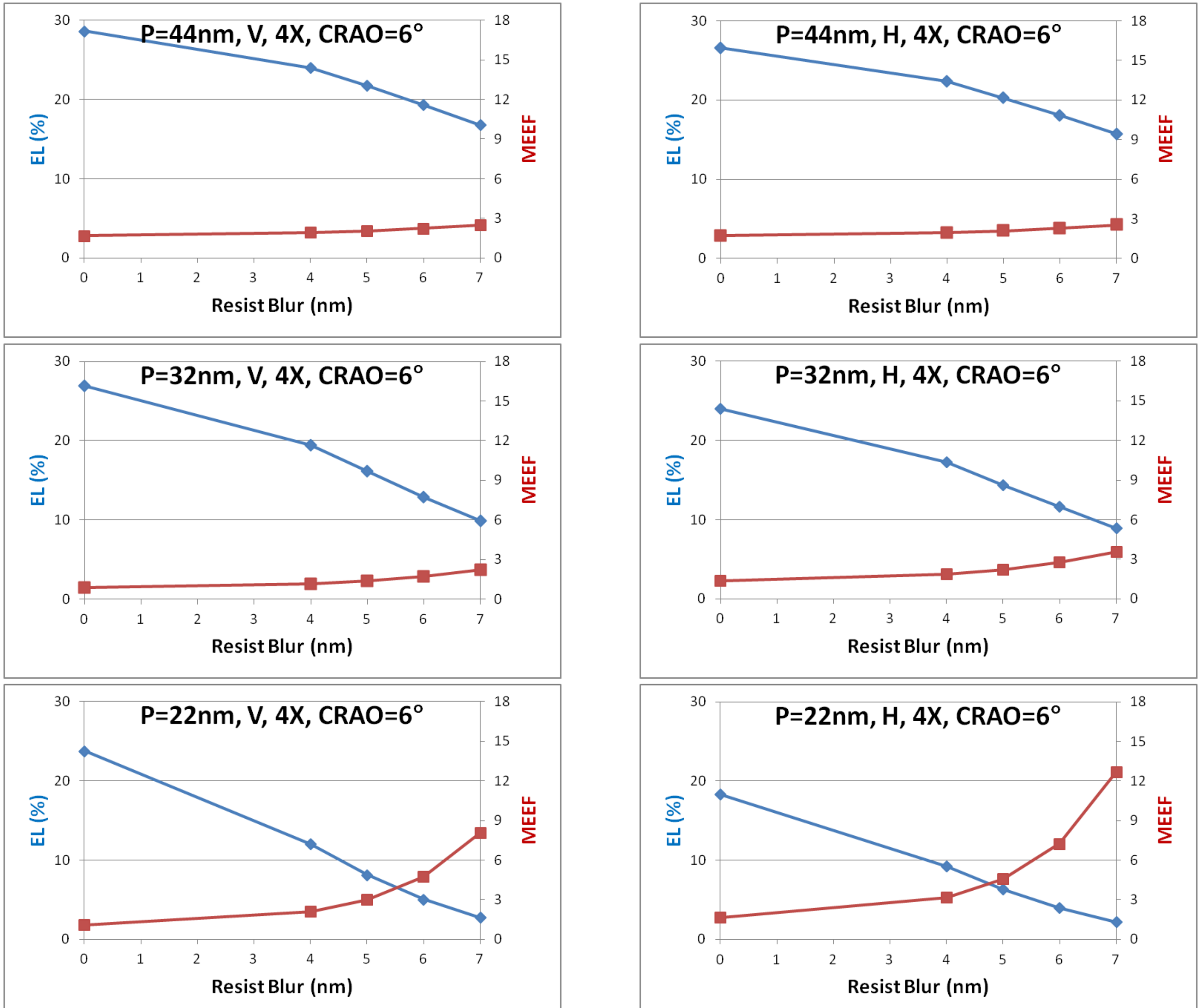
A Natural RET for EUVL

Shinn-Sheng Yu*, Yen-Cheng Lu, Chih-Tsung Shih,
Jack J. H. Chen, Anthony Yen
Taiwan Semiconductor Manufacturing Co., Ltd.

EUVL Extensibility

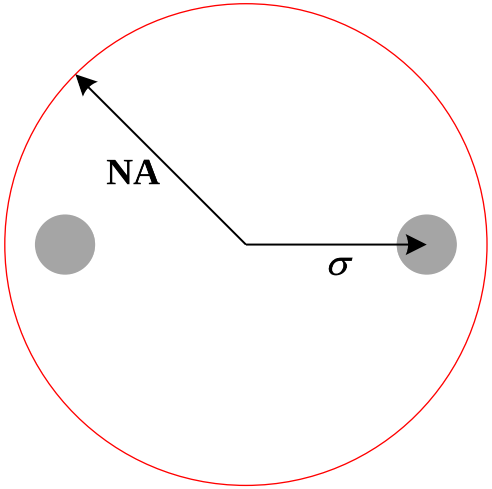
- **Single-patterning EUVL will probably end at P=22nm if by the conventional RET of OAI + 5% AttPSM.**



