Growth and Printability of Multilayer Phase Defects on EUV Mask Blanks

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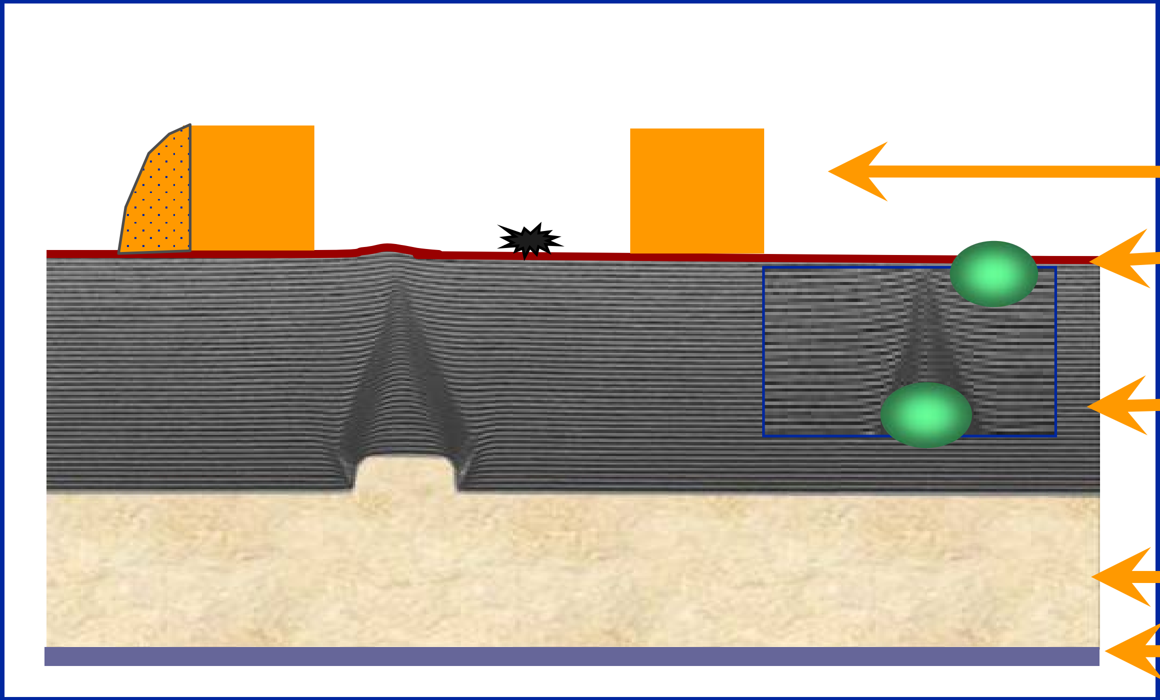
Outline

- Types of defects on EUV mask
  - Growth modes
- ML phase defects
  - MP-PDM test sample
  - Printability on resist patterns
- Defect specification
  - Resist effects
- Summary and 'final analysis'

Four Major Categories of EUV Mask Defects

- I: Substrate defects: 'propagate' to ML surface
- II: ML defects: substrate and deposition process
- III: Absorber pattern defects: mask fabrication process (Wed. talk DI-02)
- IV: 'Soft' defects: contaminations from handling and use (Poster MA-P03)



Absorber (TaN, 80nm)

ML cap (Ru, 2.5nm)

ML (Mo-Si, 280nm)
(~3nm Mo/4nm Si)

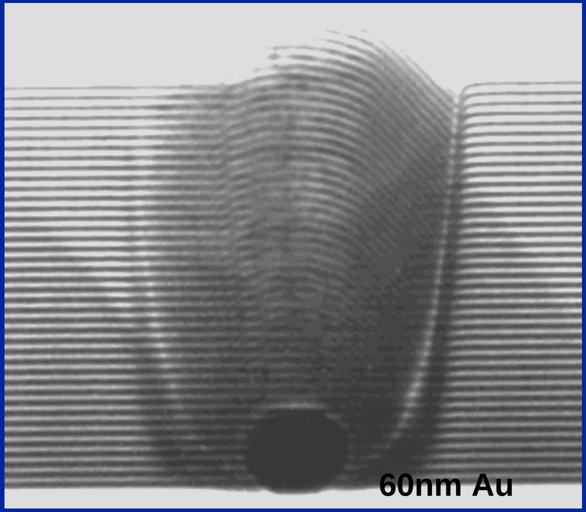
Substrate (LTEM, ¼")

Conductive layer

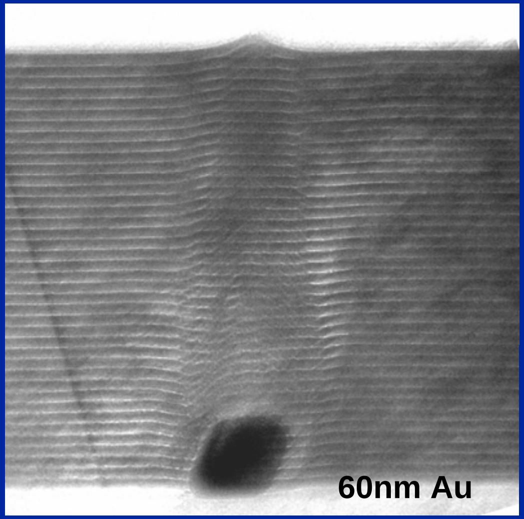
Nature and Growth of ML Defects

- IBD is widely used for ML coating for mask blanks
- Defect nature: bumps (particles) or pits
- Defect growth/evolution depends on deposition conditions

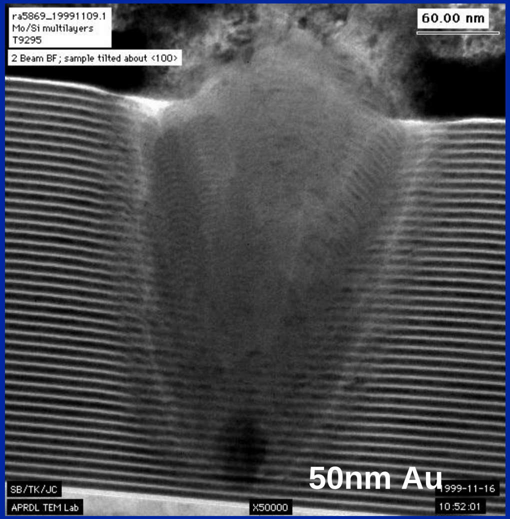
Off-normal



Near-normal



Magnetron



P. Mirkarimi

- Optical manifestations in resist printing
  - Phase
  - Amplitude
  - Or both components

