LithoVision | 2009

CEA-LETI - NIKON Joint Development Program Update

C. Lapeyre, S. Barnola, I. Servin,
S. Gaugiran, S. Tedesco,
L. Pain, A.J. Hazelton,
V. Salvetat, M. McCallum

Outline

- CEA-LETI-Minatec background
- CEA-LETI-Minatec & NIKON Joint Development Program
- Double Patterning Process development and control
- Topography impact on DP technology
- Reticle & Pellicle impact on CDU & overlay
- Experimental Nikon error model validation
- DP processing to achieve k_1 = 0.14

LETI Background

- 1,600 people on research programs (1000 CEA headcount)
- 8000m² clean room
- 160 industrial partners
- 30 startups
- 1600 patents portfolio
- 250 patents in 2008

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Nanoelectronic 200mm and 300mm

- 200mm clean room (2500 m^2)
- 300mm ball room (1500 m^2)
- State of the art tools
- Full research line
- Continuous operation
  - ➔ 7 days per week/ 24 hours per day

Nikon and LETI Program

- Nikon and CEA-LETI-Minatec are partnering through a Joint Development Program to understand the sensitivities of various DE/DP techniques since early 2007.
- Placing special emphasis on ensuring next generation exposure tools satisfy DP requirements.
- Using a 0.85 NA dry ArF Nikon scanner in LETI's Nanotec 300 research facility in Grenoble, France.

NSR-S307E – 0.85 NA Dry ArF

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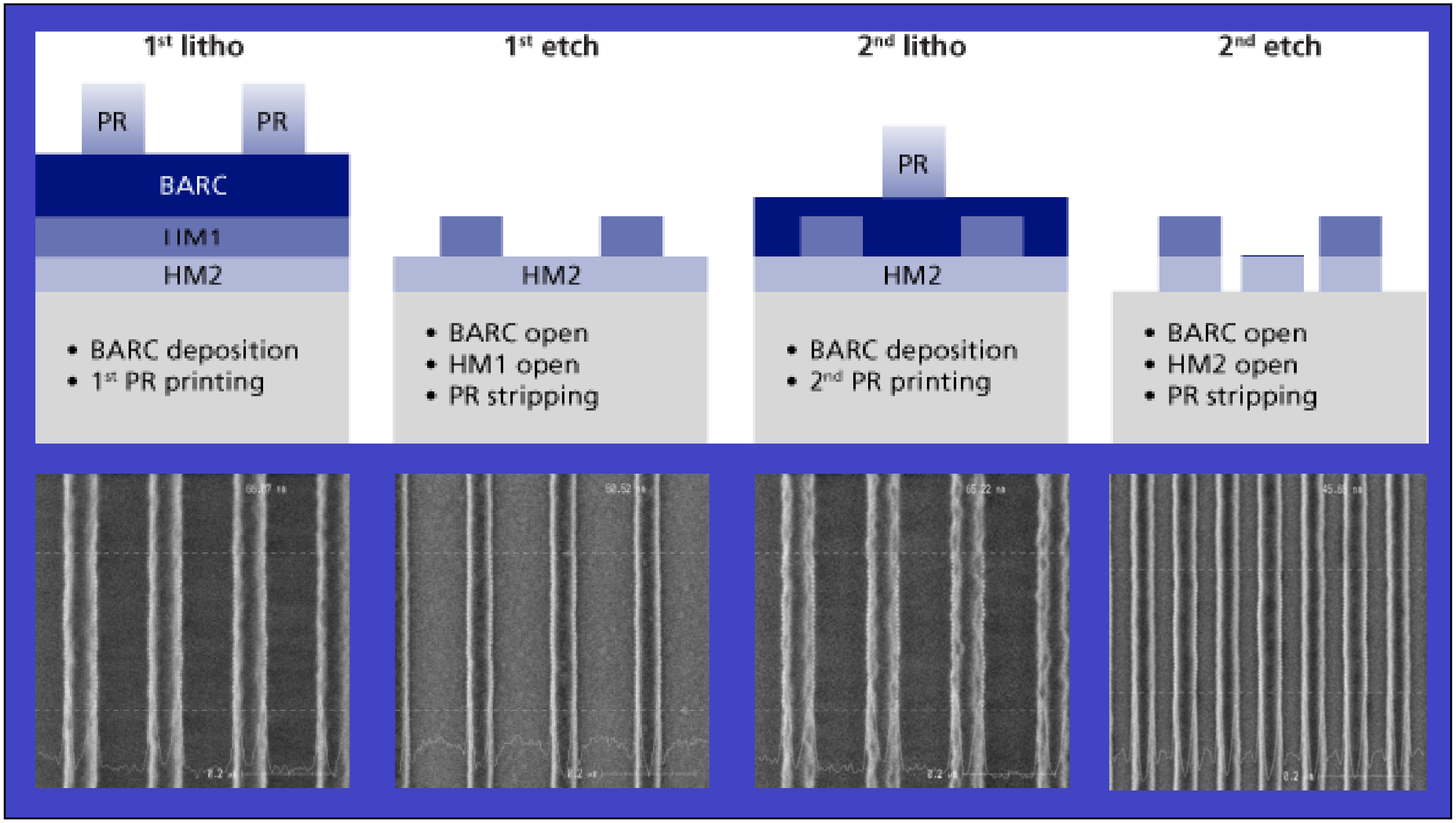
45nm Double Patterning Process

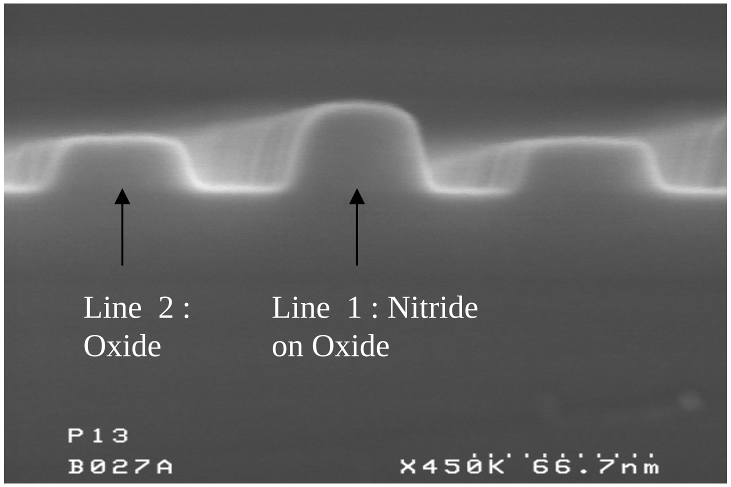
- NSR-S307E 0.85 NA ArF
- Sokudo RF3
- Lam Versys
- 45 nm L/S pattern (k_1=0.20)



cea leti MINATEC Nikon

DP Process Control (1/3)