SPIE 8679.56

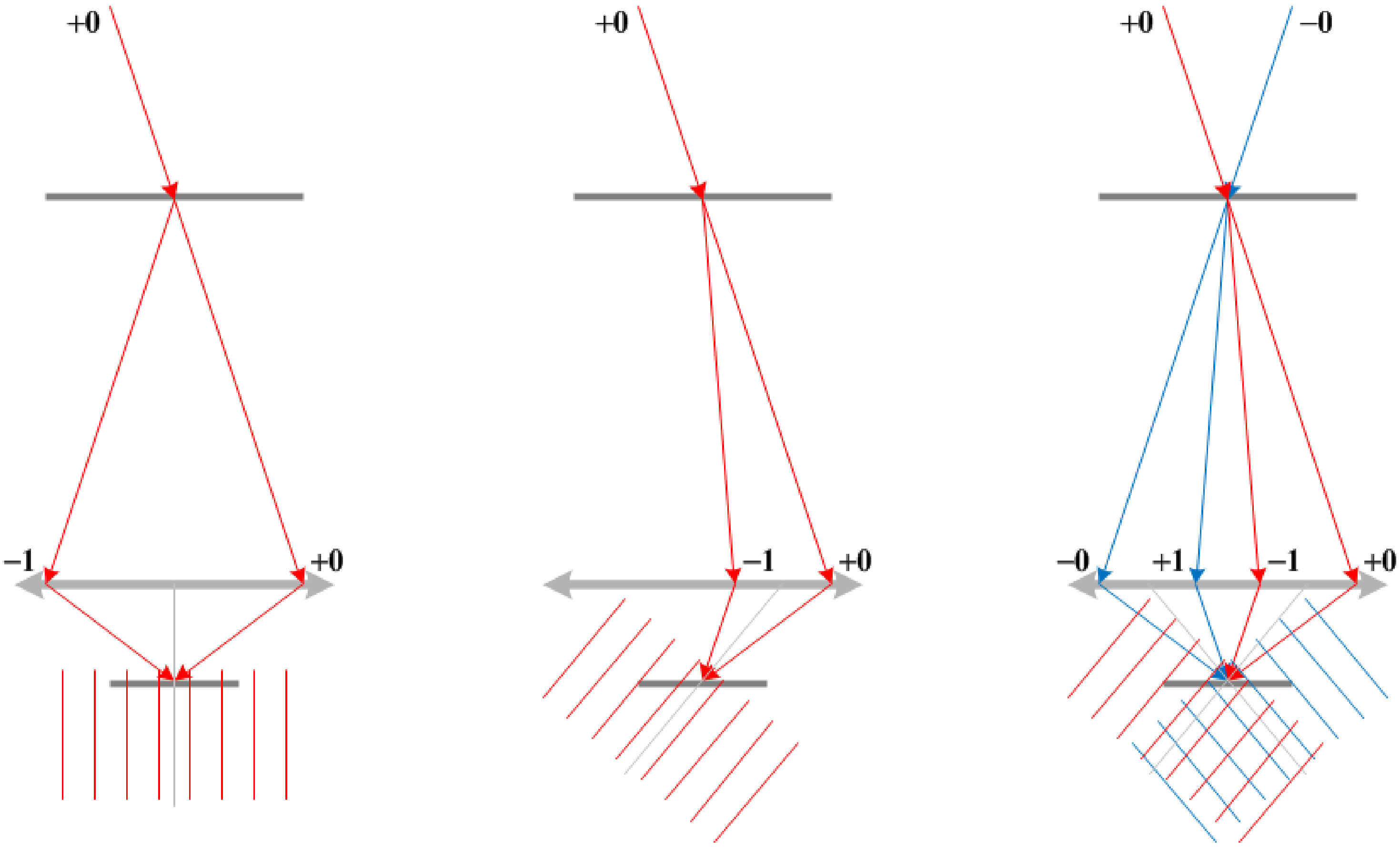
Conventional RET: OAI + 5% AttPSM

- For the OAI, we used dipole illumination consisting of two point sources with their separation optimized for the respective pattern pitch, i.e., $2\times NA\times\sigma = \lambda/p$.
- The 5% AttPSM is realized by a thin absorber of 28-nm thickness (n/k=0.881135/0.044277).



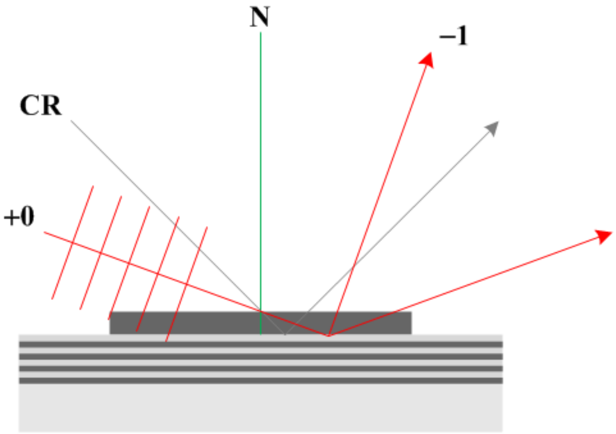
OAI in Optical Lithography

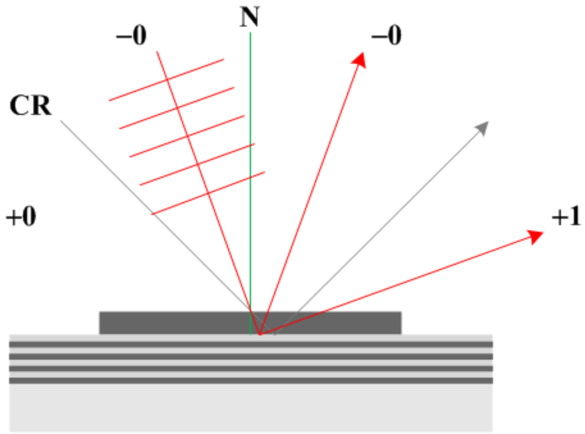
- **To use OAI, two incident beams symmetric with respect to the optical axis are needed to avoid pattern shift when defocus if patterns are not of the optimized pitch.**
- **In optical lithography, the AOI's of the two incident beams on the mask are the same.**

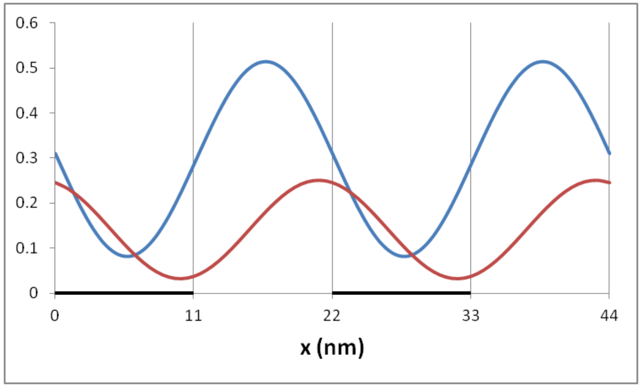


OAI in EUVL

- In EUVL, since CRAO ≠ 0°, the AOI's of the two incident beams on the mask are different.
- Since a MLM is used, the reflectivities of the two incident beams are different.
- For either incident beam, the two diffraction orders travel different absorber thickness, leading to different amplitude attenuation and phase accumulation.
- Hence, $I_{min} \neq 0$ and I_{min} shifts in position.
- Since the positional shifts of I_{min} of the two incident beams are different, their superposition leads to further contrast degradation.

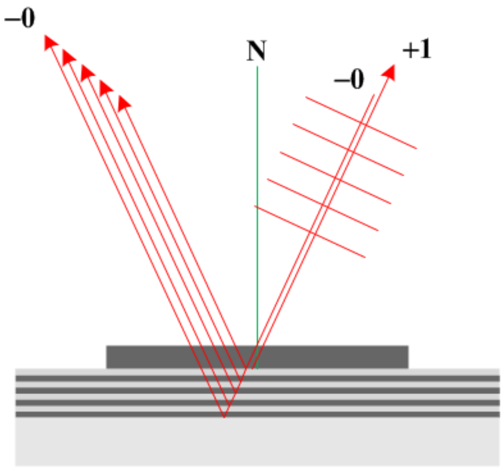


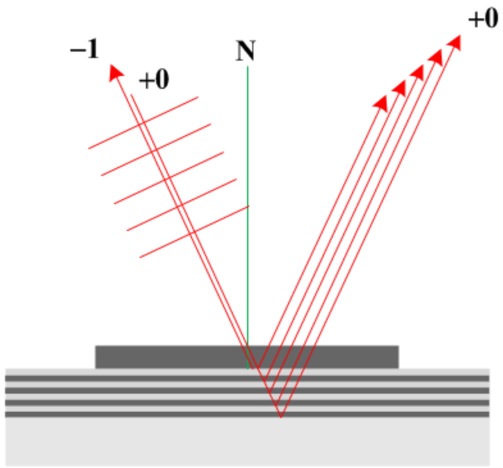


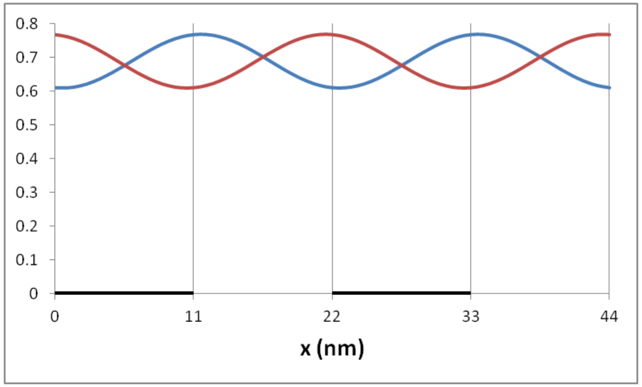


OAI in EUVL

- Even if the absorber thickness is reduced to 1 nm and the CRAO is set to 0°, the locations of I_{min} of the two incident beams are still different.
- This is because the diffraction orders are reflected not by a single interface, but by a number of interfaces.