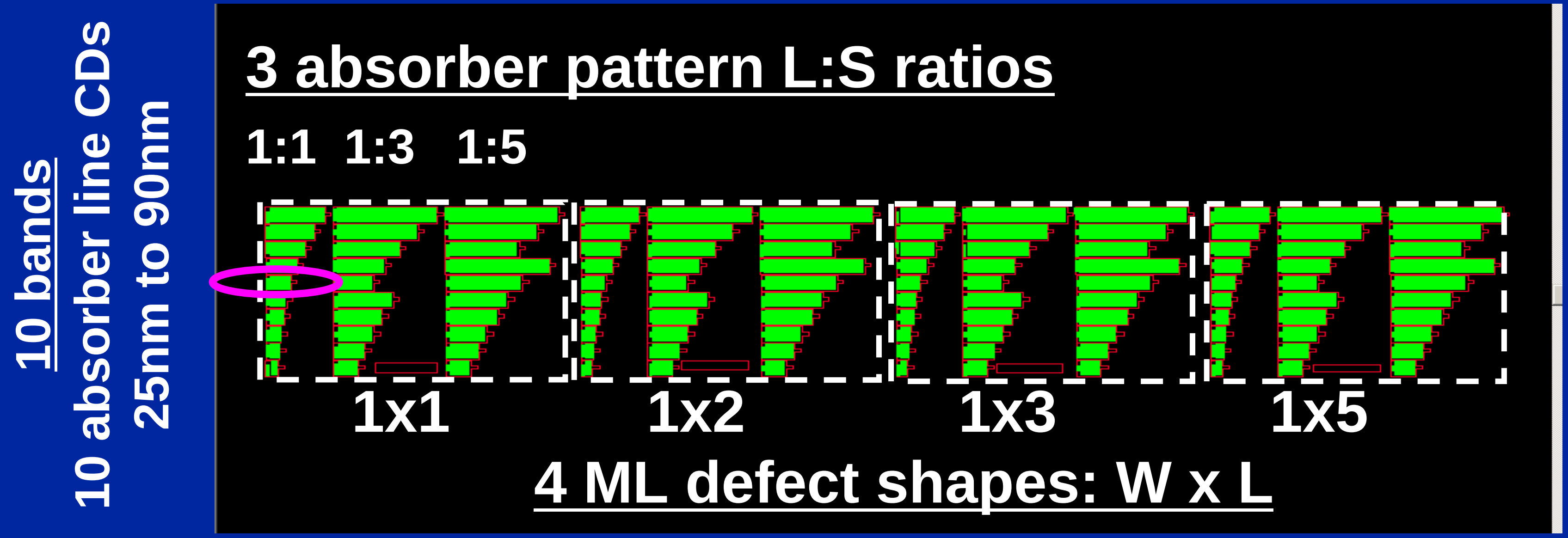
Acceptable ML Defect Spec

- **ML defects are extremely complex**
- **Defect understanding necessary for defect reduction**
  - Defect sources
  - Impact to resist printing of mask patterns
  - Detection and disposition
- **Defect specifications shall achieve universal acceptance**
  - Specs define the amount of development required for blank quality and inspection tool capability ($$) – suppliers vs. users
  - Specs must be data-based – resist printing and validated modeling
- **We use well-characterized 'model' system – PDM**
  - Programmed defect mask

MP-PDM Design

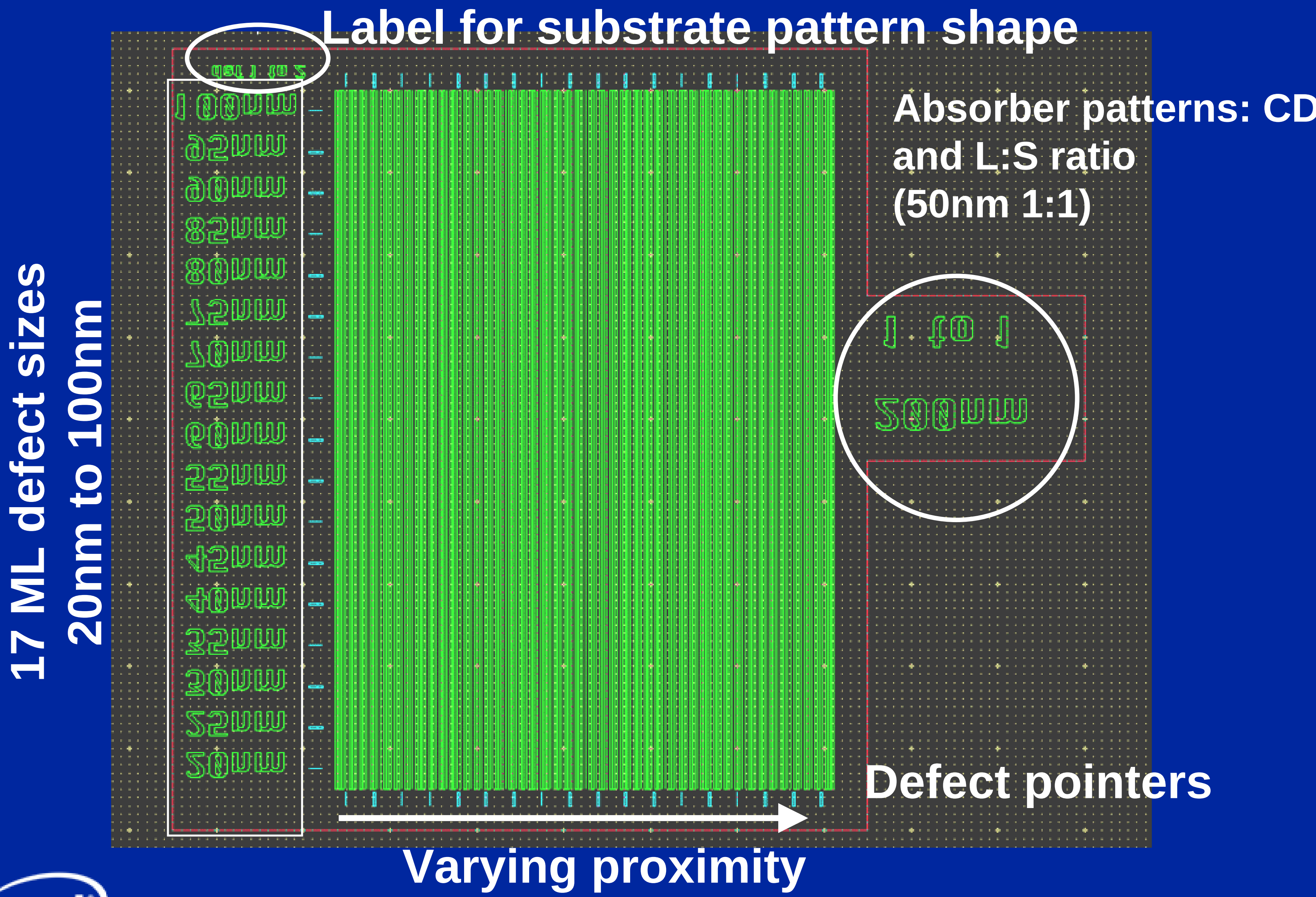
- MP-PDM: ML defects placed near absorber Patterns with full range of sizes/shapes and proximity

