Absolute dose calibration using the ALS calibration and standards beamline (BL 6.3) and the SEMATECH Berkeley MET

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Present dose calibration method

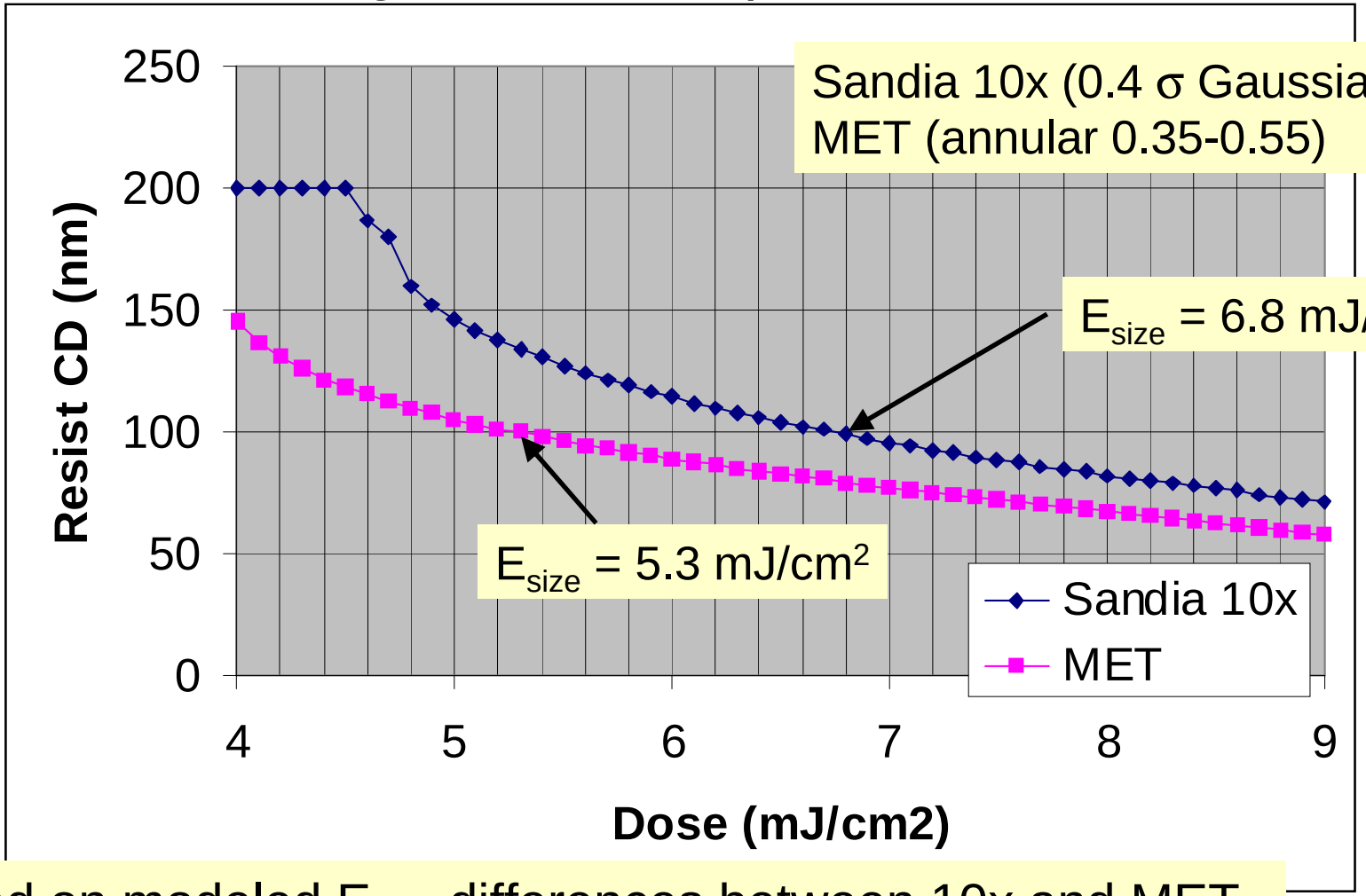
- Current EUV exposure tools are calibrated against “known” resists
- Initial calibration of the Berkeley MET (Feb. 2004) was based on the “known” Esize of EUV-2D resist for 100-nm lines and spaces
- Since that time, the calibration standard has been switched over to MET-1K and an Esize at 50-nm lines and spaces
- MET-1K used to transfer calibration from Berkeley MET to Albany MET

Problems with present method

- “Known” Esize value of EUV-2D (6.8 mJ/cm^2) actually comes from non-traceable dose numbers from the now decommissioned Sandia 10x microstepper
- Aerial-image characteristics differences between the 10x and MET put into question the transfer of Esize from one tool to the other (required detailed wavefront and flare characteristics of the Sandia 10x not available)

Prolith modeling predicts ~30% calibration error

Prolith modeling with RHEM-provided EUV-2D model



Based on modeled E_{size} differences between 10x and MET, reported dose numbers from MET's are 29% too high

Plan for absolute dose calibration of baseline resists and Berkeley MET

- Use Berkeley Calibrations and Standards EUV beamline to determine E0 by exposure and measurement of contrast curves in RHEM MET-1K and TOK-P1123
- Transfer the E0 calibration to the Berkeley MET
- Measure E0 to Esize ratios on Berkeley MET for RHEM MET-1K and TOK-P1123 to determine absolute Esize values for these two baseline resist
- Daily recalibration of Berkeley MET using Esize on baseline resist

E_0 measurement at BL6.3

- Calibrations and Standards beamline (BL6.3) enables absolute measurement of photon flux incident on wafer as well as beam profile
- Two independent measurements of RHEM MET-1K and TOK EUVR-P1123 done, respectively

