E-D characteristics and aberration sensitivity of the Micro-Exposure Tool (MET)

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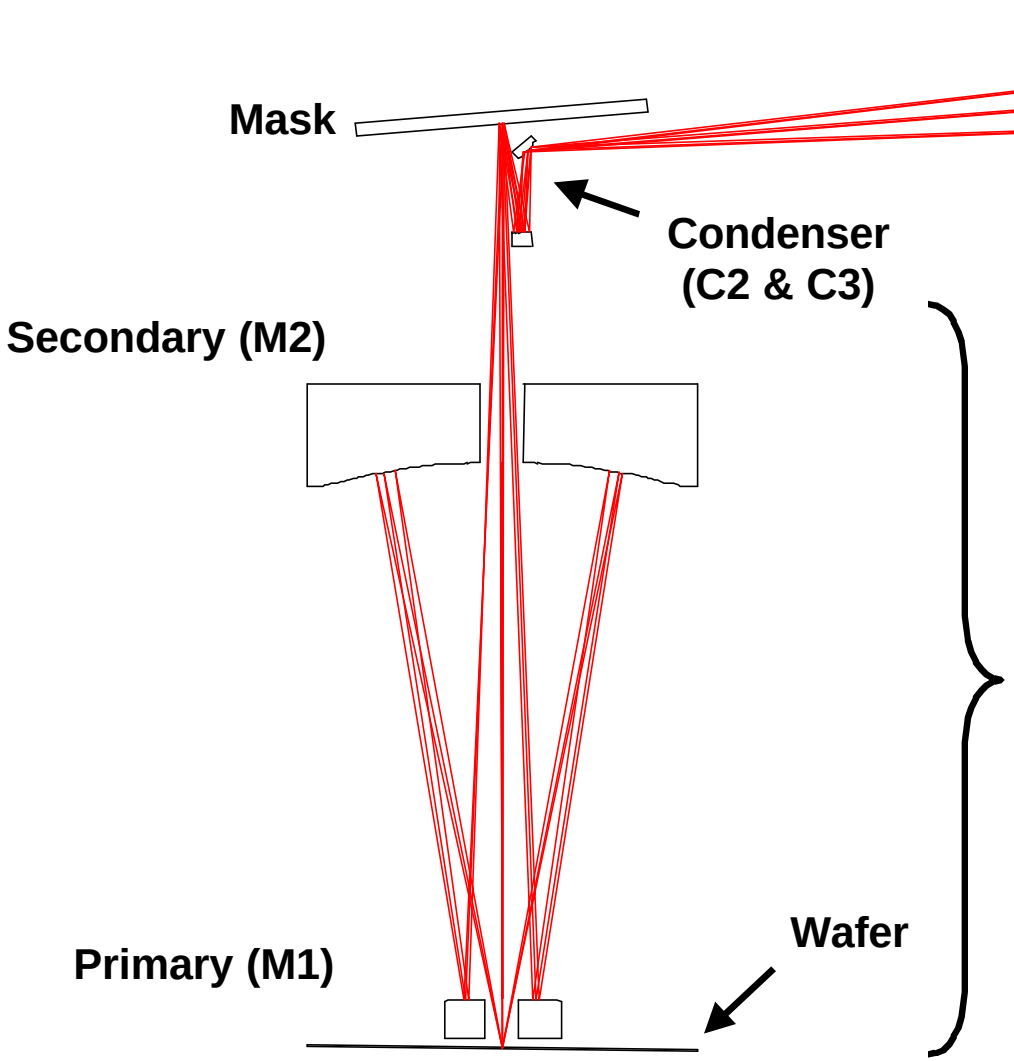
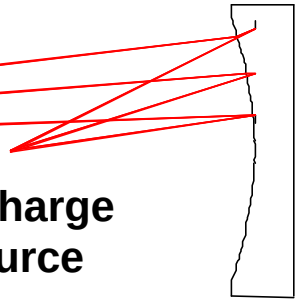
I-SEMATECH is funding the development of a small field high NA EUV exposure tool called the MET





Micro-Exposure Tool (MET) System Characteristics

- 5x reduction
- NA 0.30 (20 nm resolution)
- 600 mm x 200 mm field
- Residual WFE 0.42 nm rms
- Aspheric departure
  - M1: 3.8 mm
  - M2: 5.6 mm
- Obscuration: 10%

Motivation

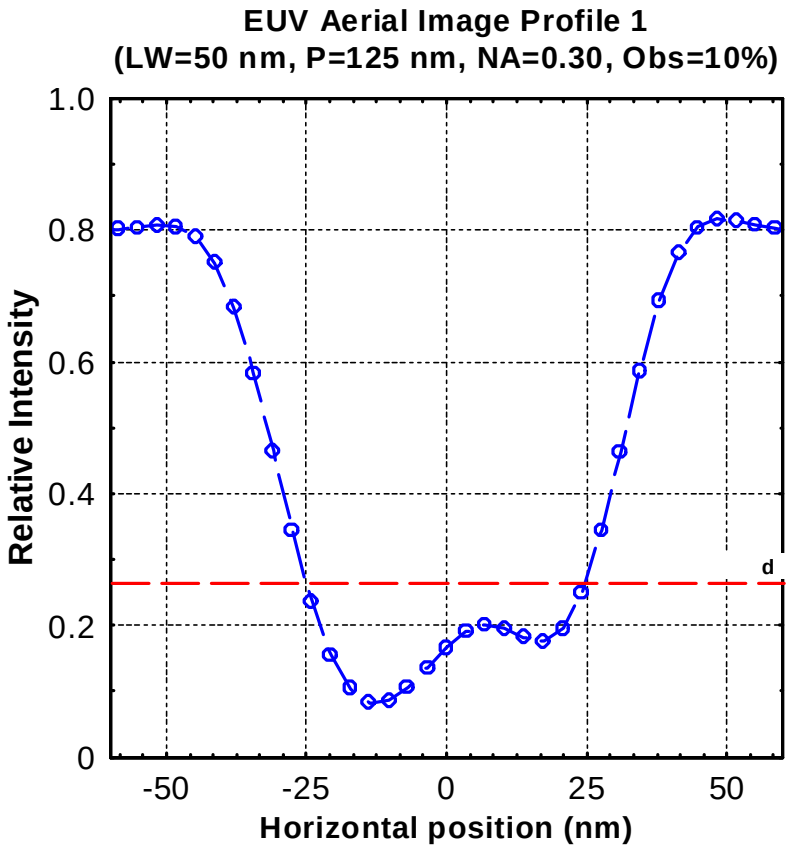
- **MET applications include . . .**
  - **EUVL extensibility, resist development, mask defect printability**
- **The MET has 3 subtle differences from a beta tool:**