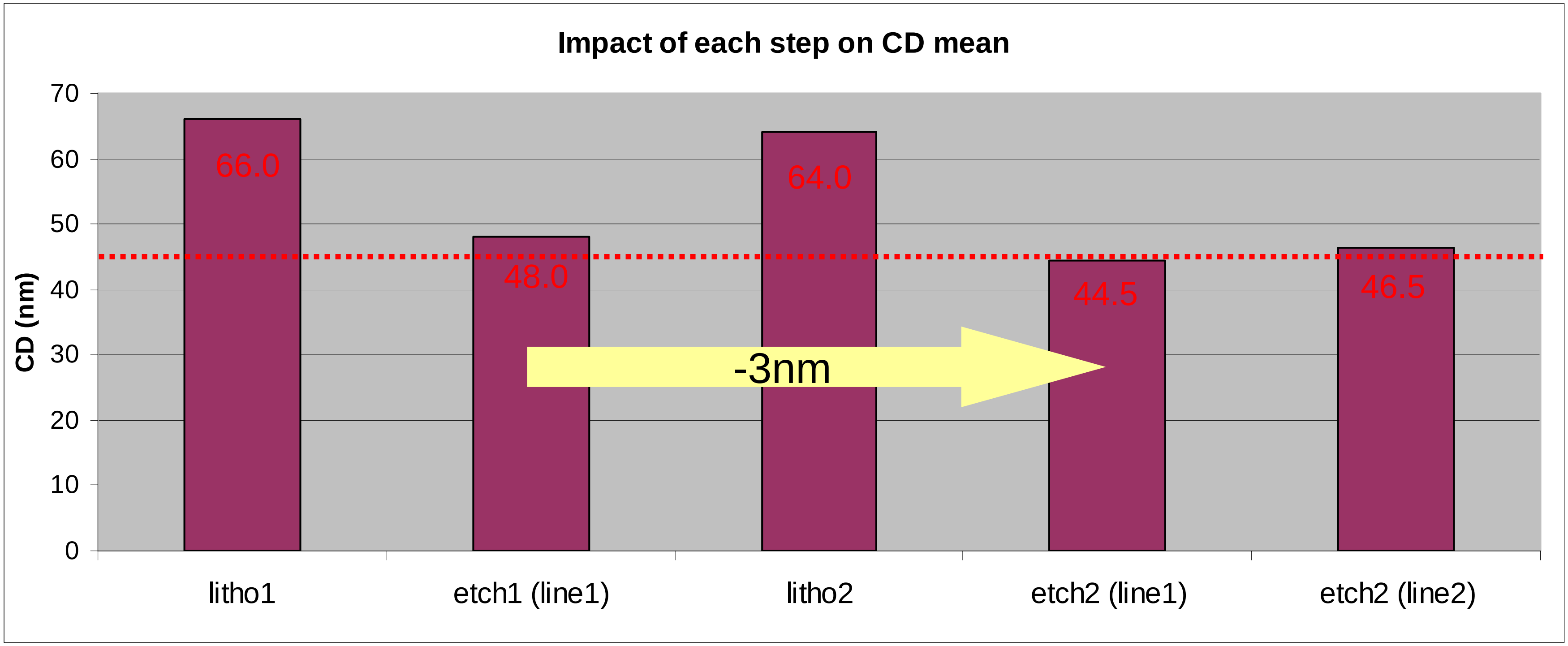
- Integration stack requirements :
  - Good selectivity HM1/HM2
  - Reduce thickness to minimize topography
  - Low temperature deposition to avoid carbon mask damage



- Etch Process optimization :
  - Ensure good resist budget margin to avoid faceting
  - Control of resist trimming
  - Etching chemistry selectivity BARC/HM1/HM2
  - Conservation of CD and profile of pattern 1 through etch2

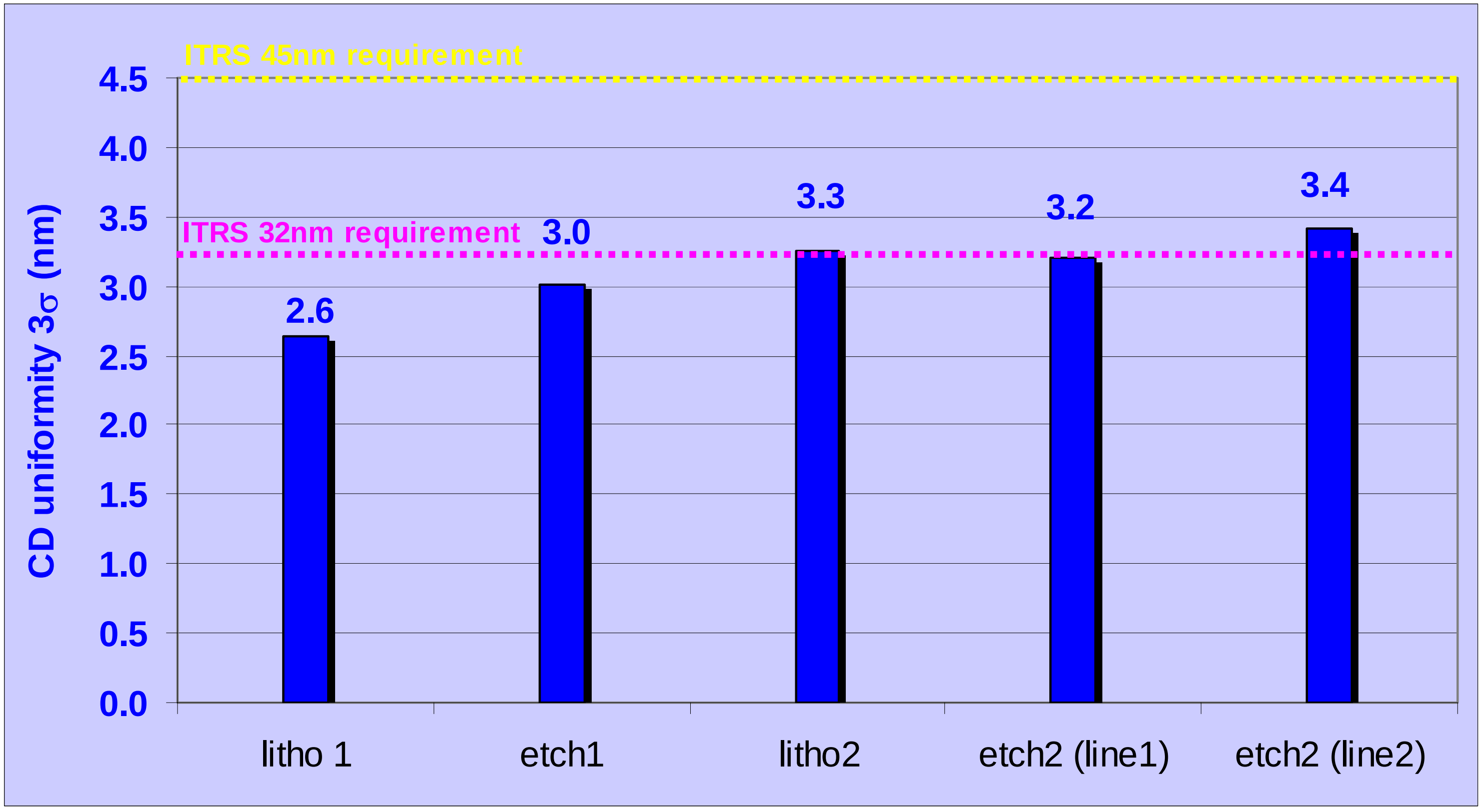
→ Good oxide/nitride selectivity
Good CD control with trimming