9/07	**10/07**
Beamline current ~20 mA	Beamline current ~250 mA
MET-1K: E_0 = 7.6 mJ/cm^2 PAB 130/60, PEB 120/90, Dev 45s	MET-1K: E_0 = 7.3 mJ/cm^2 PAB 130/60, PEB 120/90, Dev 45s
P1123: E_0 = 5.6 mJ/cm^2 PAB 120/90, PEB 100/90, Dev 60s	P1123: E_0 = 6.0 mJ/cm^2 PAB 120/90, PEB 100/90, Dev 60s

Average E_0

MET-1K: 7.45 mJ/cm^2 P1123: 5.8 mJ/cm^2

E_{size}/E_0 measurement on MET

- Berkeley MET used to measure E_{size} to E_0 ratio for baseline resists
- Two independent measurements used:
  - Separate clear field line-space field exposures
  - Single brightfield resolution cell exposure

	Separate	**Single**
MET-1K (E_{size50}/E_0)	1.84	1.80
P1123 (E_{size50}/E_0)	1.82	1.70
EUV-2D ($E_{size100}/E_0$)		1.88

Average E_{size}/E_0

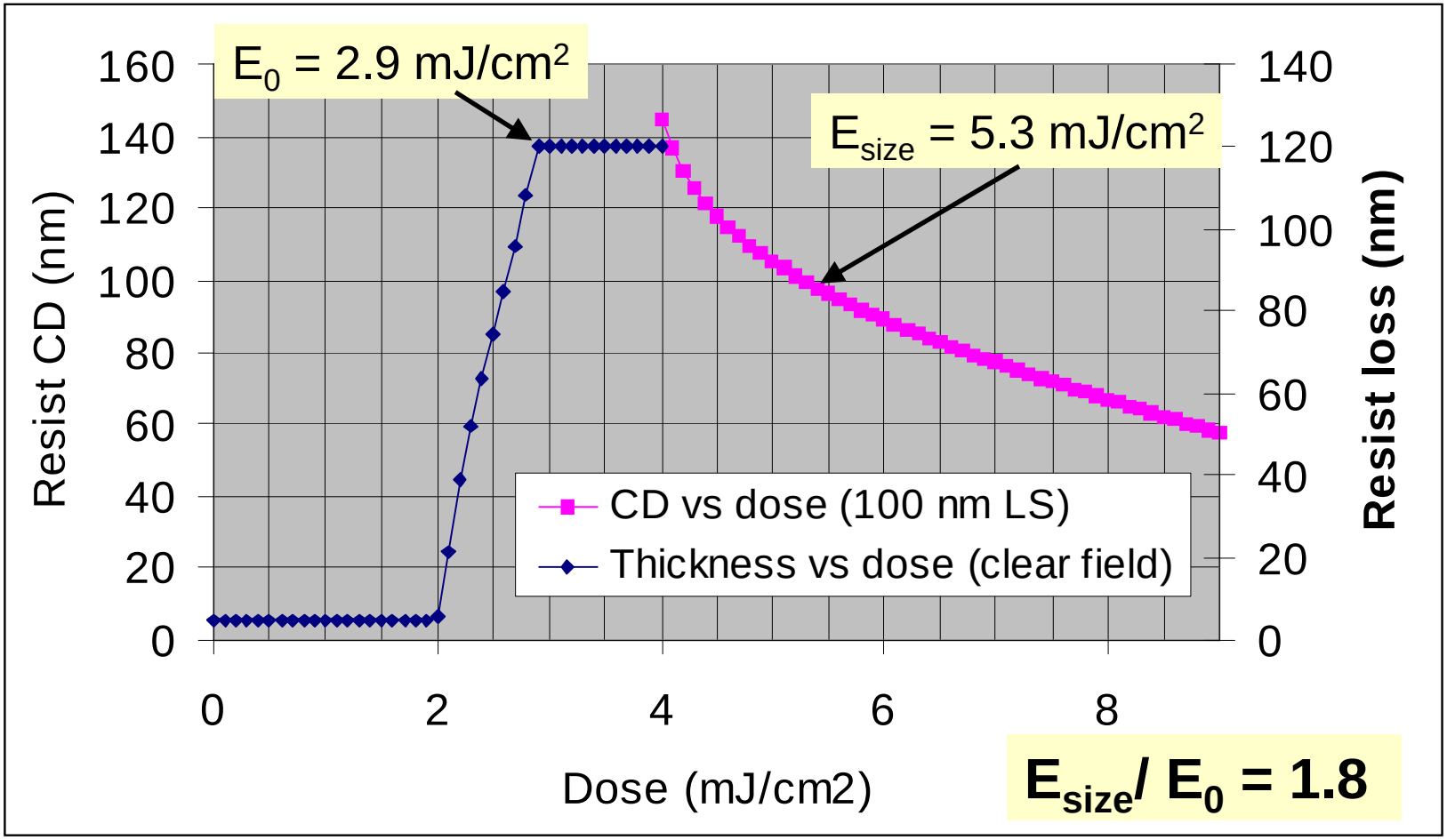
MET-1K: 1.82 P1123: 1.76

Calibrated sensitivities of baseline resists

- MET-1K: 7.45*1.82 = 13.6 mJ/cm^2 (was 25)
- P1123: 5.8*1.76 = 10.2 mJ/cm^2 (was 20)
- This corresponds to an average 1.9x calibration error
  - **Reported dose numbers from MET's are 1.9x too high**

Verify small E_{size}/E_0 ratios through modeling

Prolith modeling with RHEM-provided EUV-2D model



Based on aerial image alone E_{size}/E_0 = 2.7

Additional E_{size}/E_0 ratio modeling

- Additional EUV resist modeling was done based on full chemical kinetics for advanced 193-nm resists. These models have been validated vs. 193nm OPC models
  - Note: models not actually "validated" at EUV
- Resist A: E_{size}/E_o = 1.81 (E_{size} @ 50 nm L/S)
- Resist B: E_{size}/E_o = 2.23 (E_{size} @ 50 nm L/S)
- Resist models support observed E_{size}/E_o magnitudes