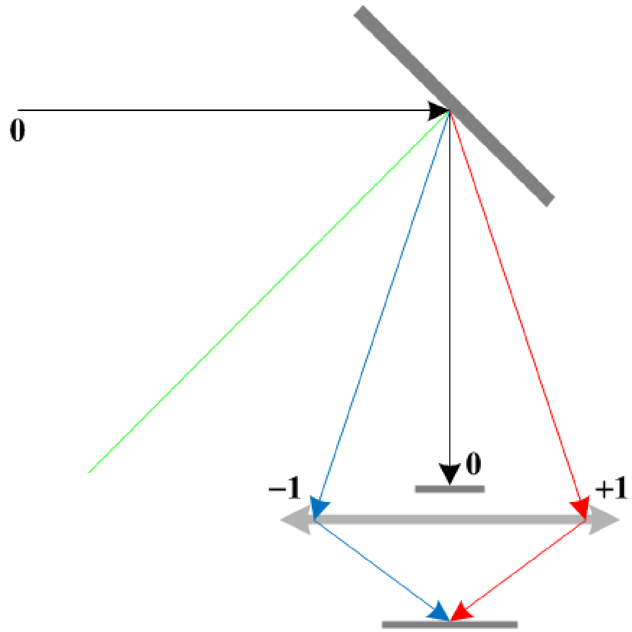






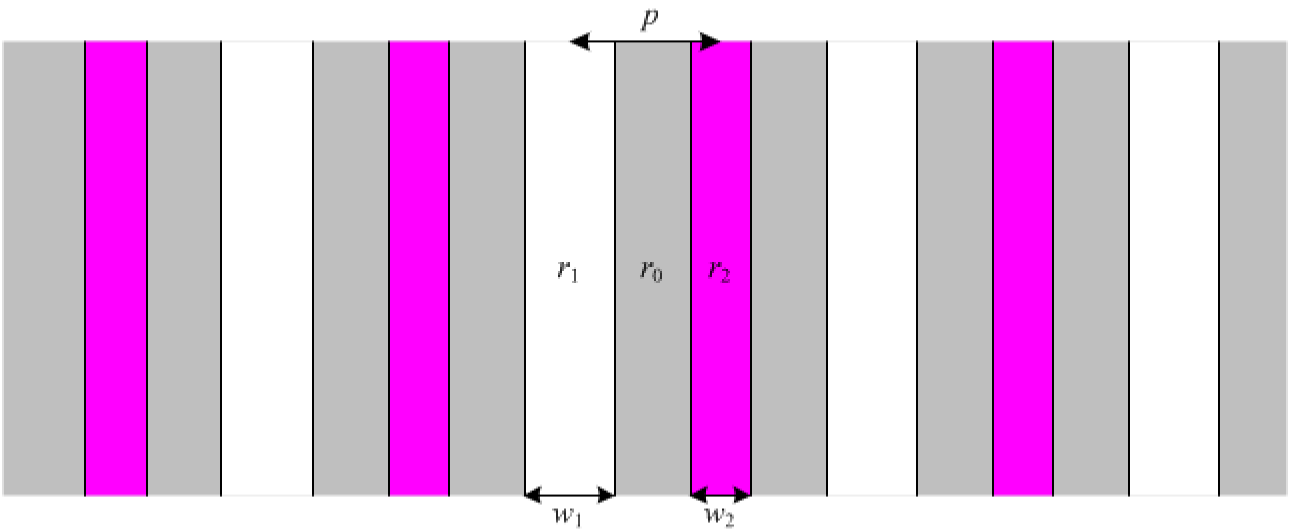
Our Proposed RET for EUVL

- **Since OAI cannot be used, we have no choice but to use on-axis illumination (ONI).**
- **Since 3-beam imaging is not competitive, we remove the 0th diffraction order to achieve the same P_{min} as that by OAI under the given NA.**
- **Since +1st and –1st diffraction orders are balanced in strength, the EL is maximized.**
- **On the pupil plane, since +1st and –1st diffraction orders are of the same distance from the pupil center, the DOF is also maximized simultaneously.**



Three-State Mask

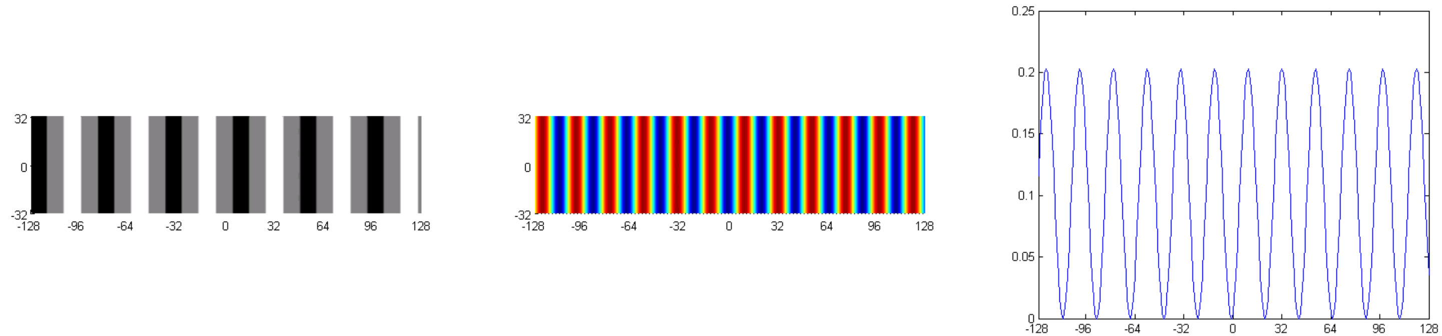
- **Since removing the 0th diffraction order leads to spatial frequency doubling, we need to do spatial frequency halving on the mask to obtain the desired patterns on the wafer.**
- **This can be achieved by a mask with three states, i.e., three different reflection coefficients, and by assigning different states to adjacent polygons and the field.**



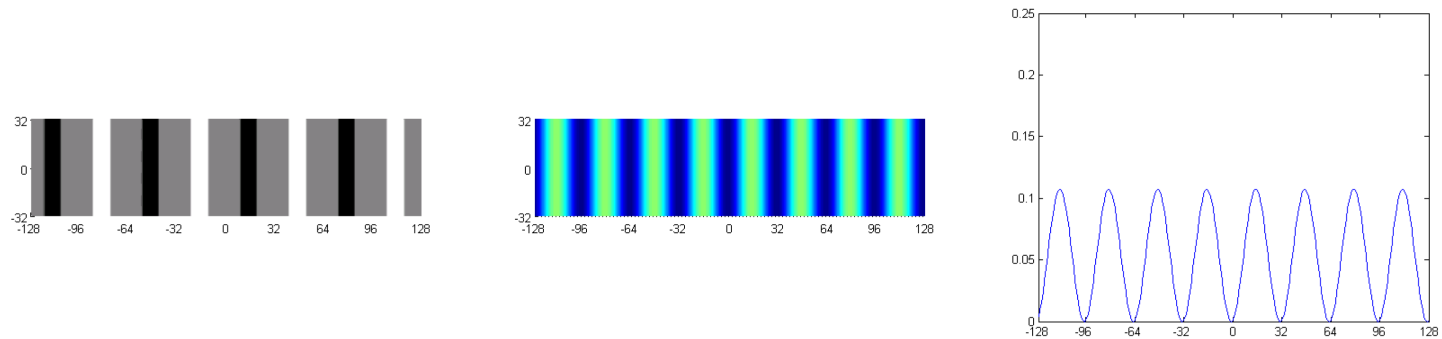
Through-the-pitch L/S Imaging

- .

