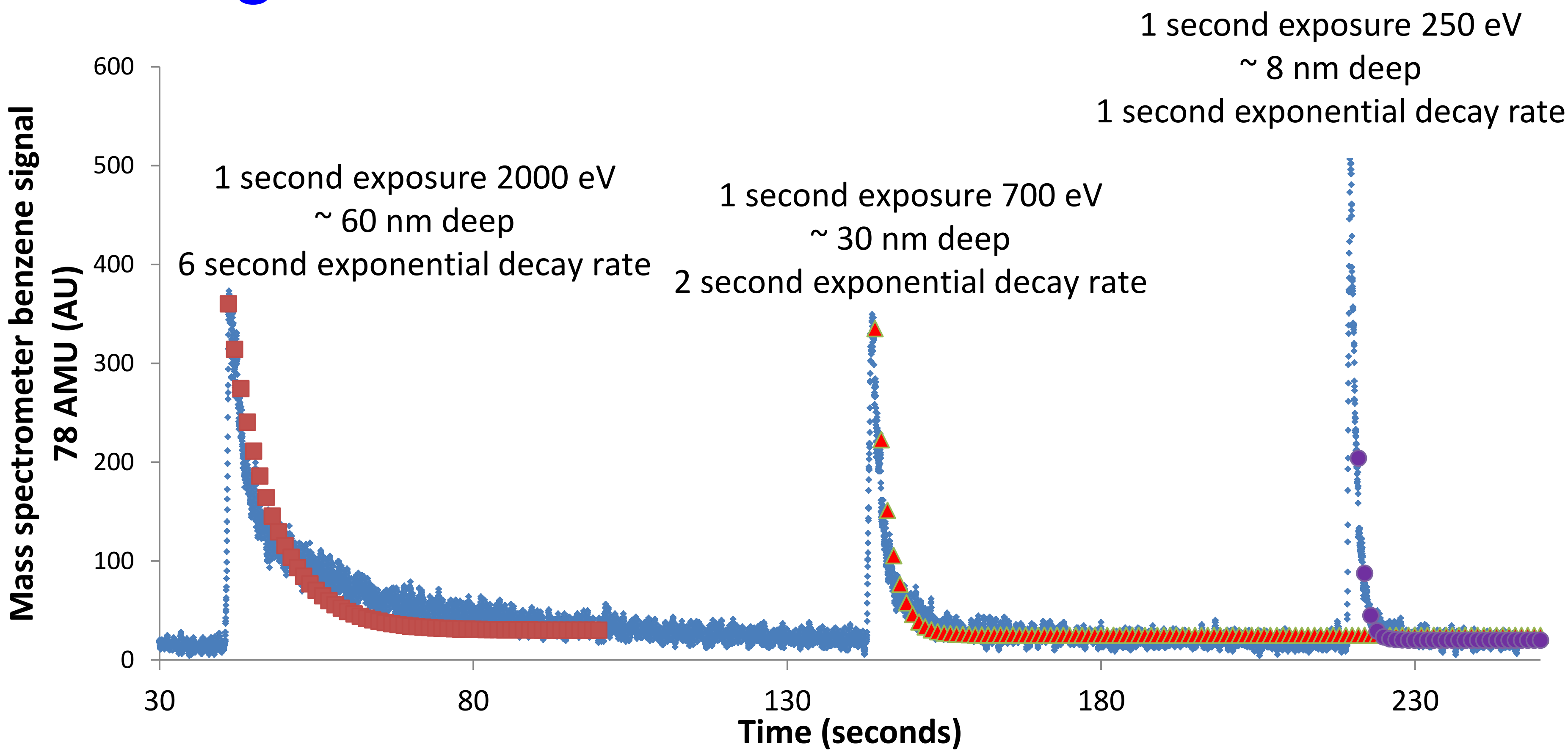
Polymer



Measure the PAG reactions by the outgassing products

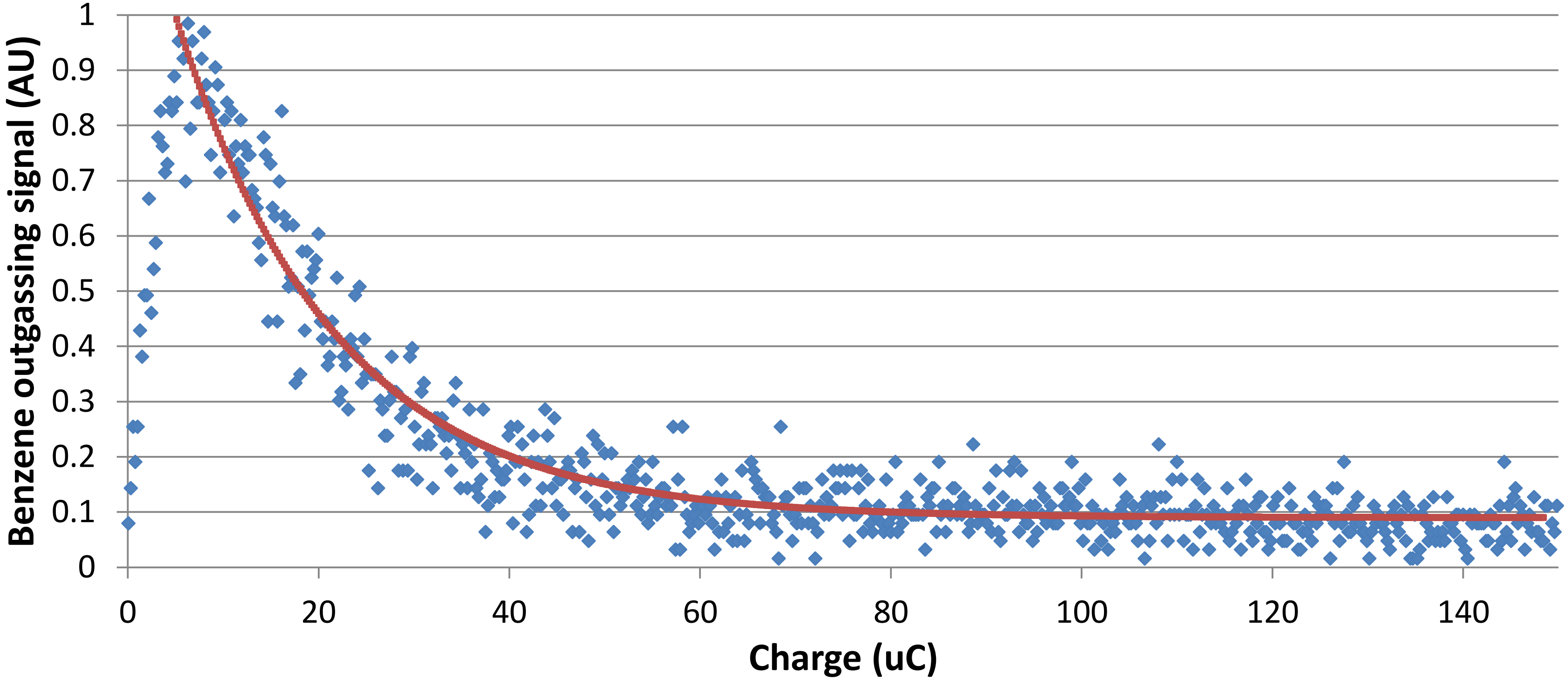


Fast response indicates benzene is a good indicator of PAG reactions



Diffusion through full film is fast enough to be a real time indicator of PAG decomposition reactions