Modeling results provided by Tom Wallow AMD

Summary

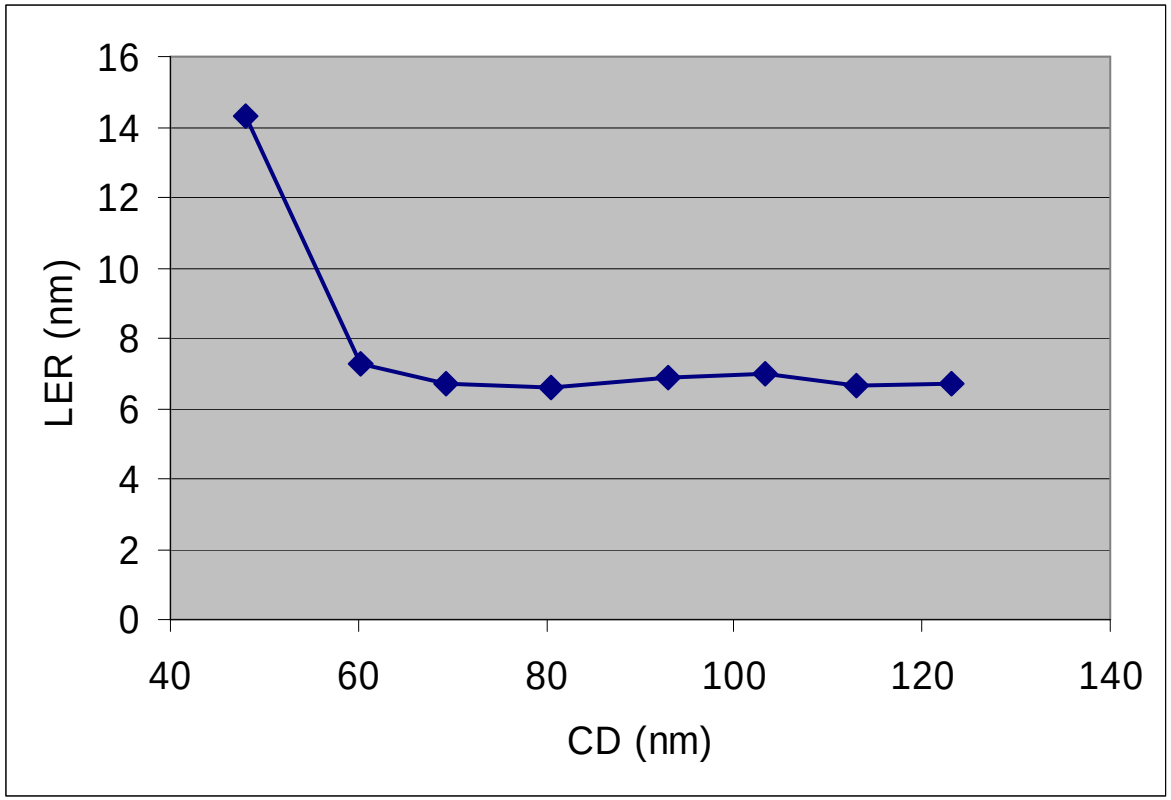
- Reported dose numbers from MET tools factor of 1.9x too large
  - 1.3x error likely due to original EUV-2D E_{size} calibration error due to imaging characteristics differences between Sandia 10x and MET
- Remaining 1.46x error likely due to absolute calibration error in reported Sandia 10x dose values
- WE BELIEVE EUV RESISTS ARE ~2X FASTER THAN PREVIOUSLY REPORTED

Brief comments on shot noise

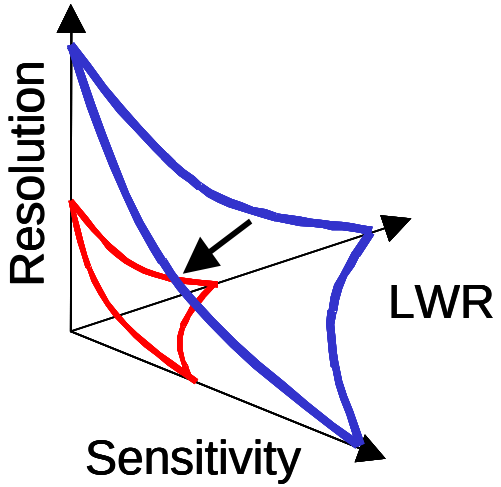
Photon noise is our ultimate concern for the LER vs sensitivity debate

- Photon noise arises from the random arrival of photons (Poisson statistics)
- The smaller the number of photons, the larger the noise [SNR = sqrt(N)]
- Once photon-noise limited, amplification cannot help
  - Only spatial averaging (resolution loss) can help
- For large number of photons Poisson statistics approach Gaussian
- Difficult to experimentally distinguish photon noise from other noise sources in resist
  - Just because it looks Gaussian does not mean it's photon noise
  - Central limit theorem makes most noise sources look Gaussian

Must be careful not to convolve resolution loss with LER increase



EH27-C resist
(Brainard)