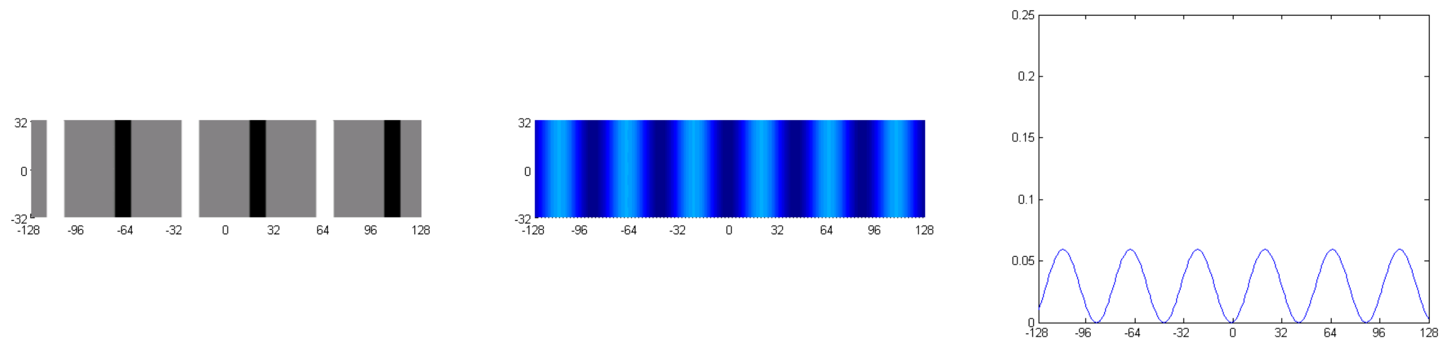
P22



P32



P44



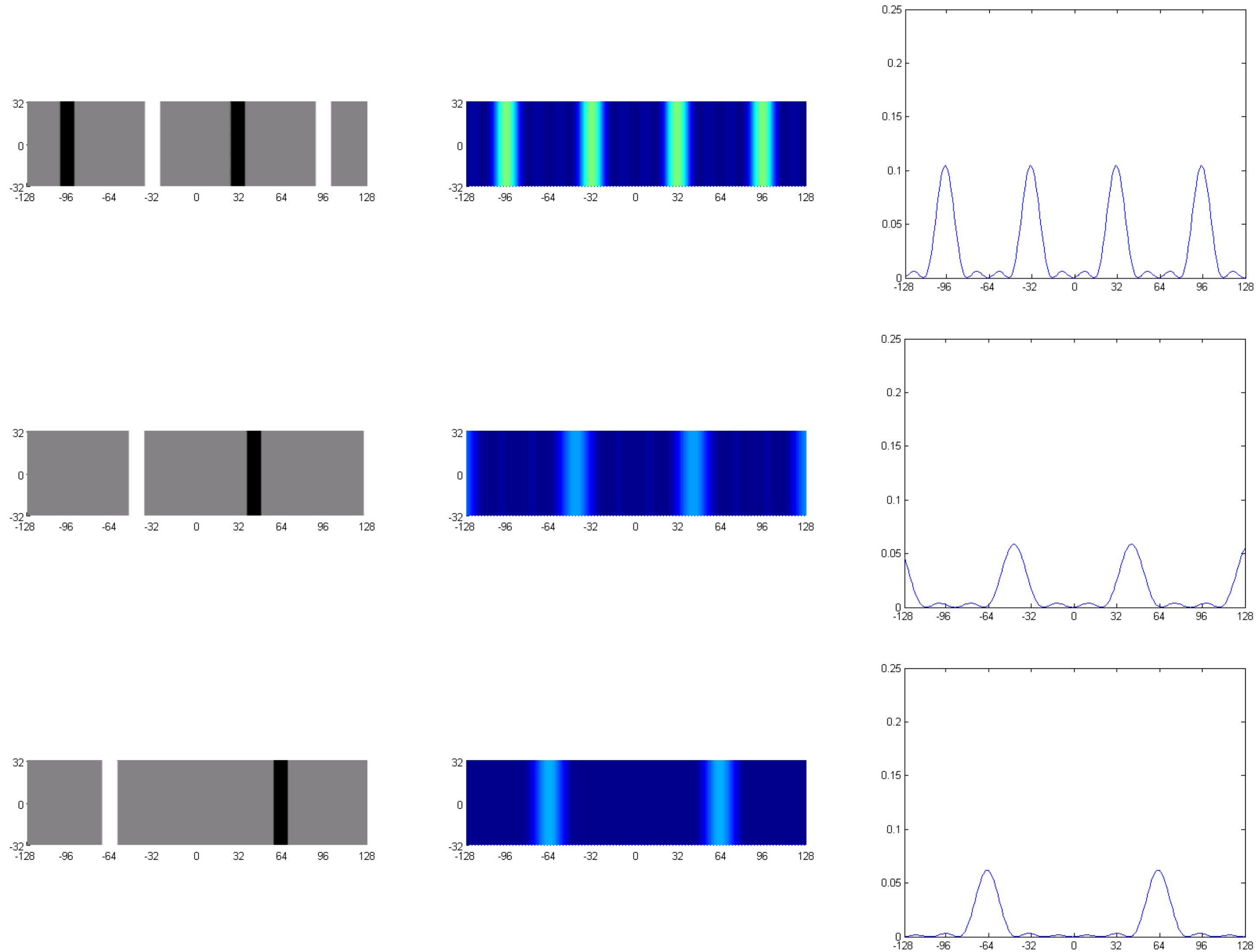
Through-the-pitch L/S Imaging

- .