Mass spectrometer signal measures real time PAG concentration

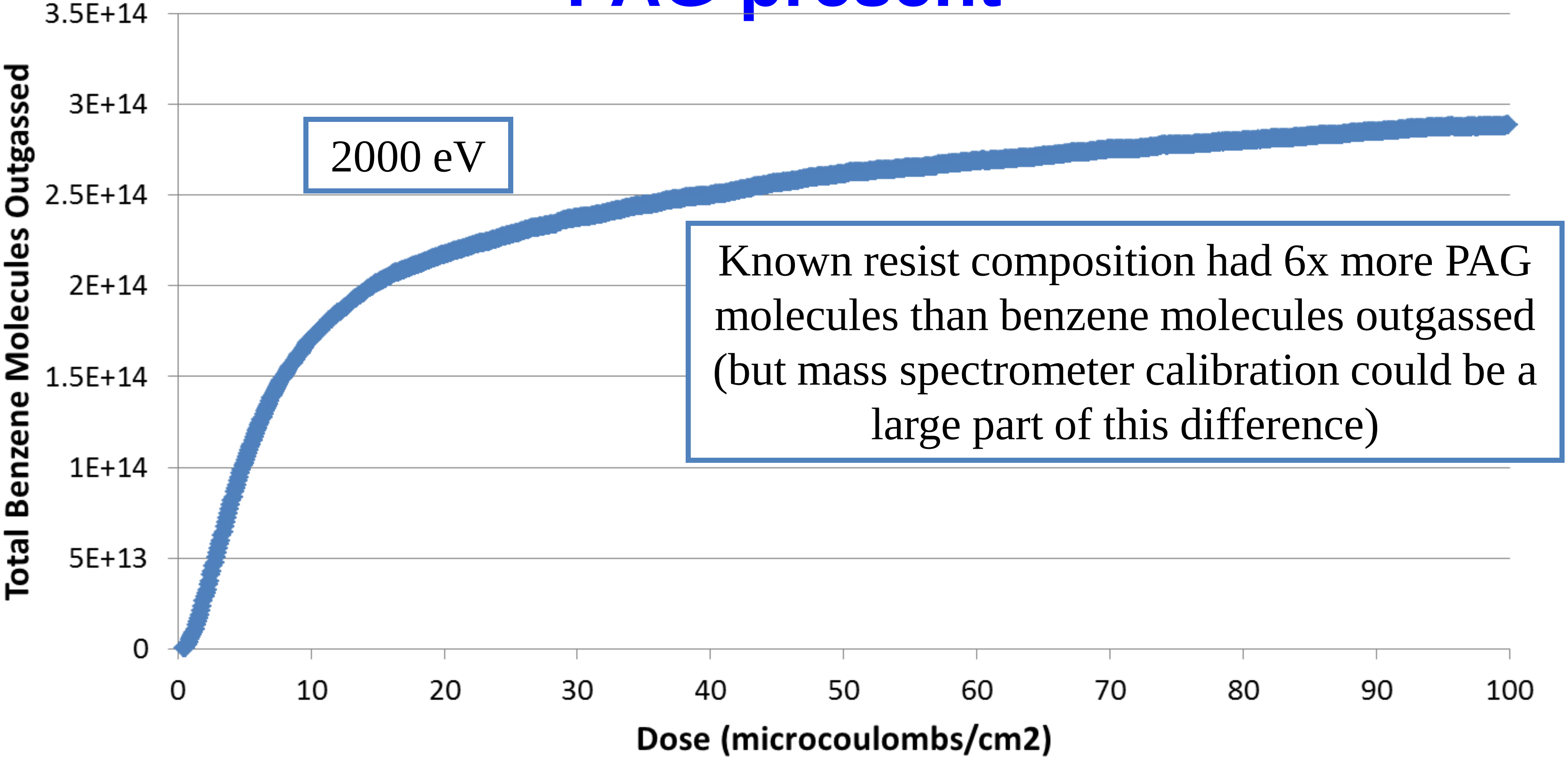


2000 eV electron exposure of 60 nm OS4 resist

Exponential decay during exposure to saturation implies that both:

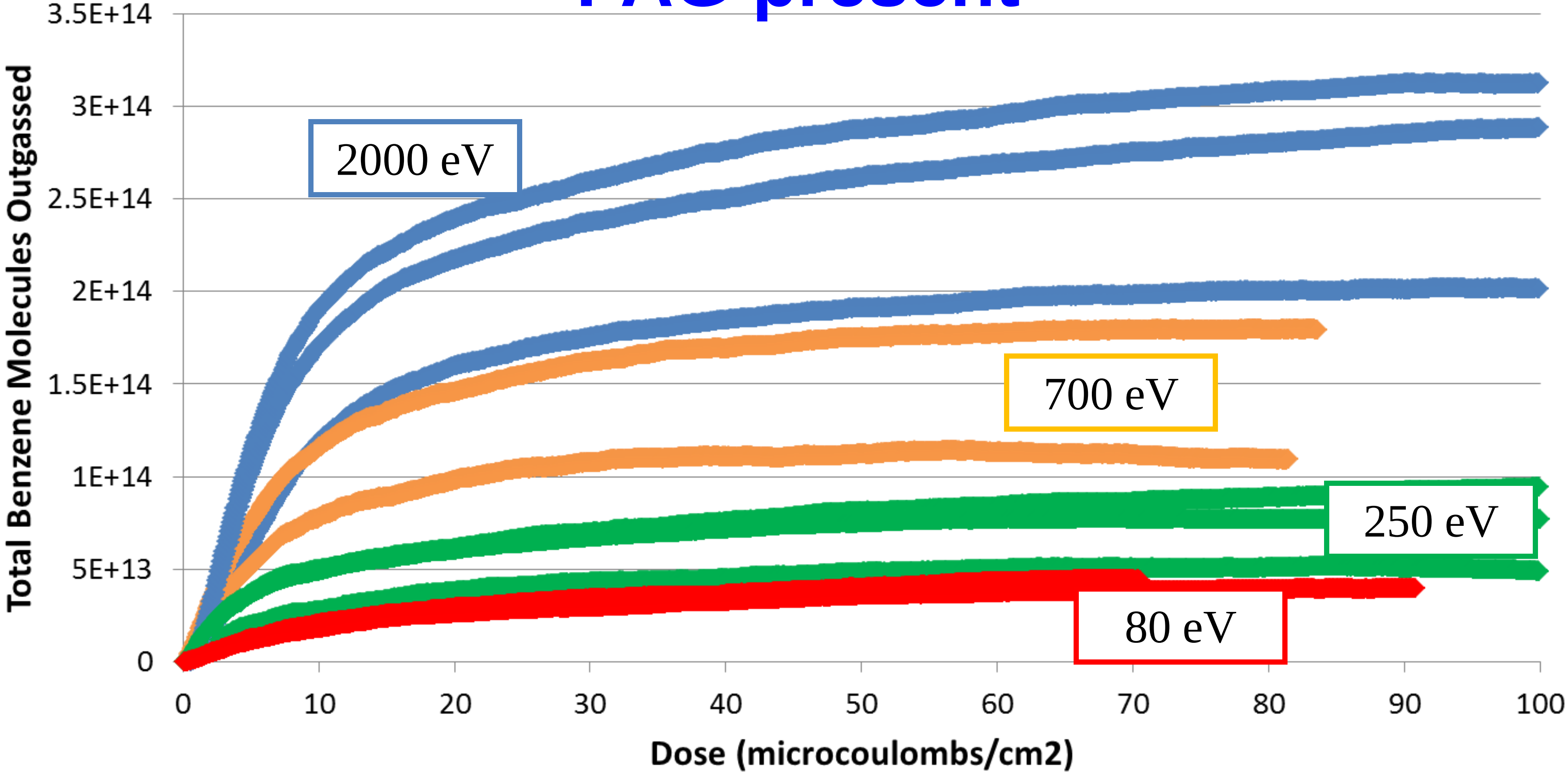
1. PAG decomposition scales with PAG concentration
2. Outgassing directly measures the PAG decomposition reactions

Exposure to saturation to calibrate to total PAG present



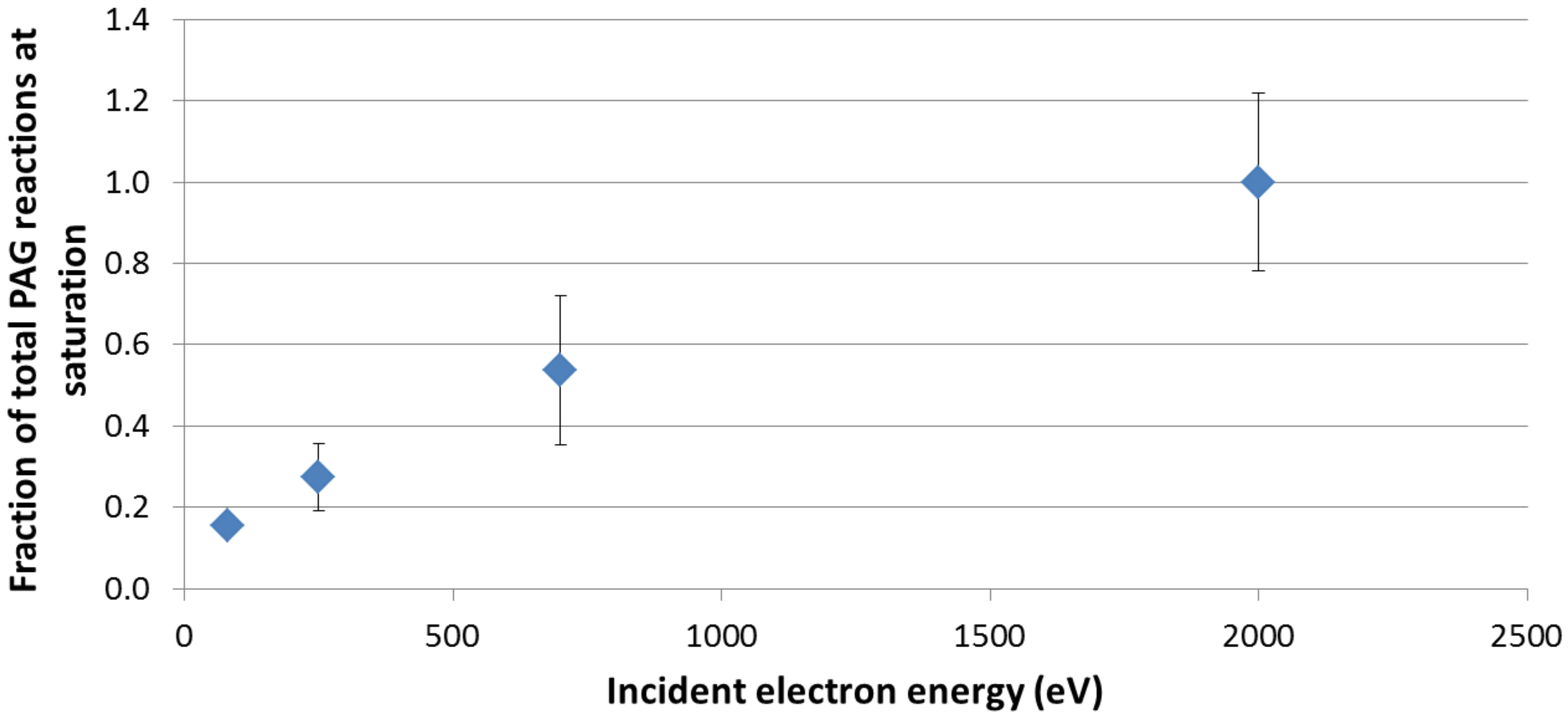
- **<u>Preliminary</u> calibration indicates that for this resist and these process conditions, 6% of the PAG decomposes at E0 (1.1 uC/cm2)**
- **Slope of this curve – PAG reactions per electron is a measure of the efficiency**