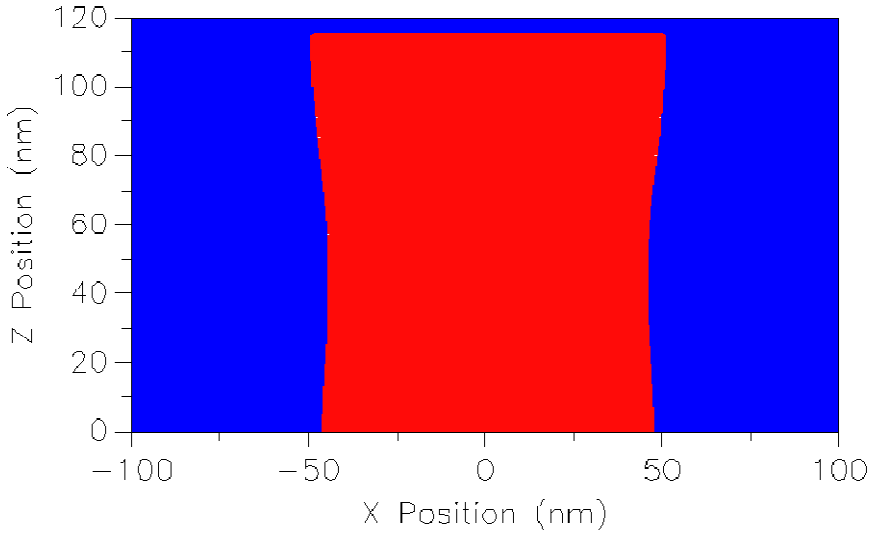


Extra Slides

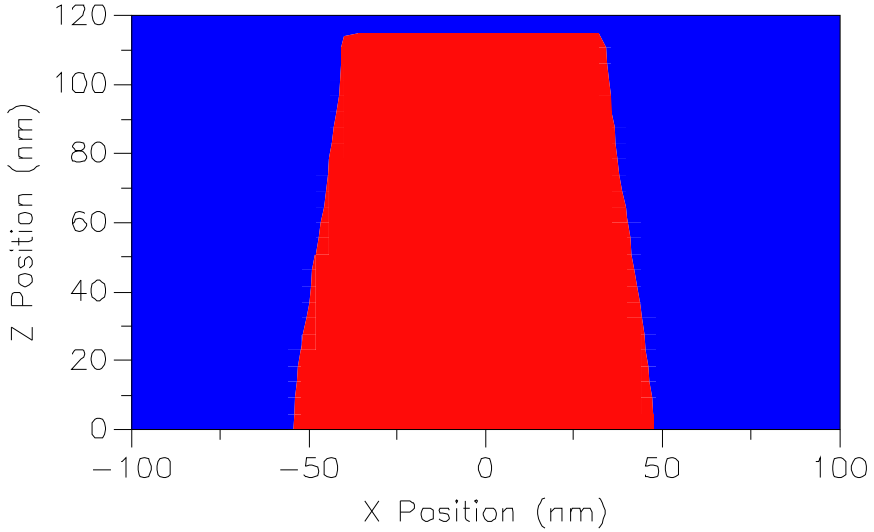
Prolith modeling predicts ~30% calibration error

Prolith modeling with RHEM-provided EUV-2D model

Sandia 10x (0.4 σ Gaussian)
E_{size} = 6.7 mJ/cm^2



MET (annular 0.35-0.55)
E_{size} = 5.2 mJ/cm^2

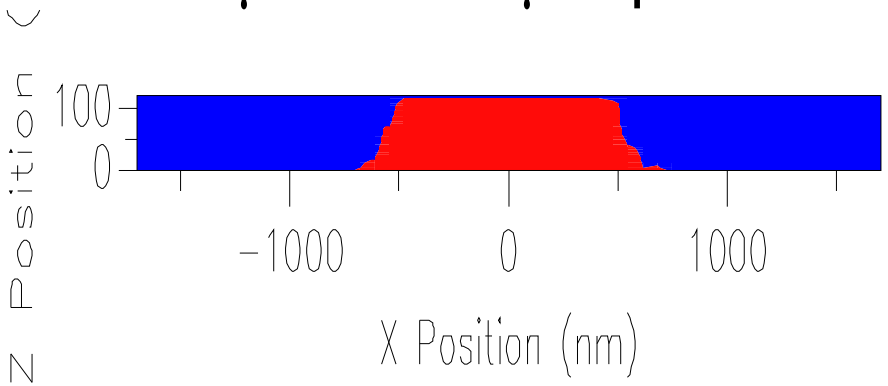


Based on modeled E_{size} differences between 10x and MET, reported dose numbers from MET's are 29% too high

Verify small E_{size}/E_0 ratios through modeling

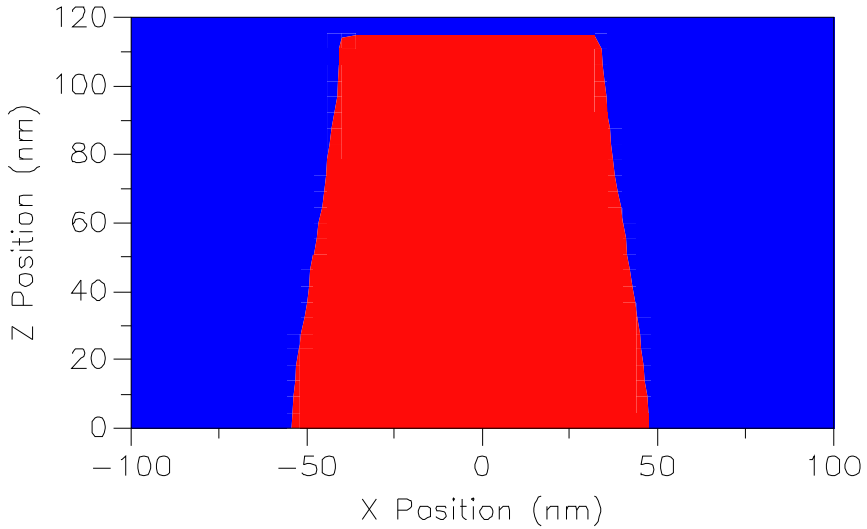
Prolith modeling with RHEM-provided EUV-2D model