DP Process Control (2/3)



CD1 is well maintained through etch2 : CD bias ~-3nm
Etch process very robust : CD1 and CD2 controlled independently

DP Process Control (3/3)



CD uniformity remains around 3nm throughout the DP process in agreement with ITRS 32nm requirements

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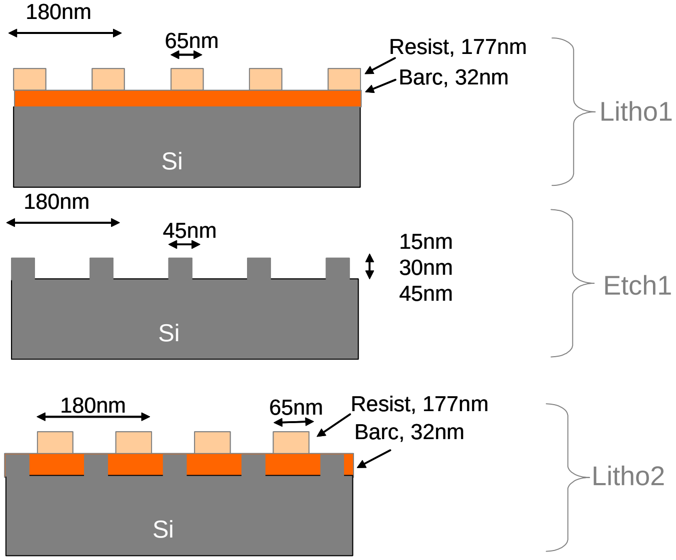
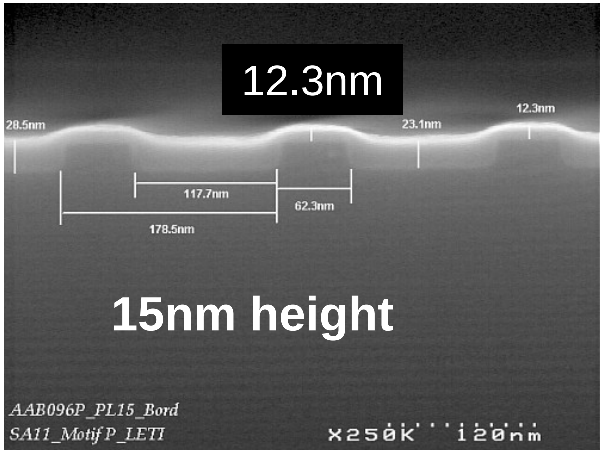
Topography Impact on Litho (1/3)

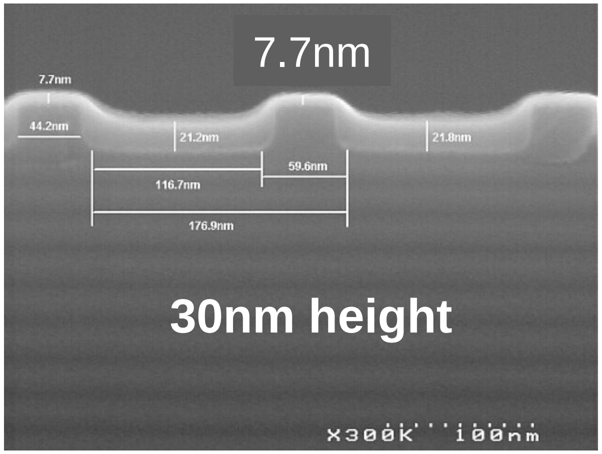


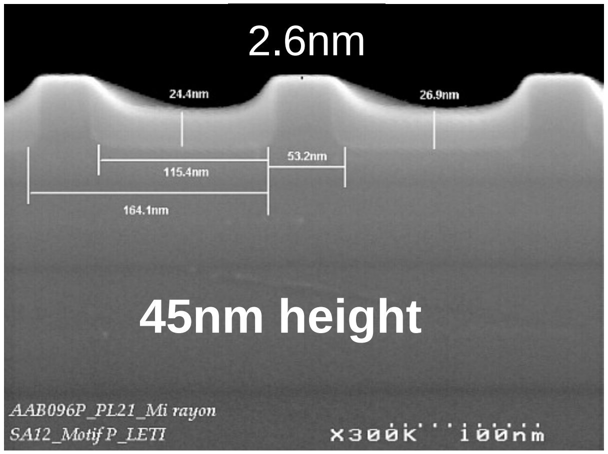
- Substrate topography ➔ BARC thickness variation on features

