Measurement of the role of secondary electrons in EUV resist exposures

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International Workshop on EUV Lithography

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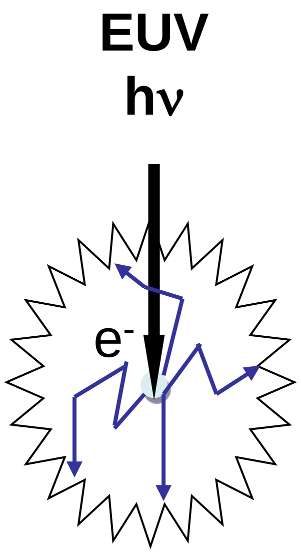
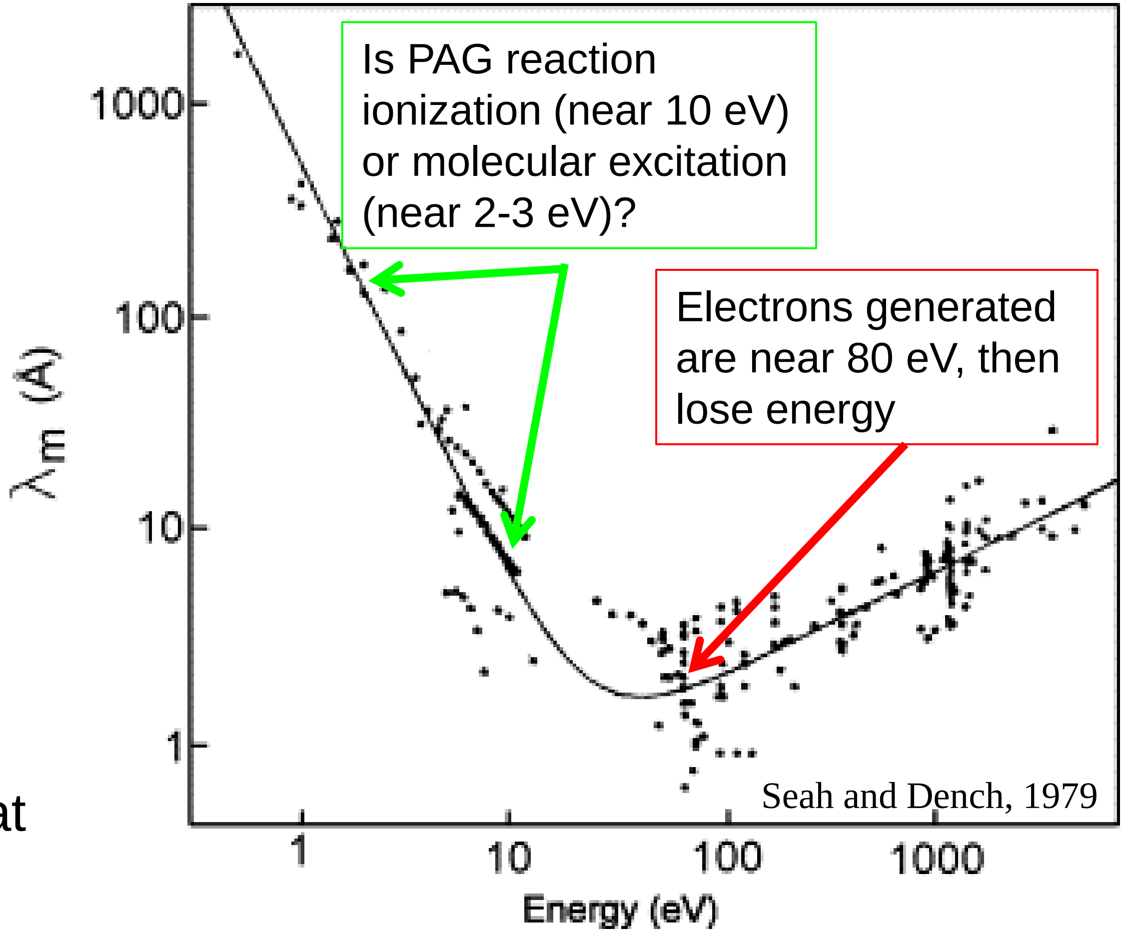
Why we care about electrons for EUV exposures



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

"Universal" curve for electron inelastic mean free path (IMFP)



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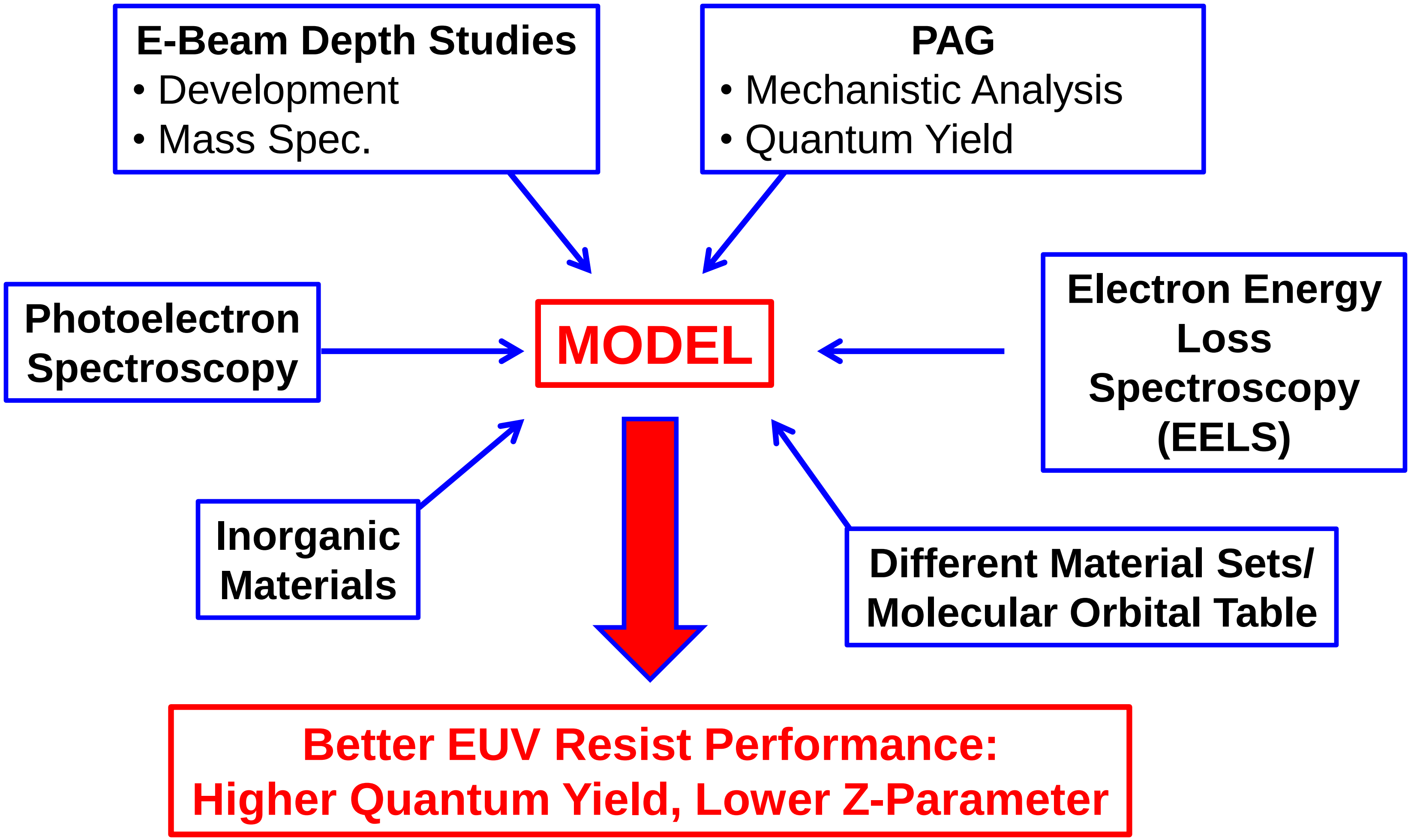
Secondary electron program overview



