FULLFIELD 27NM CD CONTROL AND MODELING

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SYNOPSYS®
Predictable Success

imec

ASML EUV ADT AT IMEC

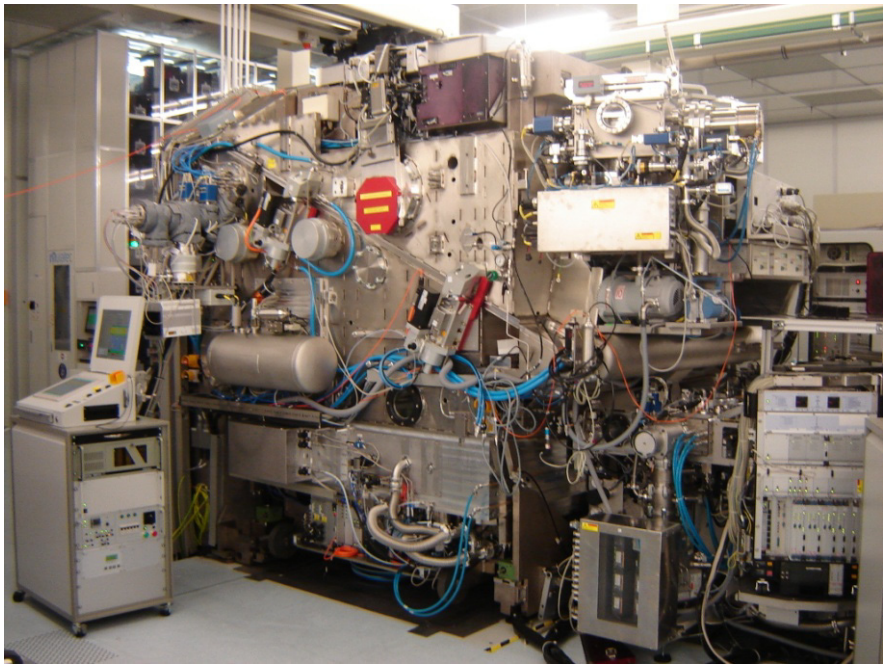
Main specifications

- Field size: 26x24mm^2
- NA=0.25 and σ=0.5
- Flare < 16%
- Wafer CDU 40nm LS < 10% 3σ

Interfaced to TEL ACT12 track

Site acceptance on June 4, 2008

XTREME 170W/2π DPP source (July 2009)



