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# Out of Band Radiation Effects on EUV Resist Patterning

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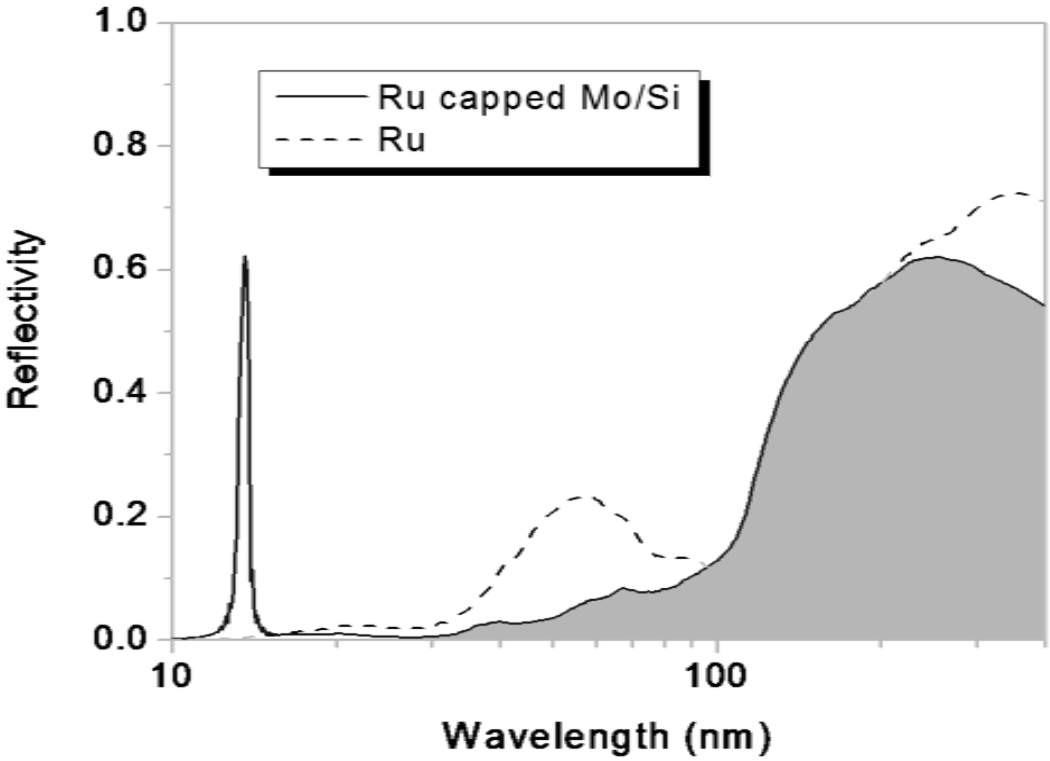
# Outline

- Out of Band Problem
- Recap of Modeling and Results
- OOB Exposure Studies: 0.3NA B-MET
  - Patterning and LER Results: two baseline resists
  - Environment Effects
- Summary

# The Out of Band Wavelengths of Concern



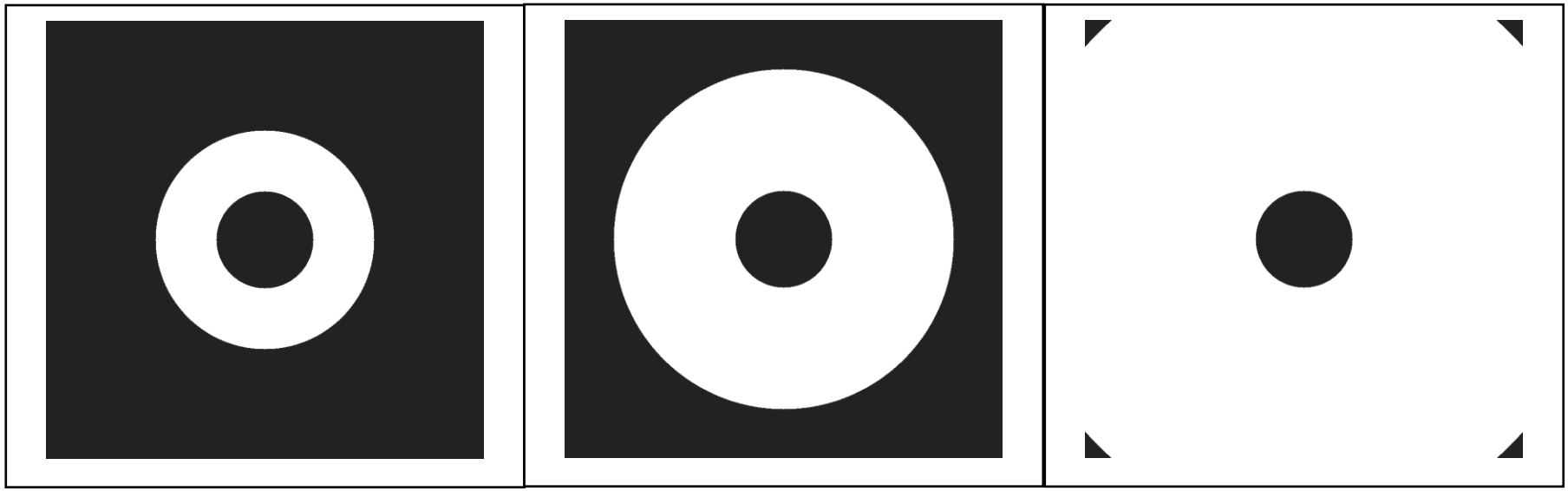

[**100-300**] nm

Data courtesy of Dr. Eric Gullikson

# Resist Contributed **OOB Flare Effect** at Wafer

| Wavelength (nm) | Sensitivity Factor | 11 Mirrors, 10% OOB at IF (%) | 10 Mirrors, 10 % at IF (%) |
|---|---|---|---|
| *13.5 | x | 100 | 100 |
| 157 | 4 x | 3.15 | 3.74 |
| 193 | 0.24 x | 0.35 | 0.42 |
| 248 | x | 0.83 | 1.01 |
| Total Effective OOB flare on wafer (Ru capped MLM) | | **4.34** | **5.17** |

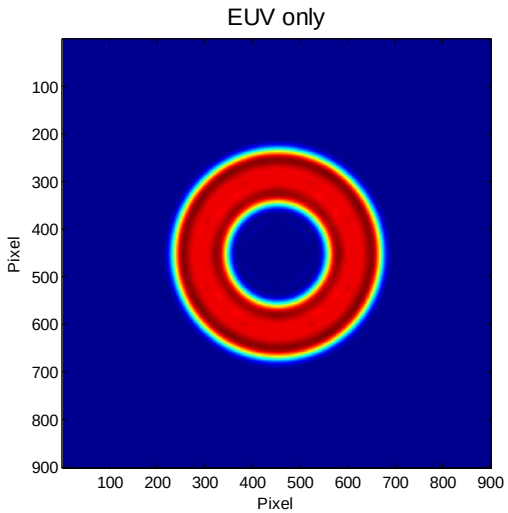
# Point Spread Function Based 2D Model

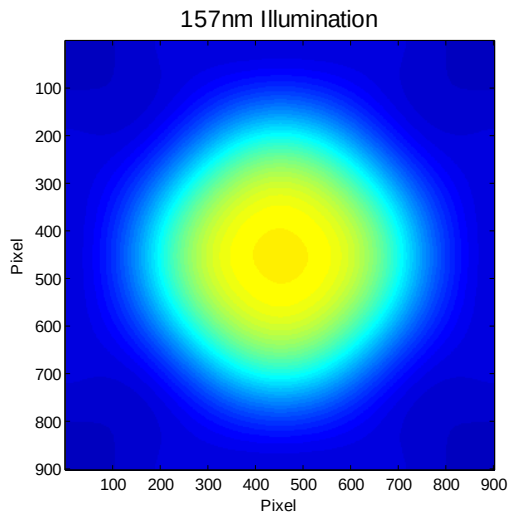


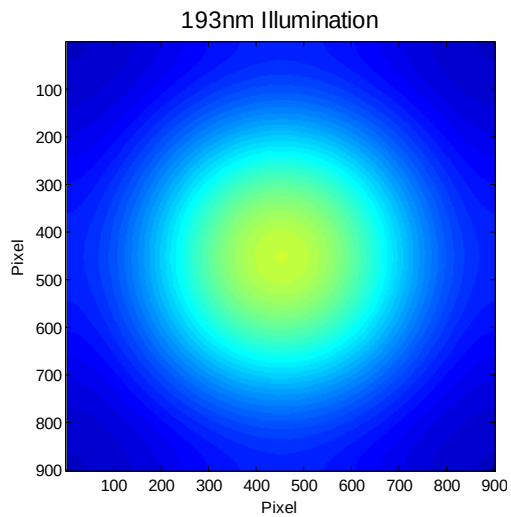
250 nm bright area radius | 500 nm bright area radius | 1000 nm bright area radius