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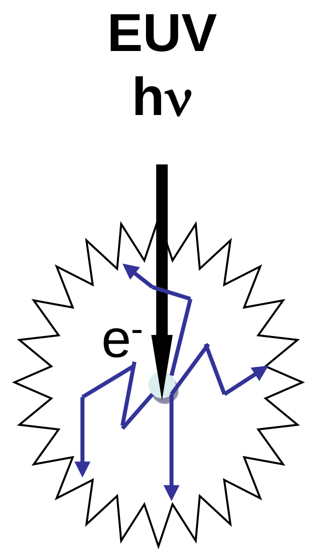
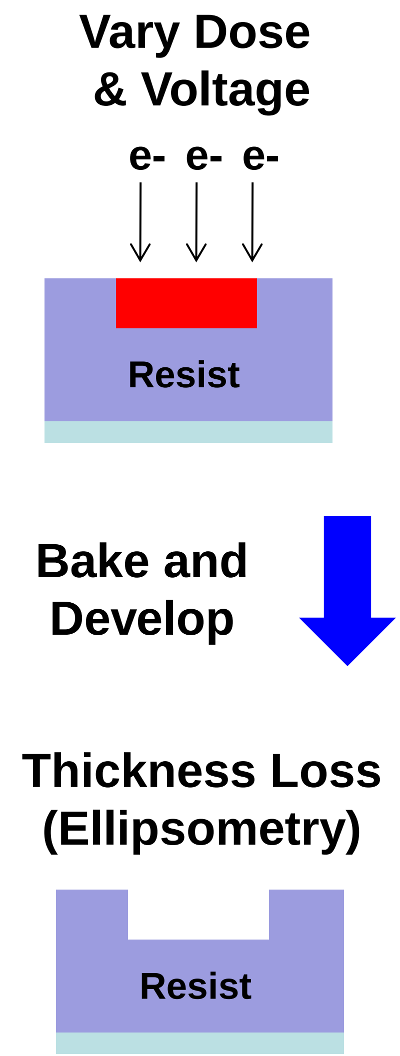
E-beam depth of penetration studies

How far do they go?

Important for understanding Resolution and LER

- From the central absorption event, there will be a maximum range (laterally) for the electrons.
- We measure the range by top down exposures and measuring the depth to represent the lateral electron travel away from the EUV absorption site in real exposures.

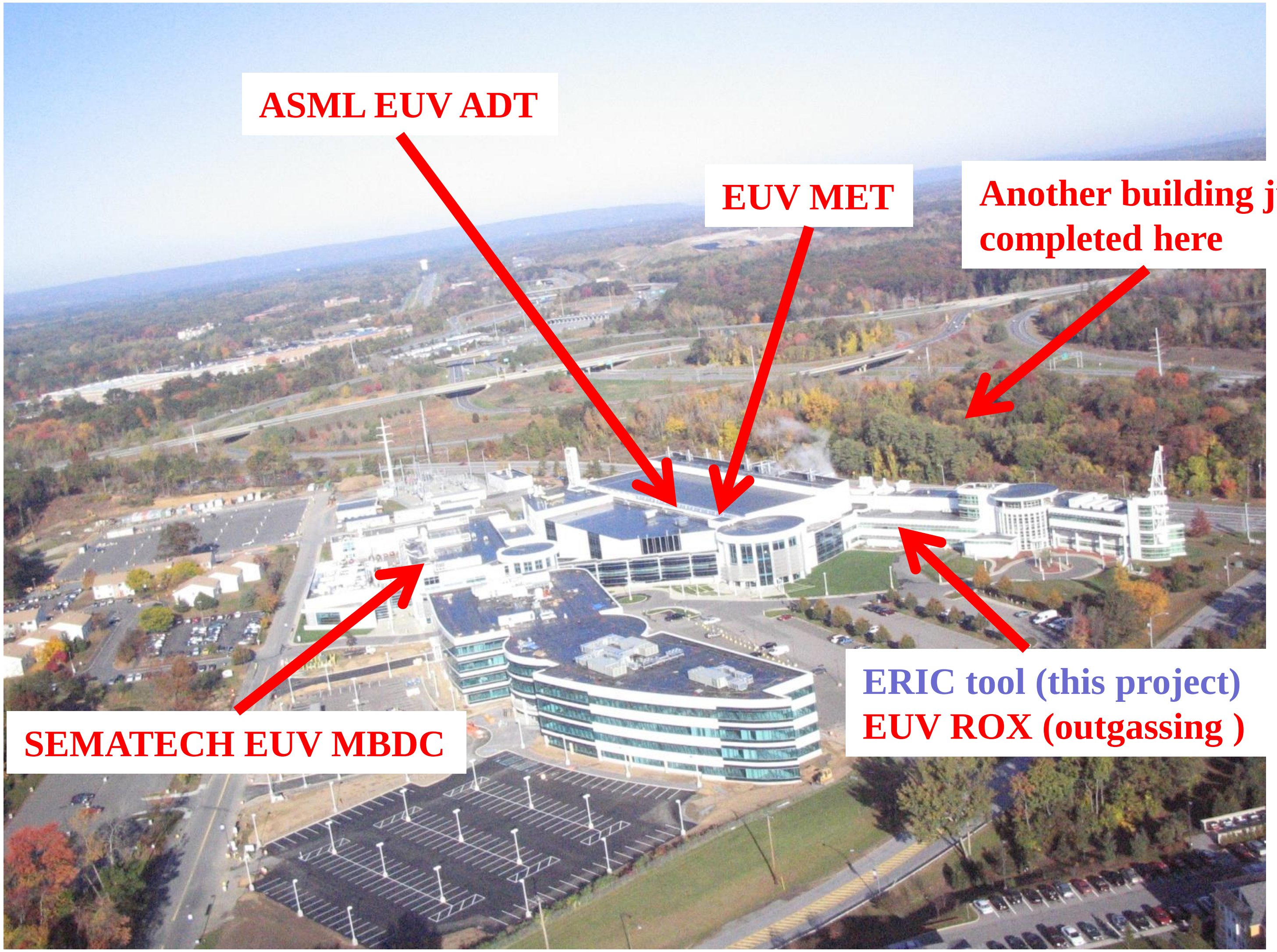




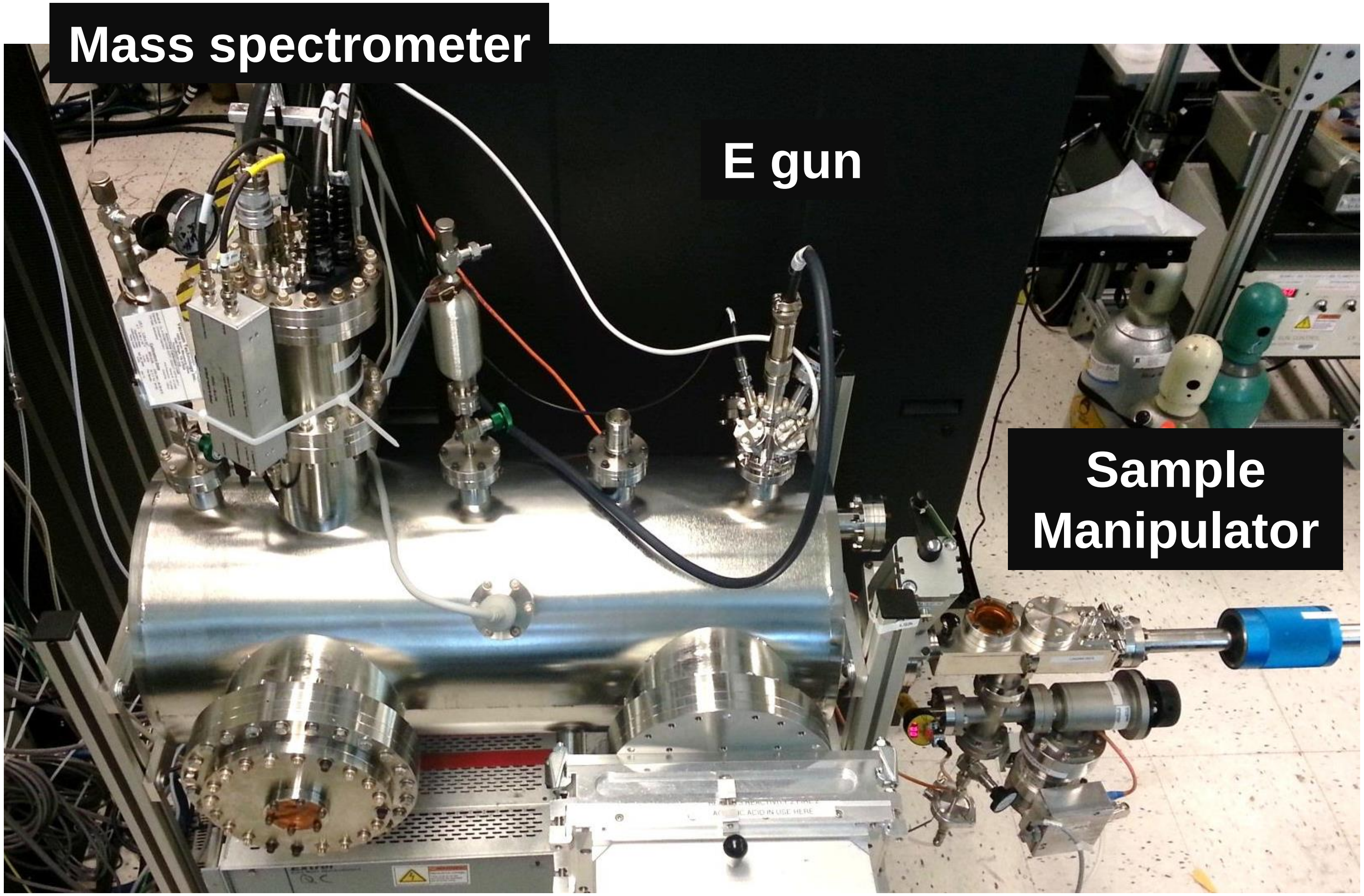
E-Beam Penetration Study:

- Expose commercial CAMP resist with 5-2000 eV Electrons
- Bake, develop and measure penetration using Spectroscopic Ellipsometry

The CNSE facility



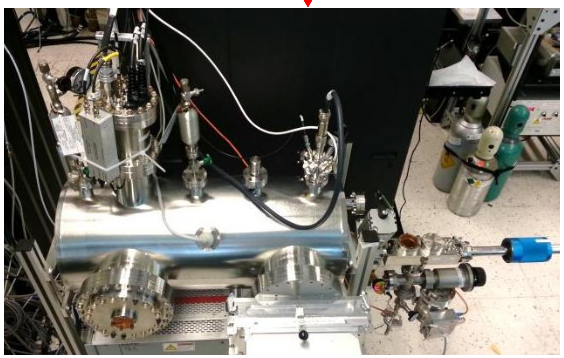
Electron Resist Interaction Chamber (ERIC)

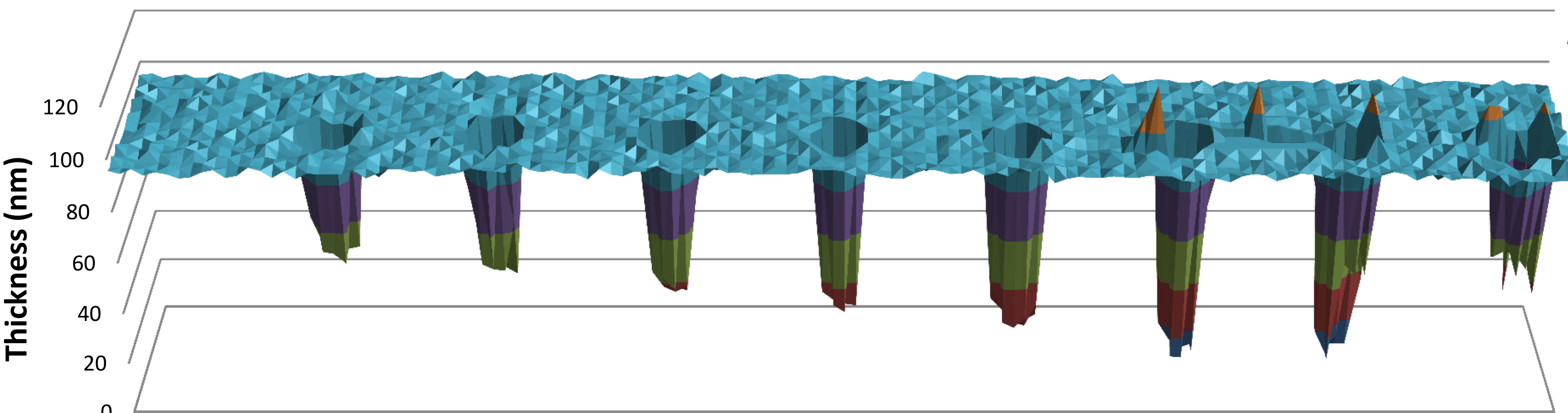


- Expose resist from 5-2000 eV across a range of doses.
- Bake and Develop
- Measure the thickness lost with ellipsometry (Woollam M-2000)

Process flow for depth measurements

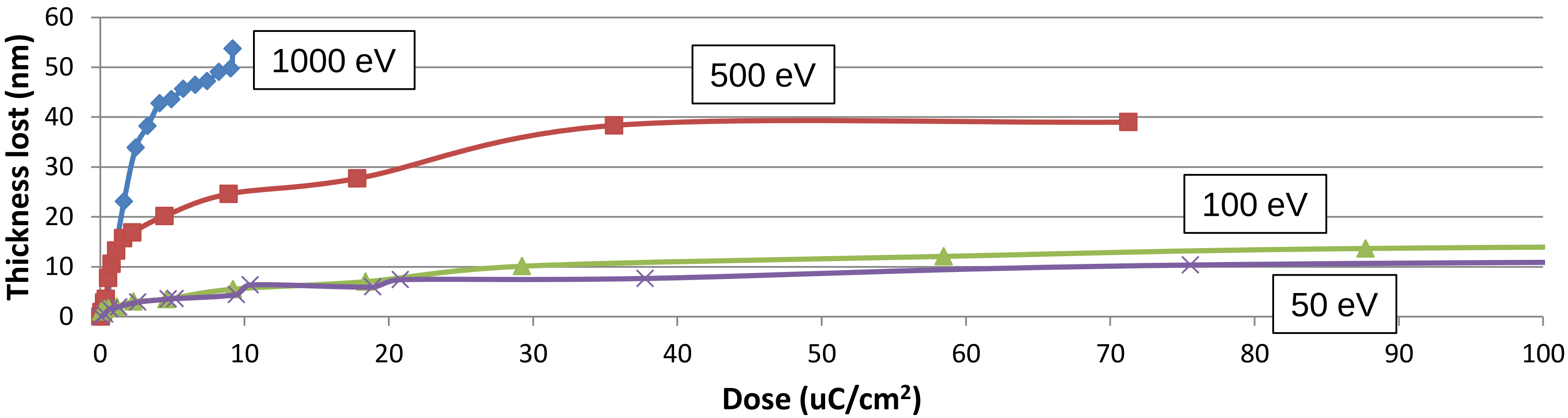
Expose (vary energy and dose) → Bake and develop → Ellipsometry for thickness measurement

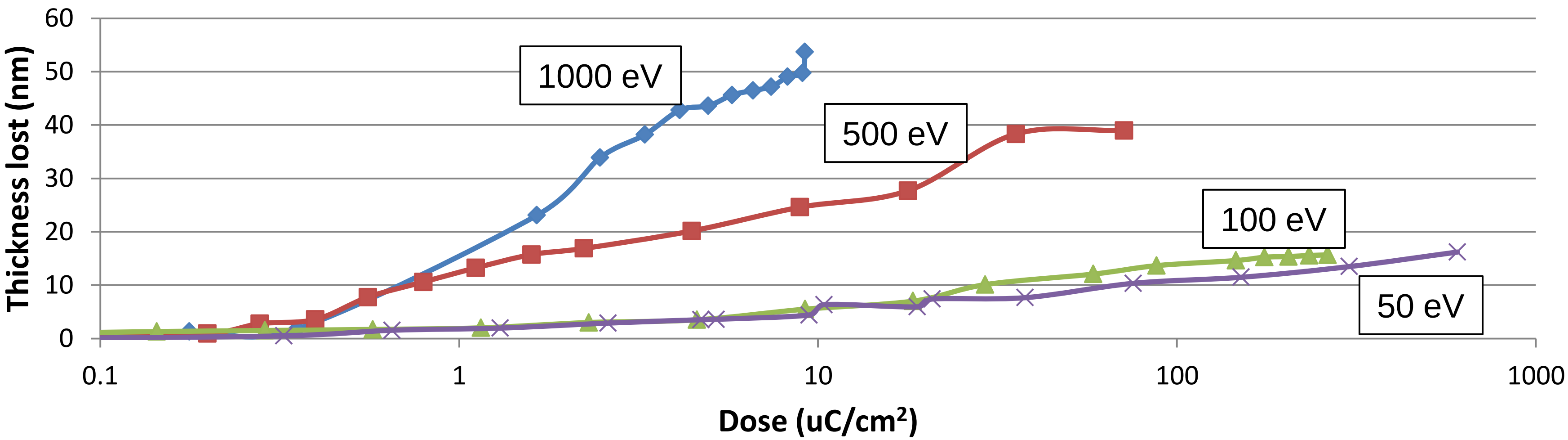




Thickness lost is where sufficient reactions occur – not final stopping point of electrons