Impact on reflectivity control

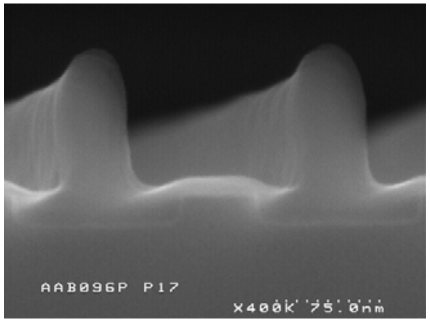
Impact on line1 etch2 dependent upon BARC/nitride selectivity



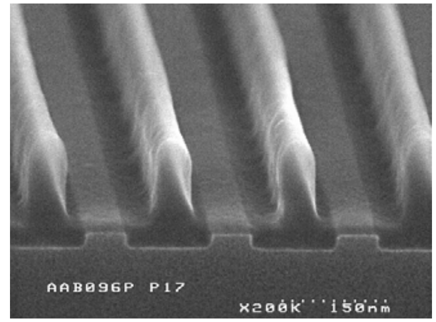


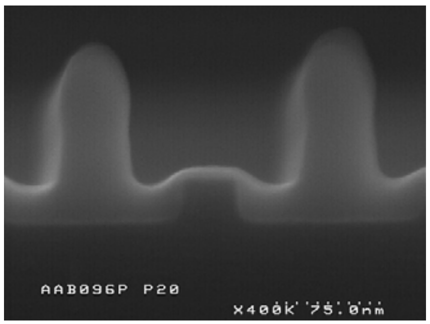


Topography Impact on Litho (2/3)

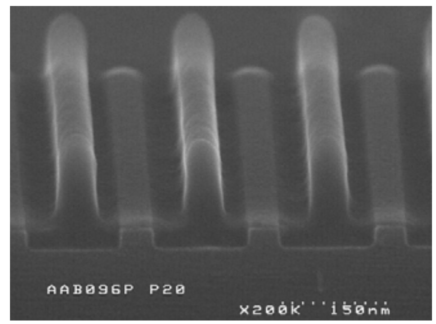


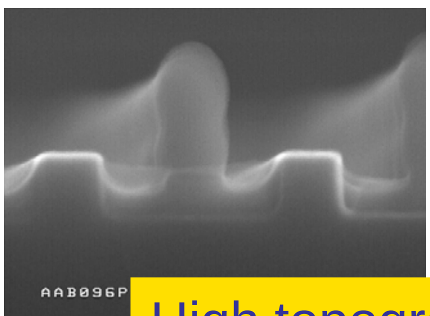
15nm height



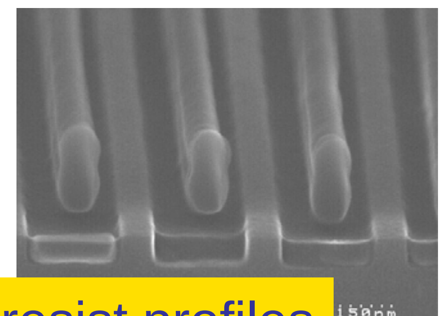


30nm height



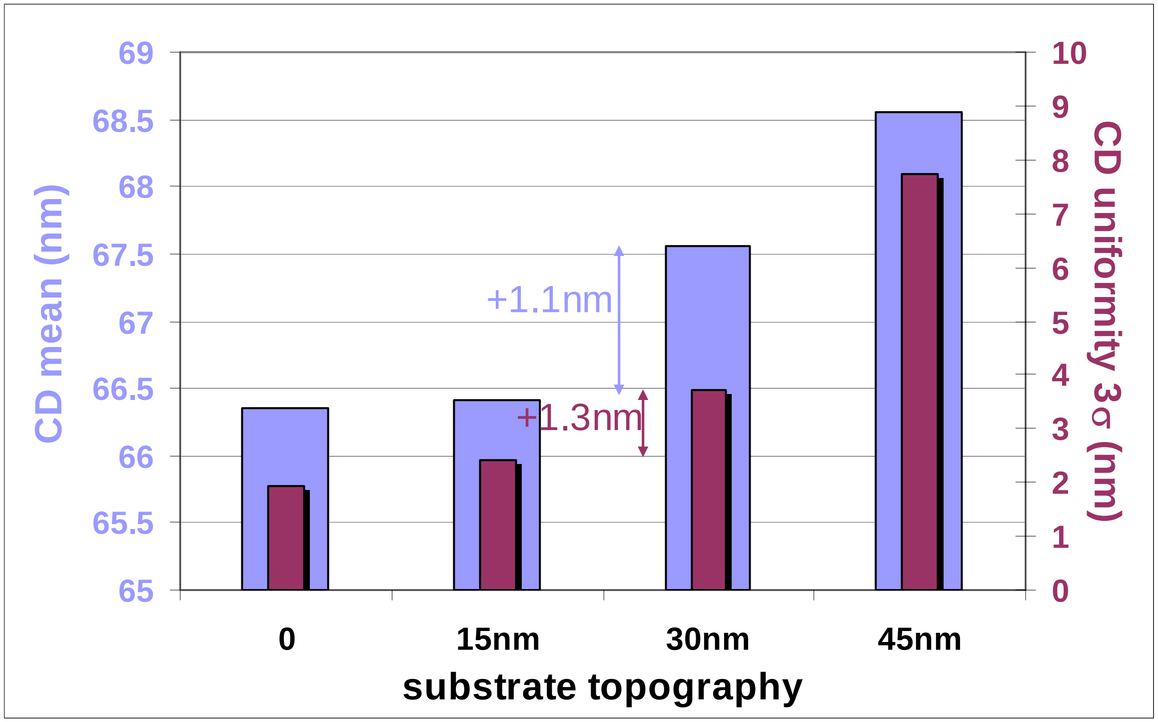


45nm height



High topography alters resist profiles

Topography Impact on Litho (3/3)



Higher topography induces: Larger CD and larger dispersion

Difference between 3σ(L2) and 3σ(L1)

Due to topography, DP requires :