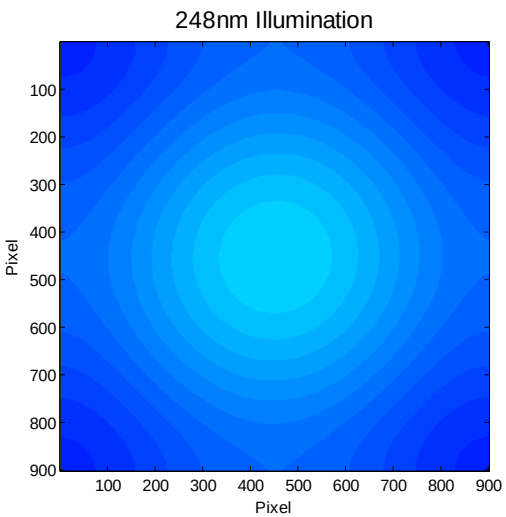
Flare Patterns used to evaluate OOB flare at the Albany ADT: **200nm post structure inside bright areas**
Hiroyuki Mizuno et. Al. Proc. of SPIE Vol. 7271 72710U-6

# Imaging through wavelengths

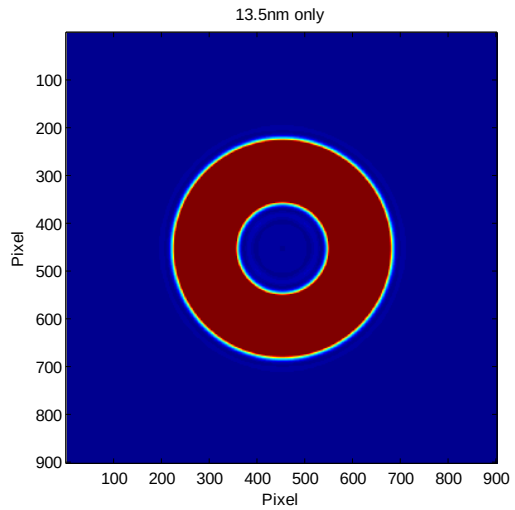


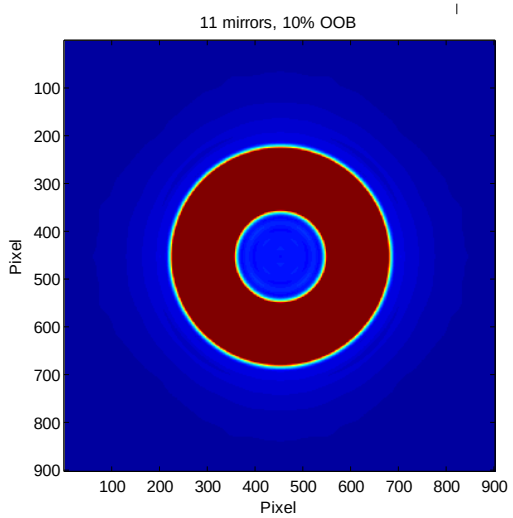



# Adding it all together…

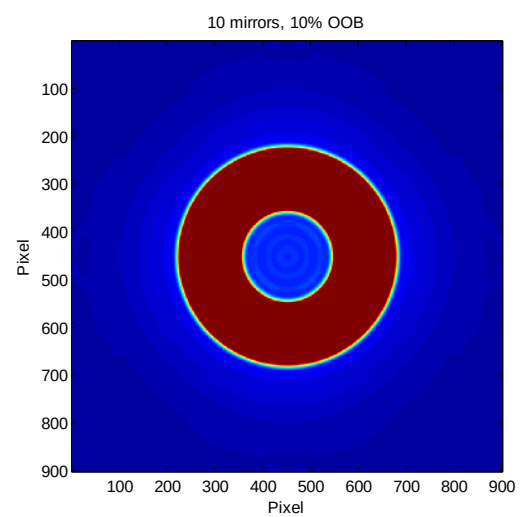



**250 nm Bright Area**
**200 nm Post**

**10% OOB at IF**

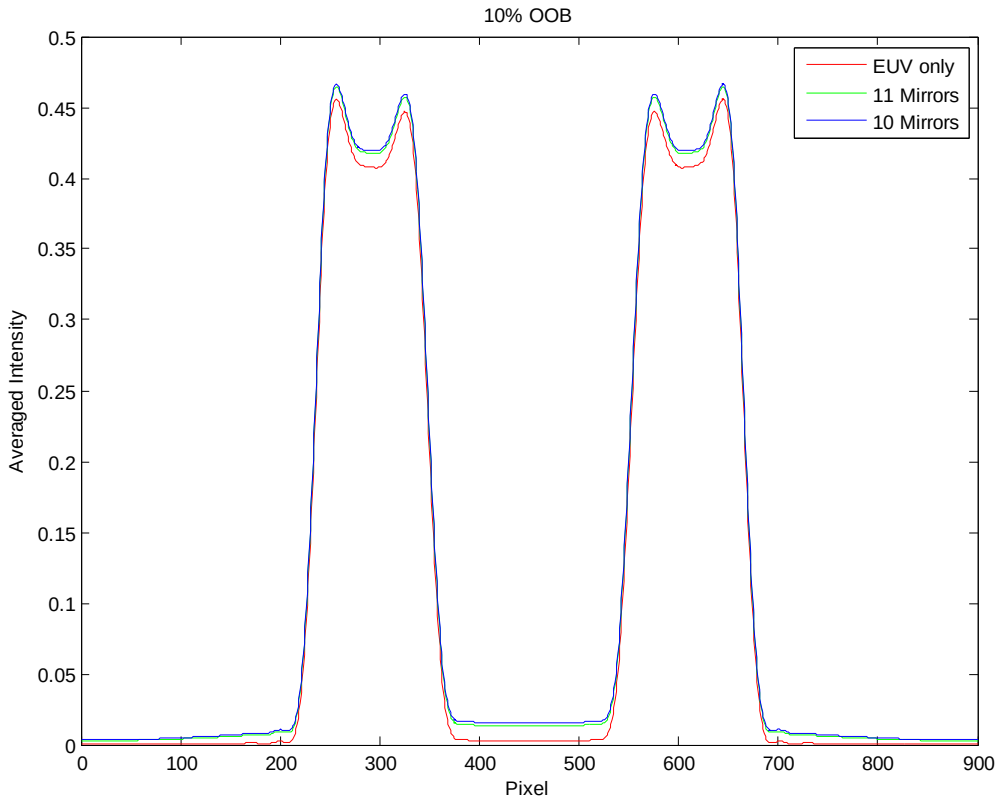



**11 mirrors**




**10 mirrors**

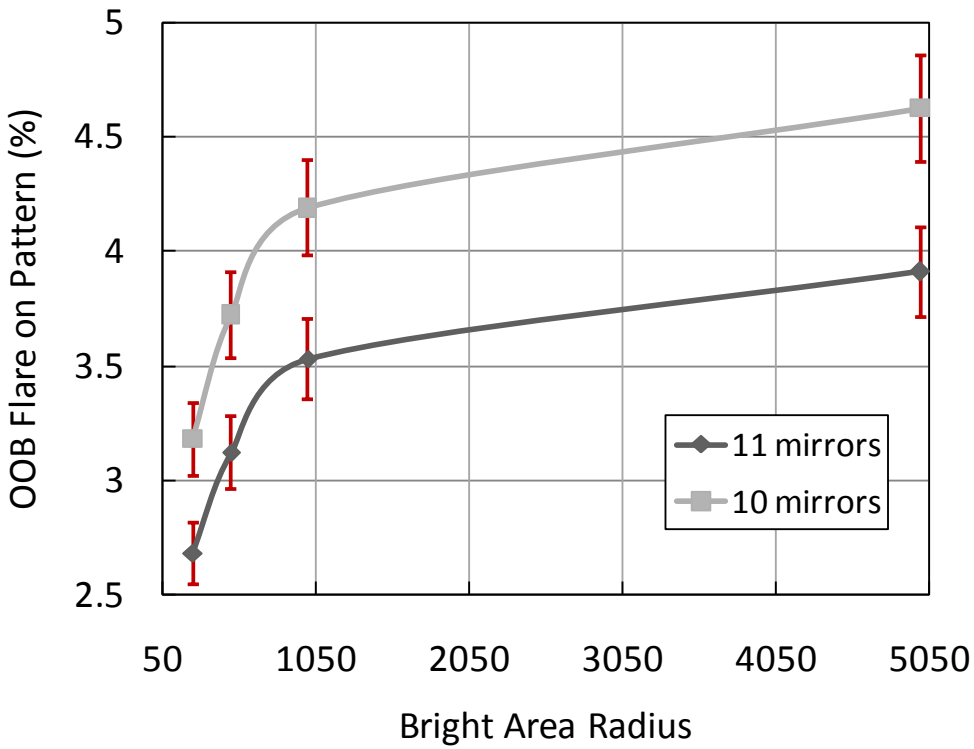
# Averaged Cross-section




OOB Flare

| | |
|---|---|
| 10% OOB<br>11 mirrors | 2.68 % |
| 10% OOB<br>10 mirrors | 3.18 % |