Cell layout



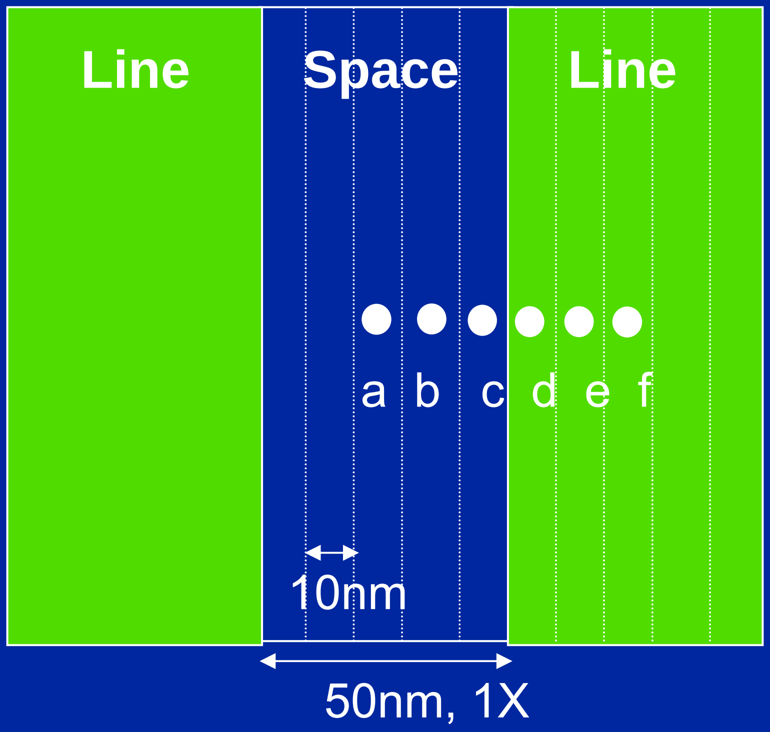
- ML defects were produced from substrate patterns
  - Specially 'tuned' ML deposition process
  - Wide range of defects on the same test plate