Development of planarizing BARC to improve DP process

Thinnest stack as possible : 30nm Si_3N_4 / 20nm SiO_2

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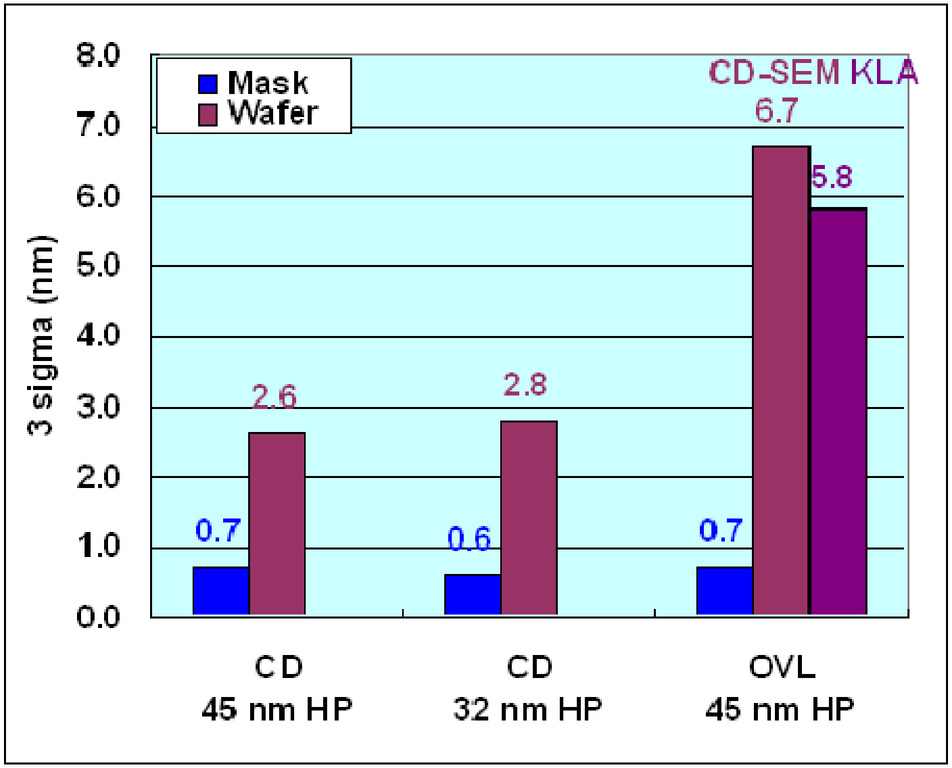
Reticle Impact on CD and Overlay

- 6% att-PSM in bright field tonality, no pellicle
- Quartz flatness 0.5µm (T)
- Designed with e-beam writer E5000
- Mask : CD tool : NANOSEM3, Registration : IPRO4 (VISTEC)
- Wafer : CD Hitachi CG4000, Overlay : CD-SEM & KLA



32 nm reticle specifications

- CD 0.5nm
- OVL 0.9nm

→ Reticle data fits ITRS

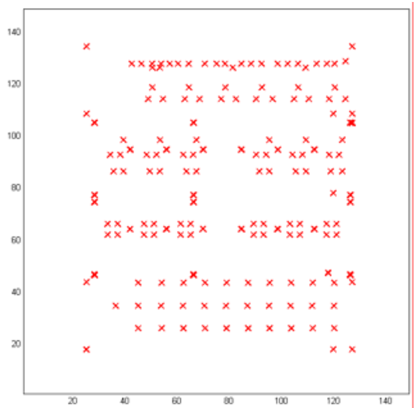
Mask CDU < ¼ of wafer CDU

Mask OVL < 10% of wafer OVL budget

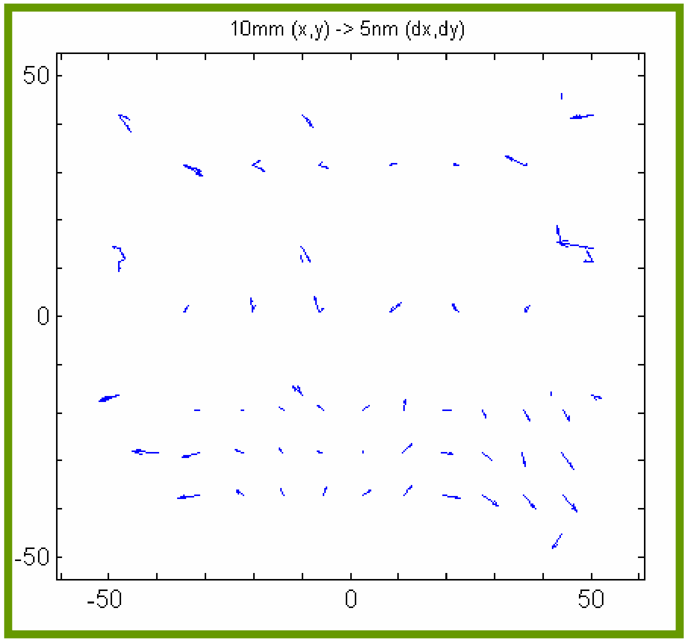
Pellicle Induced Reticle Deformation

In collaboration with Toppan Photomasks

- Mechanical performance of pellicle may introduce pattern distortions
- Image placement has been registered before and after pellicle mounting on same relevant structures spread out over the layout (10µm)



Mapping measurements



-Mask registration measured in X and Y axis
-Distortions after isotropic and orthotropic corrections
-Orthotropic corrected by exposure tool

Pellicle distortions 3σ (nm) after corrections

- X axis 3.2 nm
- Y axis 2.4 nm

Pellicle induced distortion represents 15% additional error in the image placement budget for the 45nm node