Exposure to saturation to calibrate to total PAG present

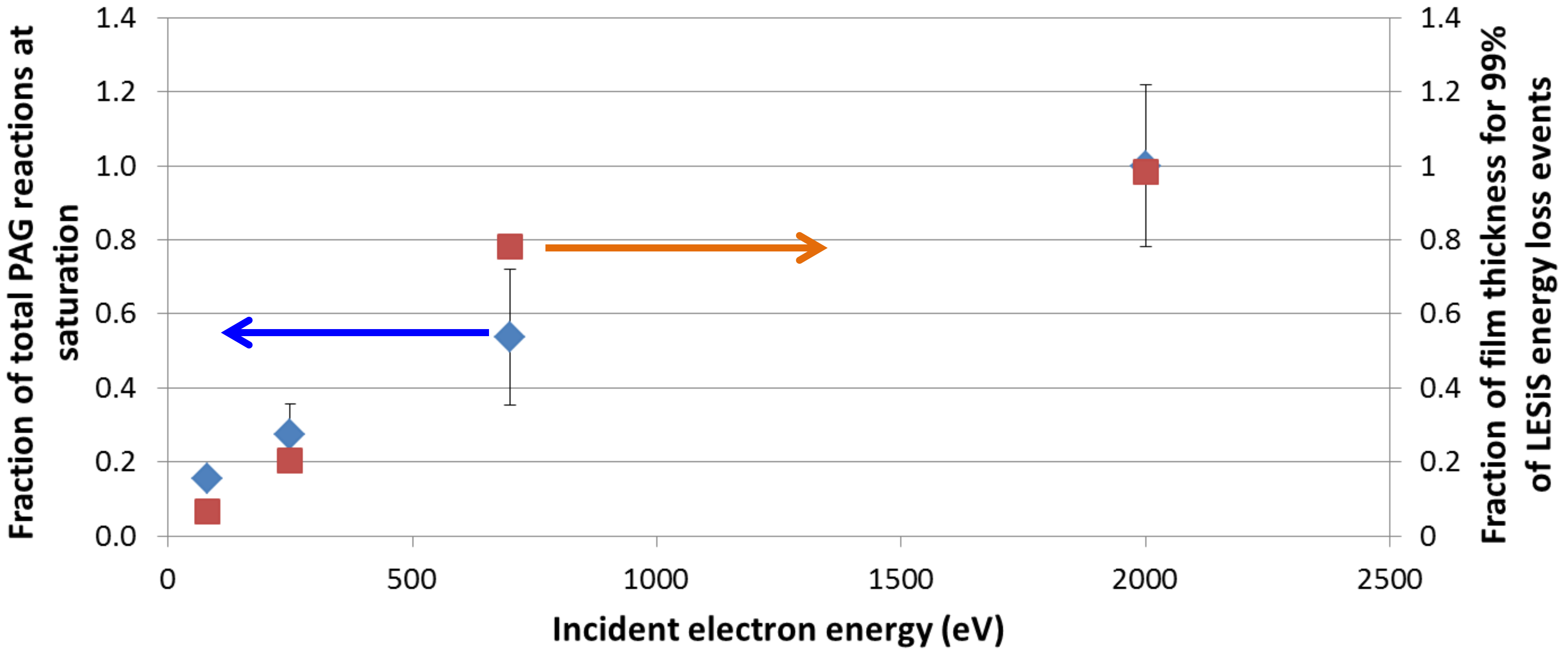


- **The saturation is an indication of the penetration depth of those electrons – if they don't expose the full 60 nm then they don't outgas as many molecules**