Electron penetration results – commercial resist

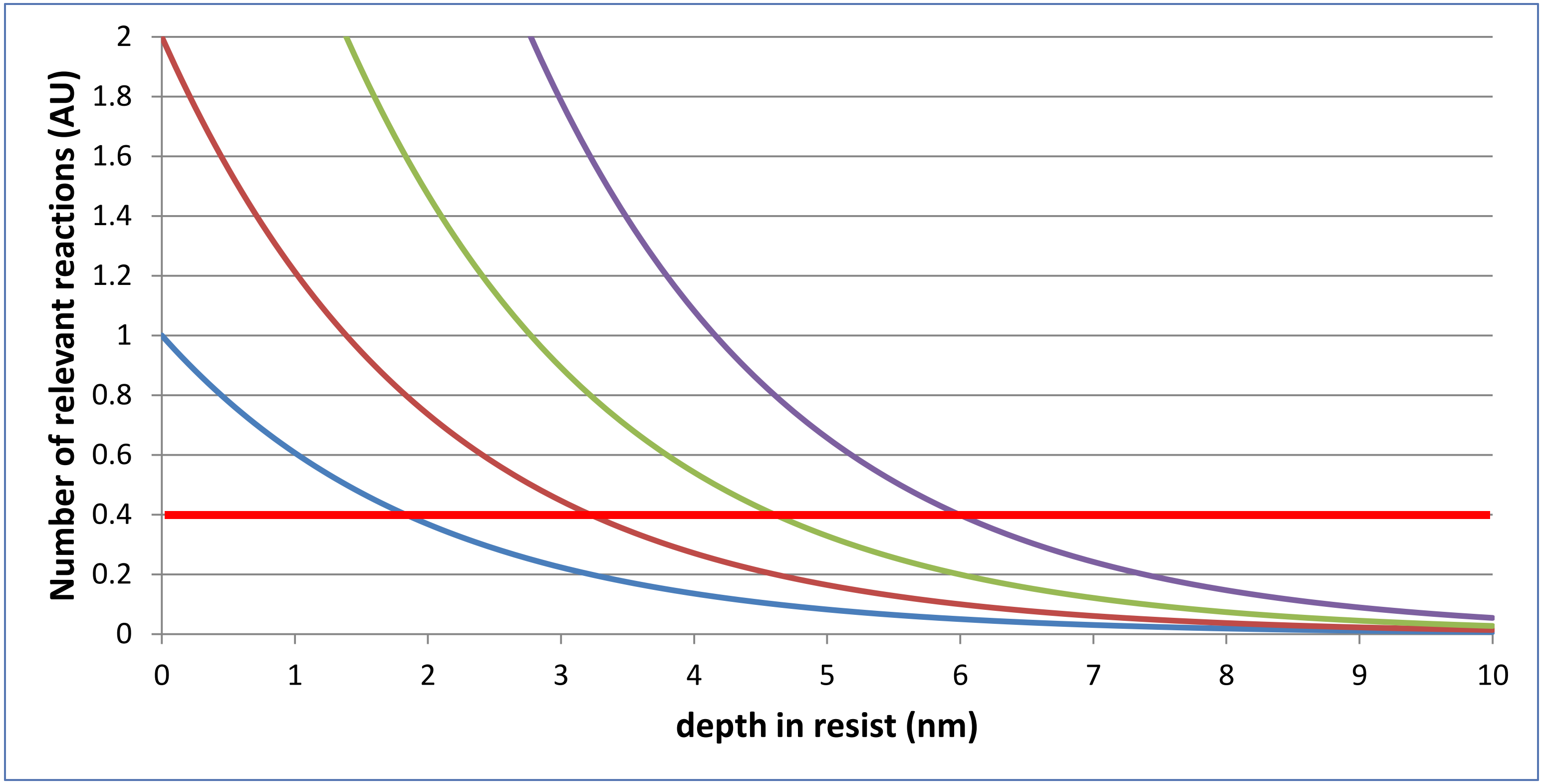




Higher energies penetrate deeper in resist – as expected
Thickness loss doesn't saturate – indicating statistical distribution of electron penetration

Determine relevant reactions from penetration measurement

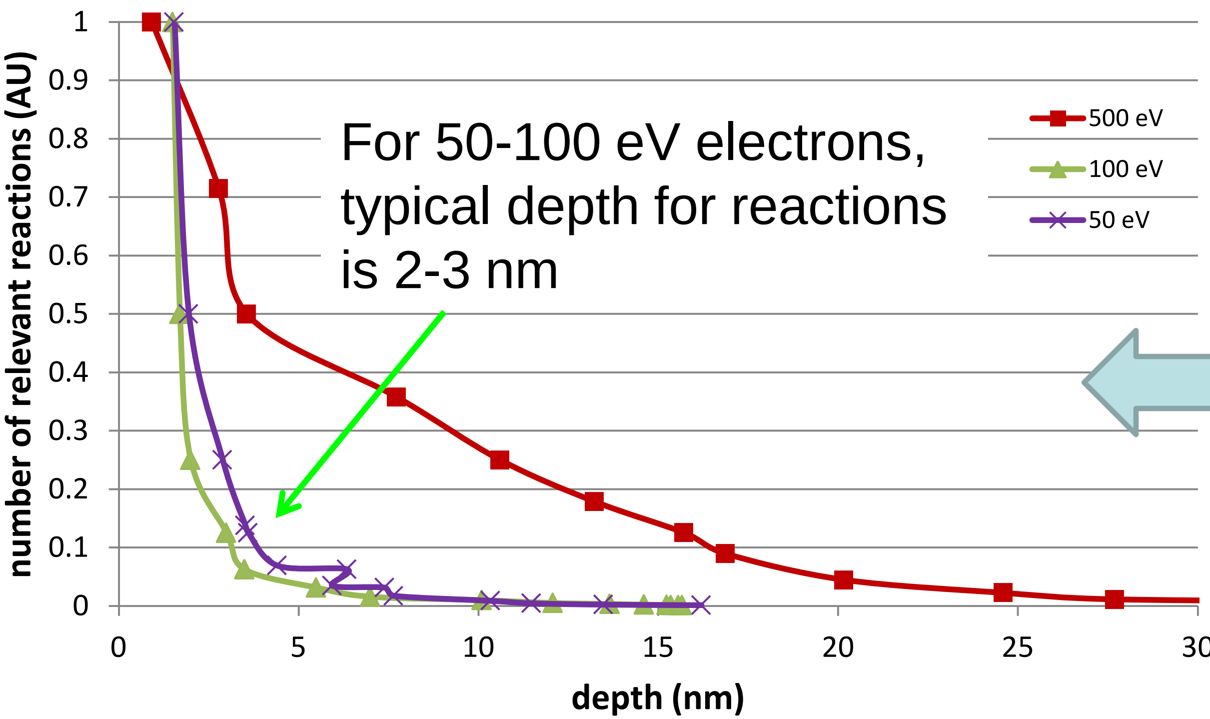
Illustration of process to measure relevant reactions at each depth from thickness loss



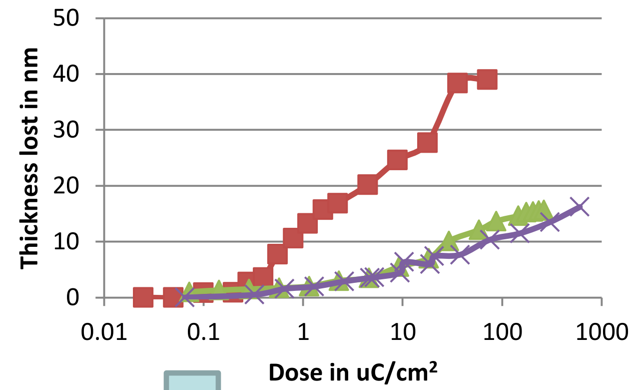
Assume there is a threshold number of reactions for clearing
Assume higher doses doesn't physically change structure

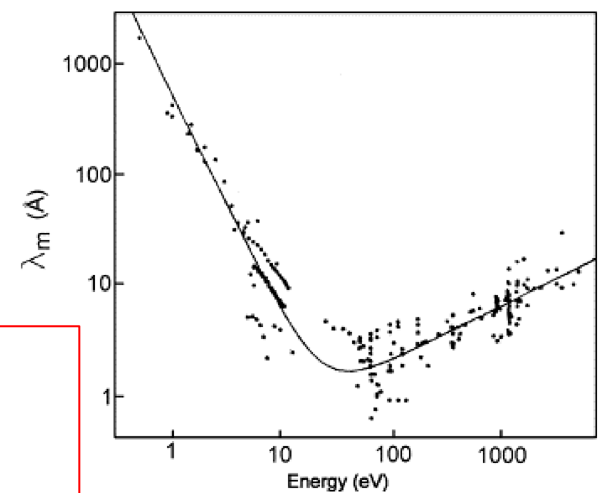
Determine relevant reaction depth

Results from measurement of commercial resist



For 50-100 eV electrons, typical depth for reactions is 2-3 nm





Result indicates that electron energy for reactions with PAG occur near 5-10 eV – or the electrons would cause reactions deeper in the resist