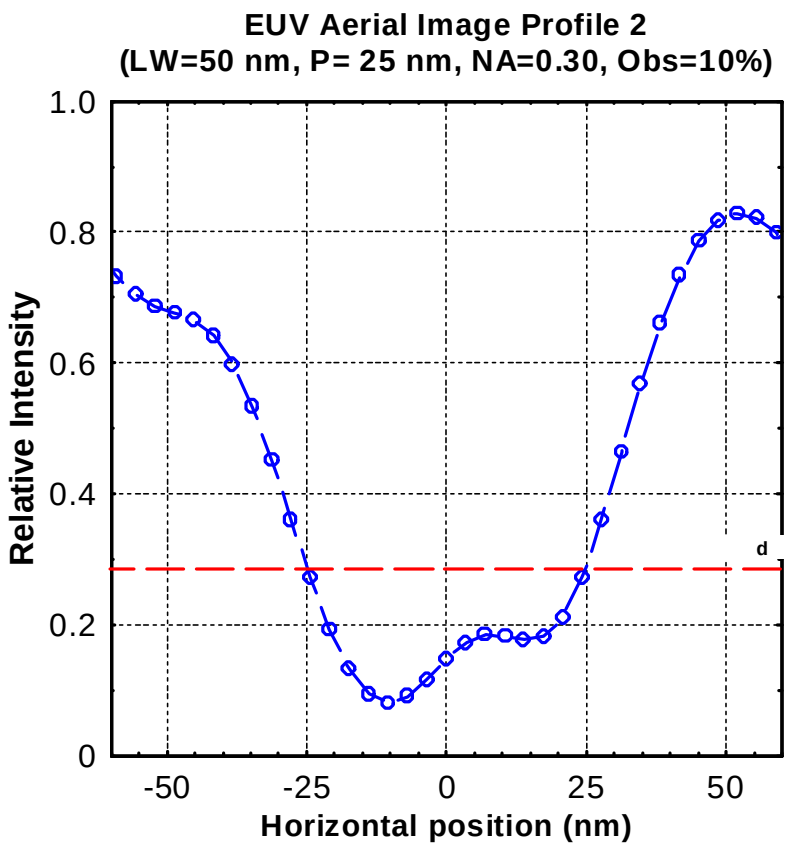
  (1) Central obscuration

  (2) Residual aberrations are rotationally symmetric

  (3) Imagery is not scan-averaged
- **For quality R&D, a well-characterized tool is needed**
- **Fundamental question**
  - **Is some DCD real, or a tool artifact?**

Example: Defect or tool artifact?



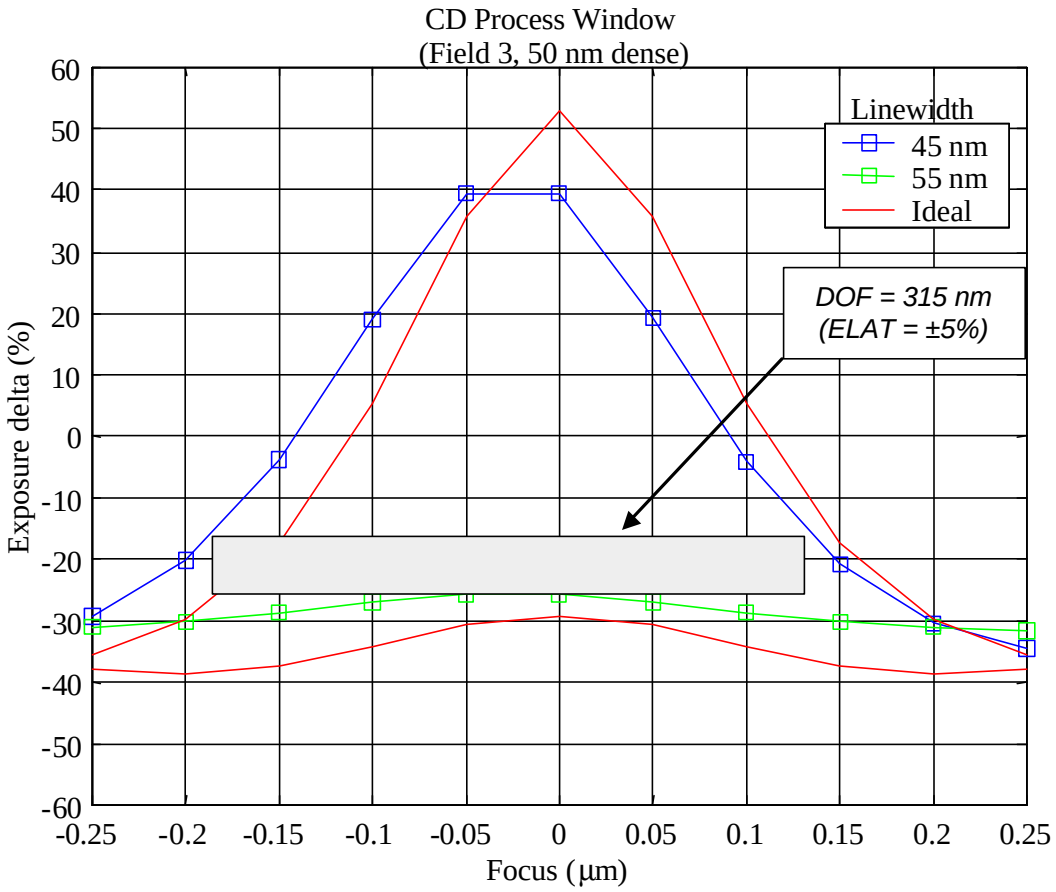


- **One profile has a "special mix" of aberrations, the other a defect.**
- **Which one is which?**