# ADT Flare Test Features Simulated

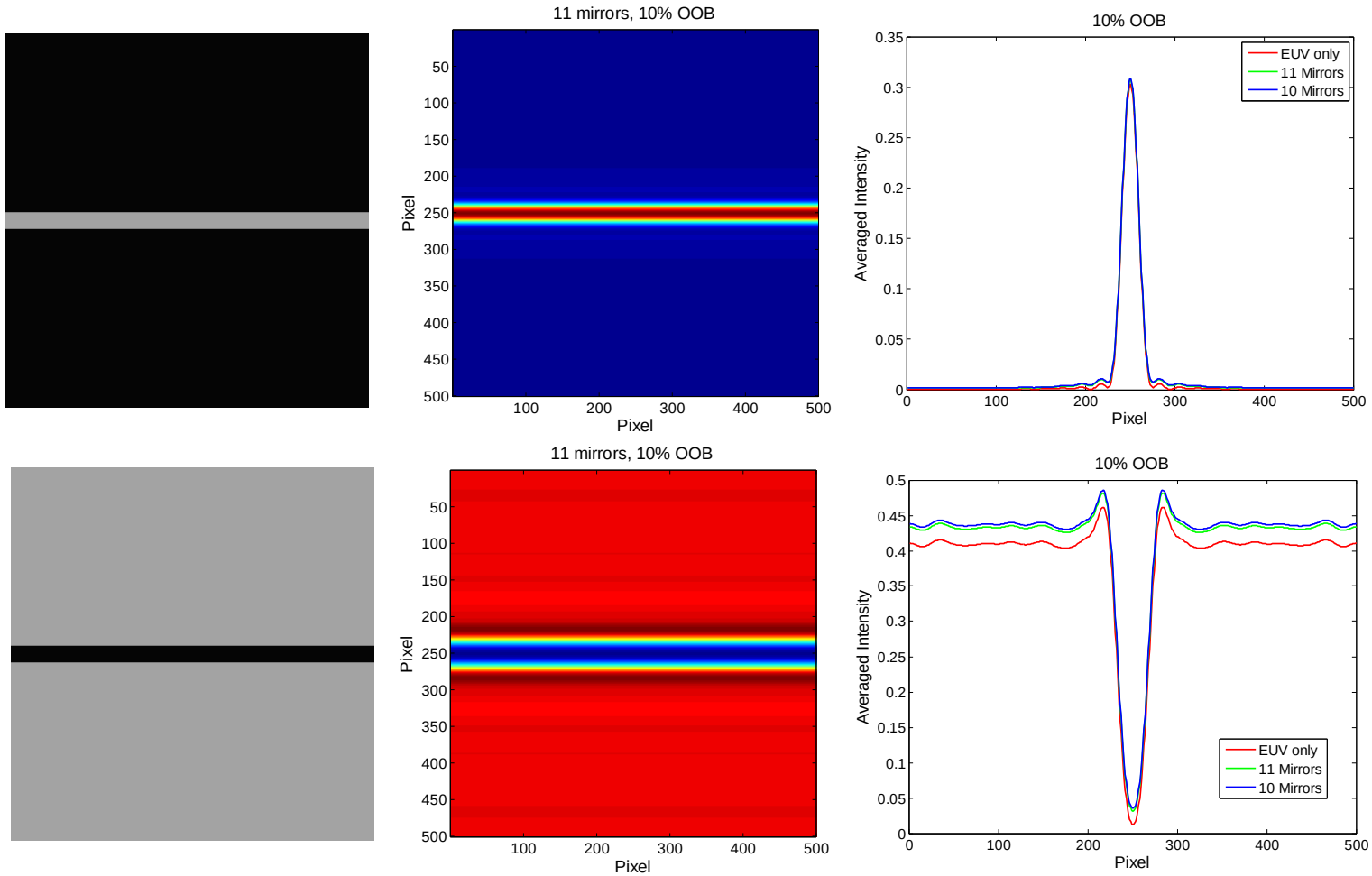



Comparable to the ADT **measured at an average of ~4% OOB**

The **flare on pattern goes up with bright area radius** increases

# 22nm Isolated Mask Patterns

Parameters: 0.32NA, 0.5 sigma circular conventional illumination



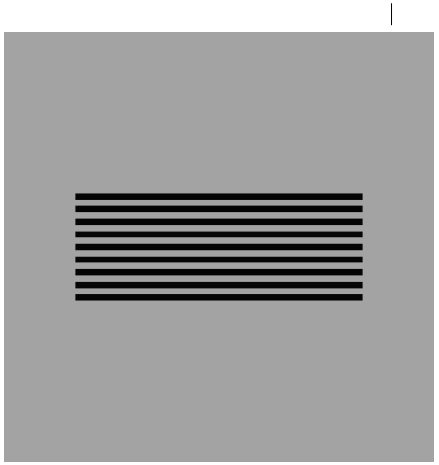

**1.72%**

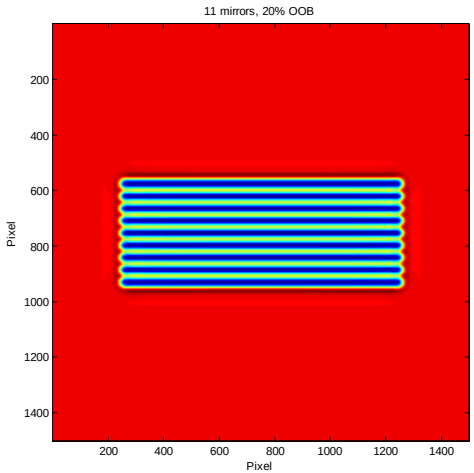
**5.42%**

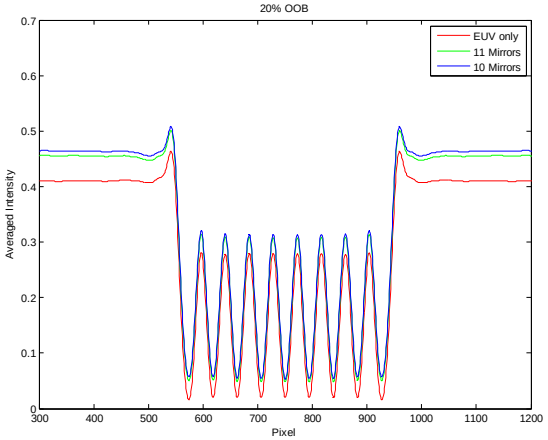
Mask

Aerial Image

# 22nm Dense Mask Patterns



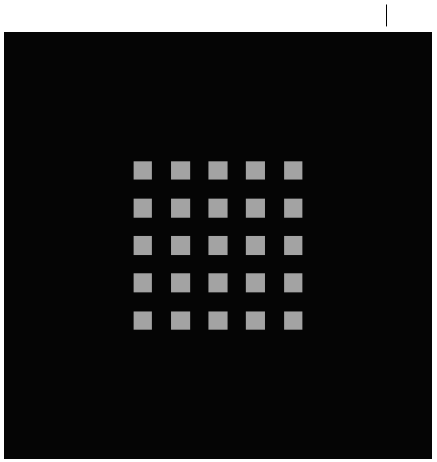


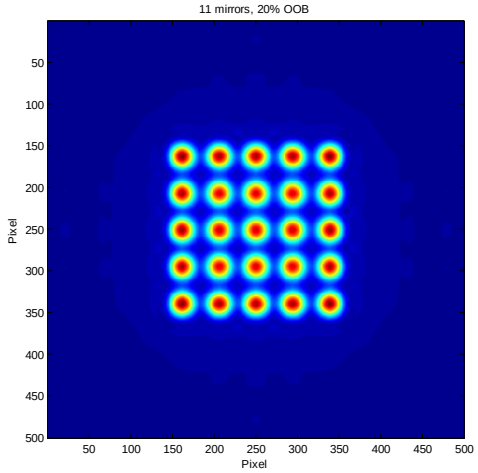



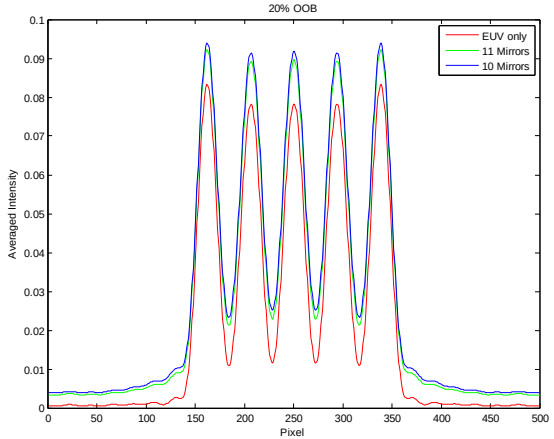

**5.04%**

**4.00%**

in Dark-field






**7.23%**

**11.23%**

in Bright-field

Mask

Aerial Image

OOB flare effects are **resist specific**

Resolution effects are **feature dependent**

# Outline

- Out of Band Problem
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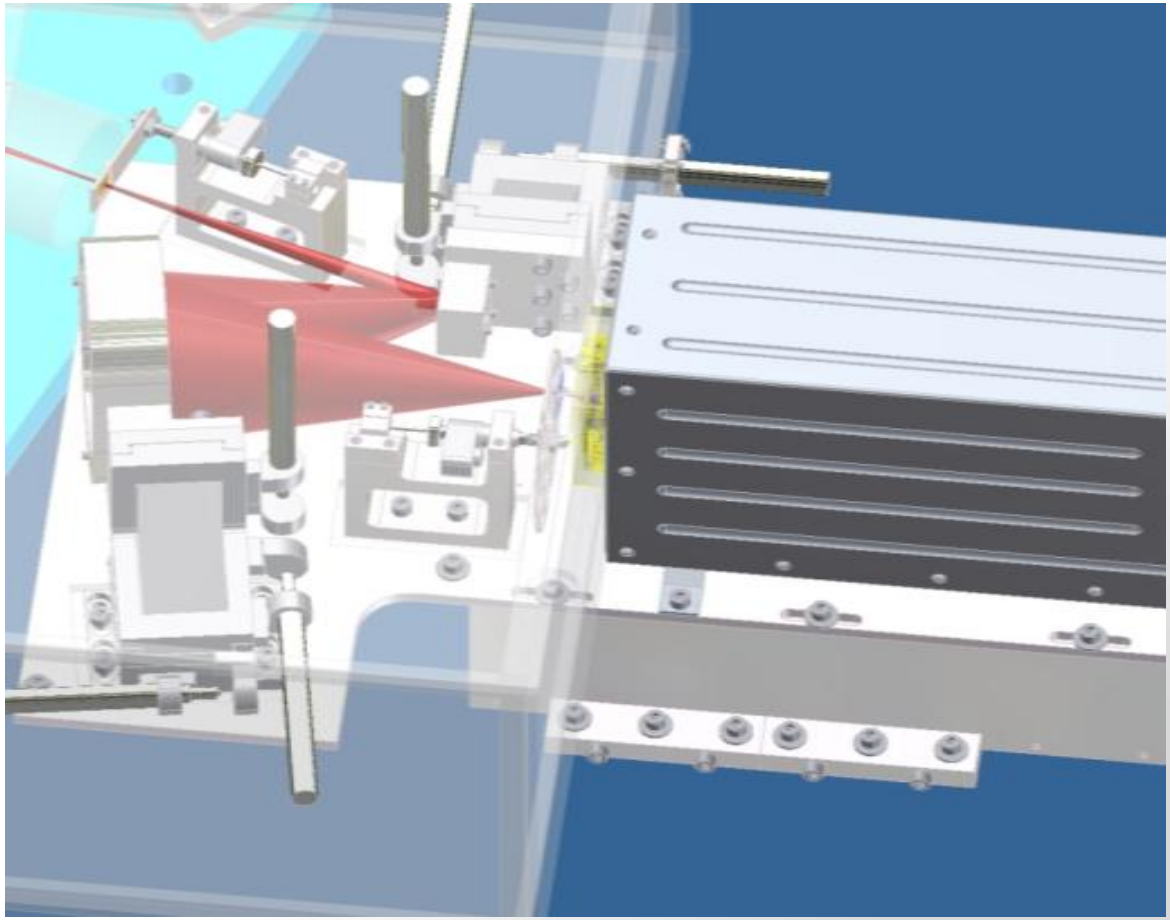
- OOB Exposure Studies: SEMATECH 0.3NA B-MET
  - Patterning and LER Results: two baseline resists
  - Environment Tests
- Summary