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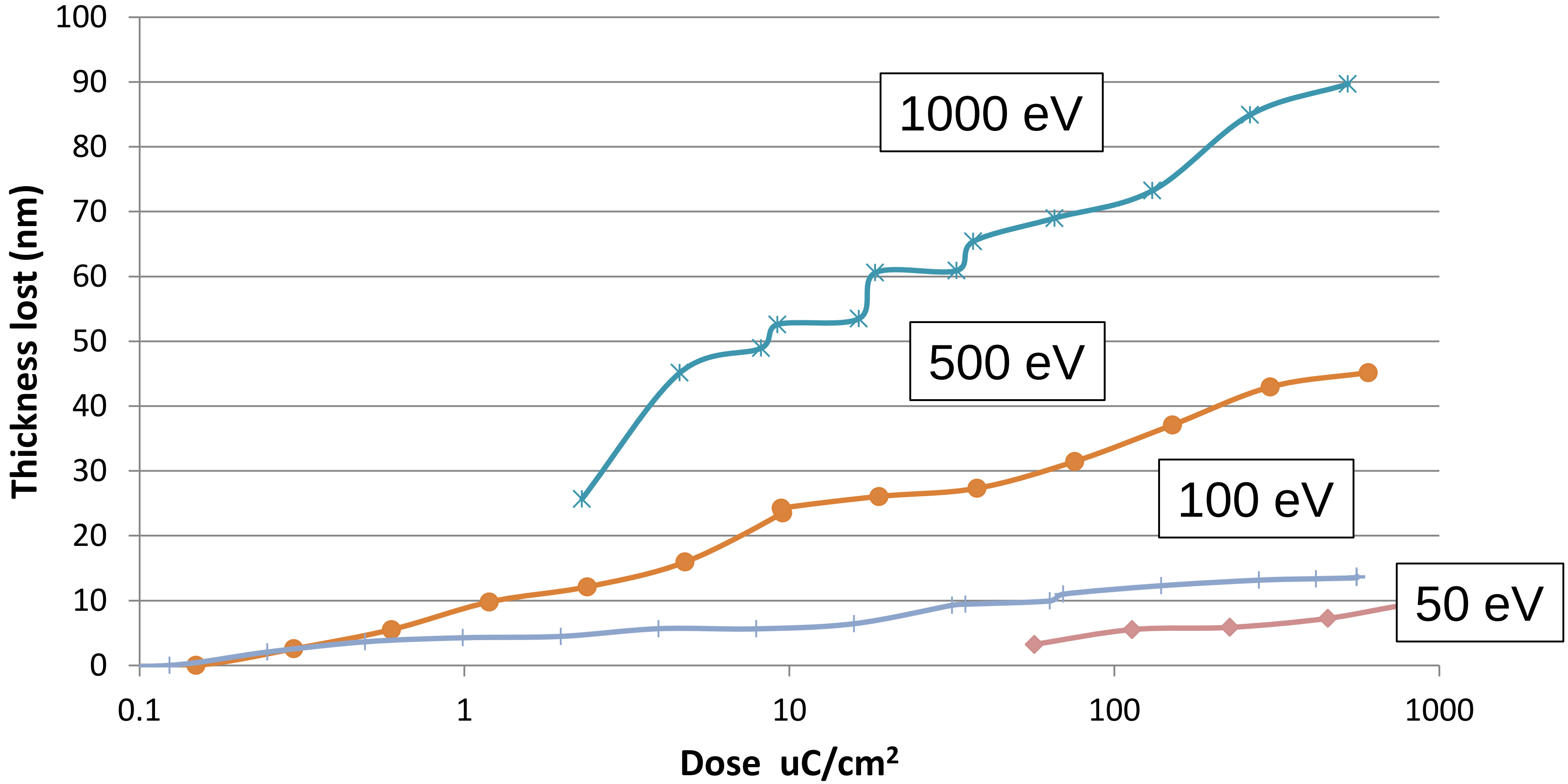
Similar result for PMMA

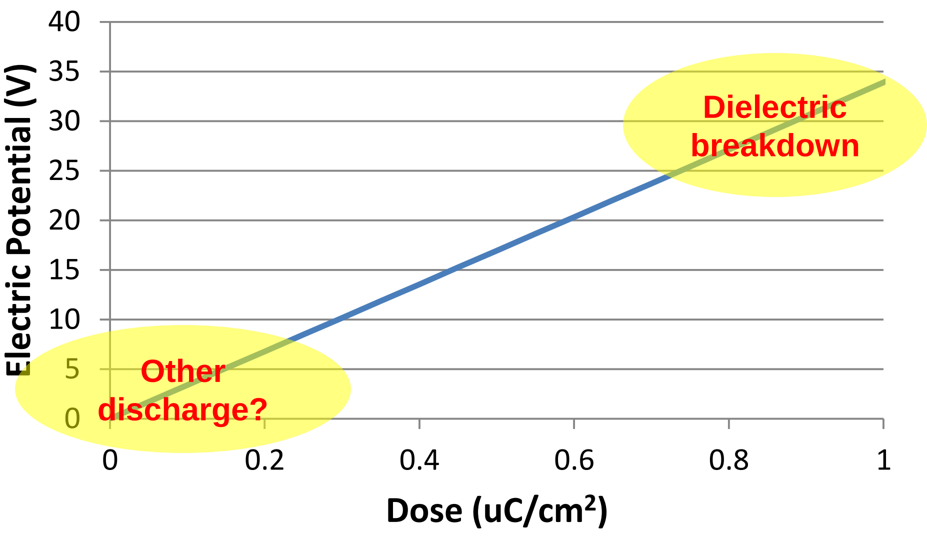


Method works for resists regardless of resist design

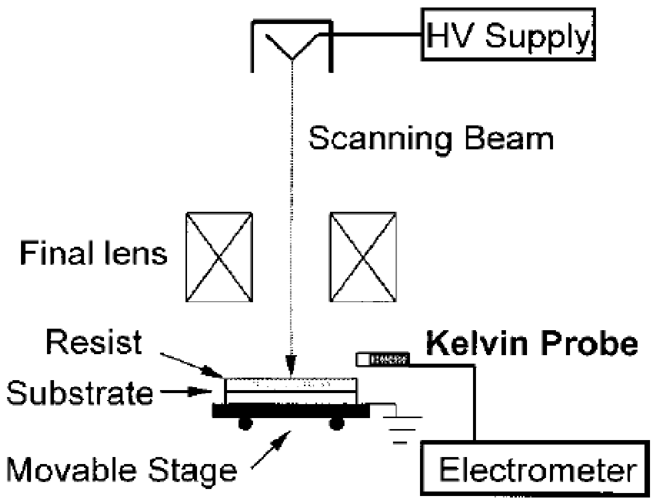
What happens to the electrons?