1-µm line 4-µm pitch



E_0 = 2.9 mJ/cm^2

100-nm line 200-nm pitch

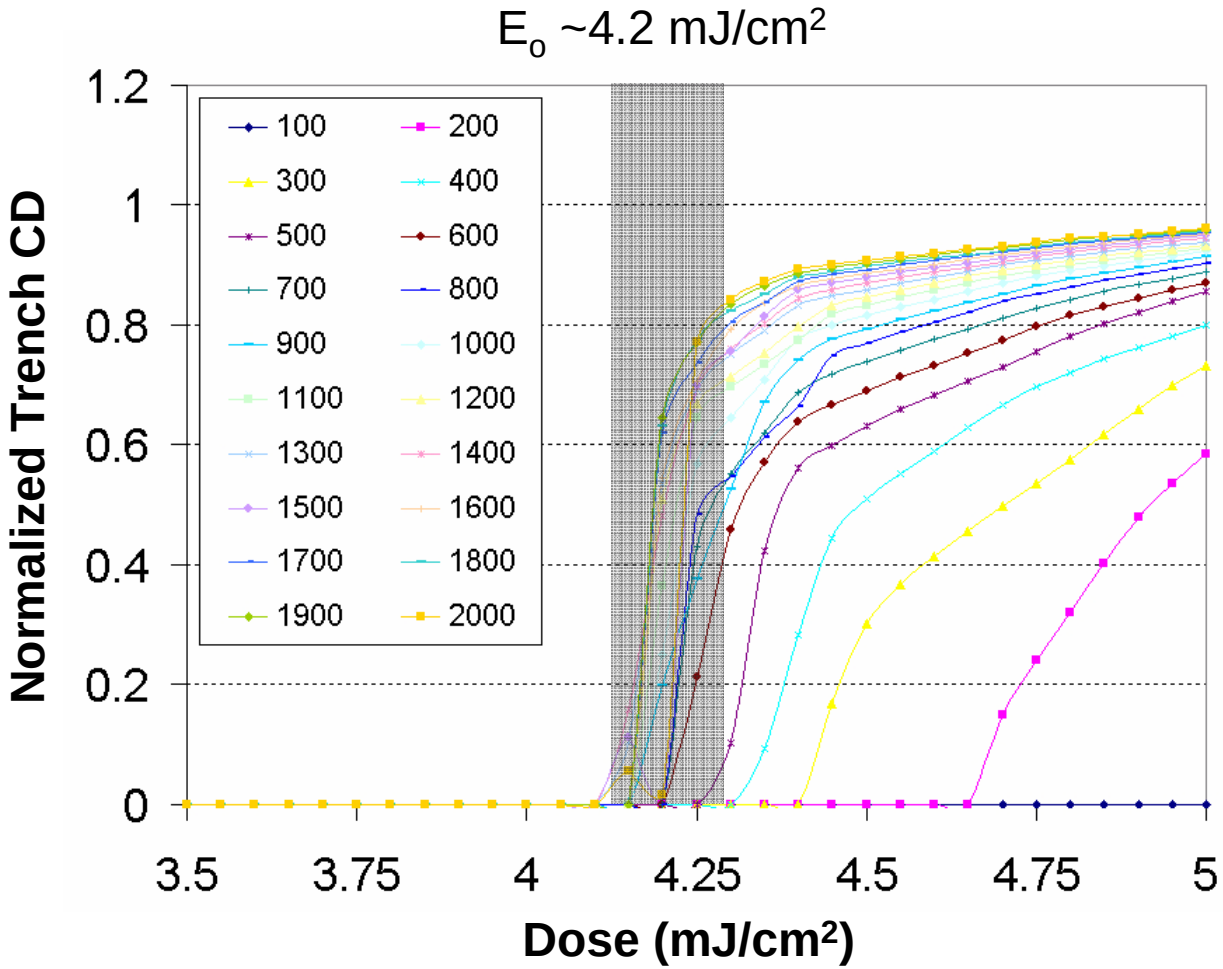


E_{size} = 5.2 mJ/cm^2

E_{size}/ E_0 = 1.8

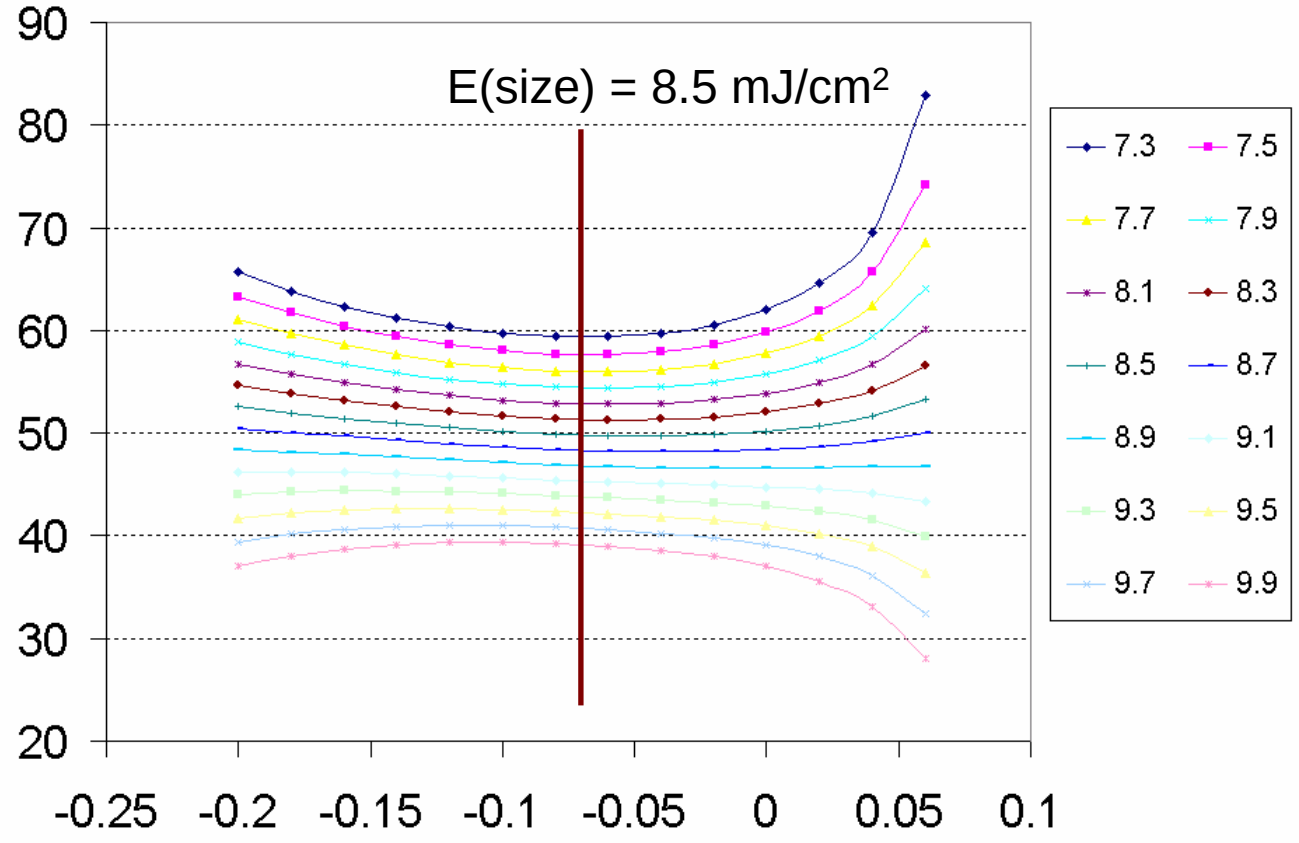
Based on aerial image alone E_{size}/ E_0 = 2.7