P64

P88

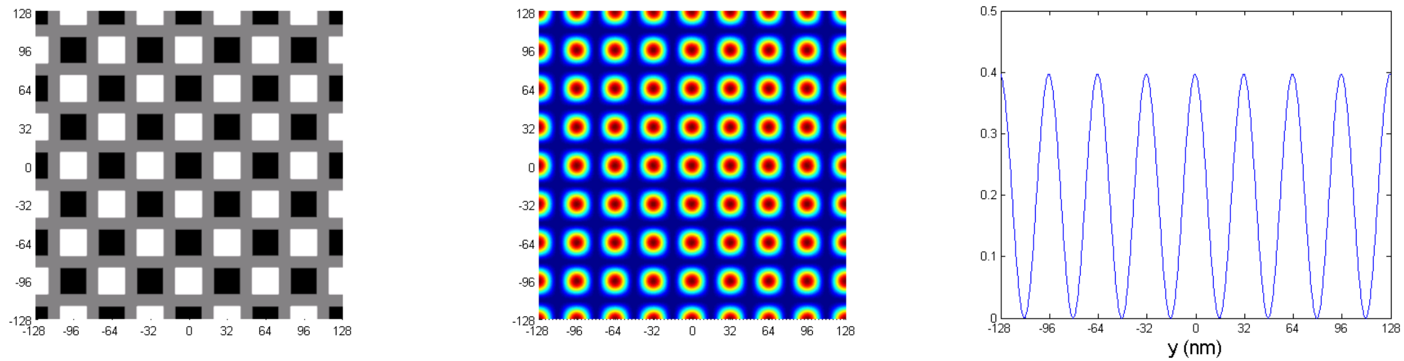
P128



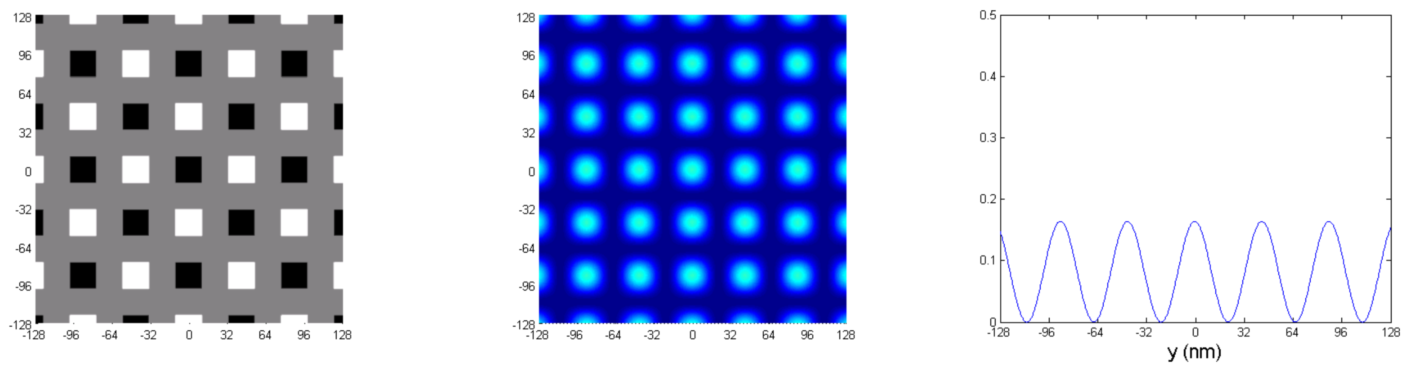
Through-the-pitch Hole Array Imaging

P22

P32



P44



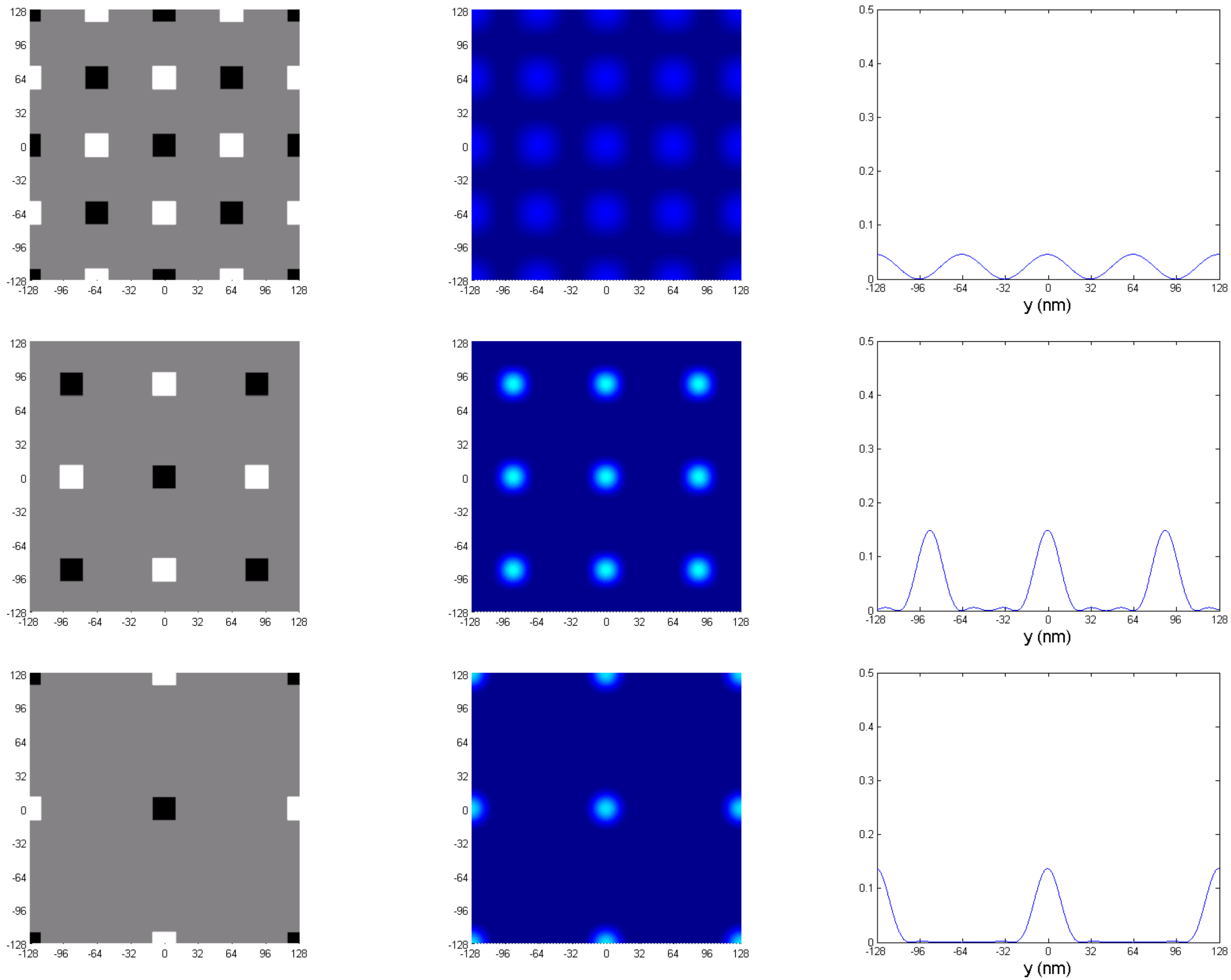
Through-the-pitch Hole Array Imaging

- .