- **<u>If</u>** all charge trapped in top surface of 60 nm film with relative permittivity of 2

  $\phi = \frac{\sigma d}{\varepsilon_0 \varepsilon_d}$, Electric potential ϕ, dose (charge/area) σ, film thickness d, permittivity of free space ε_0, relative permittivity ε_d
- Then would build up voltage
- Until dielectric breakdown
  - (near 30V for 5 MV/cm material)
- BUT… we see sample discharging at much lower dose



Past work with higher energy electrons



Charging and discharging of electron beam resist films

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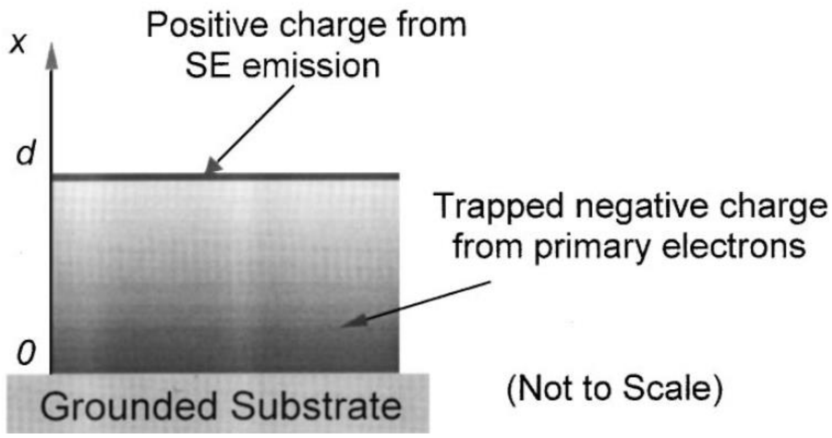
Pattern placement imprecision due to charging of the workpiece is believed to be a significant contribution to the total positional error in electron beam lithography. In an earlier work, Liu *et al.* [J. Vac. Sci. Technol. B **13**, 1979 (1995)] reported that the surface potential of exposed resist could be negative or positive according to the resist thickness and the electron energy. In that work the authors were constrained to use a flood beam. In this study, we report a new independent approach using a Kelvin probe electrometer to measure the surface potential after exposure by a focused beam. There is a qualitative agreement with the earlier work in that the surface potential tends to be less positive at lower electron energies and for thicker resists. We observed positive surface potentials at 10 and 20 keV beam irradiation. This positive charging is much more evident in polybutene sulfone than in UV5. © *1999 American Vacuum Society.* [S0734-211X(99)09906-0]

J. Vac. Sci. Technol. B 17.6., Nov/Dec 1999

For 10 and 20 keV electrons:

- Charge builds up at lowest doses then is stable – <u>radiation induced conductivity</u>
- Takes hours to discharge after exposure
- Is more negative for thicker films (more trapped electrons)

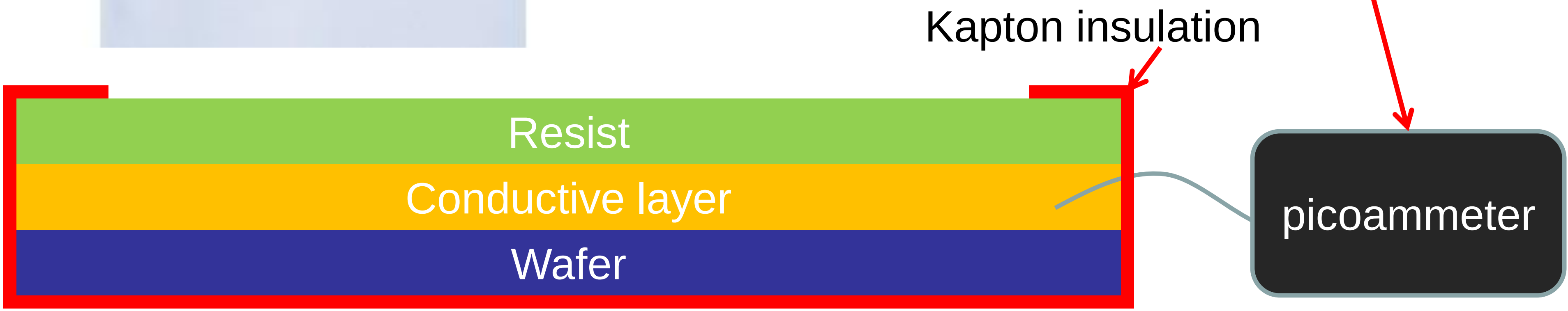


Direct measurement of electron penetration

Measure where electrons travel – not just where electrons cause reactions

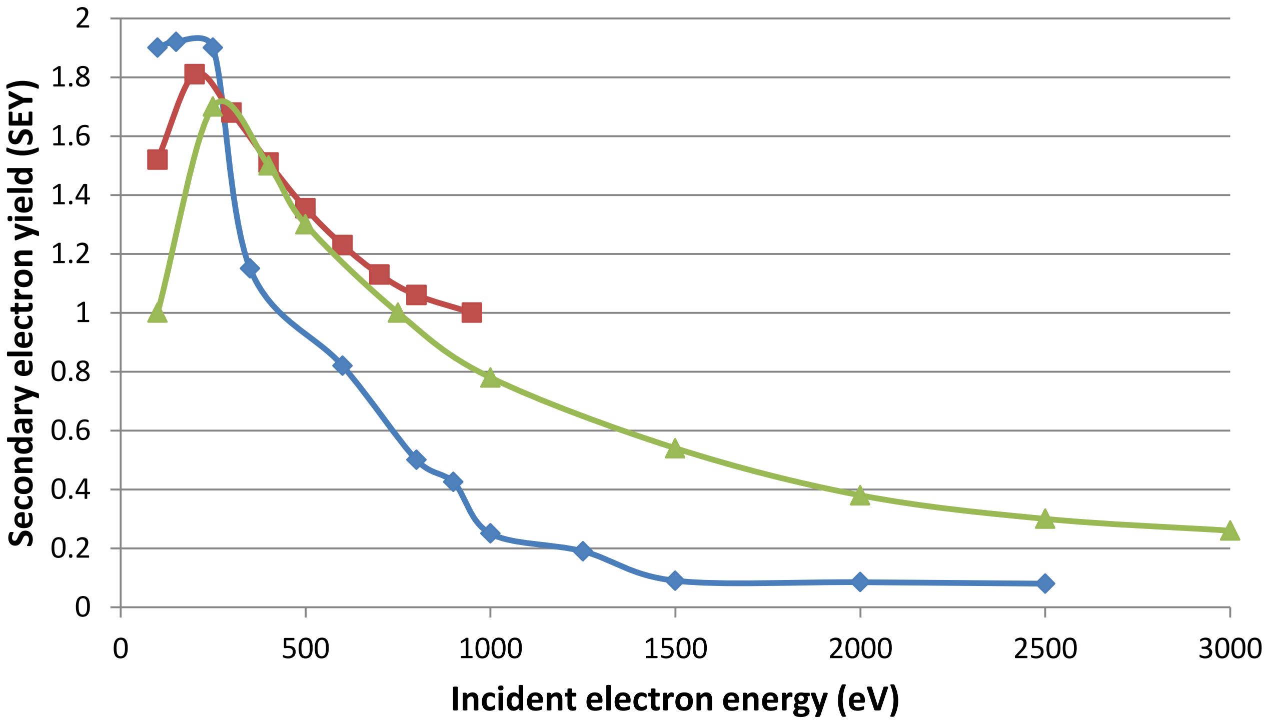
Expose selected energies and currents

Measure some reflected electrons with Faraday cup
Measure transmitted electrons through resist



Secondary electrons affect measurement

Literature search for Kapton secondary electron yield
Not photoresist, but example polymer



Surface contamination and charging may affect results, especially for energy below 1000 eV

From David Joy Database
Gross et al., 1983, IEEE Trans. On Electrical Insulation
Willis and Skinner, 1973, Solid State Comm.
Yang and Hoffman, 1987, Surf. Interf. Anal.

