CHE323/CHE384
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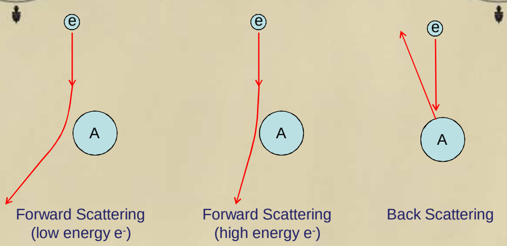
Lecture 62
Electron Beam Lithography, part 2

Chris A. Mack
Adjunct Associate Professor

 www.lithoguru.com

Rutherford Scattering

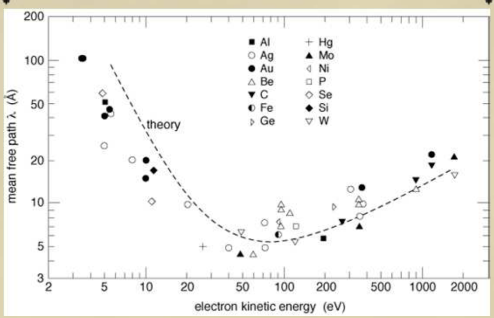
(from a screened Coulomb potential)



- Higher Z materials result in greater amounts of back scattering
- Higher electron energies result in less forward scattering
- Also, secondary electron generation
- Electrons lose energy according to the Bethe equation (dE/ds)

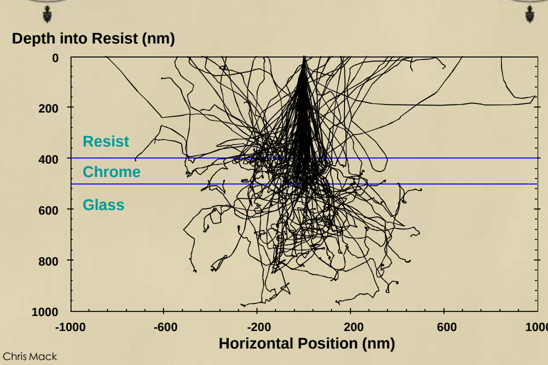
Electron Mean Free Path

(average distance between scattering events)



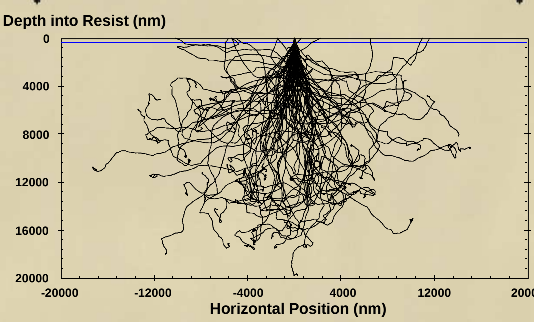
(Andrew Zangwill, Physics at Surfaces, 1988)

Monte Carlo Results - 10KeV



Monte Carlo Results - 50KeV

(same film stack and substrate)



Electron Scattering

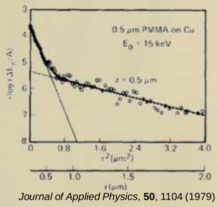
- Consider resist coated on a higher-Z substrate
- Higher electron energies mean:
  - Deeper penetration into the substrate
  - Less energy deposited into the resist per electron
  - Less forward scattering – smaller beam width in the resist
  - Longer-range backscattering due to deeper substrate penetration

Double Gaussian Model

- Higher electron-beam accelerating voltage affects forward and backscatter ranges
- Simple description: Double Gaussian fit to simulated spot energy distribution

$$P(r) = (1-\beta)\exp\left(-\frac{r^2}{2\sigma^2}\right) + \beta\exp\left(-\frac{r^2}{2\sigma_B{}^2}\right)$$

	10kV	50kV
σ_B (μm)	0.4	5.0 - 6.0
β	0.1	0.00003



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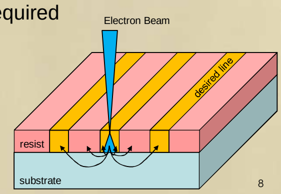
Proximity Effects

- Long backscatter range means that exposure of one feature can influence the exposure of other features microns (or tens of microns) away
  - Isolated lines can be washed away by backscatter exposure
  - Isolated spaces receive less dose than dense spaces
- Proximity effect correction is required
  - Change the exposure dose depending on the amount of nearby exposed area



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Common E-beam Resists

- PMMA (Positive Resist)
  - Very high resolution (<10nm), but very slow
  - poor etch resistance, good process control
  - polymer chain scission, solvent developer
- HSQ (Negative Resist)
  - excellent resolution (<10nm), but slow
  - good etch resistance, poor process control
- ZEP (Positive Resist)
  - good resolution (~10nm) and fast
  - good etch resistance, common in mask making

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Conclusions

- Electron-beam lithography has many advantages
  - Maskless (R&D, prototyping, mask making)
  - High resolution (20 nm easily, 5 nm with much work)
  - Very flexible
- E-beam lithography has many disadvantages
  - Very slow: hours per wafer, not wafers per hour
  - Current is limited by Coulomb-Coulomb interactions
  - Projection printing with large fields is very hard
  - Multiple beams offer some promise, but has not yet been proven practical (Mapper, REBL)

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Lecture 62: What have we Learned?

- How does scattering change with electron energy?
- How can we predict electron scattering?
- What gives rise to e-beam lithography proximity effects?
- What are the main advantages of e-beam lithography?
- What are the main disadvantages of e-beam lithography?

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