MP-PDM sub-cell: ML bump size and shape

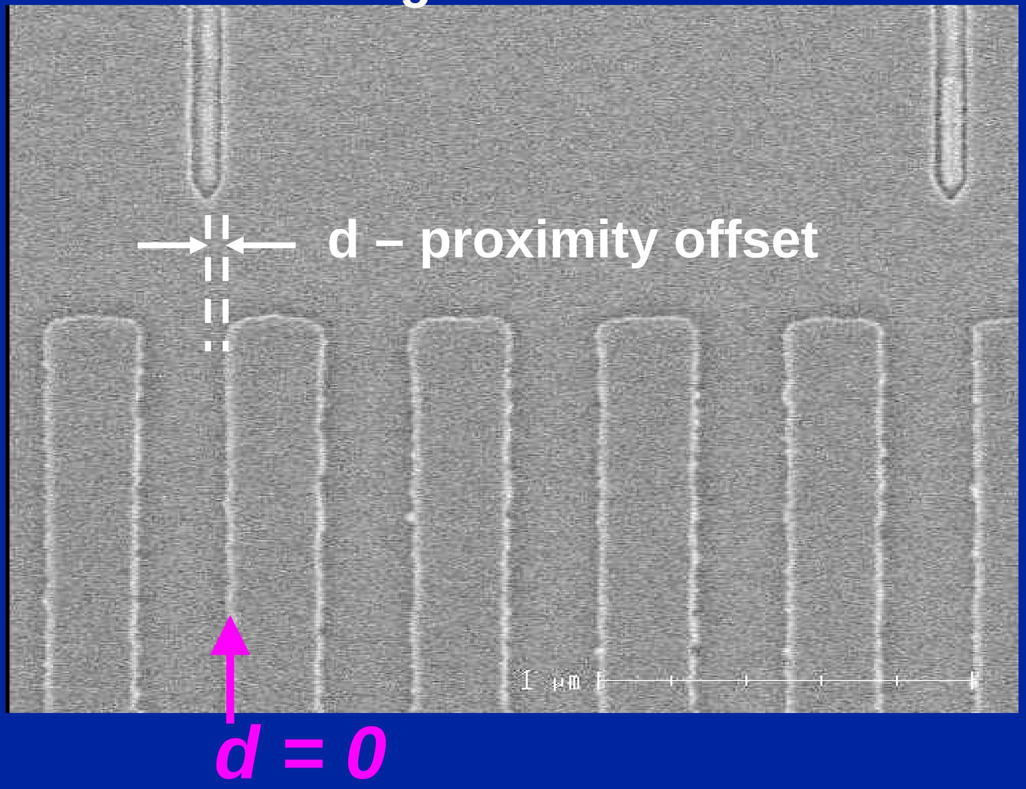


MP-PDM Sub-cell: ML Bump Proximity

- **ML bumps in full range of proximity to patterns**



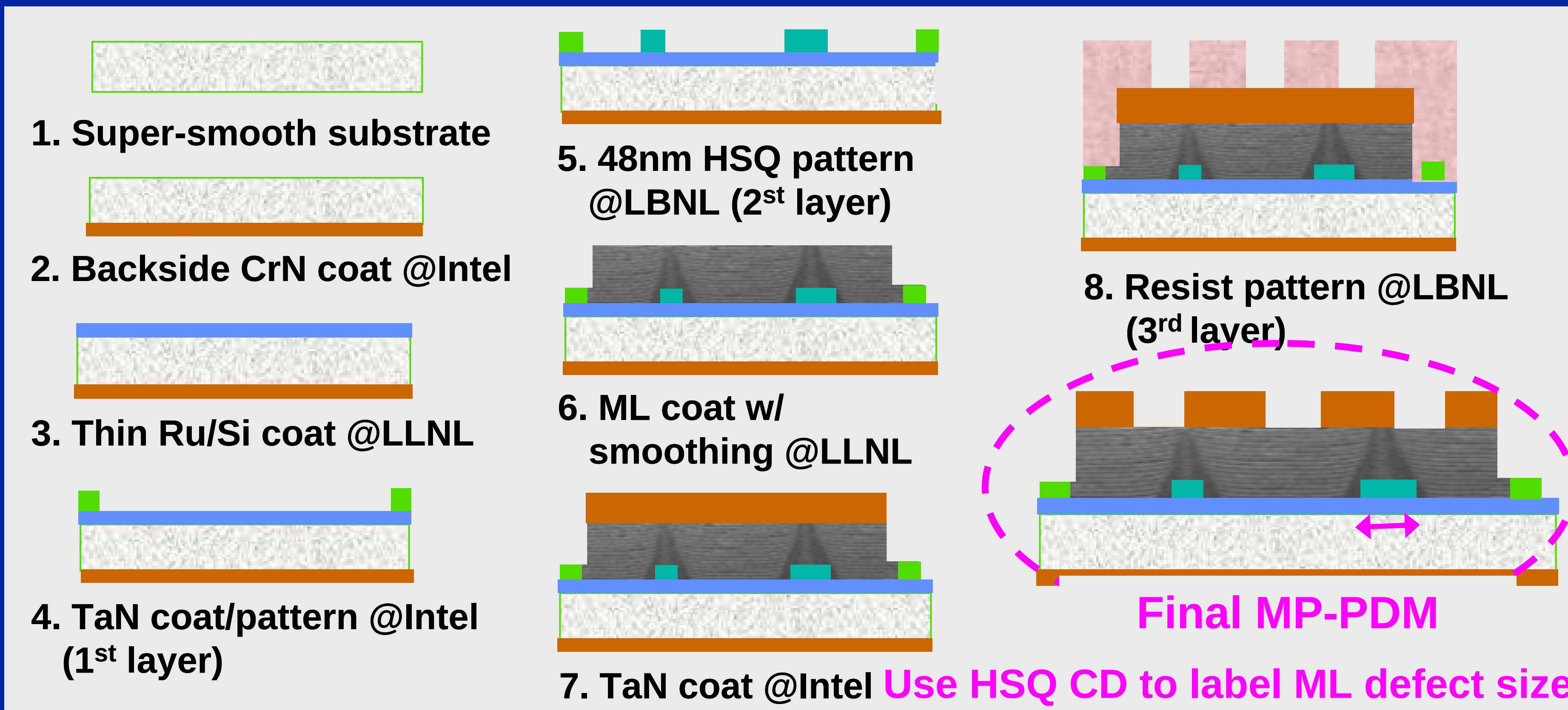
SEM image of 50nm 1:1 lines



- **Each defect size/location repeated 3 times for better statistics in printed resist CD measurements**

MP-PDM Fabrication: Key Steps

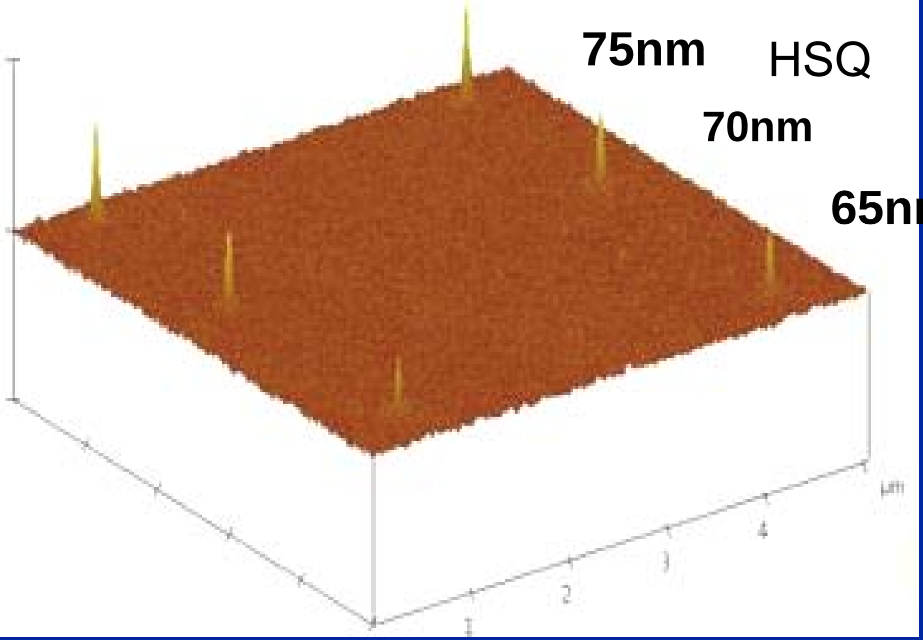
- **Three-layer patterning with alignment marks for registration**
  - Materials preparation and pattern etch at Intel
  - ML coating at LLNL
  - EB resist patterning at LBNL (Now capable at Intel)