# Current Exposure Setup for OOB Tests



Wavelength range
[170 – 300] nm

OOB exposures before EUV patterning

$N_2$ purged environment

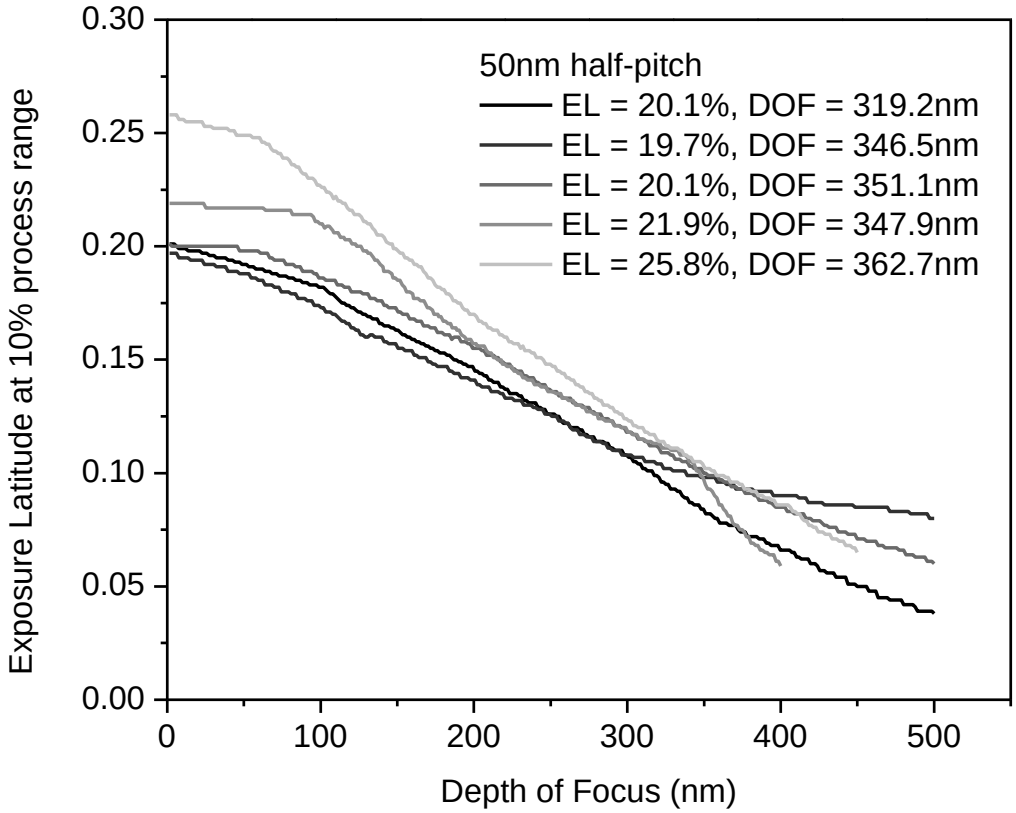
OOB dose 1mJ/cm$^2$ over EUV Pattern area

# SEMATECH Berkeley MET Baseline Resist Tests

- 0.3NA MET Illumination: **Annular (0.35/0.55)**
- Standard **EUV process conditions** used for both resists
- **Resist A**: **50 nm film on HMDS** primed substrate
- **Resist B**: Tests for **50nm film on HMDS** and on **40nm BARC undercoat**
- Repetitive measurements with over **25 process windows** evaluated

# B-MET Baseline **Resist A**

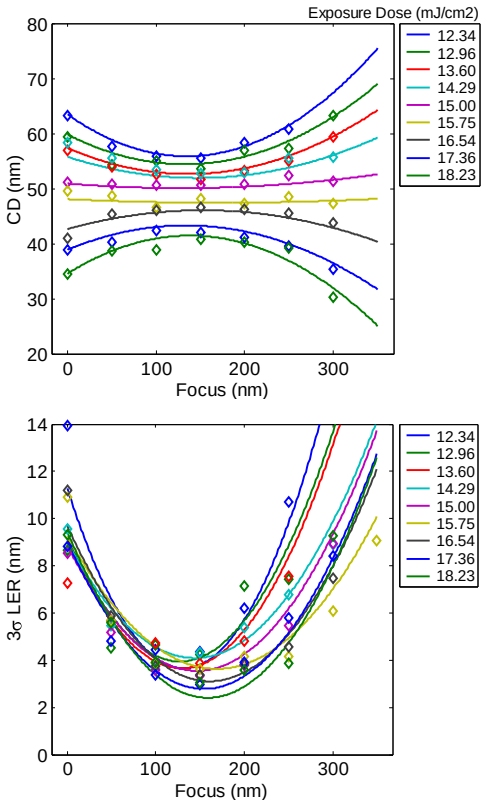
# Resist A: **50nm** HP Process Stability Standard