Wide variation in literature results

Secondary electron yield > 1
will give opposite current in measurement

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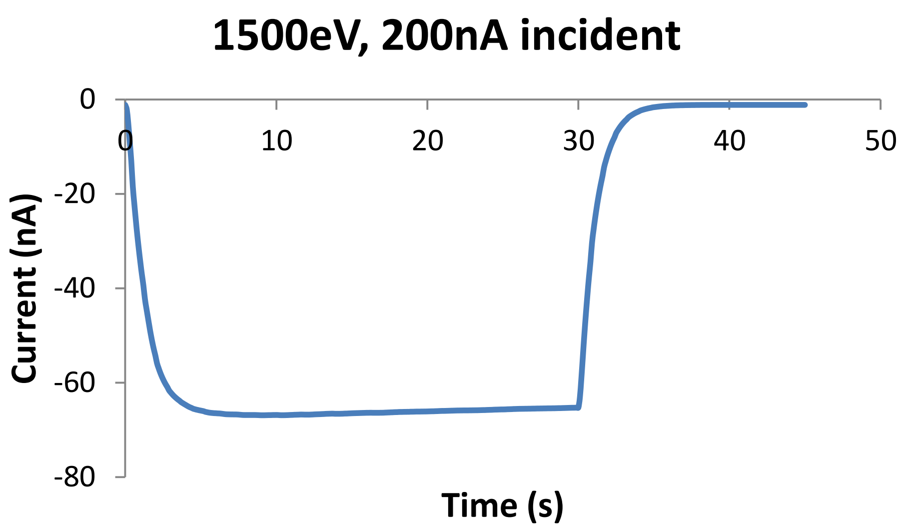
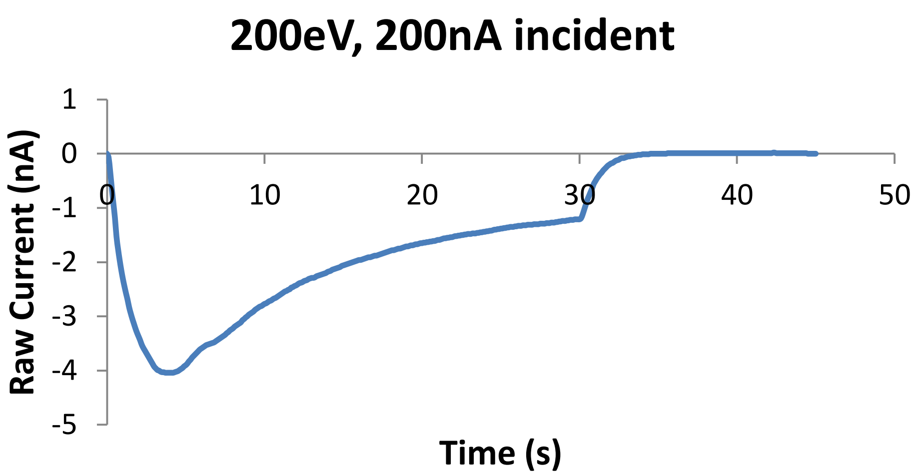
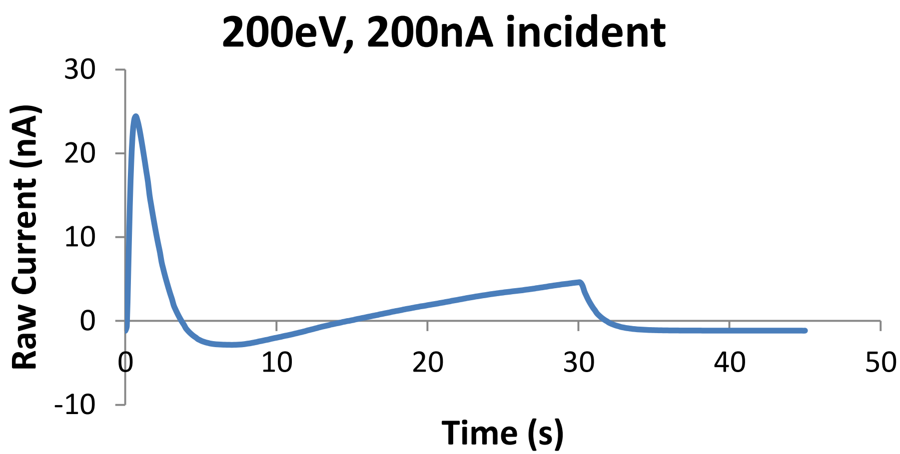
Transmitted current measurements

- Typical result that we want to see
- Current transmitted through sample when electron gun is on
- Rise and fall time are picoammeter response time

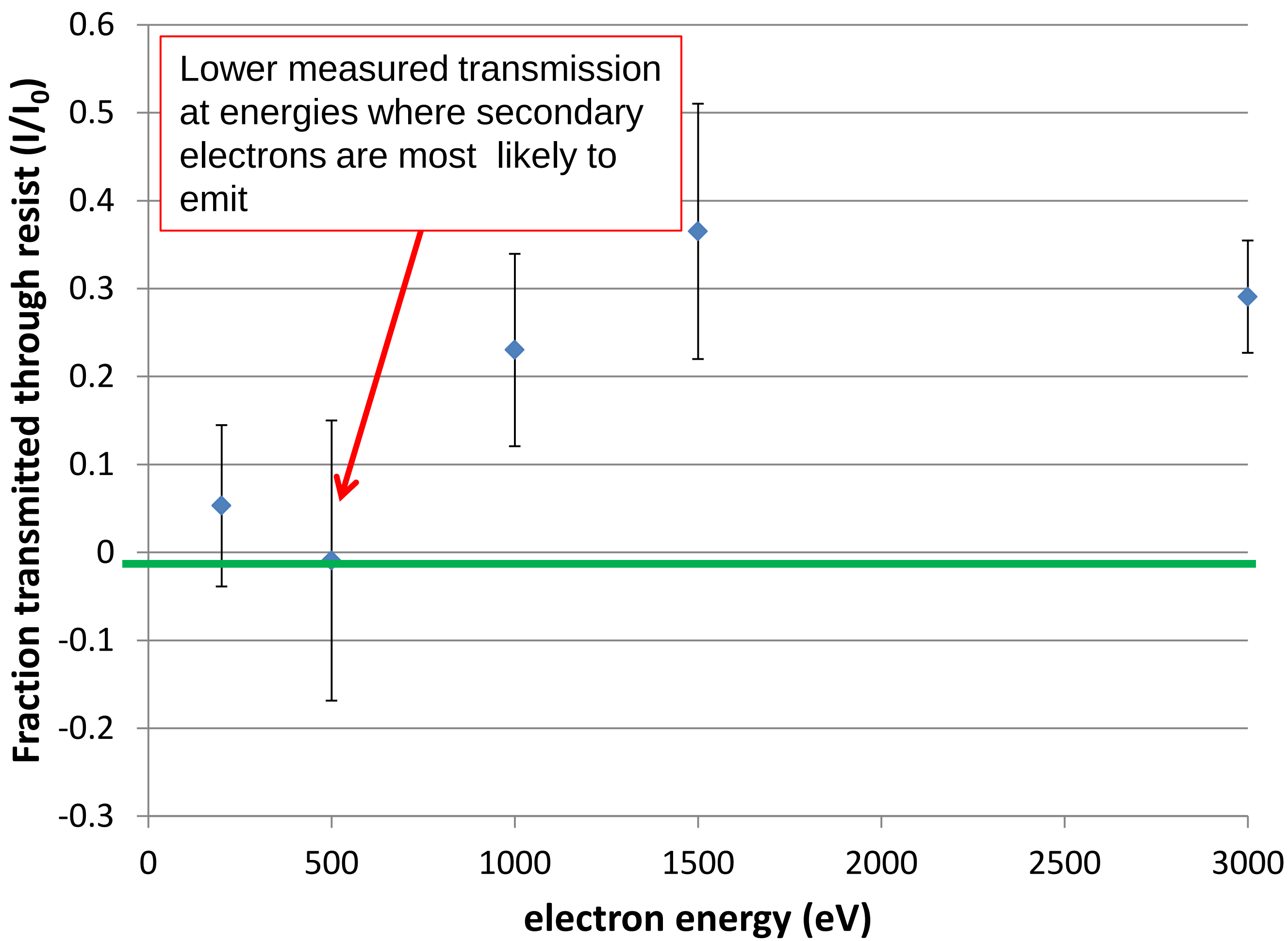


Lower energy is not as repeatable– charging effects?





Transmitted current measurements



Electrons reach the substrate for low incident energy much deeper than reactions occur in the resist

Excluded 6/4 data – all results from that sample are outliers
Excluded low current < 10 nA experiments