P64

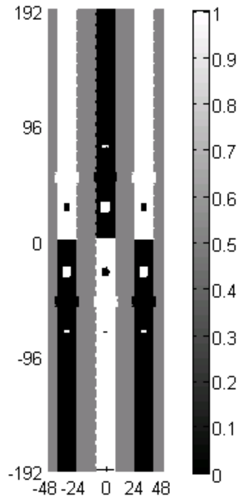
P88

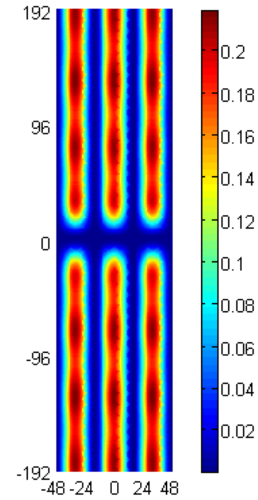
P128

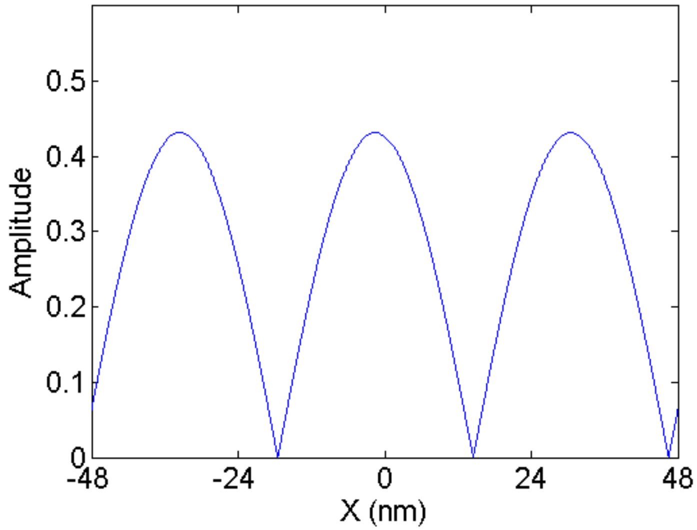


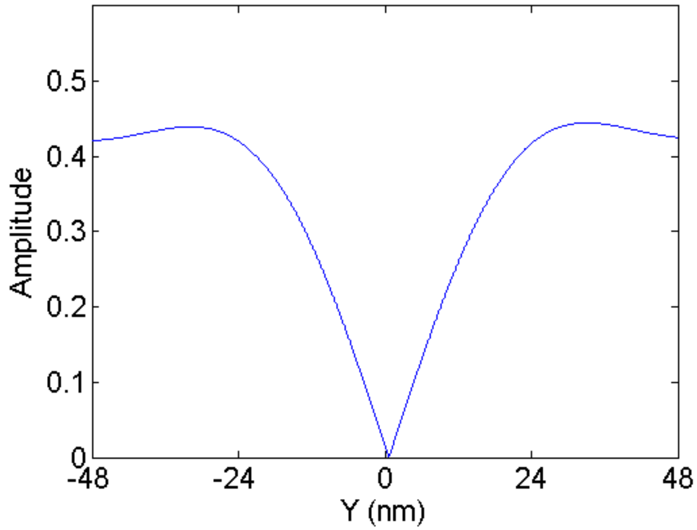
Line-End Imaging

- **L/S and E-E achieve the highest contrast simultaneously.**



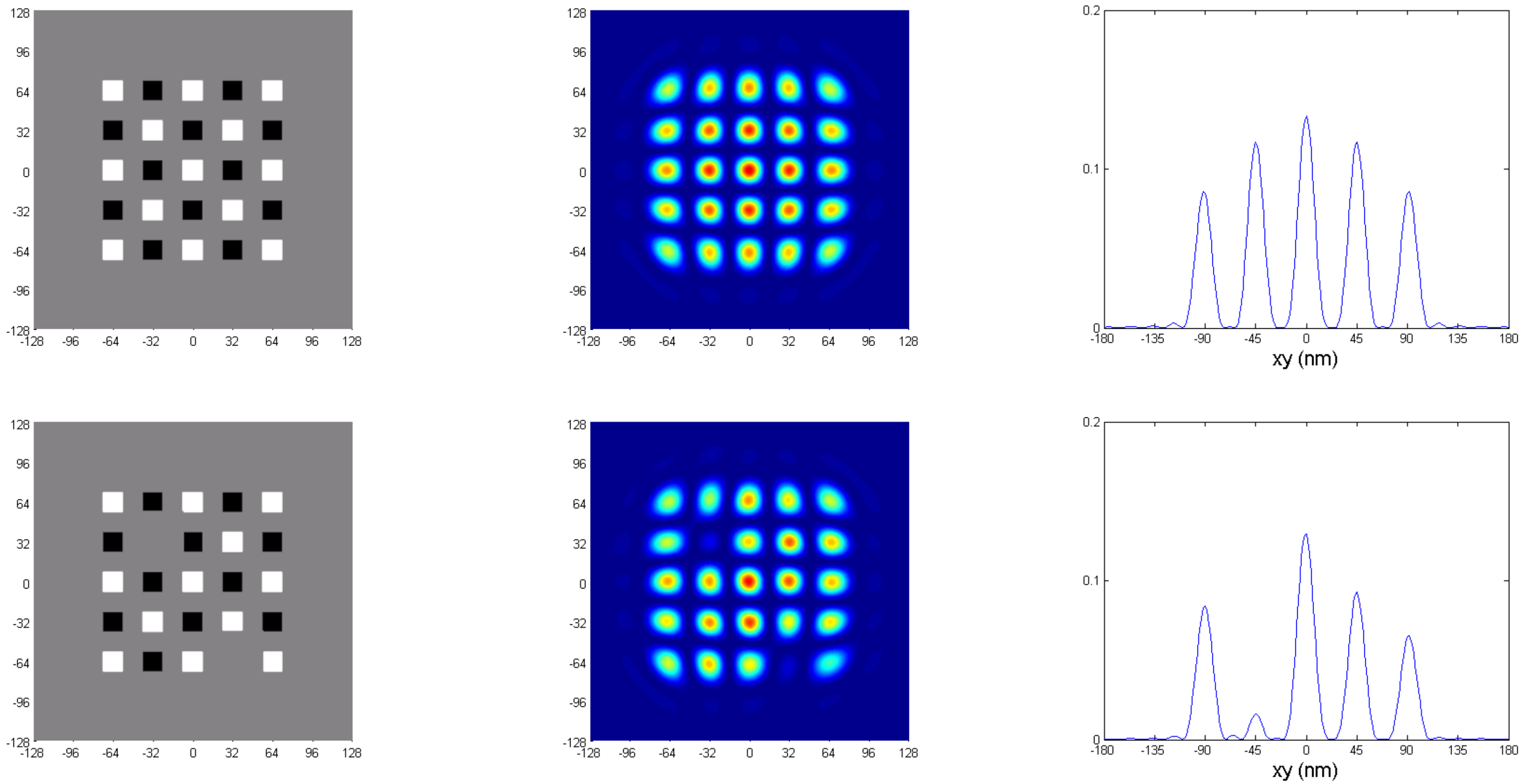






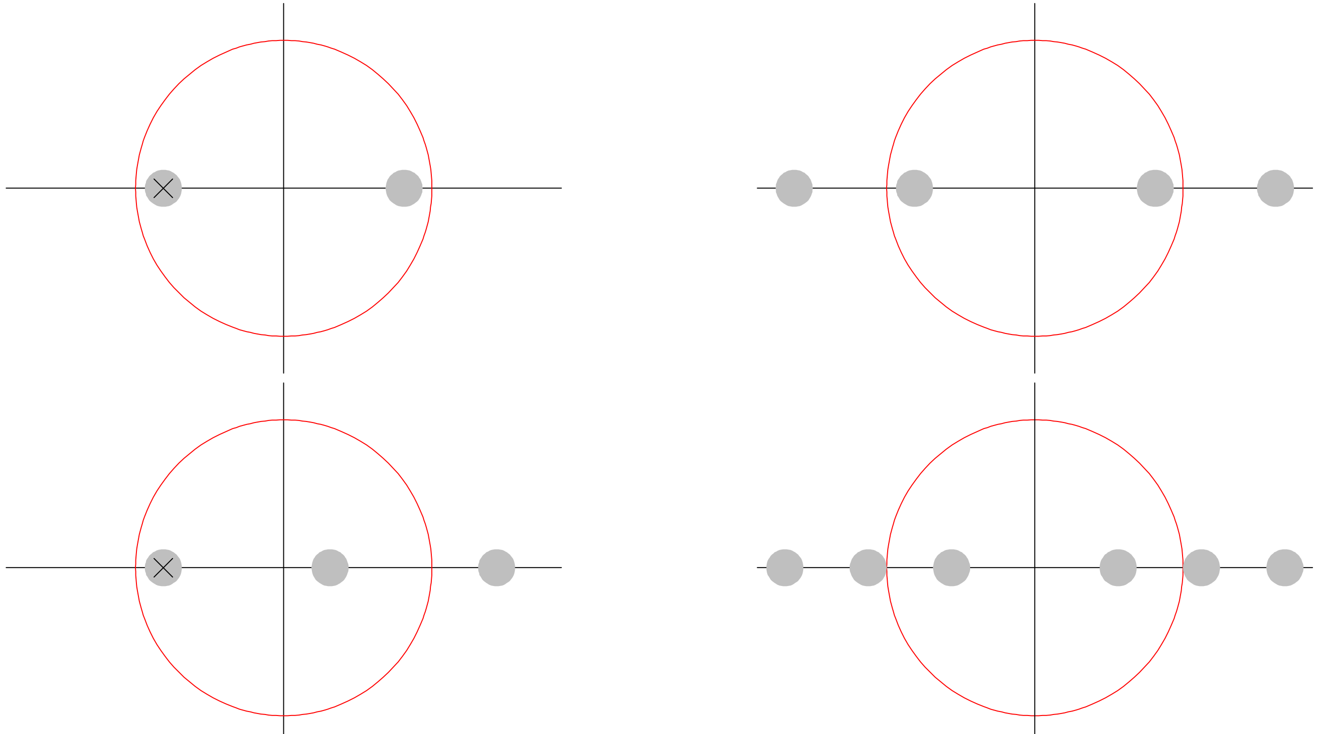
Small/Random Hole Array Imaging

- **OK if they are on-grid.**



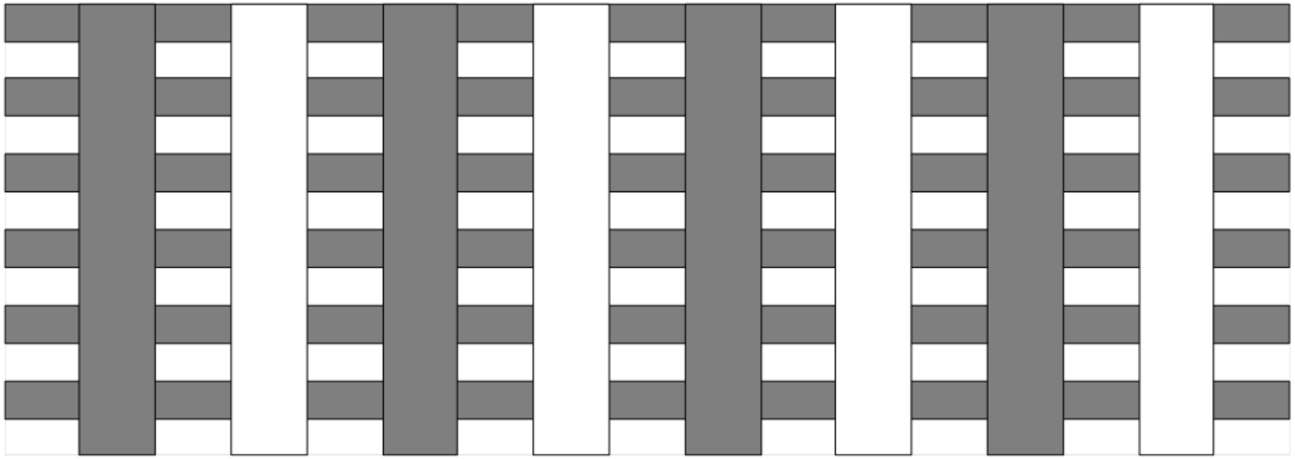
DOF

- When OAI is used, since the location of the 0th diffraction order on the pupil plane is fixed, the DOF starts to degrade once the pitch is deviated from the optimized pitch. The DOF is almost minimum for P>1.5X P_{min}. Since in the pitch range of 1.5X P_{min}~2X P_{min}, implementing AF is not helpful in increasing the DOF. We have the forbidden-pitch problem.
- By using the proposed EUVL RET, the DOF remains maximized until the 2nd diffraction orders come in. That is, the DOF is maximized in the pitch range of 1X P_{min}~2X P_{min}. There is no forbidden-pitch problem.