EUV Resist A- E_o Estimation from Large L/S Patterns

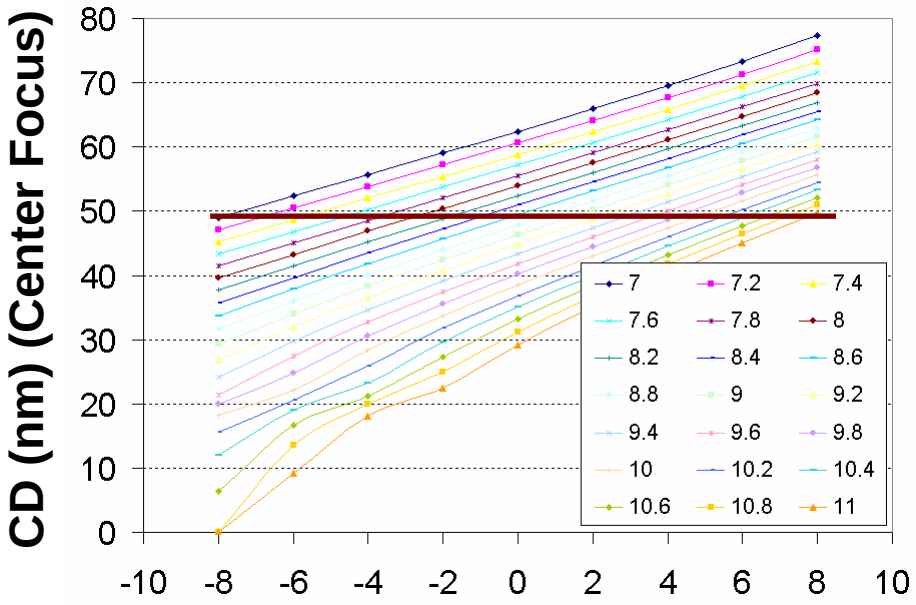


L/S larger than ~700nm half-pitch behave like clear field

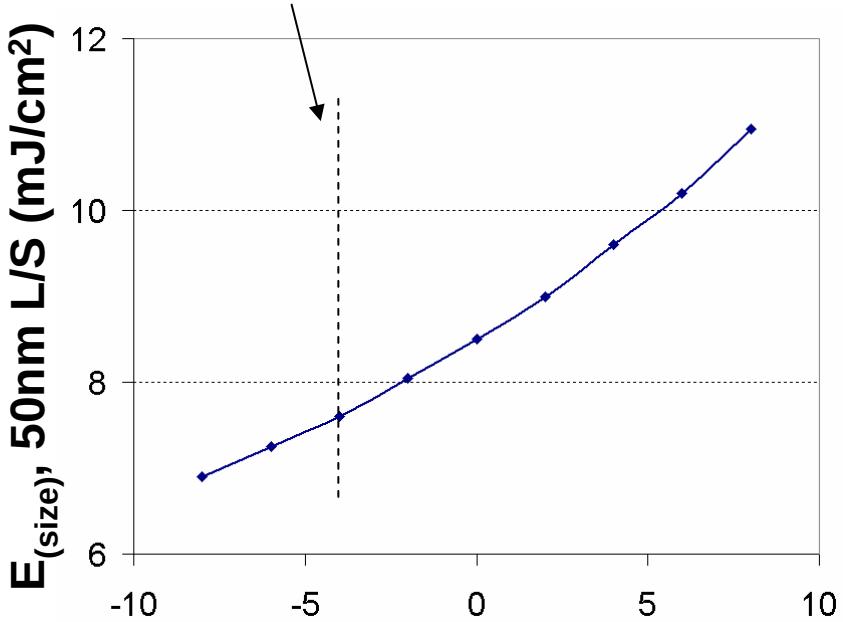