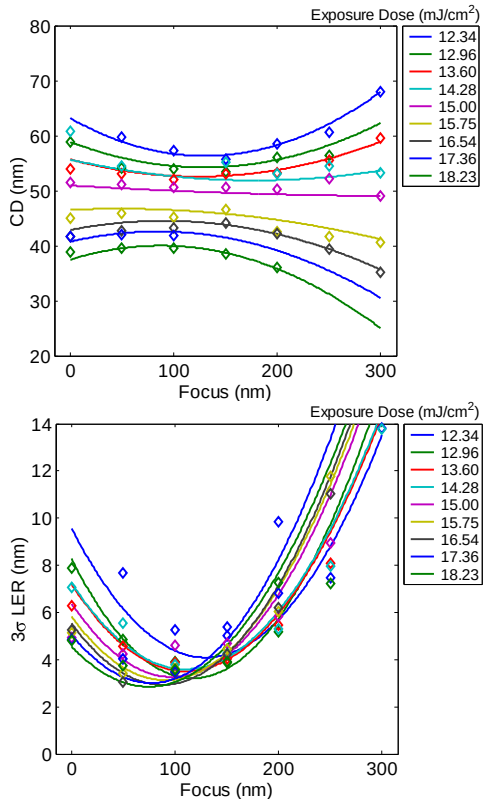

Absolute EL change = **5.7%**
Absolute DOF change = **43.5nm**

LER range: **4.0 – 4.33 nm**
Process uncertainty in LER: **0.33nm**

# Resist A: **50nm** HP Process for Environment effects



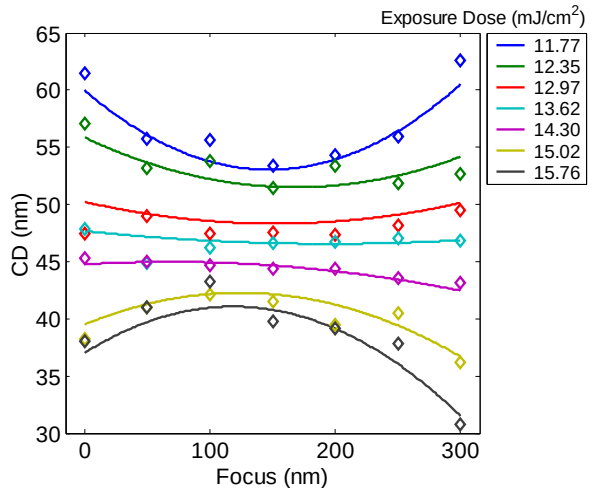

**EUV only, $E_{50}$=15.00mJ, EL=25%, DOF = 316nm, LER= 3.92nm**

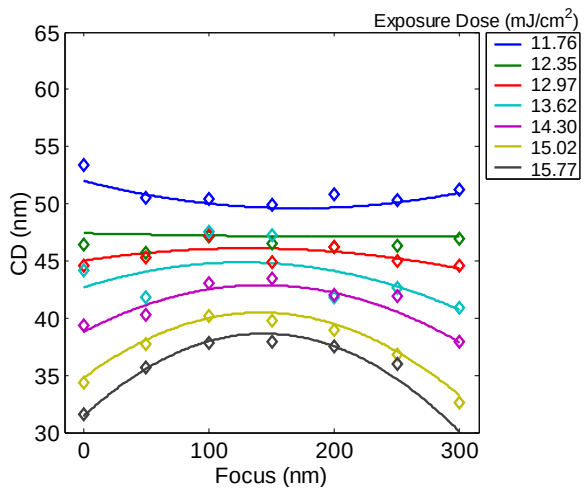


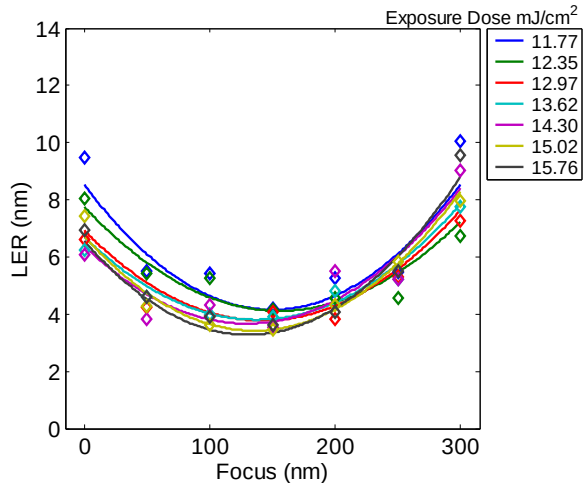

**Environment test, $E_{50}$=15.00mJ, EL=20%, DOF = 272nm, LER= 4.14nm**

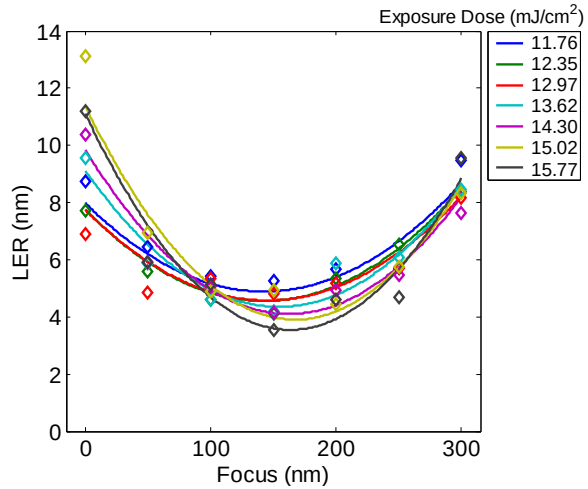
There is no OOB on film

Changes observed are **smaller than wafer to wafer process** changes




**Reference, EUV only,** Isofocal Dose = **13.62 mJ**
Isofocal CD = **47nm,** LER average = **4.1nm**

**EUV only + broadband (1.25 mJ/cm$^2$ )**
**Dose shift, LER is 5.2 nm**

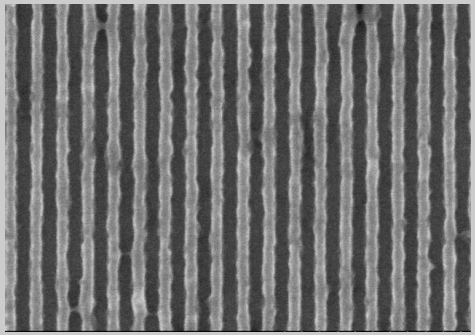
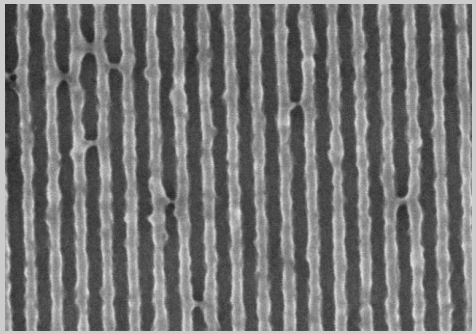
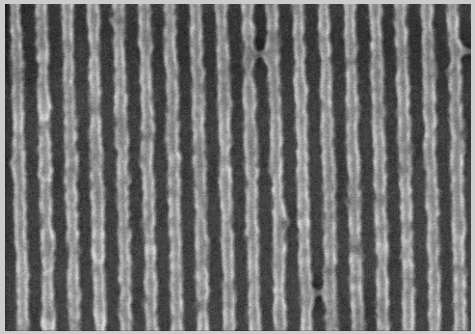
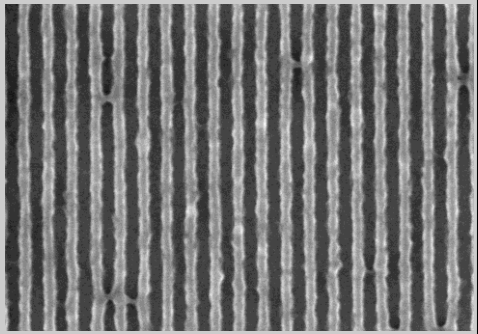
## 50nm half -pitch

Dose shift, process latitude is nominally unchanged

LER is changed for the worse

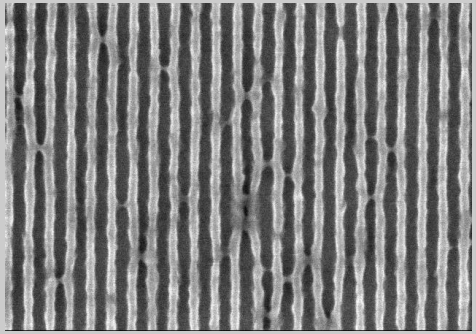
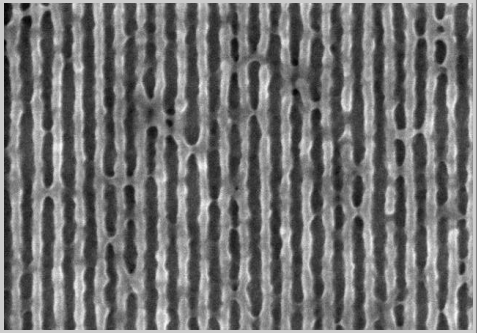
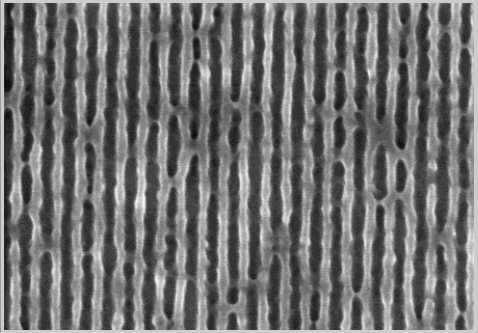
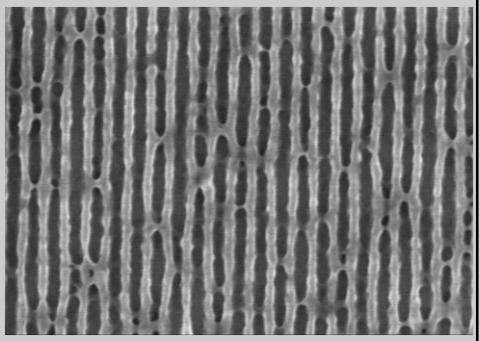
**Resist chemistry change**

# Resist A: **30nm** Half-Pitch

| Reference: EUV only<br>CD = 29.0nm<br>LER= 4.5nm | EUV + 193 nm<br>CD = 27.2nm<br>LER= 6.64nm | EUV + 248nm<br>CD = 28.0nm<br>LER= 5.42nm | EUV + Broad band<br>CD = 29.0nm<br>LER= 5.3nm |
|---|---|---|---|
|  |  |  |  |

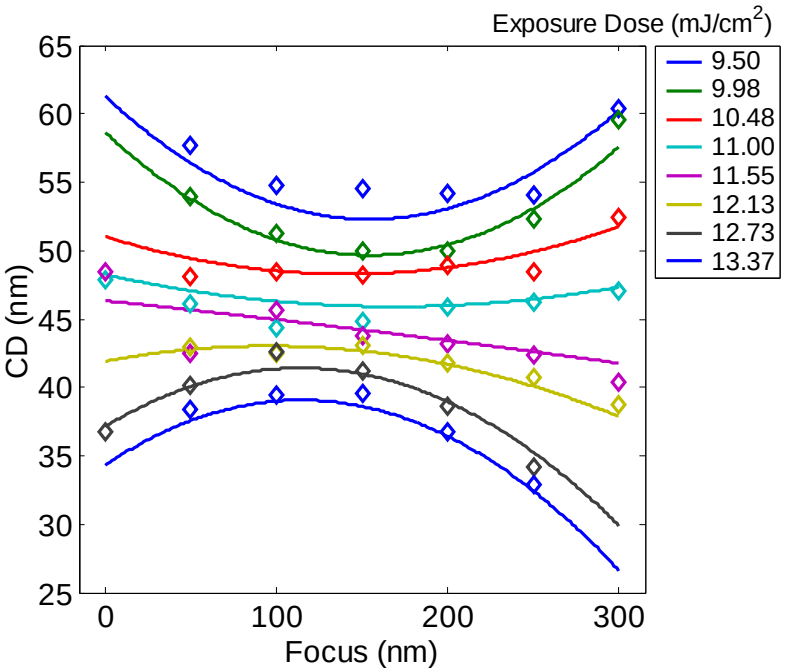
Failure free imaging at annular illumination