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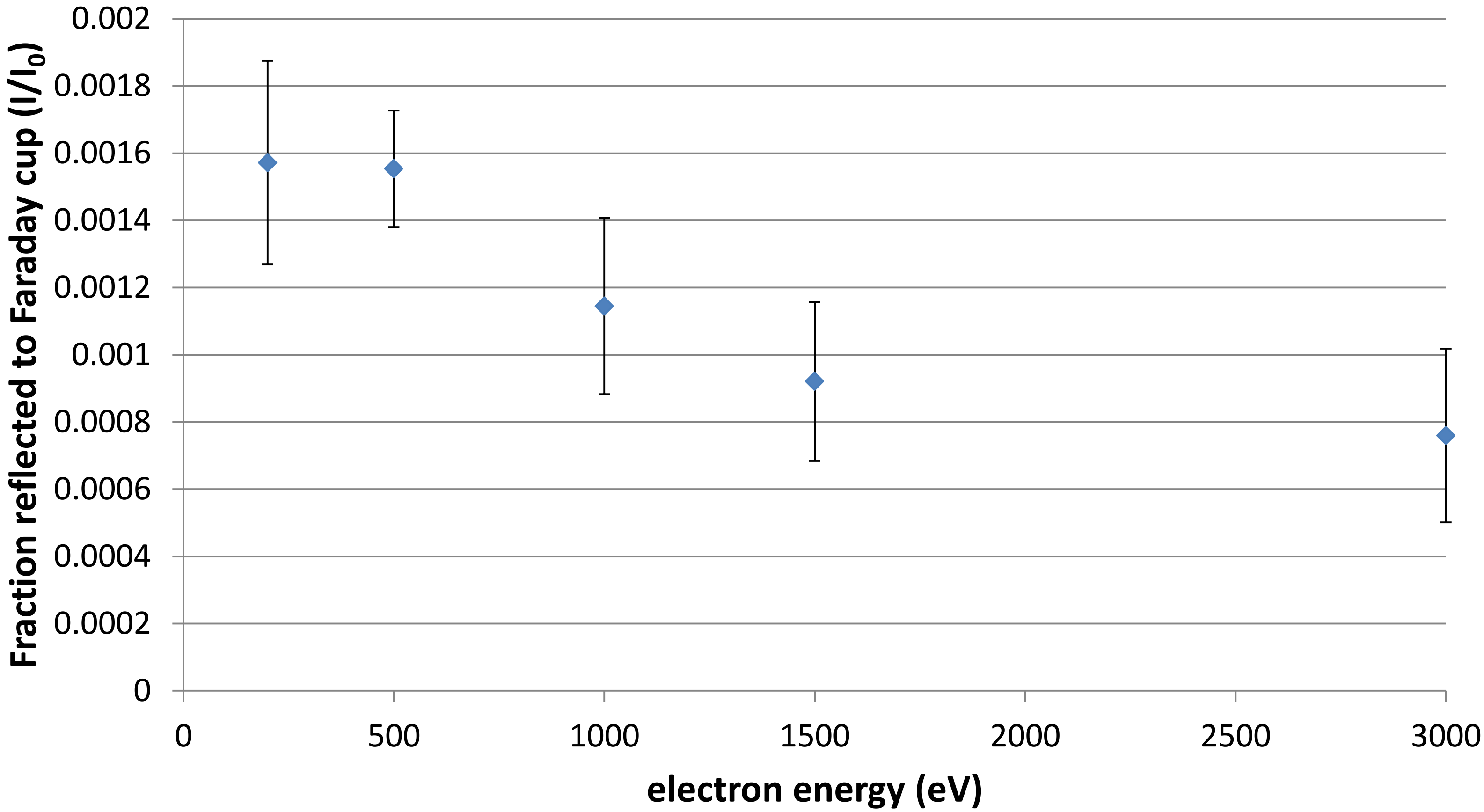
Reflected current measurements



Reflected signal closely matches secondary electron yield from literature

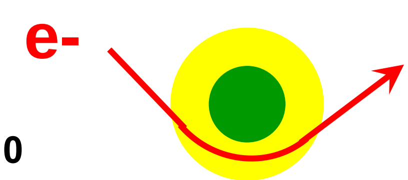
LESiS modeling program

Low Energy Electron Scattering in Solids 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.

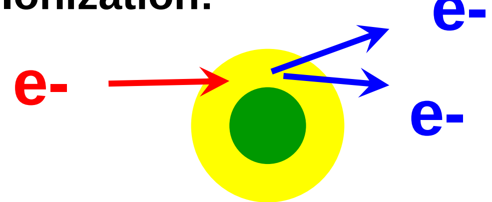
Atomic Interactions Currently Part of the Model:

Elastic Scattering:



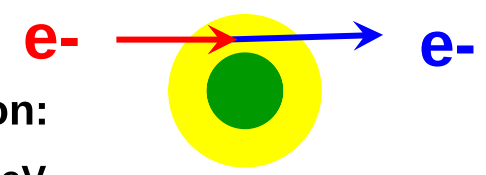
ΔE ≈ 0

Ionization:



ΔE = 6-14 eV
Ionization Energy

Plasmon Generation:



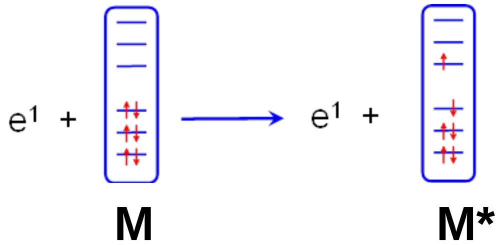
ΔE ≈ 3-12 eV

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 ≈ 3-8 eV

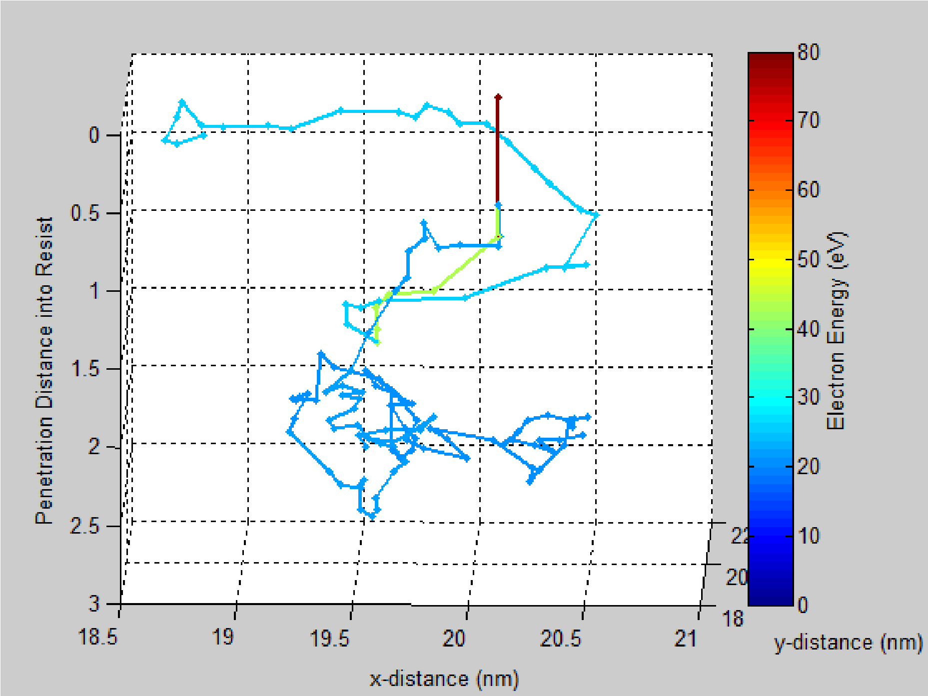
Also not yet included:

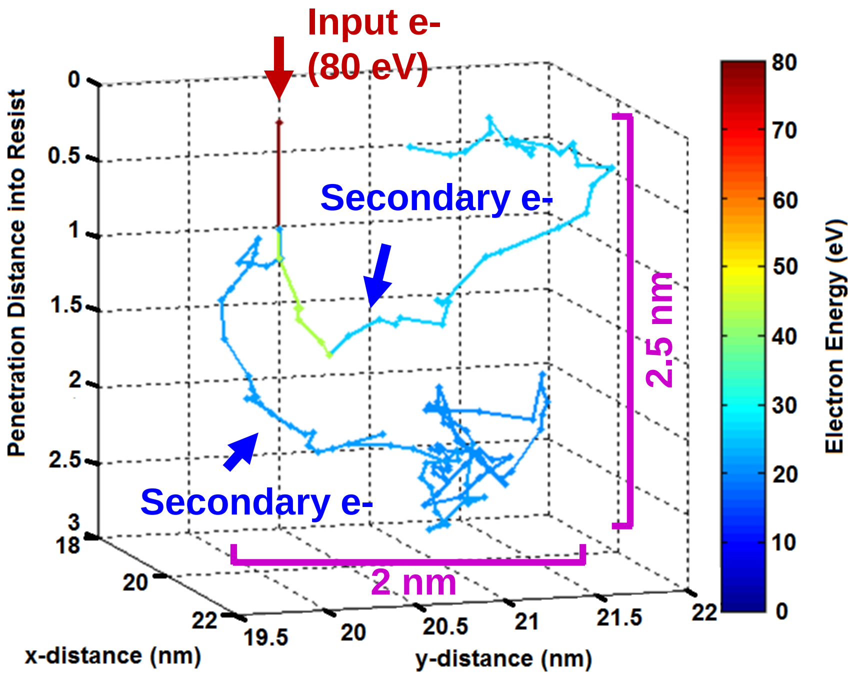
- Molecular interactions
- Creation of Phonons
- Energy lost as heat.

Electron trajectory simulations

Same commercial resist used for penetration measurements

Interactions principally with the p orbitals of Carbon and Oxygen:





Conclusions

- EUV resist exposures are based on electron chemistry
- We have developed a flexible experimental system to help understand these electron reactions
- We have measured the electron blur directly
- We are using the data to help optimize the simulation software
- We plan to
    - Determine the actual number and energy of electrons present in the resist due to EUV exposure
    - Determine the PAG reactivity – the cross section versus electron energy
  - In order to help in the development of improved efficiency resists

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