Impact of obscuration

- **Obscuration is a pupil filter that decreases modulation and ILS. It also gives rise to "coherence hump" at the center of the aerial image**
- **Questions**
  - **Is the loss of contrast and ILS acceptable?**
  - **What is the impact on the process window?**
  - **Does the "coherence hump" becomes significant relative to the threshold (I_t) under any conditions?**
  - **Due to the clipping of diffraction orders, are there any "forbidden" pitches for a given linewidth?**

Iso-linewidth contours for 50 nm dense L/S match "ideal" system with no obscuration or aberration

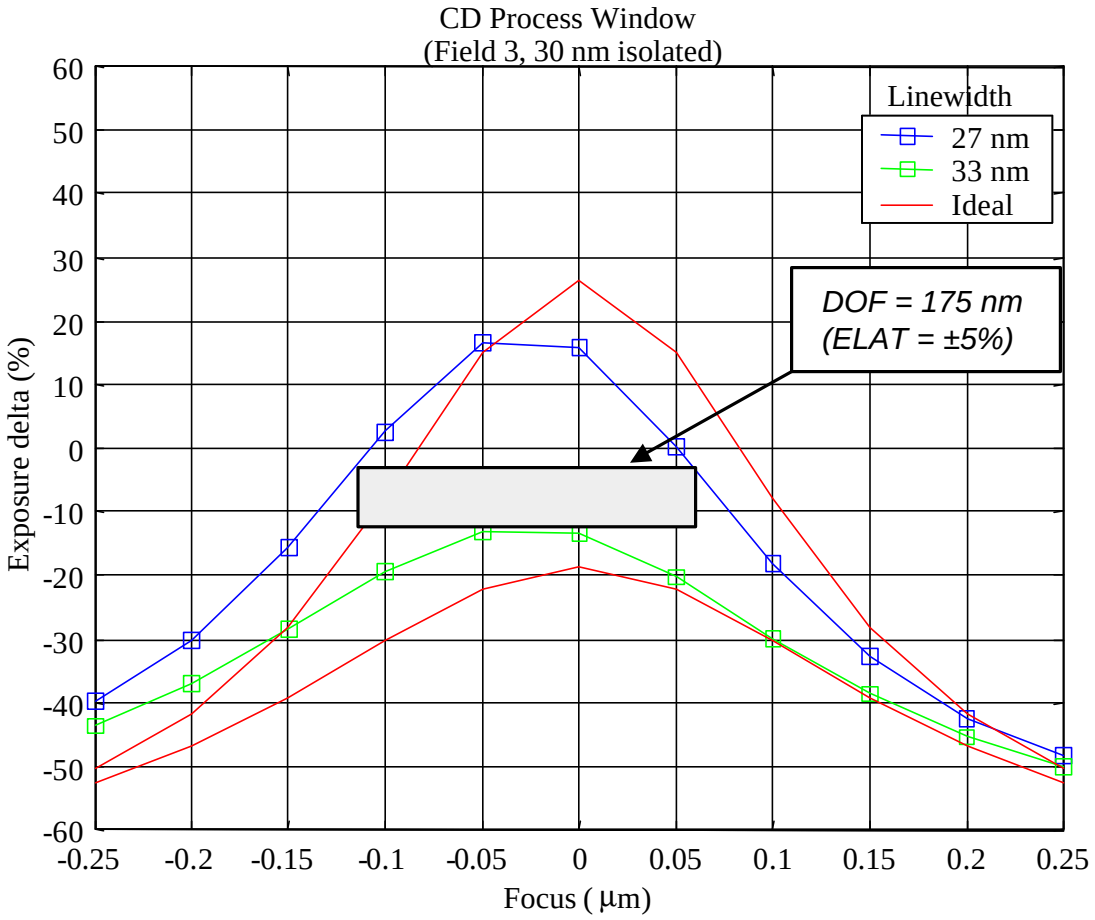


DOF = ±157.5 nm for dense 50 nm L/S

- **Assumptions:**
  - **50 nm dense L/S**
  - **NA=0.30, σ=0.70, λ=13.4**
  - **Thin mask**
- **Iso-linewidth contours**
  - **Red = ideal system**
  - **Green & blue = MET**
- **Conclusion: <u>Shape of iso-linewidth contours and size of process window is not substantially altered by MET's obscuration and residual aberrations.</u>**

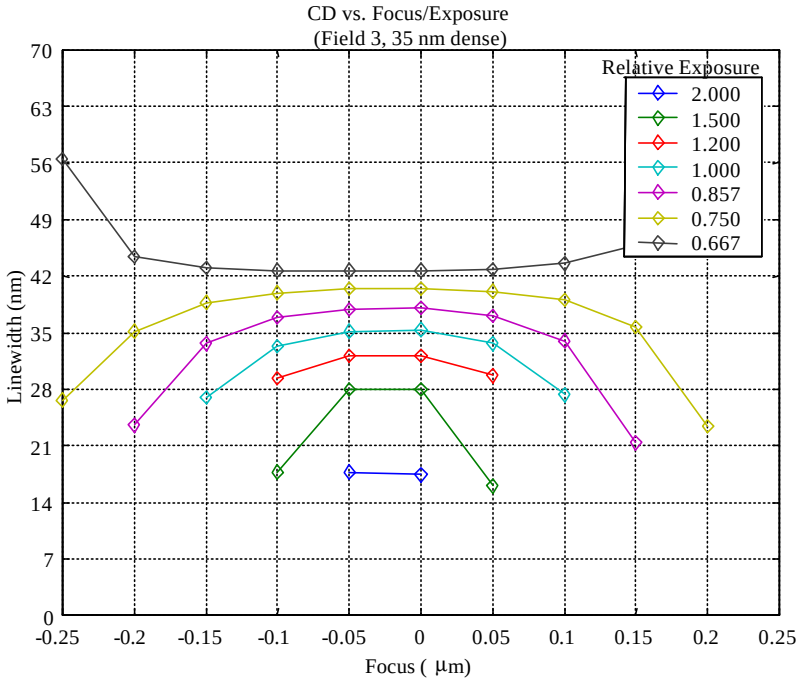
Behavior similar for 30 nm isolated features