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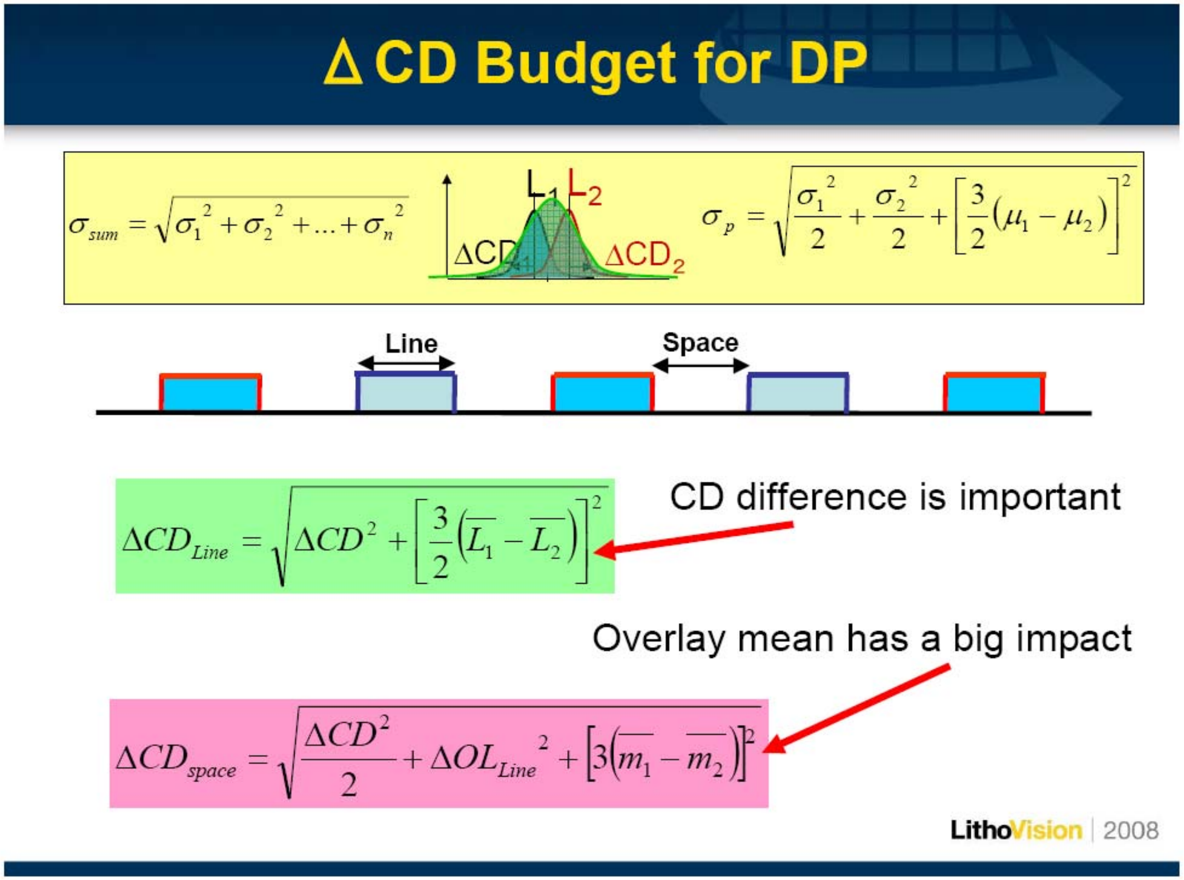
NIKON Error Model Validation

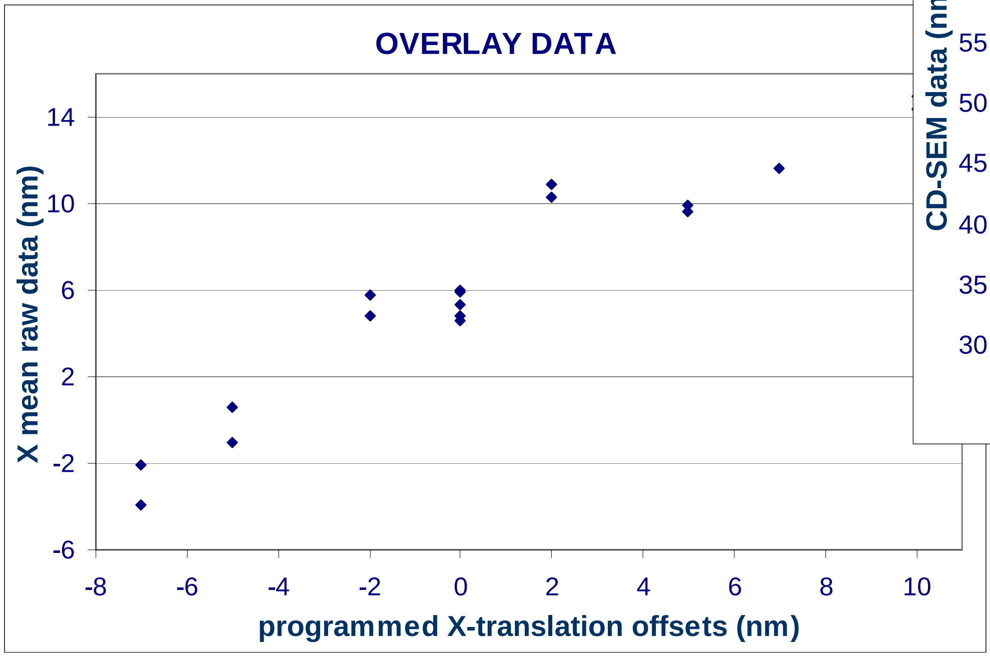
Nikon developed a theoretical model to establish the required CD and overlay requirements for DP that could be used in tool design. This was targeted for experimental verification at Leti.

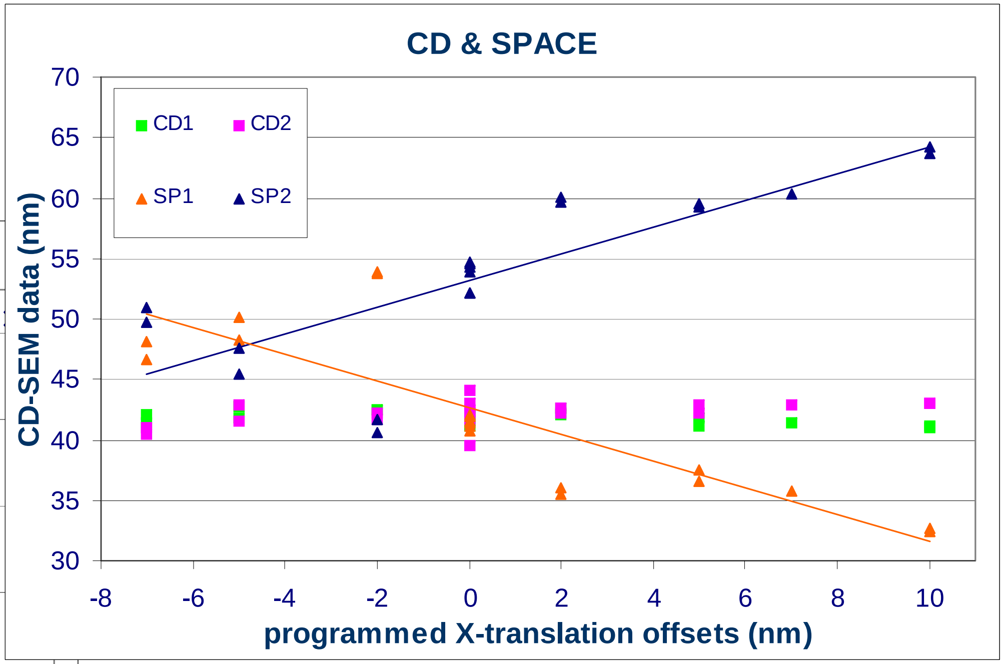


[A.J. Hazelton et. al, LithoVision 2008]