EUV Resist A- 50nm L/S E_{size}



EUV Resist A Mask Bias Response at 50nm L/S

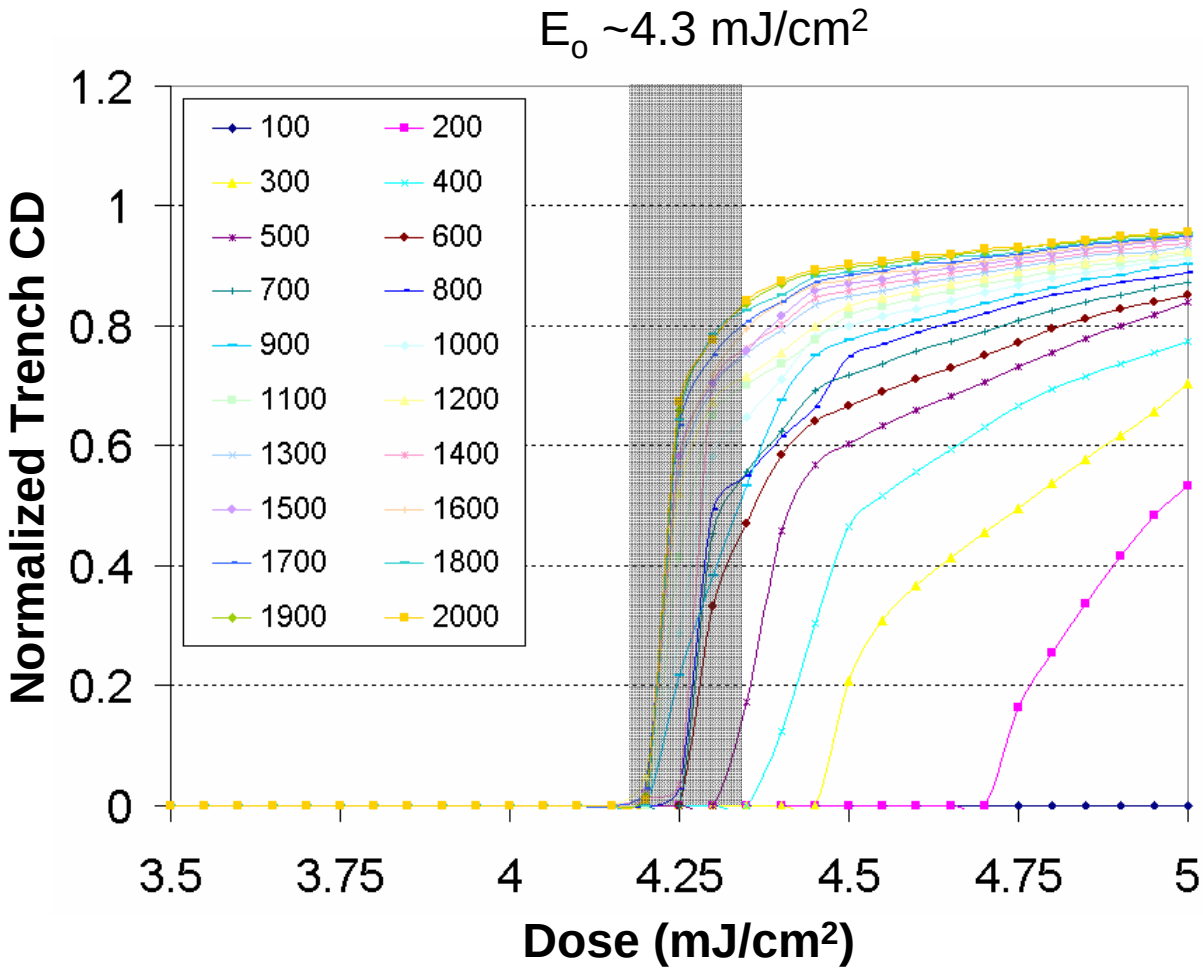


Known mask bias = -4nm



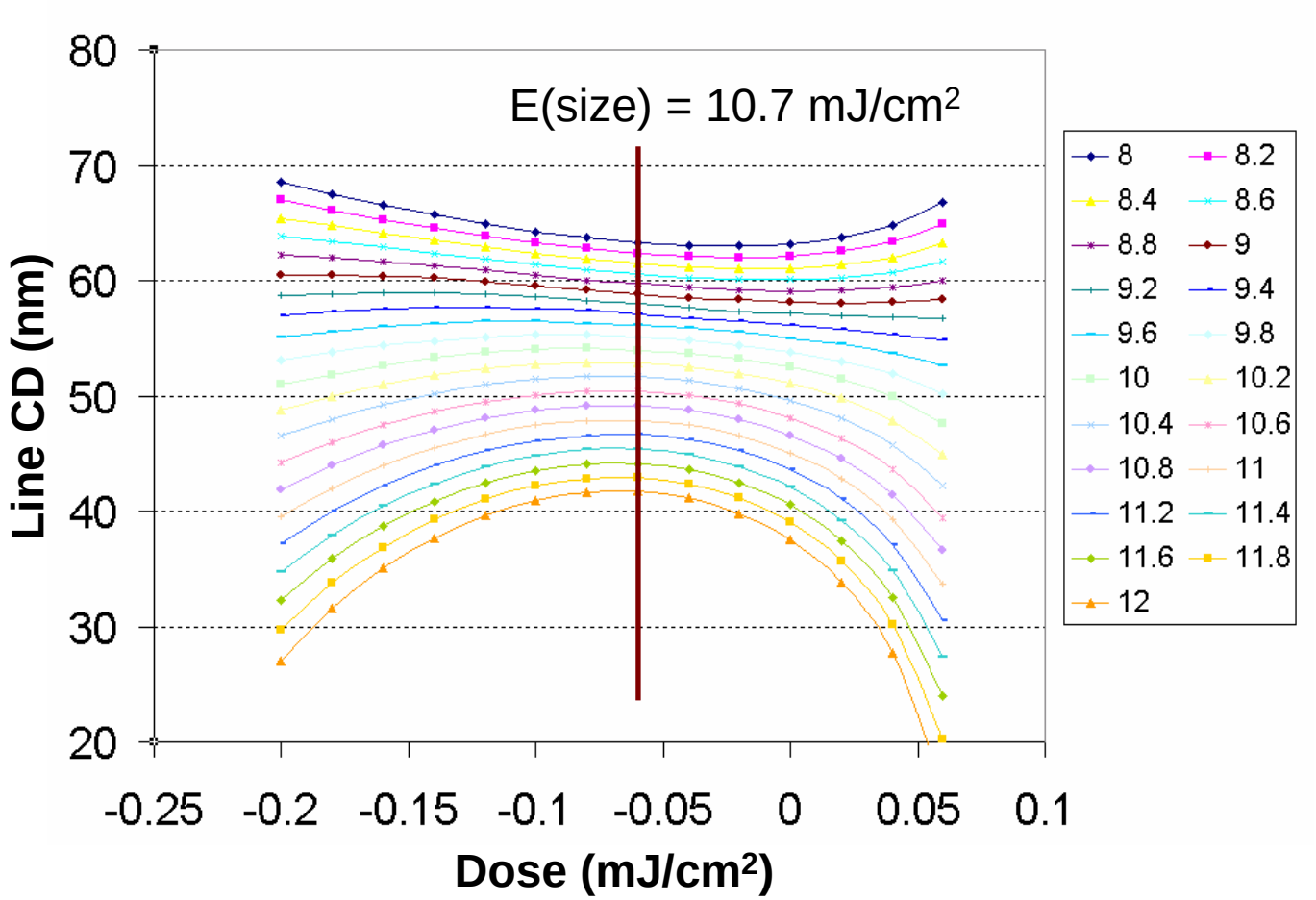
Absorber Mask Bias (nm)