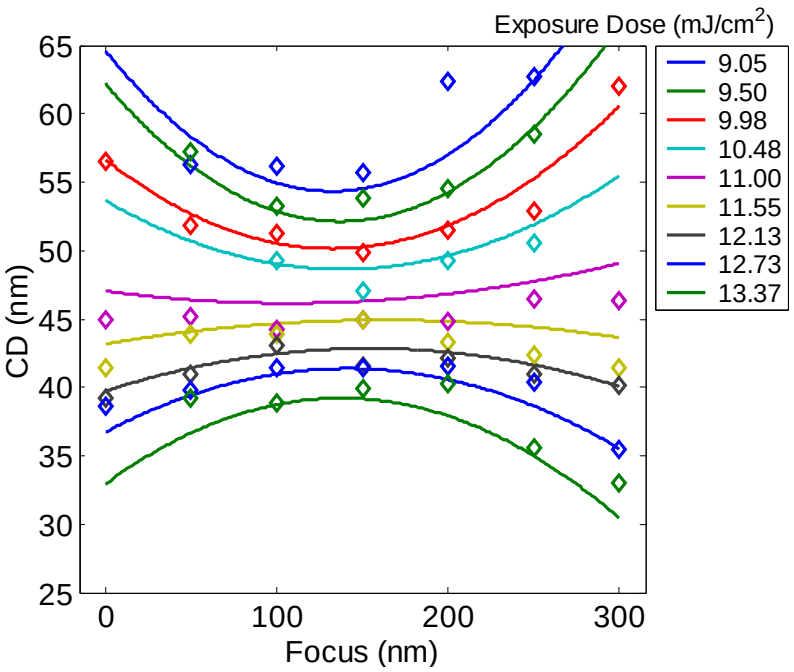
# Resist A: **24nm** Half-Pitch

| Reference: EUV only | EUV + 193 nm | EUV + 248nm | EUV + Broad band |
|---|---|---|---|
| CD = **22.3**nm | CD = **23.1**nm | CD = **22.3**nm | CD = **22.2**nm |
| LER= **6.25**nm | LER= **8.76**nm | LER= **8.49**nm | LER= **8.75**nm |
|  |  |  |  |