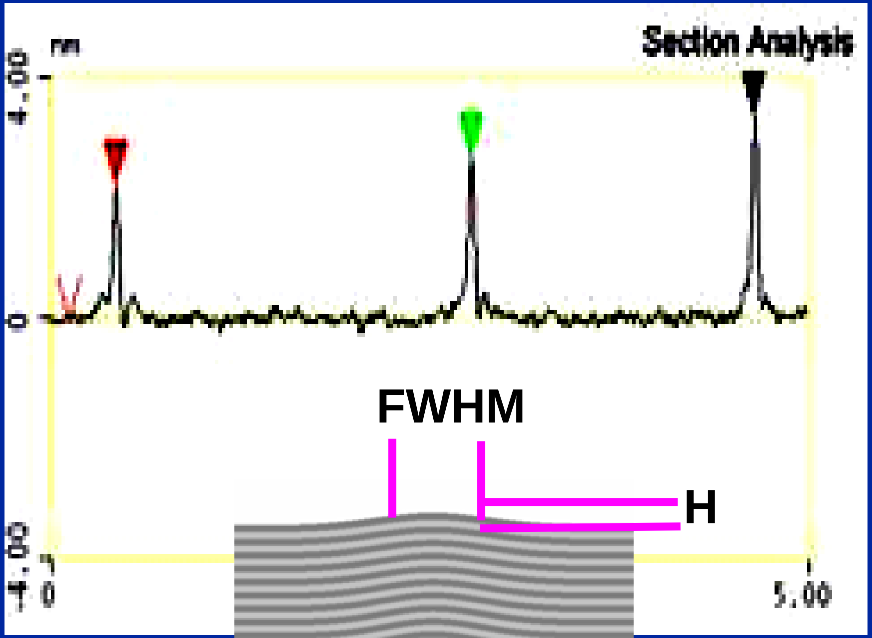
ML Phase Defect Characterization

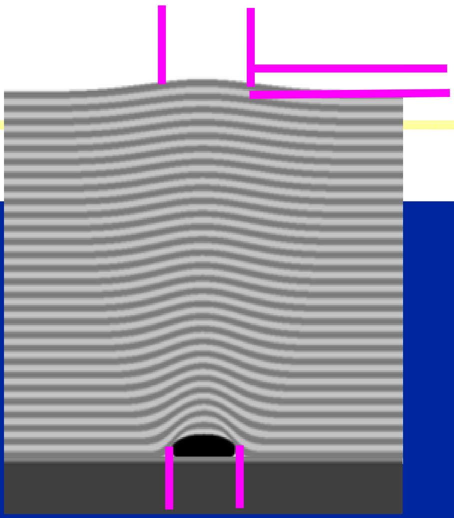
- **ML bump size measurements by fine AFM scans**

Surface profile



Line scan



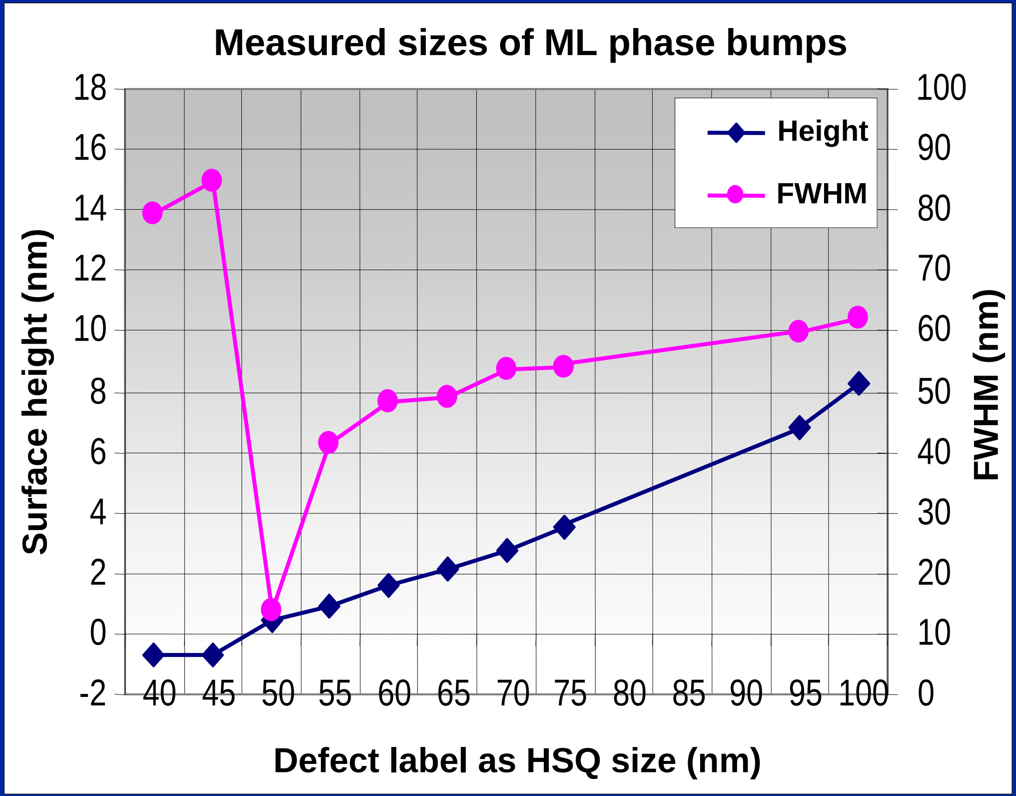


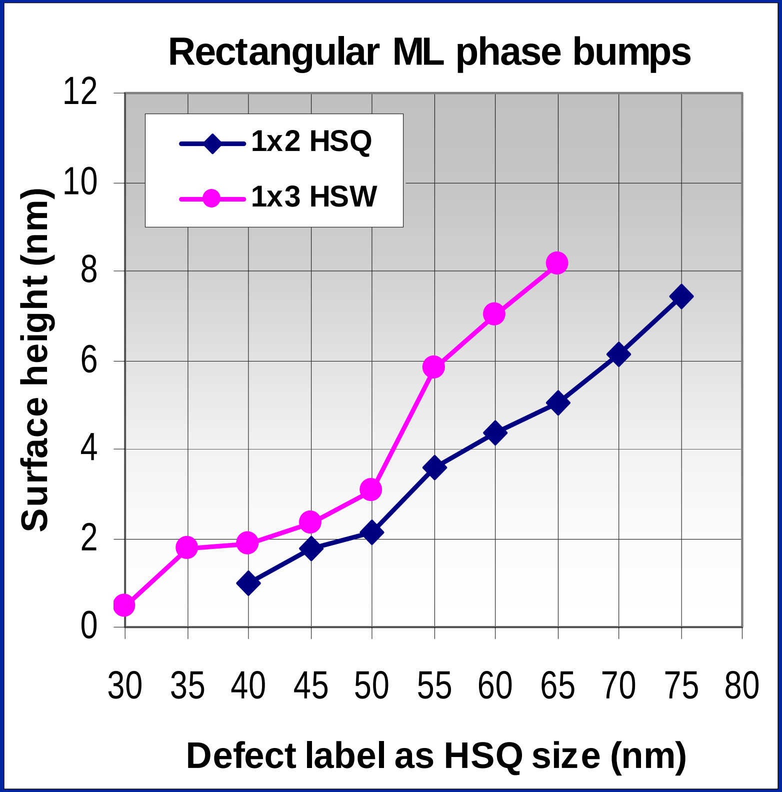
HSQ CD

- **ML defect characterized as surface bump**
  - Height x FWHM

ML Phase Defect Characterization (cont'd)