L & S Error Model Validation (1/3)

- Standard LELE process : 19 wafers with programmed x-trans offsets
- CD measurements : line1, line2, space1 and space2, and 3σ
- Overlay measurements



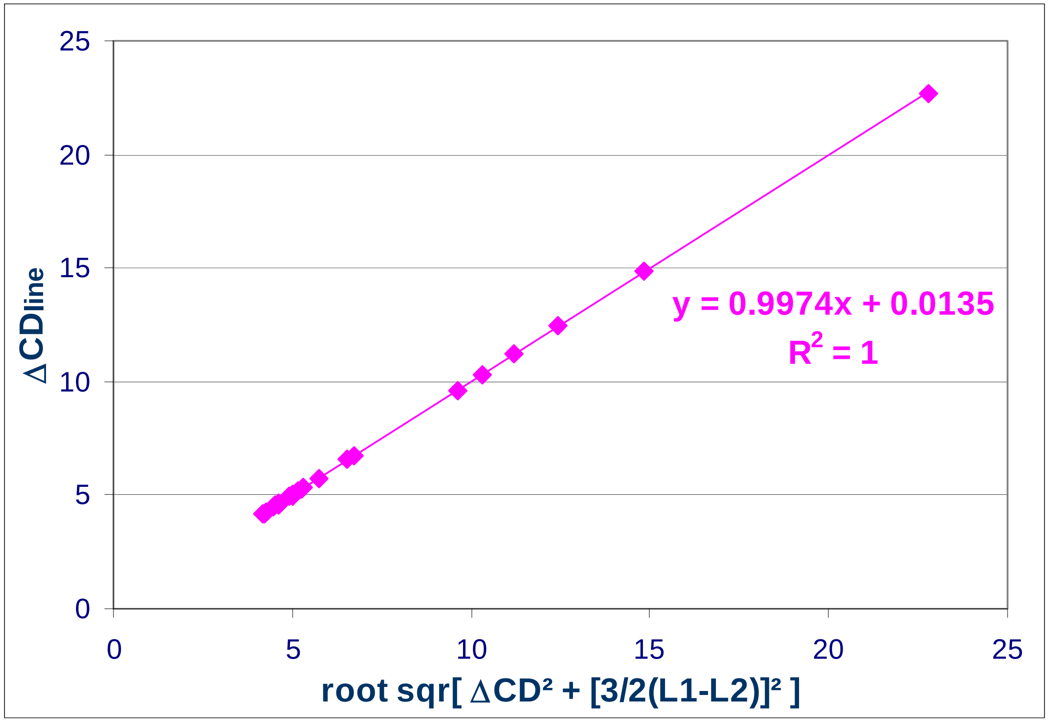


L & S Error Model Validation (2/3)

$$\Delta CD_{Line} = \sqrt{\Delta CD^2 + \left[\frac{3}{2}\left(\overline{L_1} - \overline{L_2}\right)\right]^2}$$

$$\Delta CD = \Delta CD_1 = \Delta CD_2$$

- ΔCD_{Line}: Global dispersion on the two line populations
- ΔCD: Dispersion mean of L1 and L2
- $\left(\overline{L_1} - \overline{L_2}\right)$: Difference of line CDs



- Line error model is validated experimentally by varying both CD line and CD space

L & S Error Model Validation (3/3)

$$\Delta CD_{space} = \sqrt{\frac{\Delta CD^2}{2} + \Delta OL_{Line}^{\ 2} + \left[3\left(\overline{m_1} - \overline{m_2}\right)\right]^2}$$

$$\Delta OL_{SO} = \sqrt{\Delta OL_2^{\ 2} + \Delta OL_1^{\ 2}} = \sqrt{2}\Delta OL$$

$$\Delta CD = \Delta CD_1 = \Delta CD_2$$

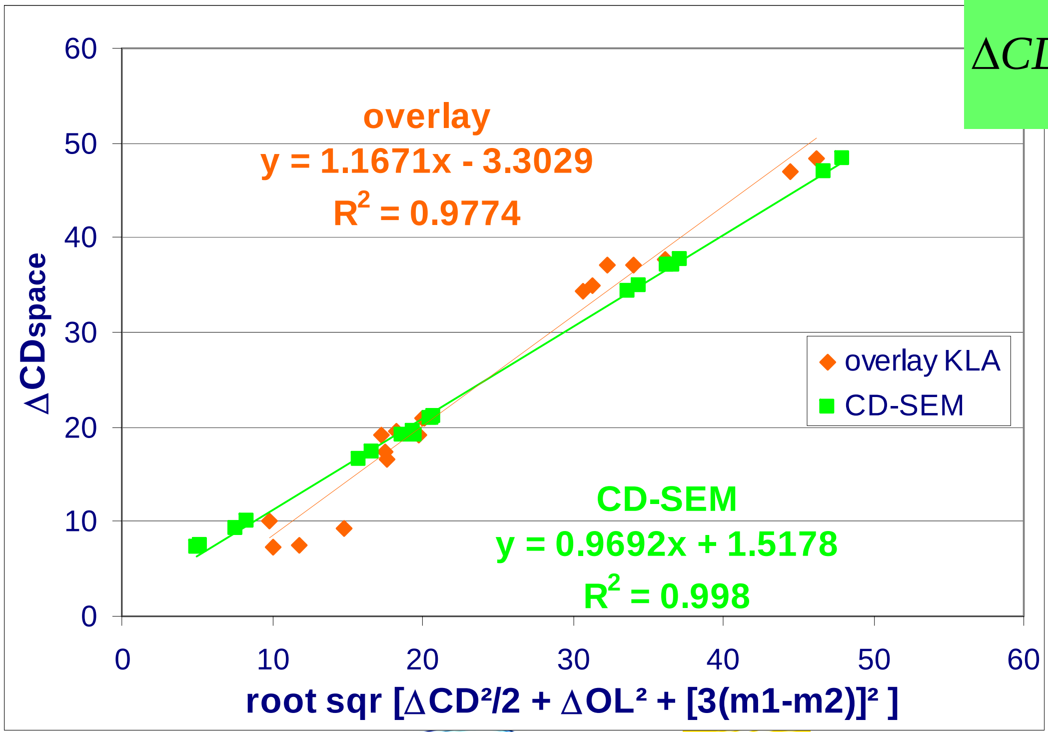
Global dispersion on the two space populations