# B-MET Baseline **Resist B**

# Resist B with BARC: **50**nm HP Process



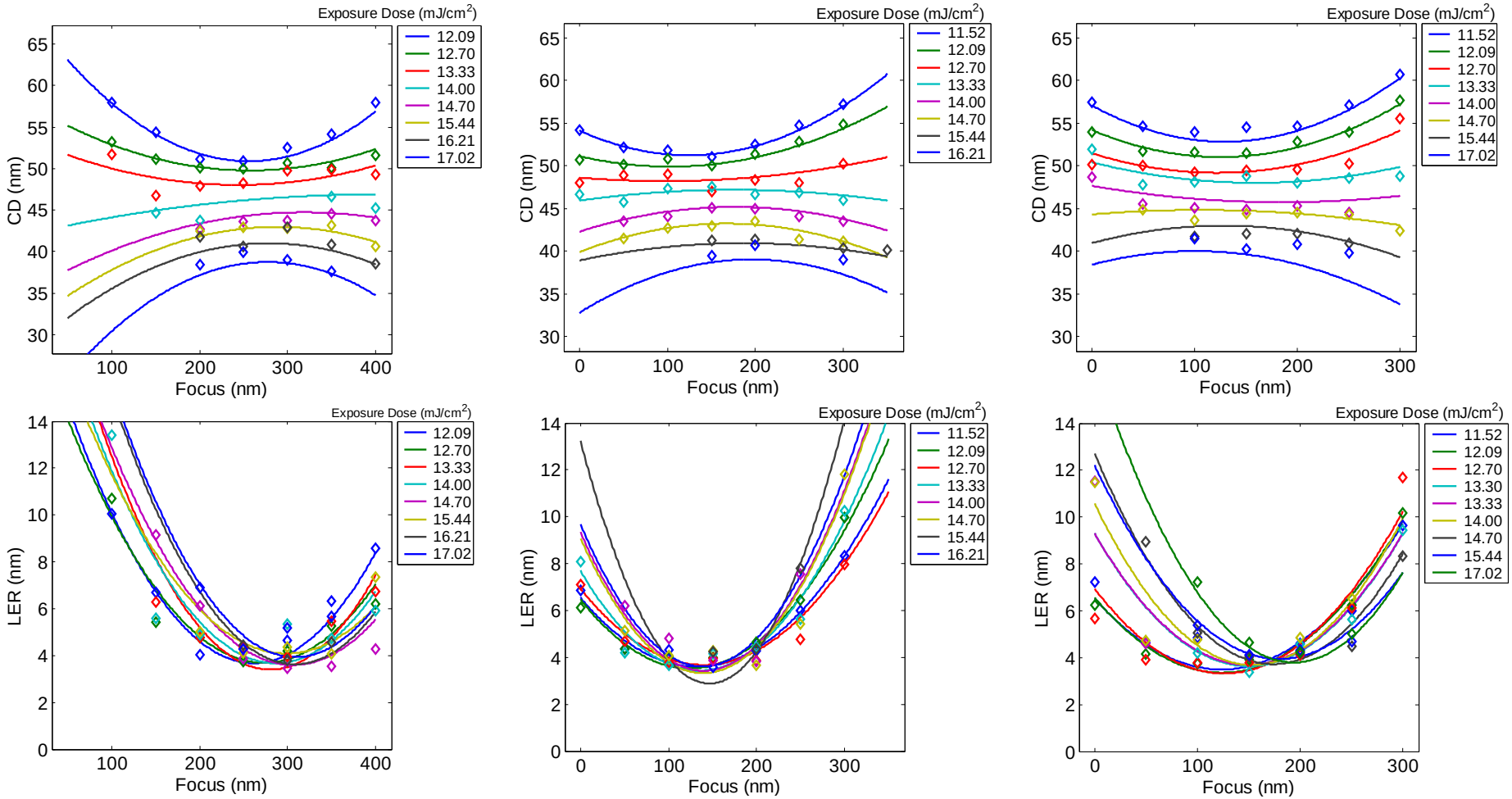




EUV only process window
LER area average = **3.98nm**

**1.00mJ/cm$^2$ uniform Broad-band + EUV**
LER = **3.08nm**

## 10% 193nm Dose

## >30% 193nm Dose

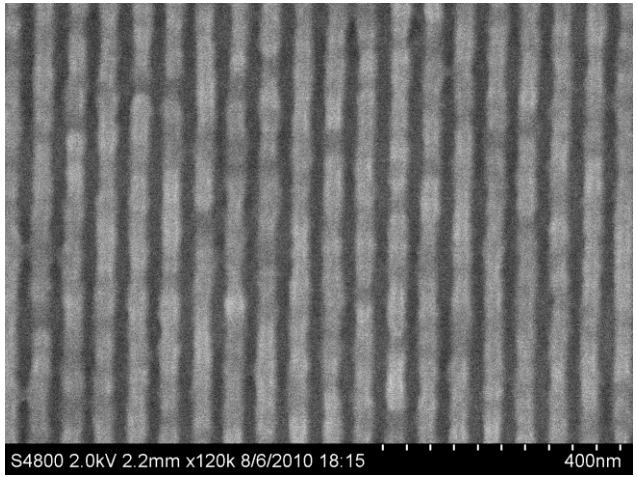


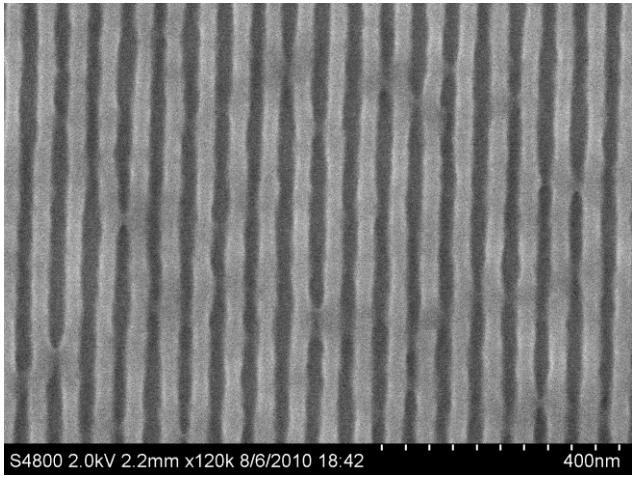

**EUV only, $E_{50}$=12.70mJ, EL=28%, DOF = 293nm, LER= 4.6nm**

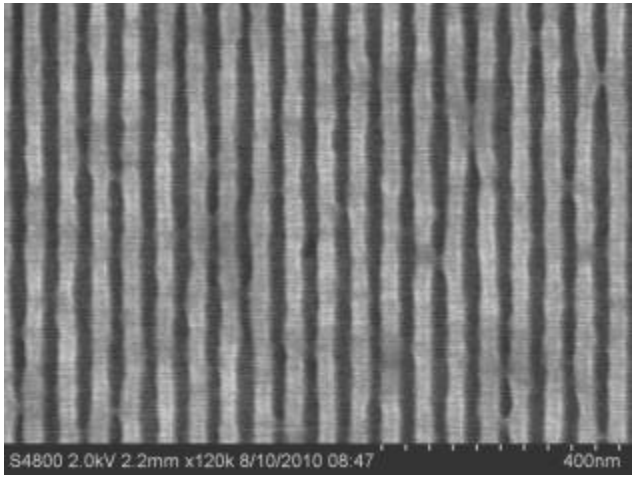
**193nm, 0.66mJ/cm², $E_{50}$=12.09mJ, EL=26%, DOF = 350nm, LER= 4.00nm**

**193nm,3.03mJ/cm², $E_{50}$=12.7mJ, EL=28%, DOF = 300nm, LER= 3.93nm**

# Resist B with BARC: **28**nm HP



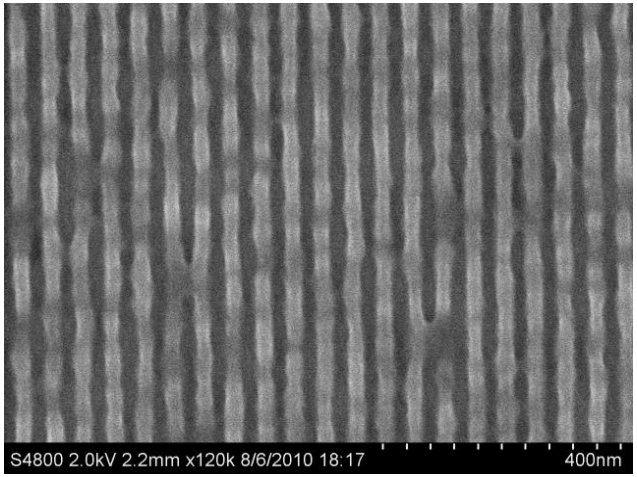



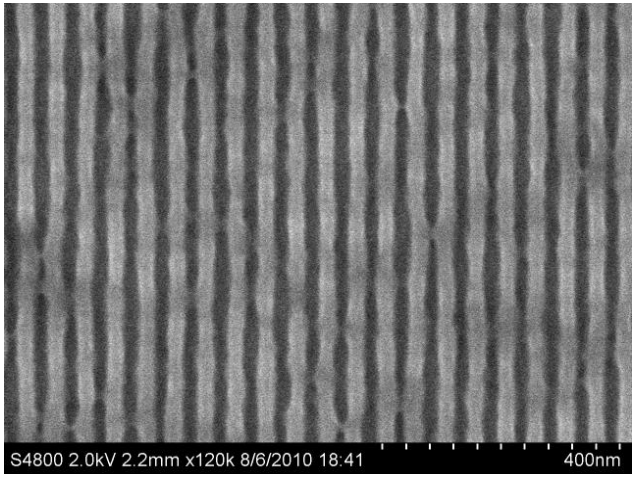

Reference
CD = **29.6**nm
LER= **6.29**nm

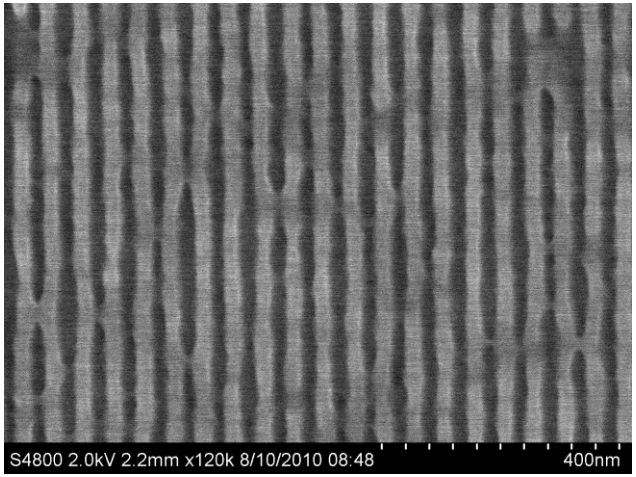
EUV + 193 nm
CD = **30.5**nm
LER= **4.82**nm

EUV + Broadband
CD = **29.3**nm
LER= **5.31**nm

# Resist B with BARC: **26**nm HP




Reference
CD = **27.5**nm
LER= **6.66**nm

EUV + 193 nm
CD = **28.1**nm
LER= **5.32**nm

EUV + Broadband
CD = **27.9**nm
LER= **6.8**nm