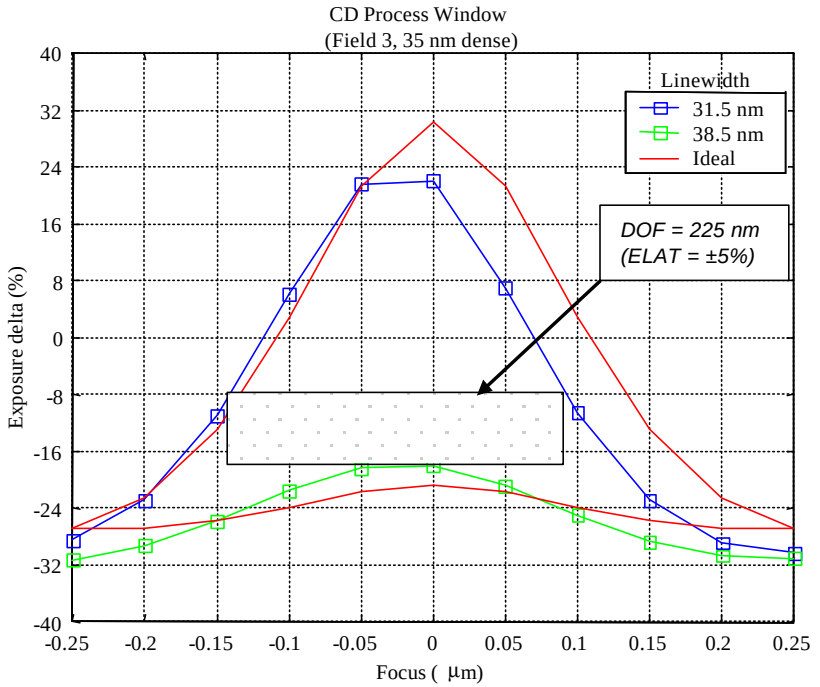
- **Assumptions:**
  - **30 nm isolated lines**
  - **NA=0.30, s=0.70, l=13.4**
  - **Thin mask**
- **Shape of MET's iso-linewidth contours compare well to ideal imaging case**
- **An iso-focal bias exists!**
- **Conclusion: <u>MET's obscuration and residual aberrations do not substantially alter iso-linewidth contours for this imaging condition</u>.**



DOF = ±87.5 nm for isolated 30 nm lines

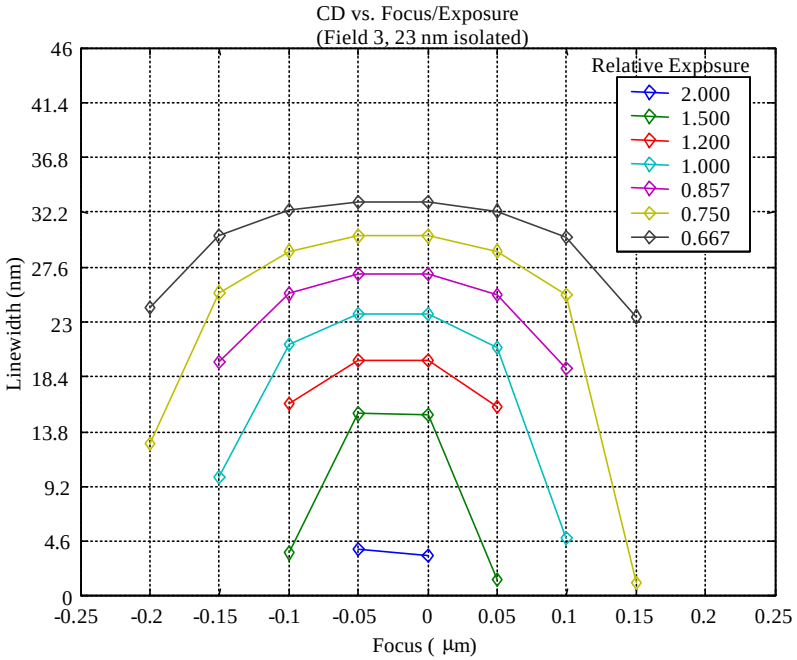
For 35 nm dense L/S, iso-linewidth contours on E-D plot are only mildly affect by obscuration

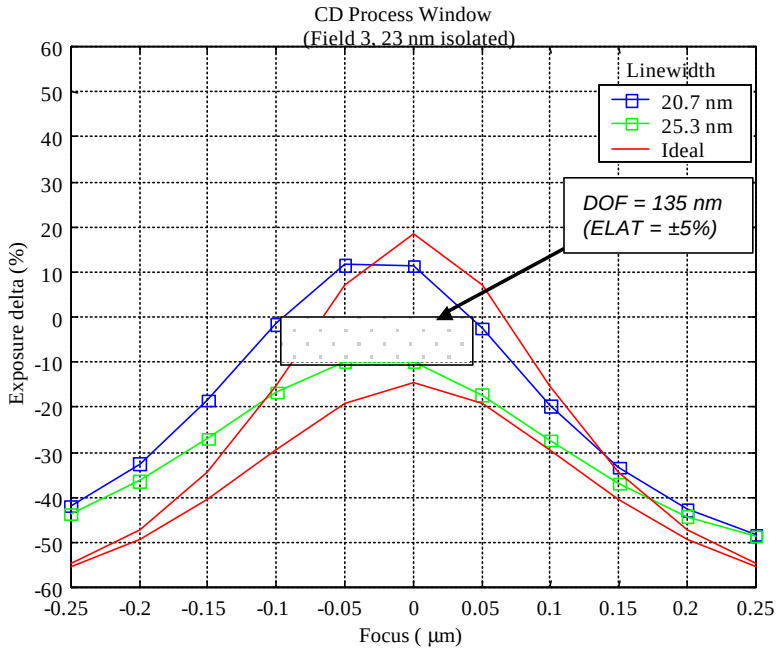




- **Assumptions: 35 nm dense L/S, NA = 0.30, s = 0.70, thin mask, threshold resist model and perfect illumination**
- **Aerial imagery has good symmetry through focus (Bossung plot)**
- **Little loss of process latitude compared to ideal 0.30 NA imaging system (red iso-linewidth curves on E-D plot)**
- **DOF = ± 107.5 nm, for dense 35 nm features**