Monitor

- June 2008 → September 2009: 40nm LS
- September 2009 → Now: 32nm LS

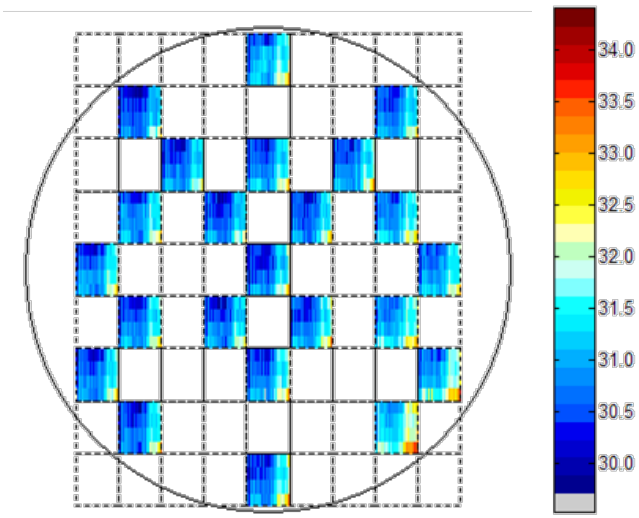
Metrology: Hitachi CG4000

Total amount of 300mm wafers exposed since Jan 2010: 1440

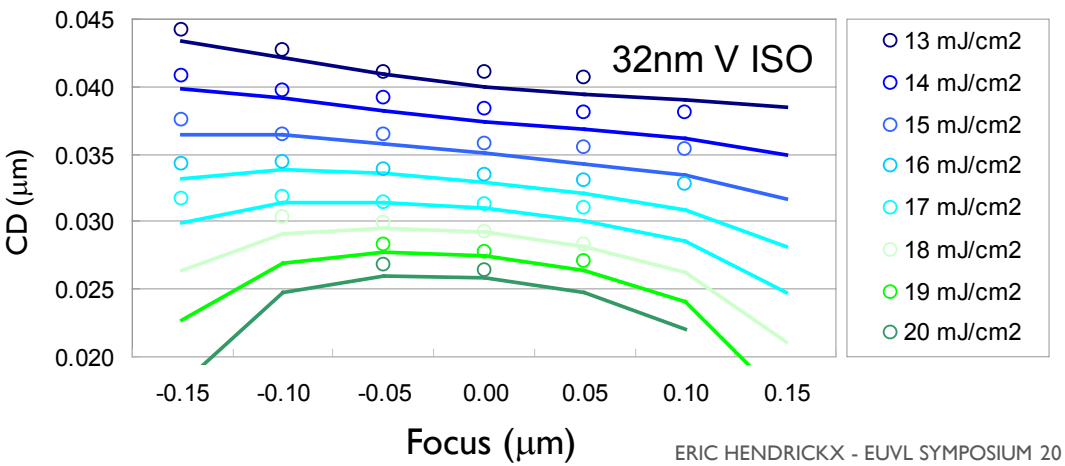
EUVL 2009 - 32NM LS ON EUVADT

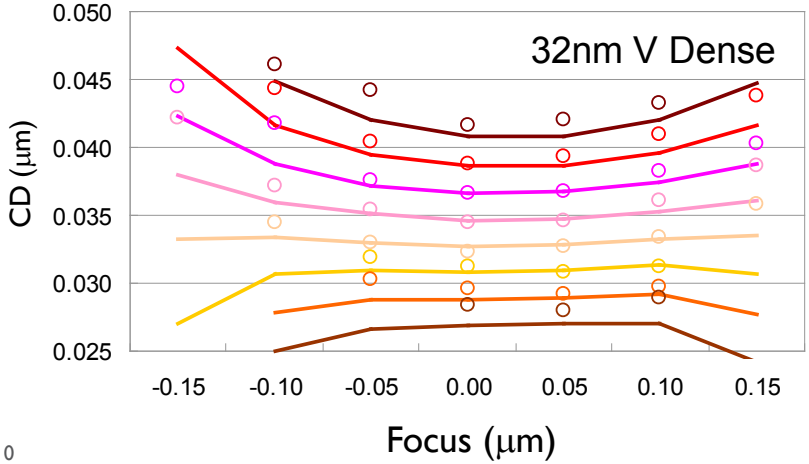
- CD fingerprint of EUV ADT at **32nm LS**

	H	V
Total 3s	2.2nm	2.0nm
Intrafield 3s	2.0nm	1.8nm
Intrawafer 3s	0.7nm	0.9nm



- Full resist model was fit to process windows (rms ~1nm)