# In Short..

| 193 nm | LER | Resolution | EL (10%) |
|---|---|---|---|
| RESIST A | Worse | Worse | Same/Worse |
| RESIST B | Better | Better | Same |

| 248 nm | LER | Resolution | EL (10%) |
|---|---|---|---|
| RESIST A | Worse | Worse | Same |
| RESIST B | Same | Same | Same |

| All | LER | Resolution | EL (10%) |
|---|---|---|---|
| **RESIST A** | Worse | Worse | Same |
| **RESIST B** | **Same/Better** | **Same/Better** | **No change** |

# Summary

- Both resists are **OOB sensitive**
- Resist A gets **worse** with OOB
- Resist B shows nearly 25% improvement in LER and the resolution seems to be **better with 193nm exposure**
- **157nm: ??**

# Acknowledgments

**CXRO and MET**: Senajith Rekawa, Kevin Bradley, Charles Drew Kemp, PaulDenham, Gideon Jones, Lorie-Mae Baclea-an, Nathan Smith, Chris Anderson, Brian Hoef

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**Energetiq**: Debbie Gustafson and team

**Intel**: Robert Sulc, Todd Younkin, James Blackwell

**Global Foundries**: Thomas I. Wallow

**IMEC**: Gian Lorusso

**Kobe Image**: http://homepage2.nifty.com/kaba/kobe-1.jpeg

# Thank You