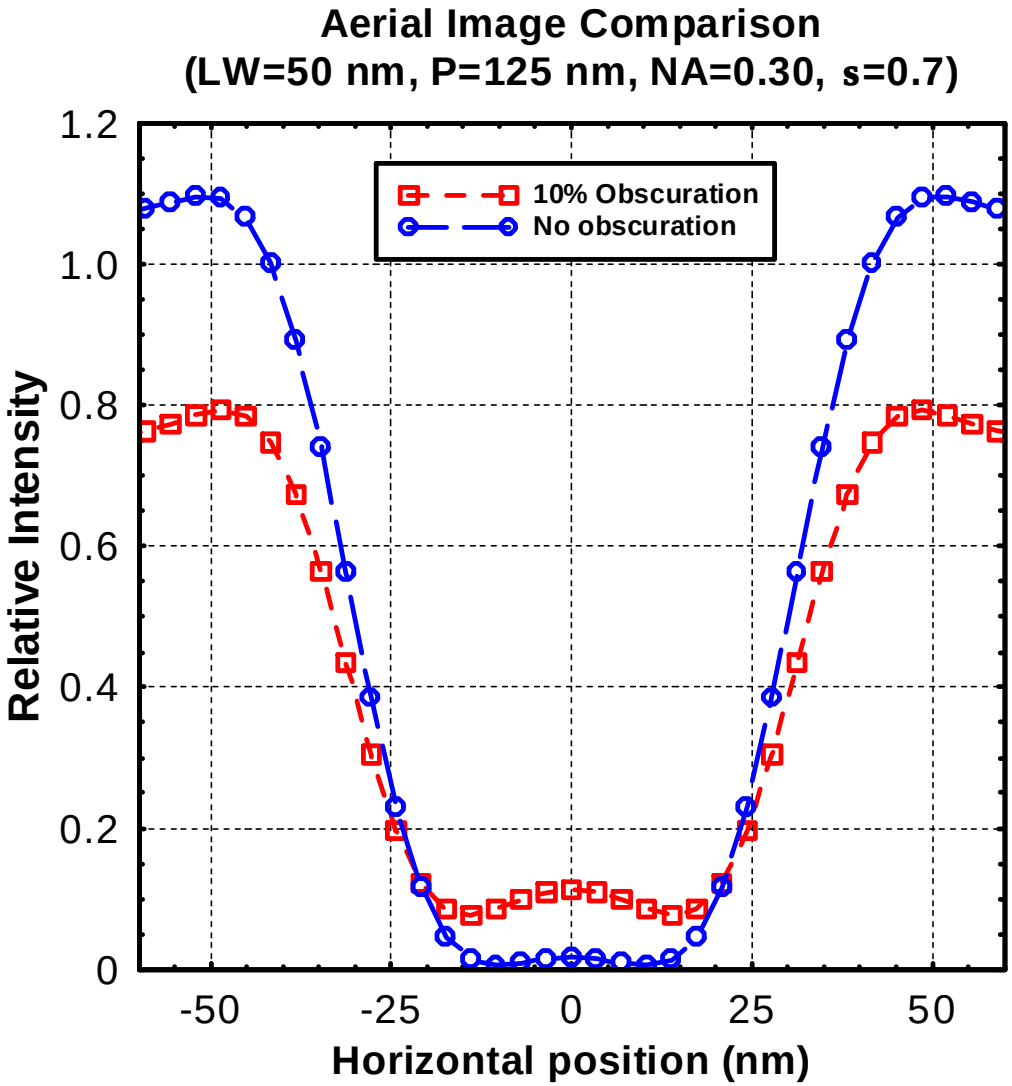
MET's iso-linewidth contours for 23 nm isolated again represent behavior of ideal imaging system





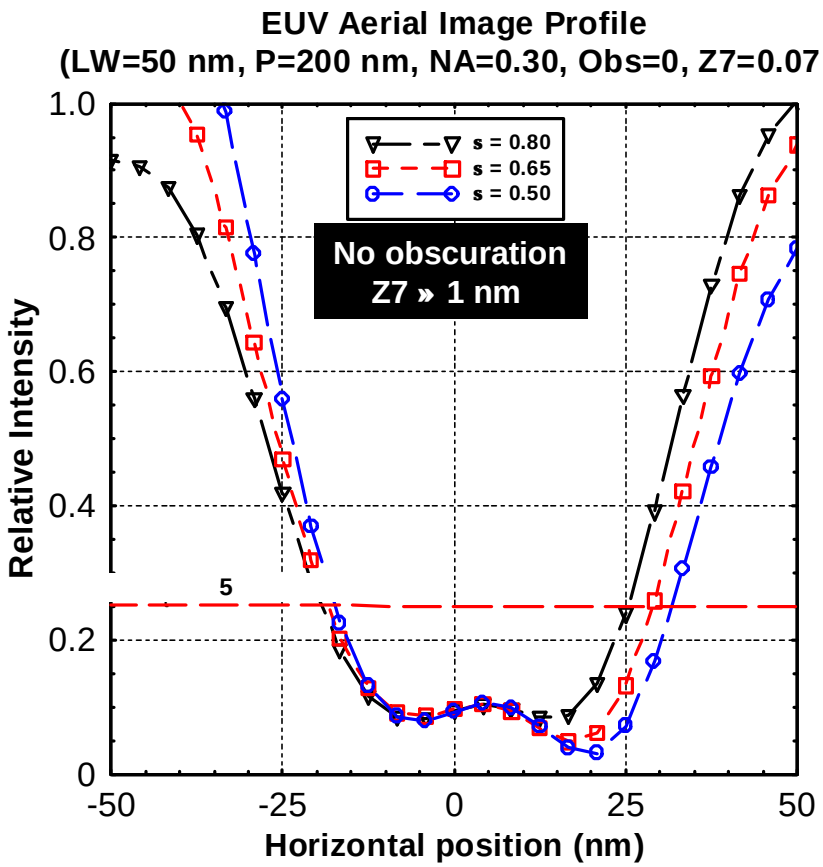
- **Assumptions: 35 nm dense L/S, NA = 0.30, s = 0.70, thin mask, threshold resist model and perfect illumination**
- **Iso-focal bias and reduction in process latitude apparent in <u>both</u> cases (MET & Ideal)**
- **DOF = ±67.5 nm ® requirement exceeds ITRS roadmap!**