Depth of penetration of electrons causing reactions can be measured by number of reactions at saturation

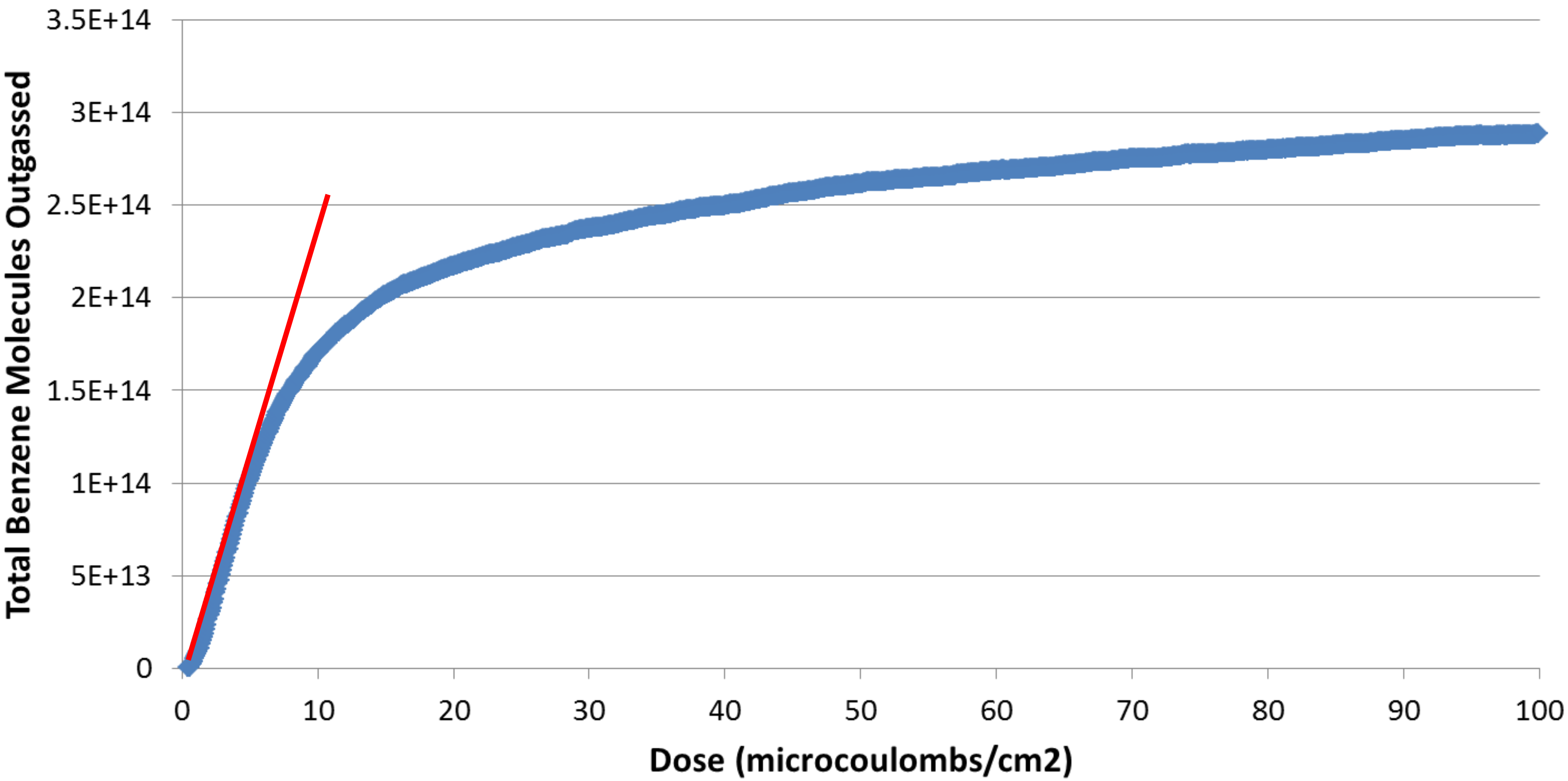


Depth of penetration of electrons causing reactions can be measured by number of reactions at saturation