Dispersion mean of L1 and L2

Overlay term : $(3\sigma)^2 + [3\text{mean}]^2$

with $m_1 - m_2 = ½ \times (CDspace_1 - CDspace_2)$

$$\Delta CD_{space} = \sqrt{\frac{\Delta CD^2}{2} + \Delta OL^{\ 2} + \left[\frac{3}{2}\left(\overline{SP_1} - \overline{SP_2}\right)\right]^2}$$



Space error model validated experimentally

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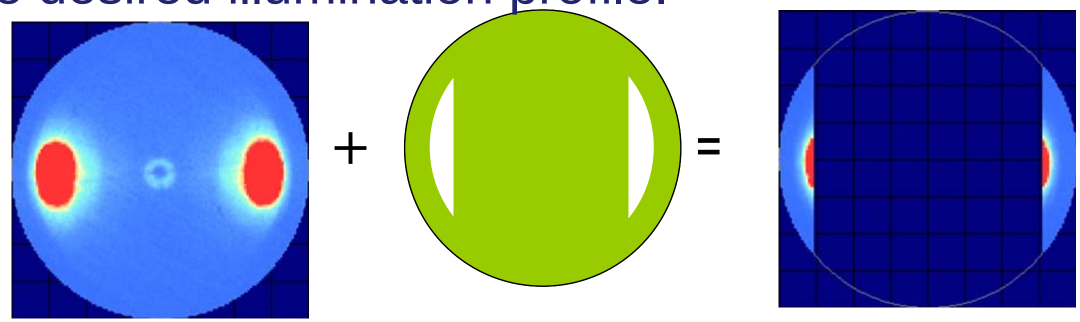
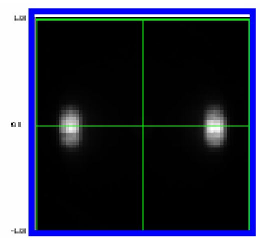
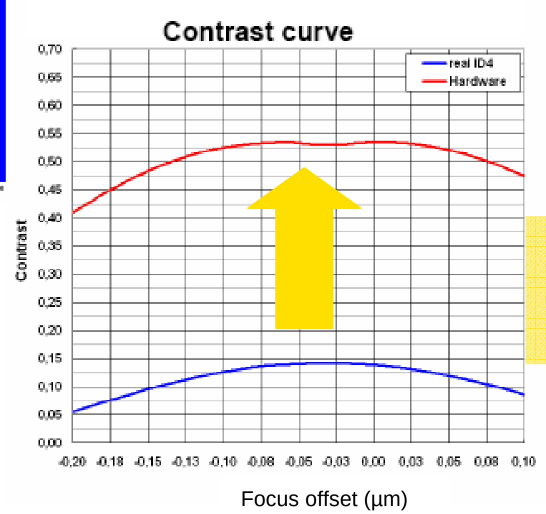
Practical Illumination Solutions

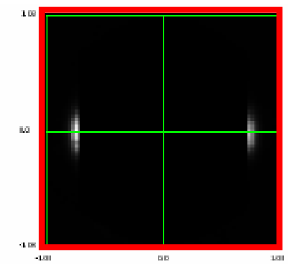
• The existing Dipole Optical Element was combined with a new aperture to produce the desired illumination profile.



real pupil distribution for ID4   pupil distribution for new hardware aperture







Simulation result using NSR illumination data and SolidE simulator

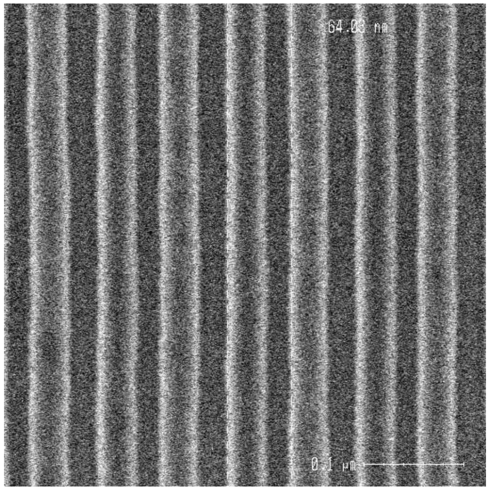
4x improvement using new aperture

****See V. Salvetat et al poster later tonight***

32 nm Using Double Patterning

• Successful DP process developed at CEA-LETI-Minatec coupled with custom illumination solution enabled 32 nm patterning with $k_1 = 0.14$ using a 0.85 NA dry ArF scanner.

$k_1 = 0.14$



32 nm with pitch 64nm
obtained with DP

Demonstrated $k_1 = 0.14$ while showing potential extendibility of dry ArF tools

Summary and Outlook

•Double patterning process developed at CEA-LETI-Minatec is step by step controlled

•Topography impact on DP process has been demonstrated

•Reticle and pellicle contributions on CD & overlay budgets have been determined experimentally on DP structures

•Nikon line & space error model validated experimentally

•Successful partnership between CEA-LETI-Minatec and Nikon demonstrating a Double Patterning process down to k_1 of 0.14 is possible.

•Nikon / CEA-LETI partnership will continue

Acknowledgements

- Brid Connolly, Ralf Ploss, **Toppan Photomasks**
- Amandine Pikon, Christophe Brault, **Rohm&Haas Electronic Materials**