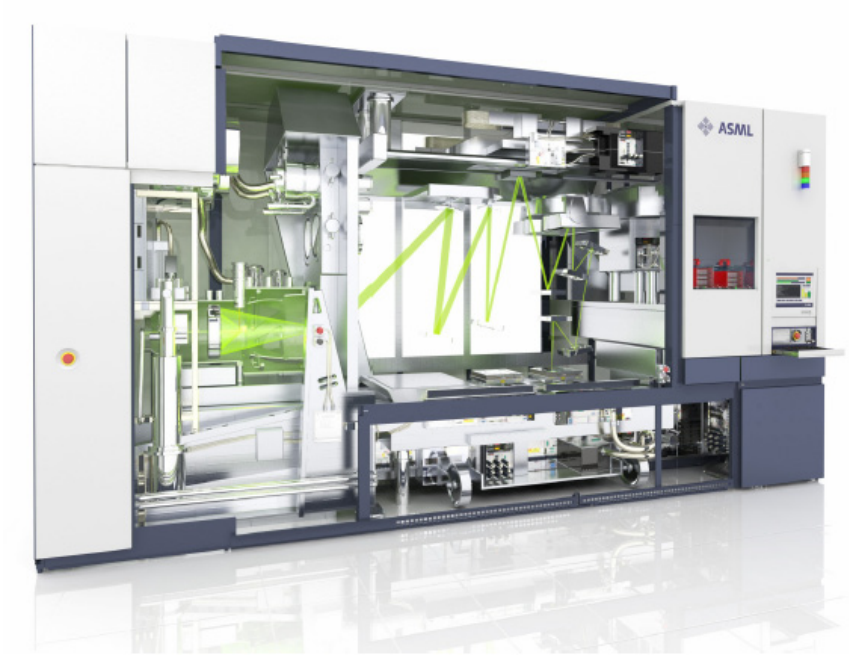


TOWARDS NXE:3100 AT IMEC

Main specifications

- Field size: 26x33mm^2
- NA=0.25 and σ=0.8
- Flare < 8%
- Wafer CDU **27nm LS**

Site acceptance target Q2 2011



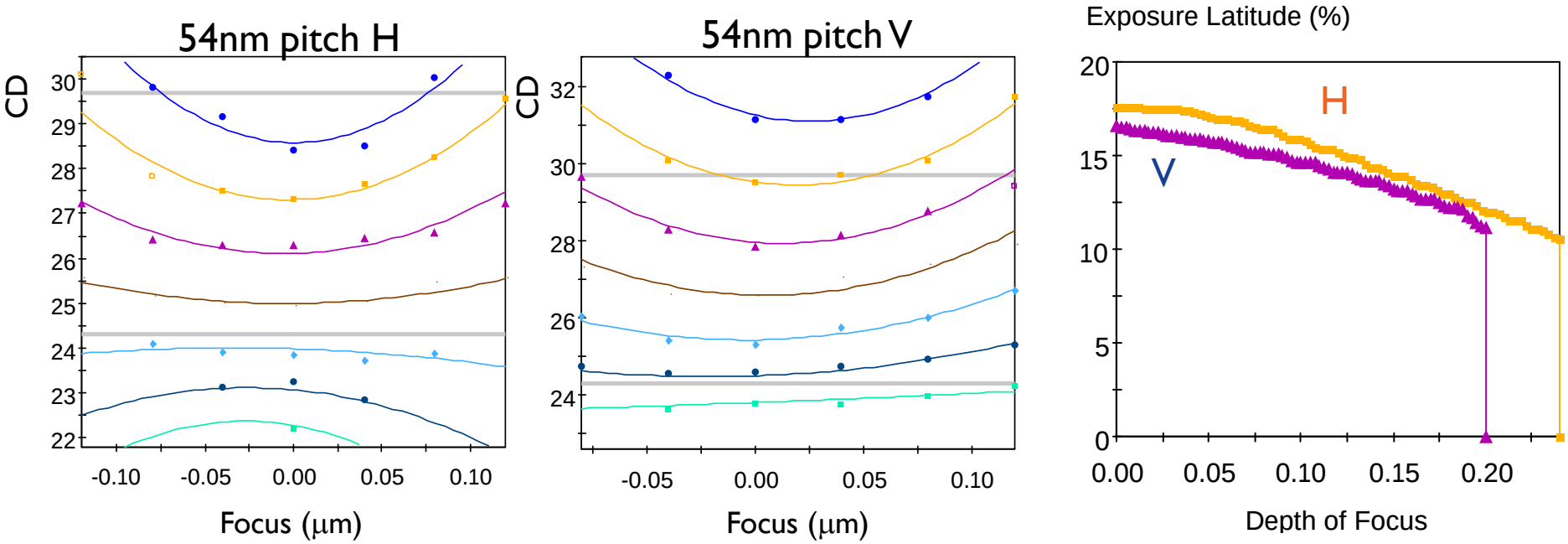
Interfaced to **TEL Lithius™Pro™-EUV track**

Site acceptance ongoing

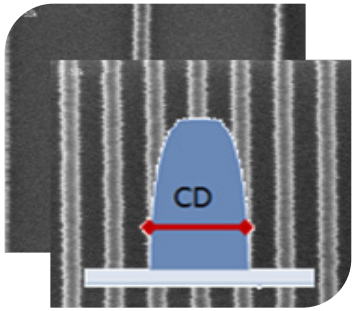
Can we demonstrate NXE 3100 27nm LS uniformity specifications on EUV ADT – ACT12?

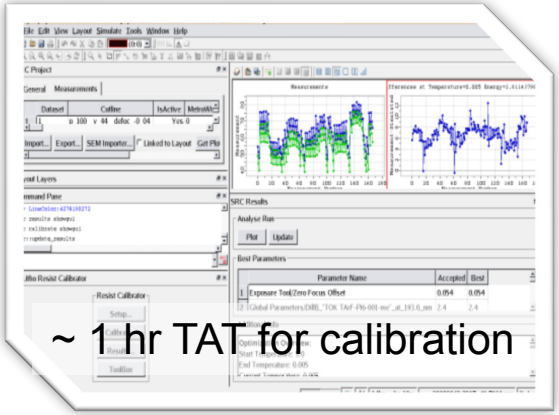
IMPROVEMENTS REQUIRED TOWARDS 27NM LS - PROCESS

- When printed to 27nm line CD at 54nm pitch, 32nm LS POR resist, coated to 65nm, showed pattern collapse
- New POR selected for 27nm offers sufficient process window at 54nm pitch
  - 20nm Brewer underlayer
  - Resist coated at 50nm thickness
- Constant mask HV CD bias was used to compensate HV CD shadowing offset