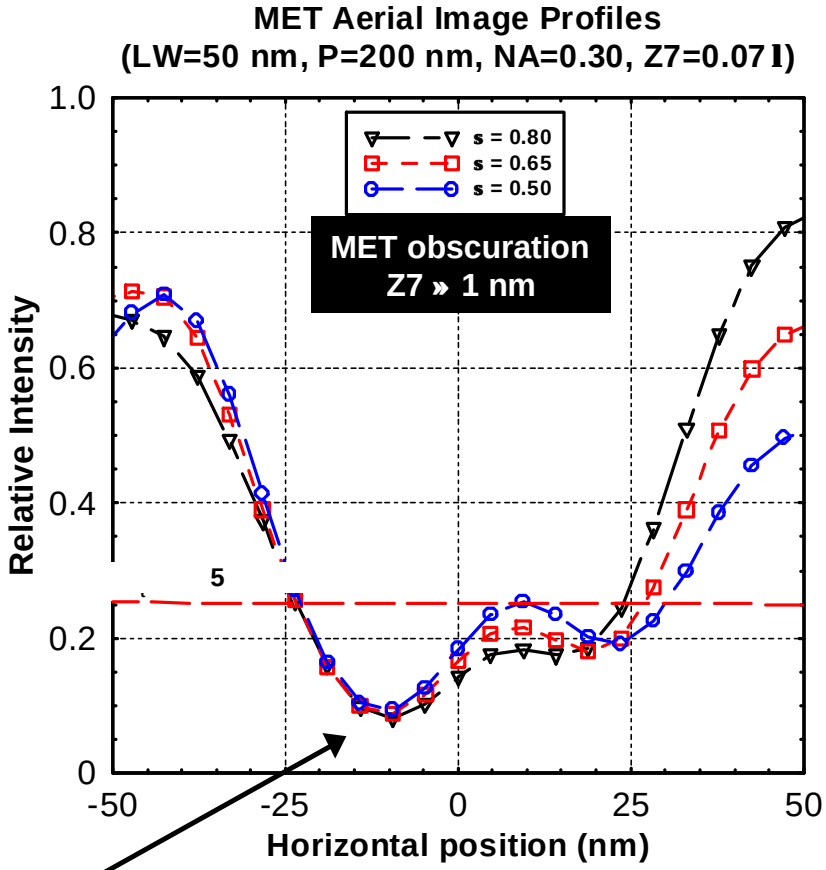
In addition to a contrast and ILS loss, the obscuration and enhances "hump" in aerial image center



- **Obscuration impact**
  - **Small ILS loss (0.13 nm^{-1} vs. 0.16 nm^{-1})**
  - **Small contrast loss (0.83 vs. 0.98)**
- **Contrast and ILS loss acceptable based on process window analysis**
- **<u>Important fact: MET passes at least 2 diffraction orders for any pitch. Therefore, no "forbidden" pitches exist!</u>**
- **But, we need to study this coherence "hump" more . . .**

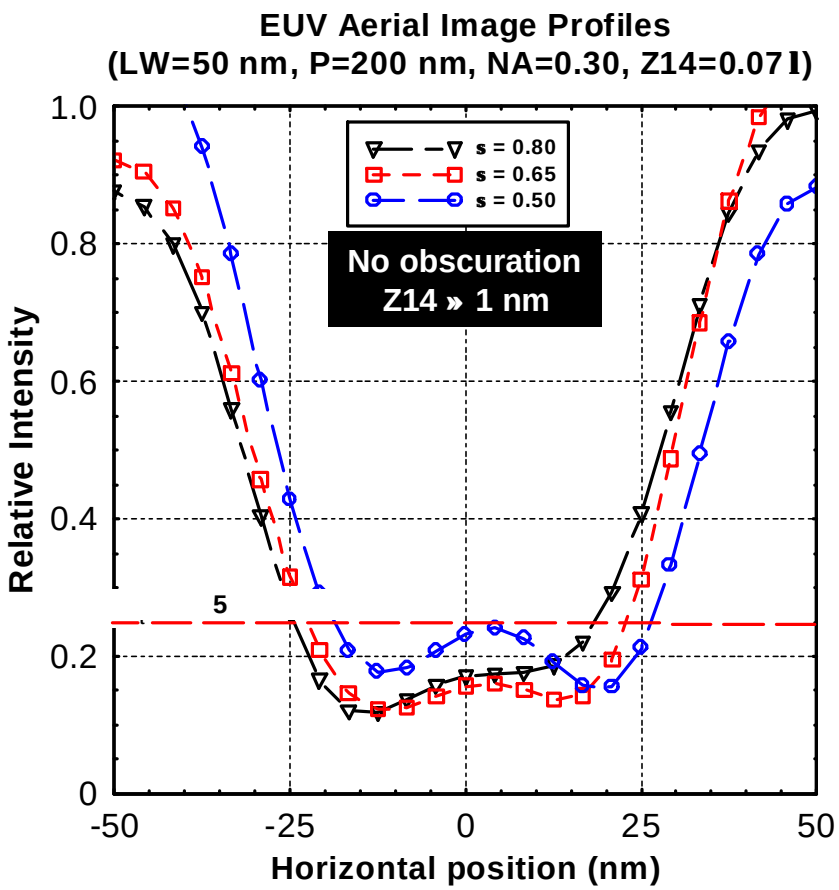
Obscuration increases aberration sensitivity relative to threshold in presence of low-order coma (Z7~0.07λ)