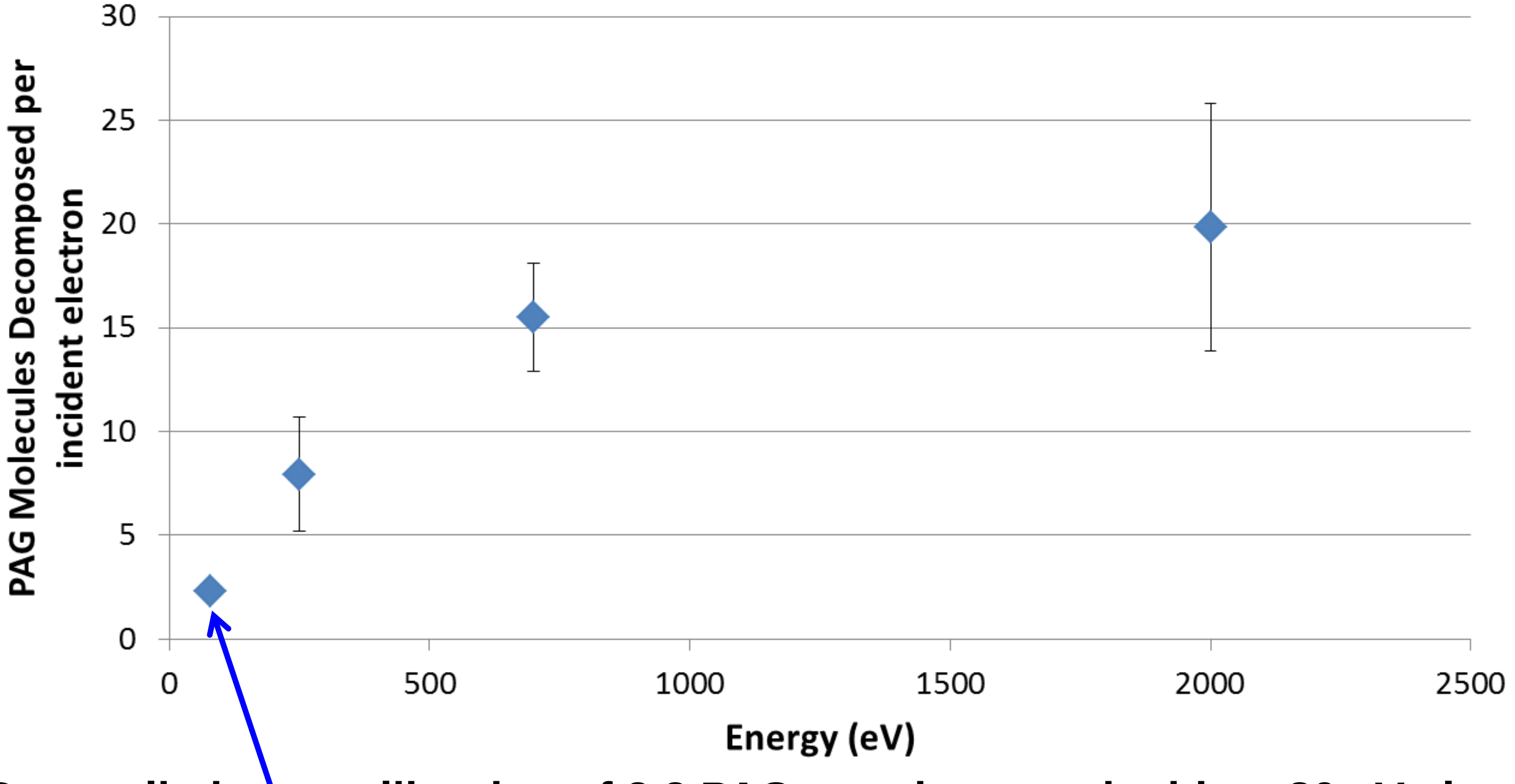
- The depth of penetration measured by saturated outgassing agrees with depth of penetration of the LESiS simulations