EUV Resist B- E_o Estimation from Large L/S Patterns

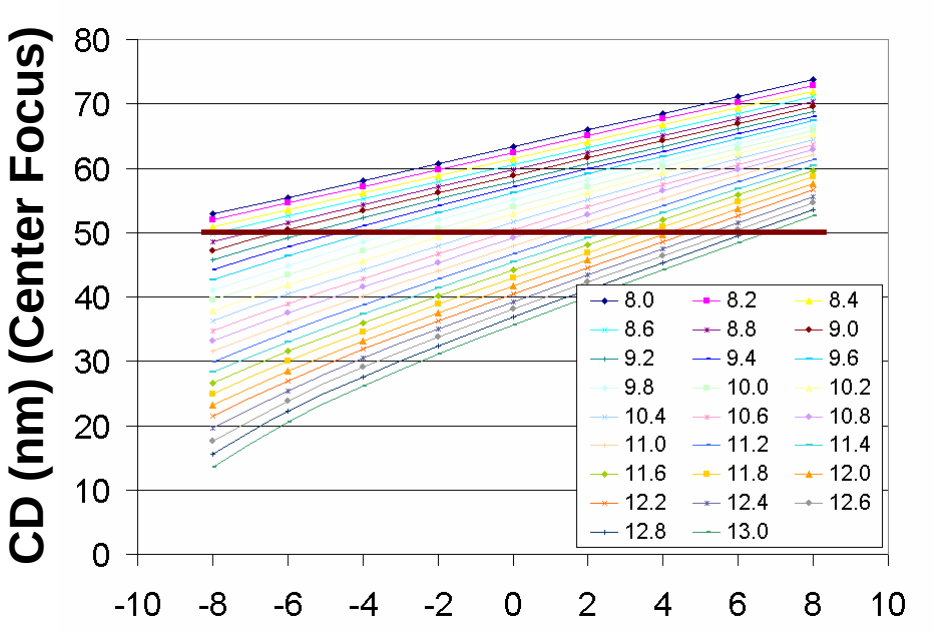


L/S larger than ~700nm half-pitch behave like clear field

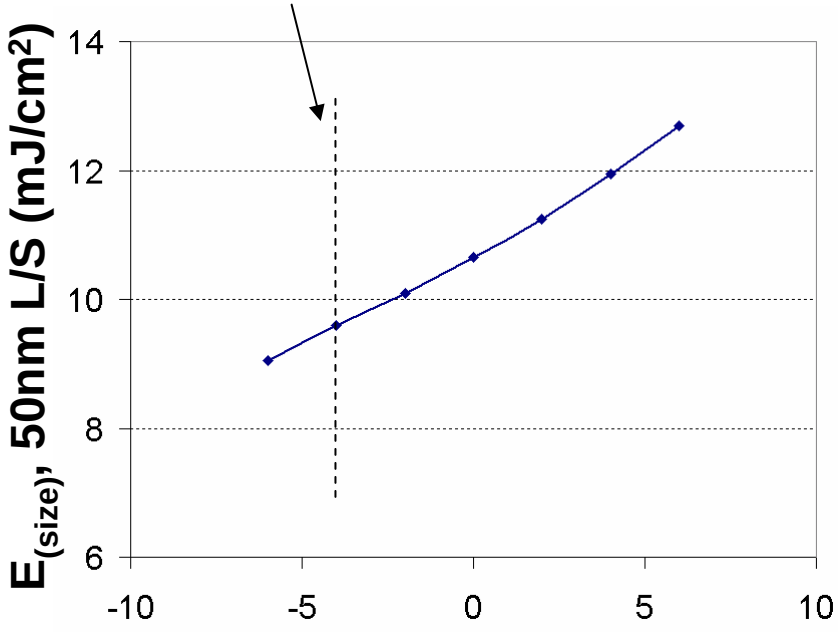
EUV Resist B- 50nm L/S E_{size}



EUV Resist B Mask Bias Response at 50nm L/S



Known mask bias = -4nm



Absorber Mask Bias (nm)

Preliminary Conclusions

For Resist A, predict:

- E_{size}/E_o = 2.02
- E_{size}/E_o at -4 nm absorber bias = 1.81

For Resist B, predict:

- E_{size}/E_o = 2.48
- E_{size}/E_o at -4 nm absorber bias = 2.23

→ Esize/Eo ~3 is not supported from these simulations

→ Known absorber bias will give lower experimental E_{size}/E_o ratio, but correcting does not give E_{size}/E_o > 2.5, even for Resist B.