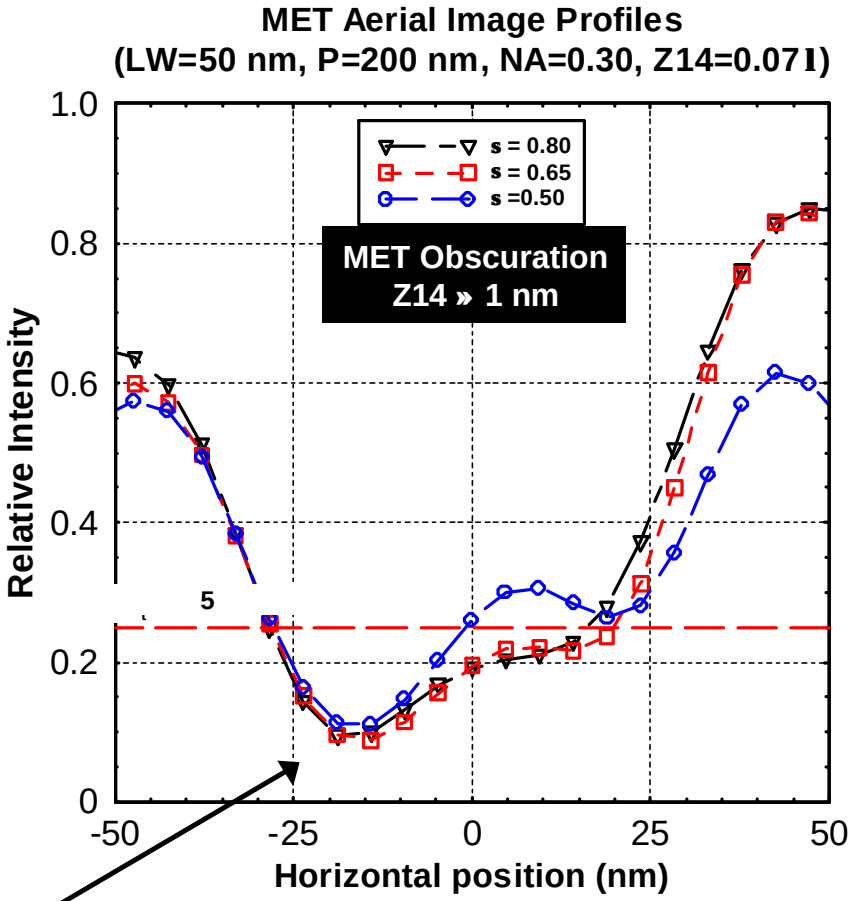




In the presence of the obscuration, coma (Z7) enhances "hump" and drives it toward threshold

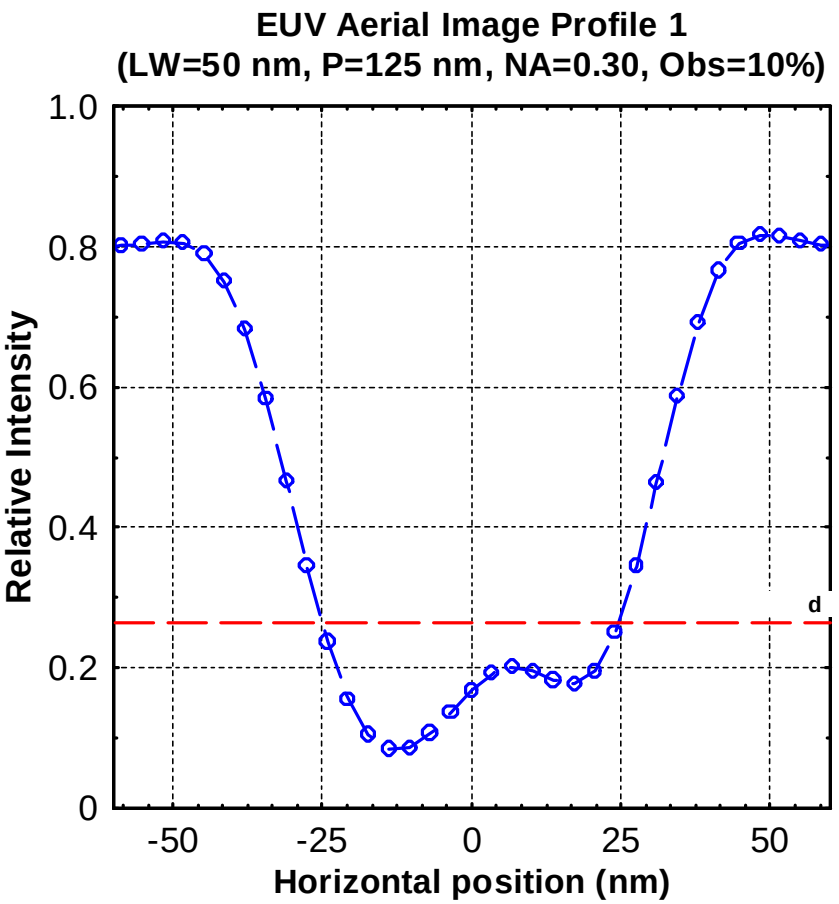
Similar effects occur in presence of higher-order coma (Z14~0.07λ)