Determining the Quantum Efficiency



- **In the linear regime, the slope of this data provides the number of PAG reactions/electron (after the mass spectrometer calibration to total PAG present)**

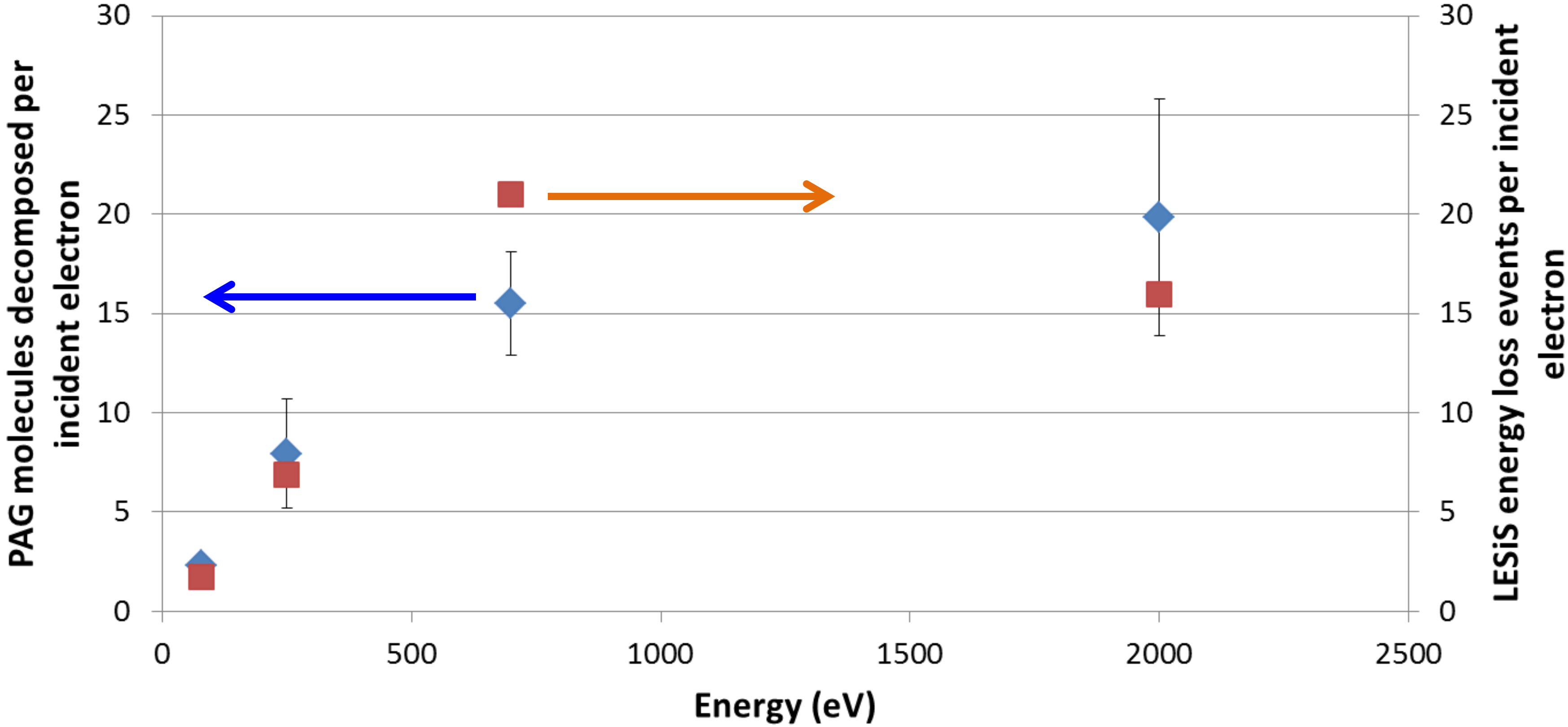
PAG decomposition reactions per incident electron



Our <u>preliminary</u> calibration of 2.3 PAG reactions per incident 80 eV electron is in reasonable agreement with previous measurements for this material of 3.6 H+/absorbed EUV photon

(Craig Higgins, Ph.D. Thesis, 2011 CNSE, University at Albany)

PAG decomposition reactions per incident electron



Good agreement in trends of reaction versus energy between experiment and LESiS simulation

Acknowledgements

Project Funding By:
College of Nanoscale Science and Engineering (CNSE)

Brainard and Denbeaux Group Members:

Craig Higgins

Brian Cardineau

Bill Earley

Yudhishthir Kandel

CNSE:

Tim Groves

Alain Diebold