- **Wide range of sizes**
  - Height: 0 to 8nm
  - FWHM: 30nm to 70nm

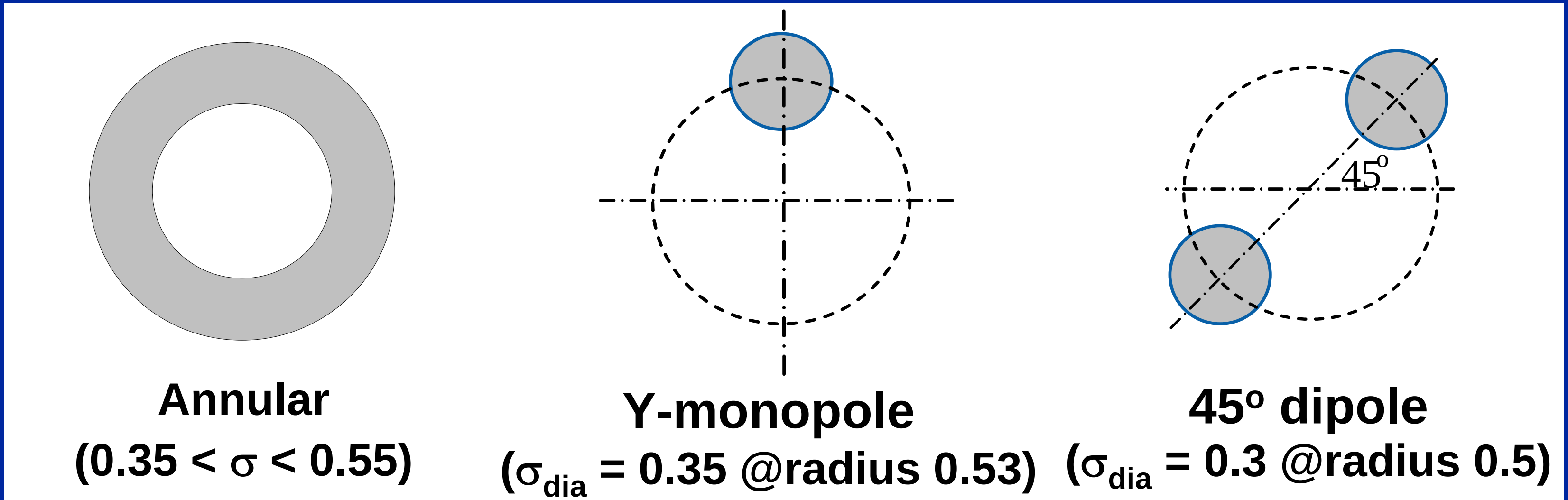




- **This talk focuses on square ML bumps (point defects)**

EUV Exposure Conditions

- **MET: N.A = 0.3, 5X reduction, ~4° incident**
  - @Intel: Annular pupil fill only
  - @Berkeley: Annular, Monopole, Dipole, …

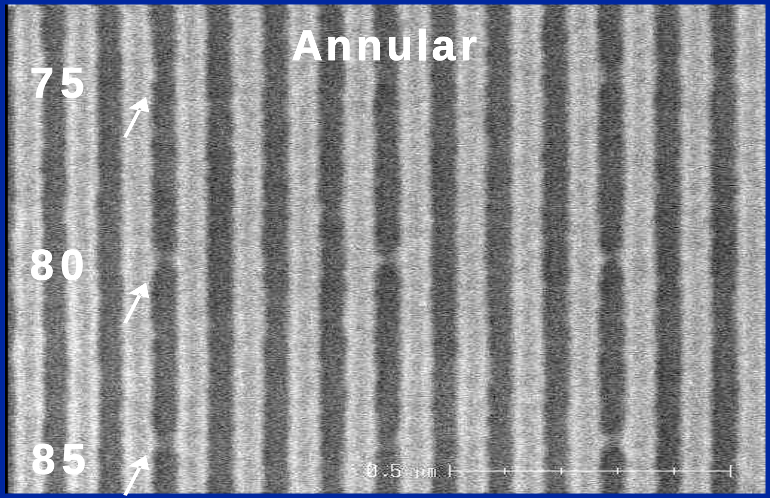


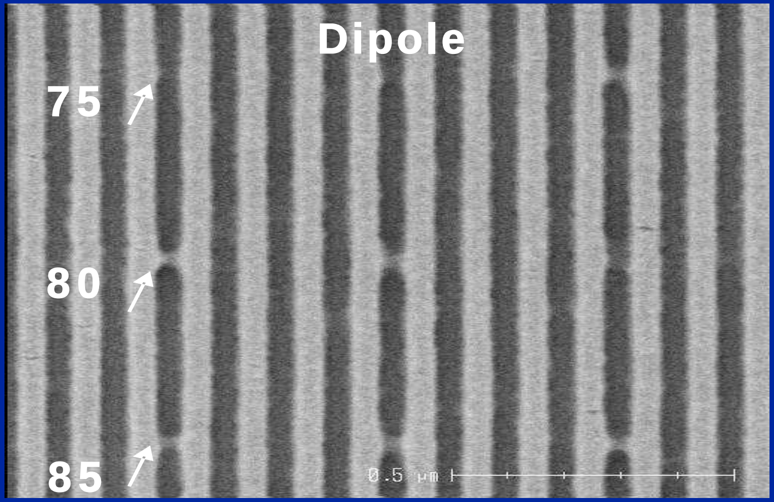
- **Resist: 112nm, ~20mJ/cm²**
  - Resolution limits: >40nm
- **Process window (11x17 FEMs)**
  - DOF: ~ ±150nm
  - Exposure latitude: ~ ± 5%

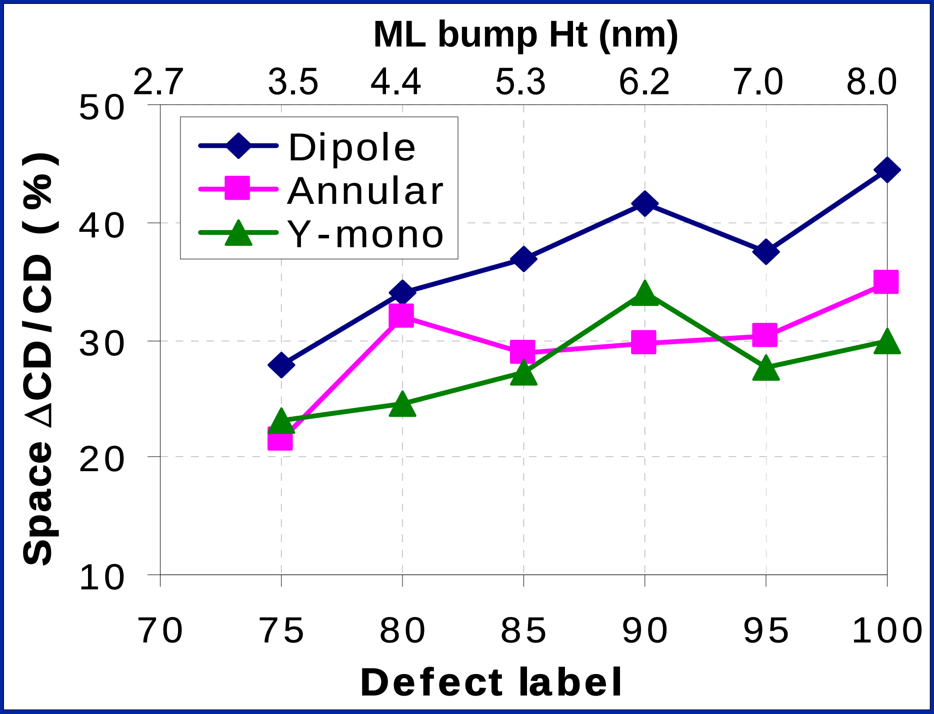
1. P. Naulleau et al, *Proc. SPIE*, Vol. 6151 (2006).
2. T. Liang, et al, *Proc. SPIE*, Vol. 6283 (2006)