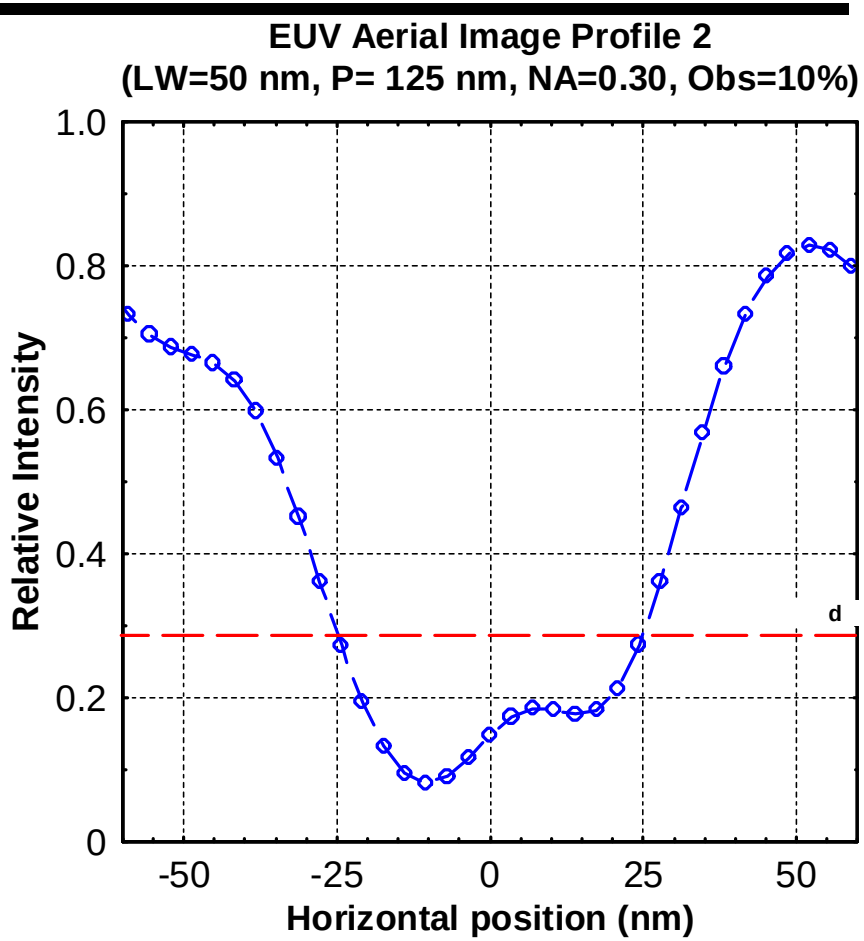




Increased asymmetry and the original threshold is crossed before the nominal line edge is reached!

The answer: left profile contains a defect!

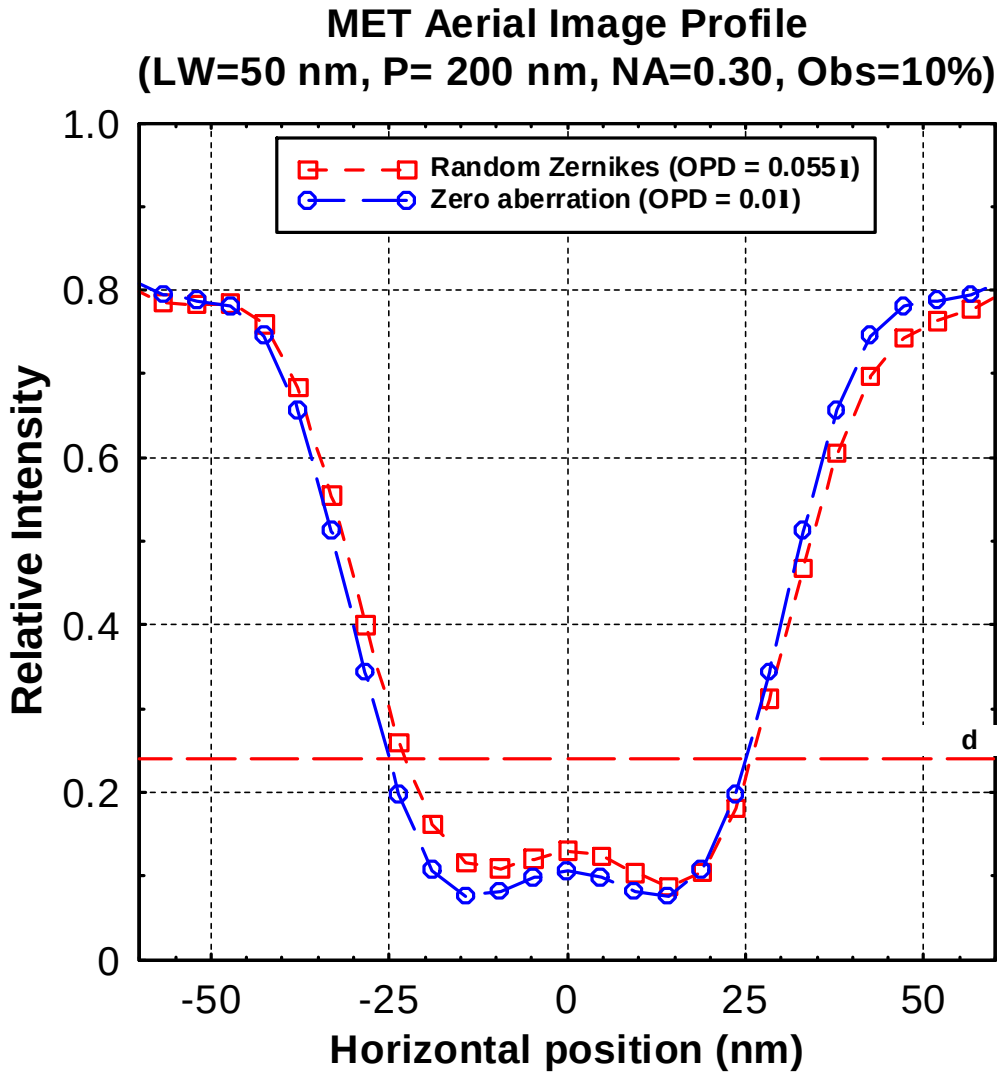




10 nm wide λ/4 phase defect located 15 nm from line edge right (defect would not print!)

MET aerial image profile assuming Z7 = 0.07λ (~1 nm coma)

Limiting individual Zernikes allows system to approach "zero-aberration" condition



- **Random combination of Zernikes such that total RMS OPD < 0.055λ**
- **Set limits such that Zi < 0.13 nm RMS (5 £ i £ 36)**
- **Approach "zero aberration" condition**
- **No enhanced asymmetry in aerial image**
- **"Hump" stays well below threshold in all cases**

Lessons learned

- **Obscuration does not present a limitation in the MET**
  - **Small, but acceptable, loss in modulation and ILS**
  - **Small reduction in available process window**
  - **No "forbidden pitches" exist – MET passes at least 2 diffraction orders for all feature geometries**
- **However, subtleties associated with obscuration exist in presence of moderate aberration levels (~0.07λ)**
  - **Increased aberration sensitivity to both low-order (Z7-Z8) and high-order (Z14/Z15) coma**
  - **Coma can masquerade itself as a mask defect**

Lessons learned cont'd

- **Effects are mitigated by placing limits on individual Zernike terms**
  - **Initial analysis supports $Z_i < 0.125$ nm for $5 < i < 36$**
  - **Undesirable to have any individual dominate RMS**
    - **Especially true for comatic terms**
- **Partial coherence**
  - **"Hump" is really a coherence effect**
  - **To depress this feature, beneficial to set $\sigma = 0.80$**
  - **Improves thru-focus performance**
- **Work is on-going!**