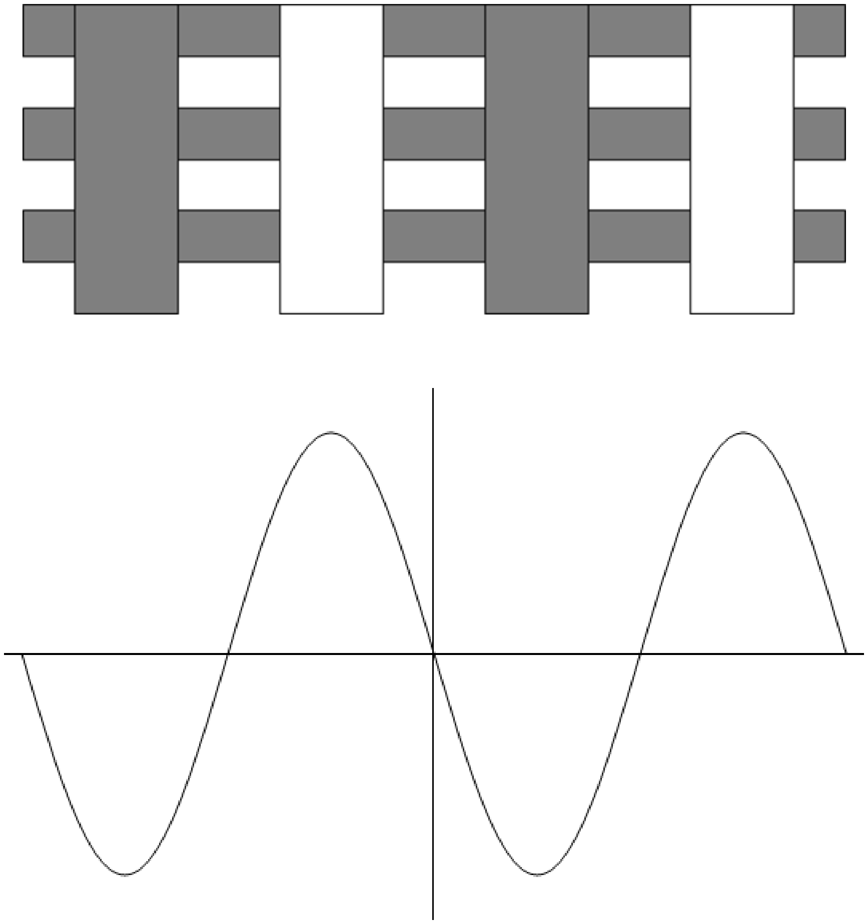
Two-Tone Mask

- **To simplify mask fabrication, the proposed EUVL RET can also be realized by a two-tone mask. In addition to the two states generated by with and without absorber, SRAF can be implemented to create a 3rd state with intermediate reflectivity.**
- **The size of SRAF using ONI is 2X larger than that using OAI. There should be no mask fabrication issue.**



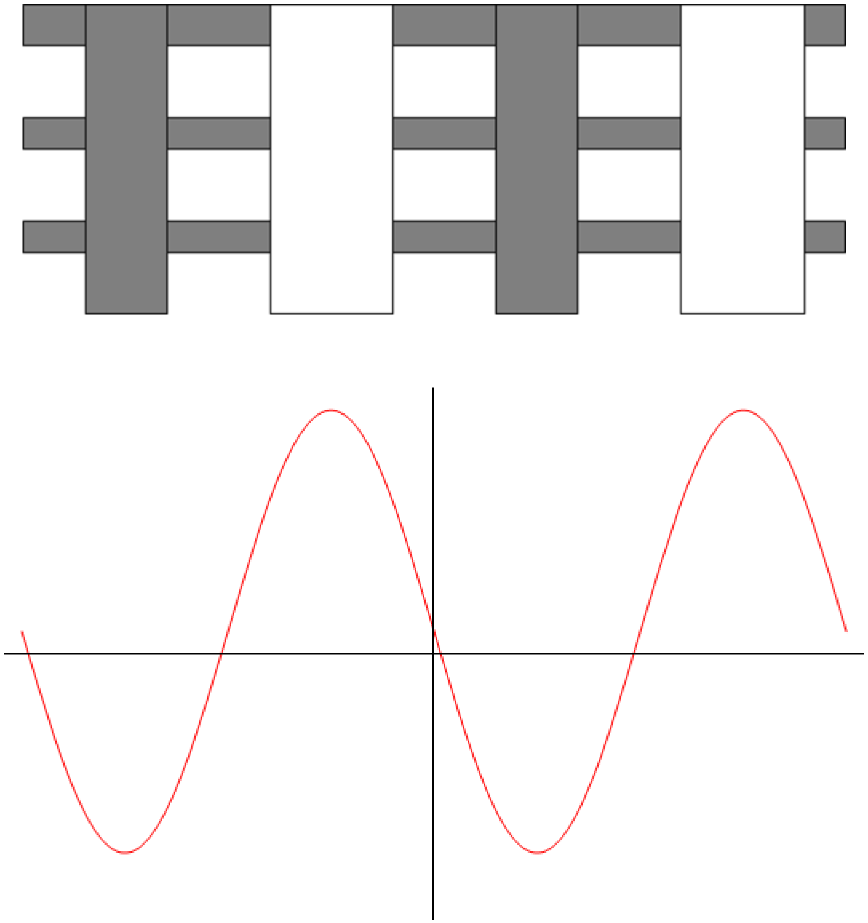
An Ultra-Low MEEF Process

- **Using a two-tone mask, an ultra-low MEEF wafer process can be realized.**



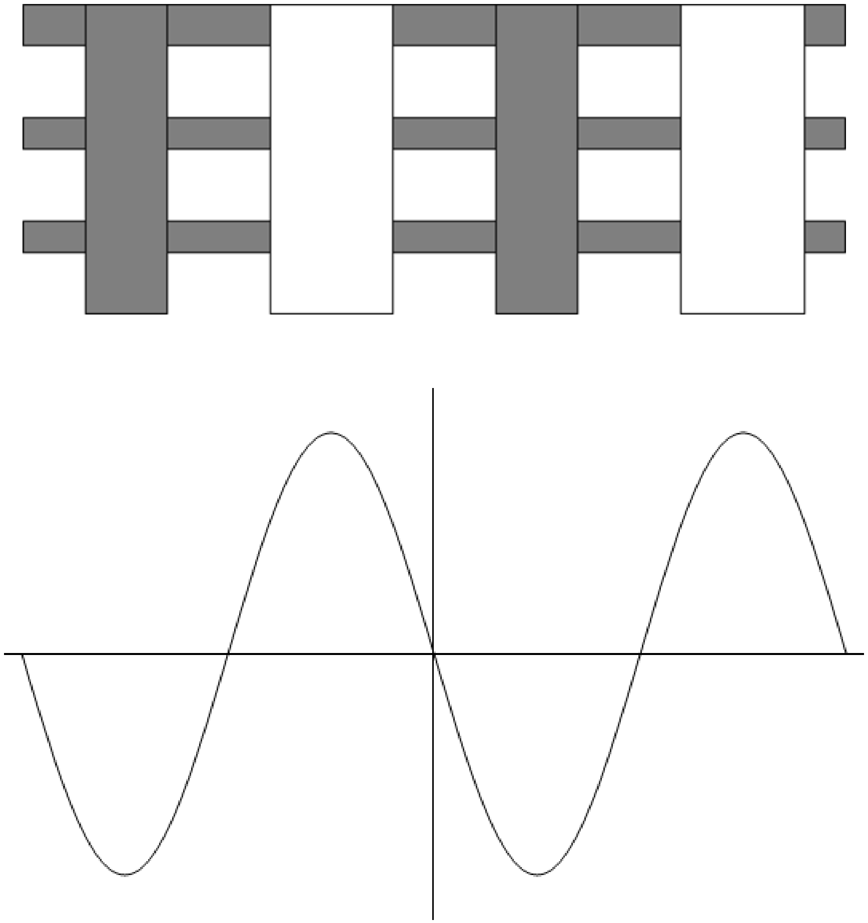
An Ultra-Low MEEF Process

- **If there is mask CD error..**
- **To the first order of the mask CD error, the amplitude of the 1st diffraction order is not changed.**