Effect of Illuminations

- Example: 3 sets of defects at between 50nm 1:1 lines



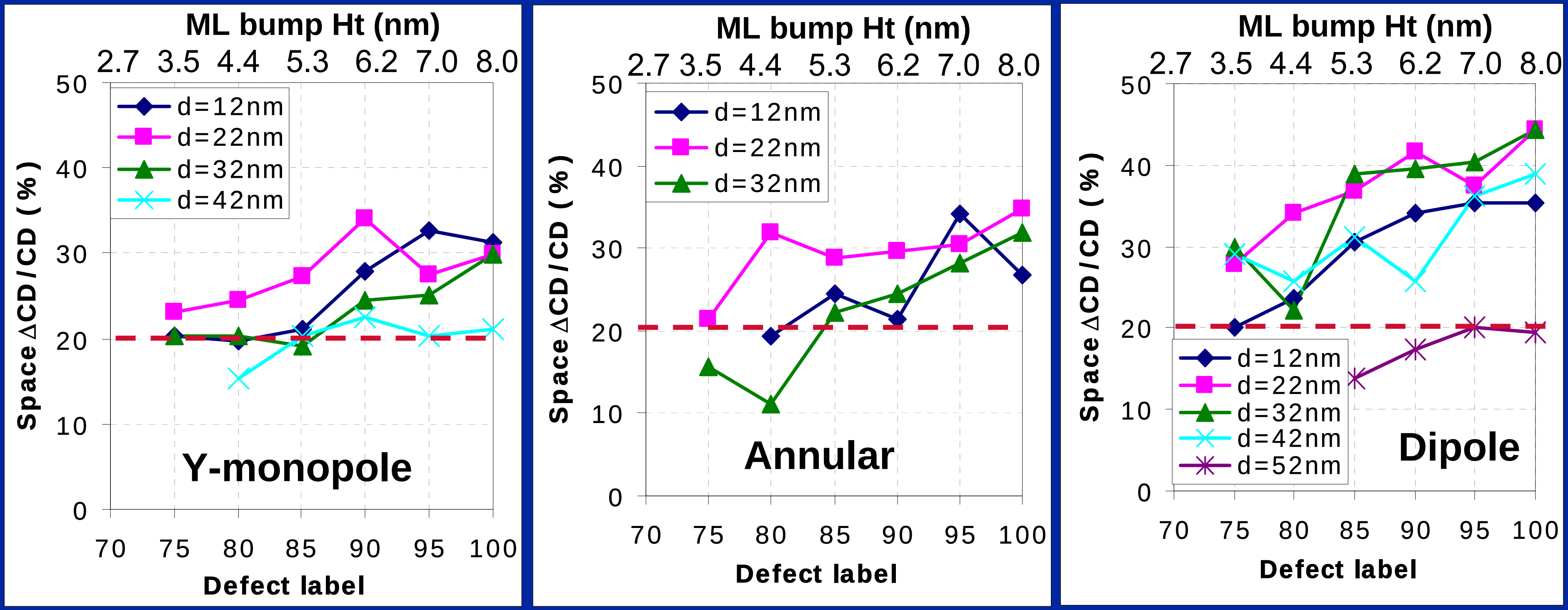




- **Defects are more printable under dipole illumination**
  - Possibly due to higher resol. in both horiz. and vert. directions

Effect of Defect Proximity

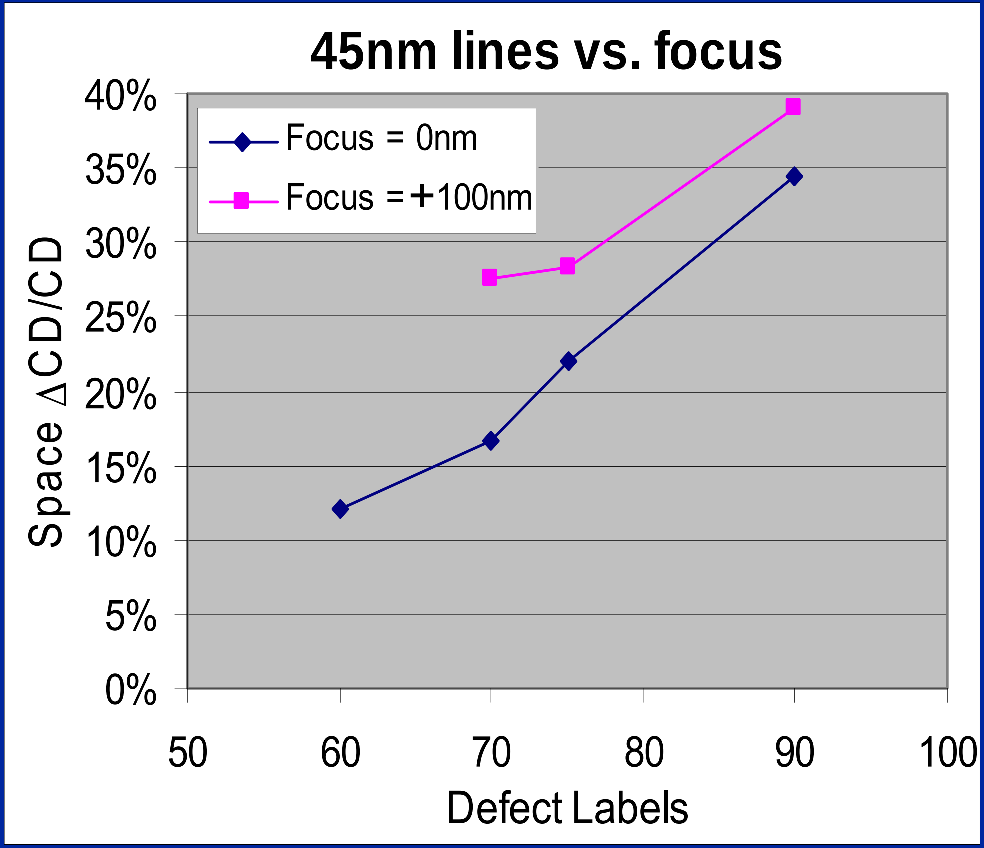
- **Resist CD change (% ΔCD/CD) for 50nm 1:1 lines**



- **Defects are most printable at center between 2 lines**
- **Defects are 'non-printable' when ≥1/2 under absorber line**
  - Pattern covering is effective to render defect non-printable

Effect of Defocus

- Phase defect printability is expected to vary with defocus

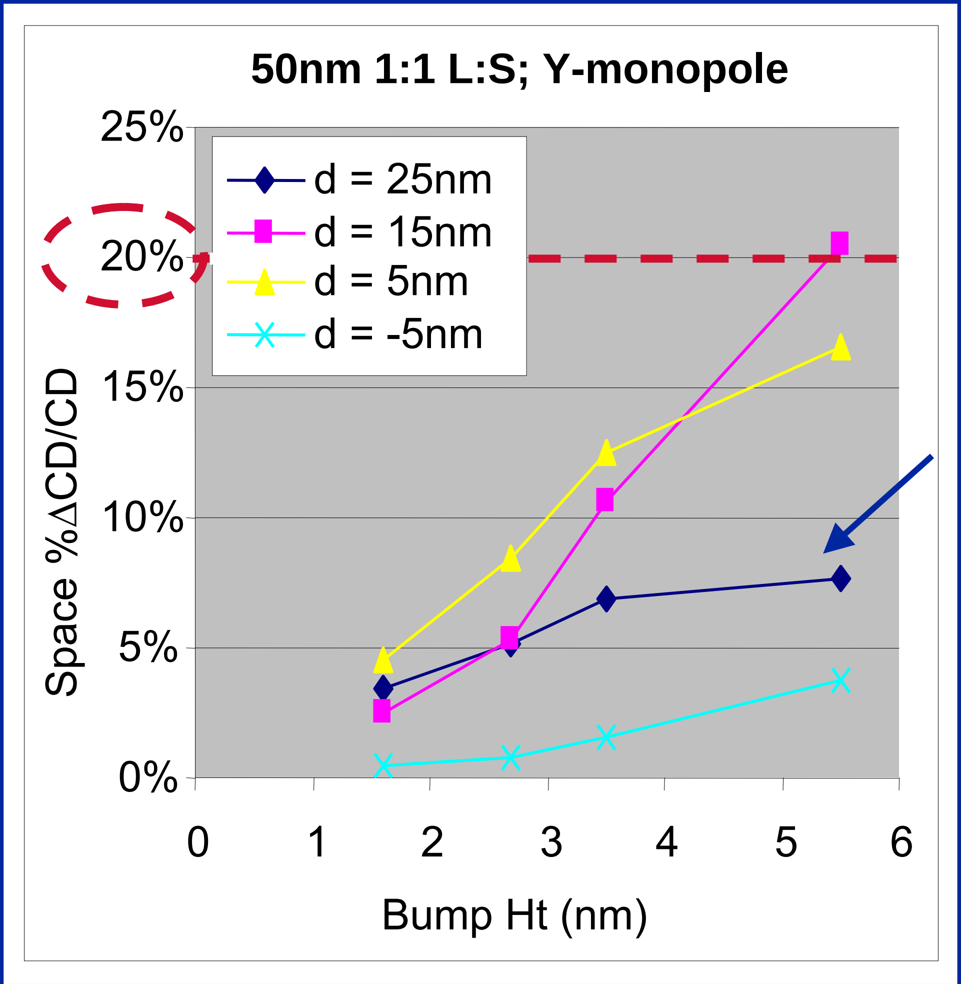


- Effect reduced for larger ML defect
  - Larger defects have amplitude components

Comparison with Simulations

- **There is mismatch with <u>aerial image only</u> simulations**
  - Under-predicts printability
  - Disagrees in proximity effect
- **Possible causes**
  - Resist effects (resolution, EL)
  - ML defect size/shape accuracy
- **Resist effects need further Investigation**
  - Resist model
  - AIM measurements

SSA simulated results



ML Defect Specification Discussion

- For example: 50nm 1:1 line printing
  - 2.5nm x 50nm at center of line considered critical
  - Non-printable at line edge
- Factors to consider in ML defect specifications
  - Exposure conditions
  - Allowable %ΔCD/CD: layer dependent ~20%
  - Proximity effect: Pattern placement with respect to defects
  - Resist effects and limitations (resol., LWR, EL)
  - Post-resist processing
- Non-linear resist effects makes scaling defect spec to smaller device patterns difficult, if not impossible
  - Resist model unreliable to extend to patterns beyond the calibrated pattern geometries/size
  - Aerial image simulation under-predicts printability when EL is small*

*Ref: Zhang and Liang, BACUS 2007

- Further defect printability studies require adequate resist performance

Defect Specification Discussion (cont'd)

- **<u>Substrate defect specification</u> is more complex – strongly depends on deposition conditions**
  - Near-normal: <30nm (producing 2.5nm ML bump)
  - Off-normal: << 30nm due to 'decoration' phenomenon
    - 30nm → 25nm ML bump
    - Off-normal process shall be avoided
  - Moderate smoothing: >30nm
- **Smoothing or other 'rendering' scheme highly desirable, probably a must**
  - Impractical to expect a tool for substrate inspection with 100% capture rate @<30nm
  - 'Invisible' substrate defects (sub-threshold) are high risk

Summary

- **ML defects are complex – use ‘model’ MP-PDM for comprehensive investigations of true ML phase defects**
- **ML phase defect printability is sensitive to exposure conditions and resist process**
- **Aerial image simulation seems to under-predict defect printability**
- **Covering defects, even partially, with absorber patterns is very effective (‘rewarding’) to ‘render’ defects non-printable**
  - ‘Useful’ ML blanks may not be necessarily ‘defect-free’
  - Max. # of allowable defects depends on device layer structures

Acknowledgements

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