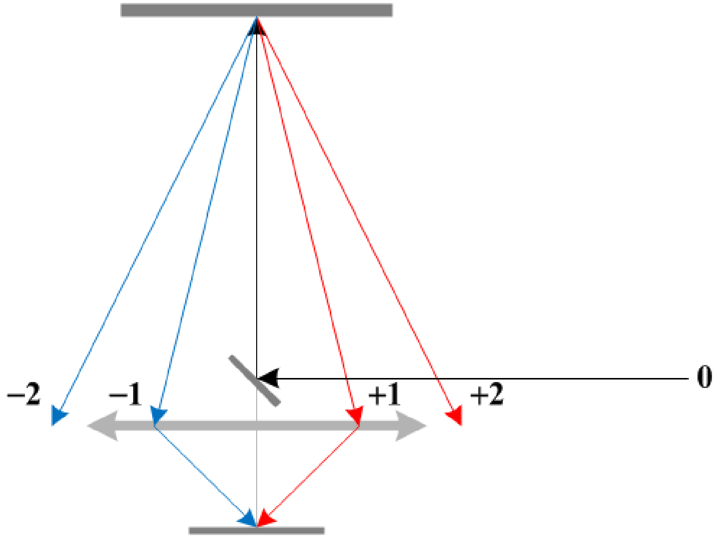
An Ultra-Low MEEF Process

- If there is mask CD error..
- The aerial image is restored if the 0th diffraction order is removed.



Mask Shadowing Effect

- **In the proposed EUVL RET, since only ONI is needed and the 0th diffraction order is removed afterwards, we can choose a 0° CRAO to completely eliminate the mask shadowing effect.**
- **Then, +1st and –1st diffraction orders are exactly balanced, irrespective of pattern pitch/CD, absorber material/thickness. There is no mask 3D effect.**
- **This eliminates non-telecentricity at the mask side. There is no mask defocus induced overlay error.**
- **This should help in increasing the accuracy of an empirical model, making EUVL OPC much easier.**



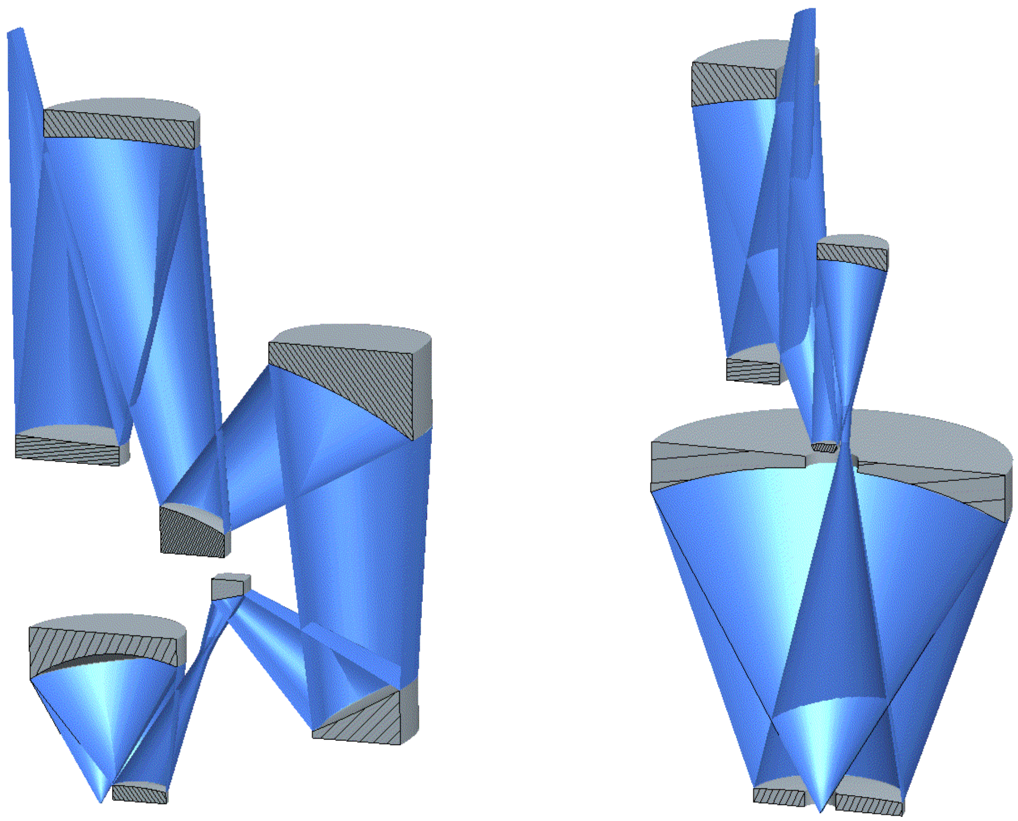
PSM

- **We don't need a PSM for aerial image contrast enhancement since we have achieved the highest aerial image contrast by removing the 0th diffraction order.**
- **Nevertheless, we still can use the PSM for throughput enhancement.**
- **In this case, the mask control can be much relaxed since the disappearance of the 0th diffraction order is by, e.g., a pupil filter, rather than mask design.**

Exposure Tool: High-NA POB Design

- **According to Zeiss, if central obscuration is allowed, the number of mirrors in a <u>high-NA</u> POB can be reduced from 8 to 6, which means 2X throughput enhancement.**
- **By the same reasoning, if central obscuration is allowed, can the number of mirrors in a <u>medium-NA</u> POB be reduced from 6 to 4?**

NA=0.5



SPIE 7636.03

If we use the conventional EUVL RET..

- The EL is degraded.
  LWR is an issue.
- The DOF is very small.
  There is a forbidden-pitch problem.
- The MEEF is very large.
- May need 2 additional mirrors for the higher-NA POB, throughput→1/2.
- May need a quarter field to reduce the CRAO, throughput→1/4.
- To keep the same shot nose level for the next technology node, throughput→1/2.

If our proposed EUVL RET is adopted..

- The EL is maximized.
- The DOF is also maximized simultaneously.
  There is no forbidden-pitch problem.
- The MEEF can be close to 0.
- Can use a PSM to enhance throughput without the need of accurate mask control.

And More..

- May choose a 0° CRAO to totally eliminate the mask shadowing/3D effect.
- Can eliminate mask defocus induced overlay error.
- Can have a more accurate empirical model for EUVL OPC.
- No mask black border effect (excess dose at the field edge/corner due to residual reflectivity of the absorber).
- No impact from OOB radiation.
- Can reduce mask phase defect printability.
- Can enhance mask phase defect repairability.
- May have the possibility to simplify the illuminator. (A single illumination mode can print all layers.)
- May have the possibility to reduce the number of mirrors in the POB since central obscuration in the pupil plane is allowed (in fact, needed).

Another Choice!

- **If scanner transmission can have 2X improvement by simplifying the illuminator,**
- **And if scanner transmission can have another 2X improvement by reducing the number of mirrors of the POB,**
- **Plus at least 2X improvement in mask transmission by introducing a PSM,**

Another Choice!

- **Then, the needed EUV source power for HVM becomes 1000W/2X/2X/2X=125W!**