CALIBRATION OF FULL RESIST MODEL IN S-LITHO FOR EUV





Accurate S-Litho resist model

$$RMS := \sqrt{\frac{\sum_i^N w_i \left(CD_{meas}^i - CD_{sim}^i\right)^2}{\sum_i^N w_i}}$$

rms target <1nm

Input

- FEM of Dense & Iso LS pattern
  - 54, 60, 64nm pitch
  - 210, 245nm pitch
- All FEM images inspected
- Total ~ 200 CDs
- Flare ~4% using calibrated ADT PSF
- Measured mask CD values

SentaurusLitho

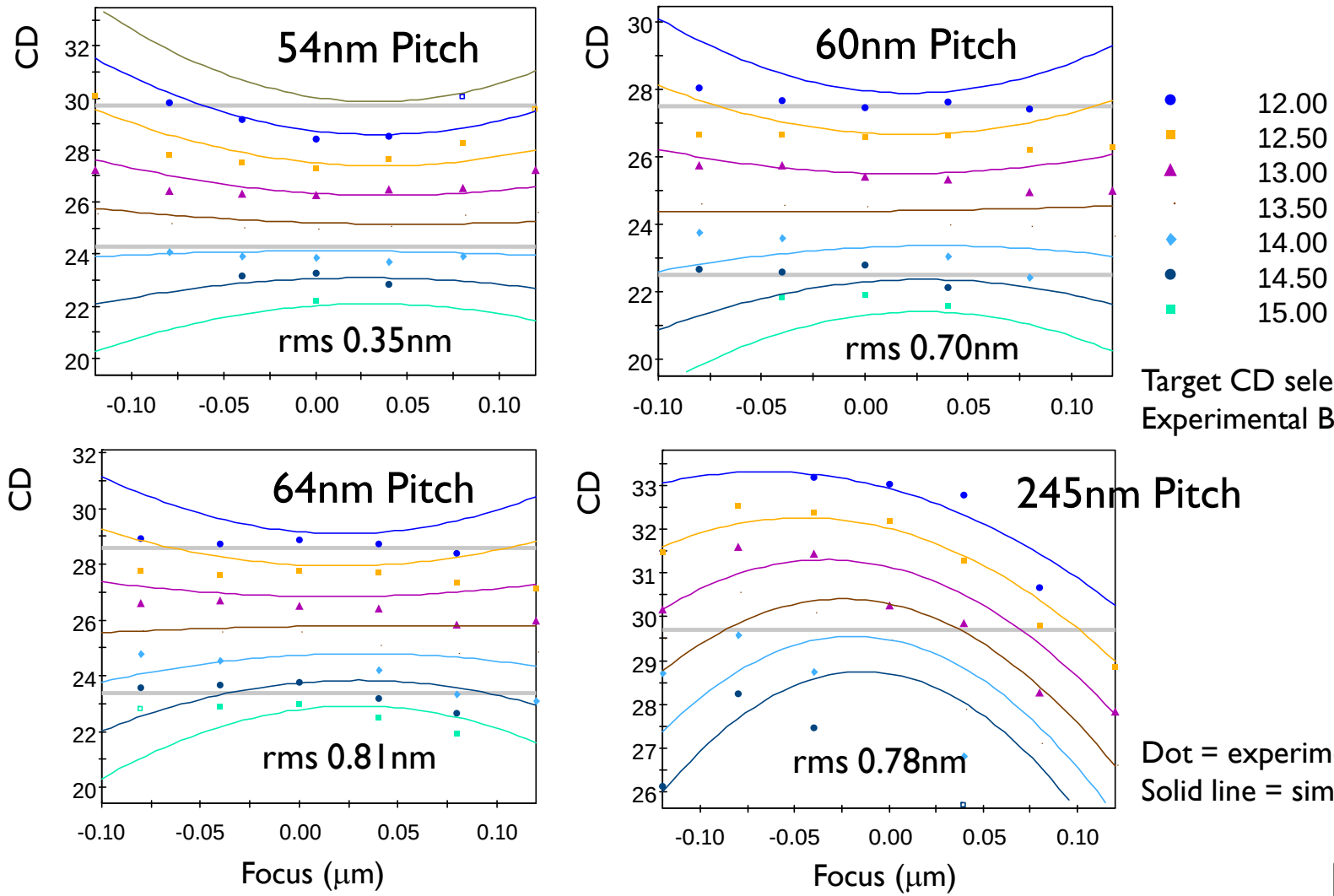
- Constant flare model
- 3D mask

Validation

- FEM of 64nm pitch CH
- MEEF of
  - 54, 60, 64nm pitch
  - 210, 245nm pitch

FULL RESIST MODEL CALIBRATION

- Good match between Experimental FEMs (points) and FEM from rigorous simulation (full resist model) – unweighted rms values below 1nm

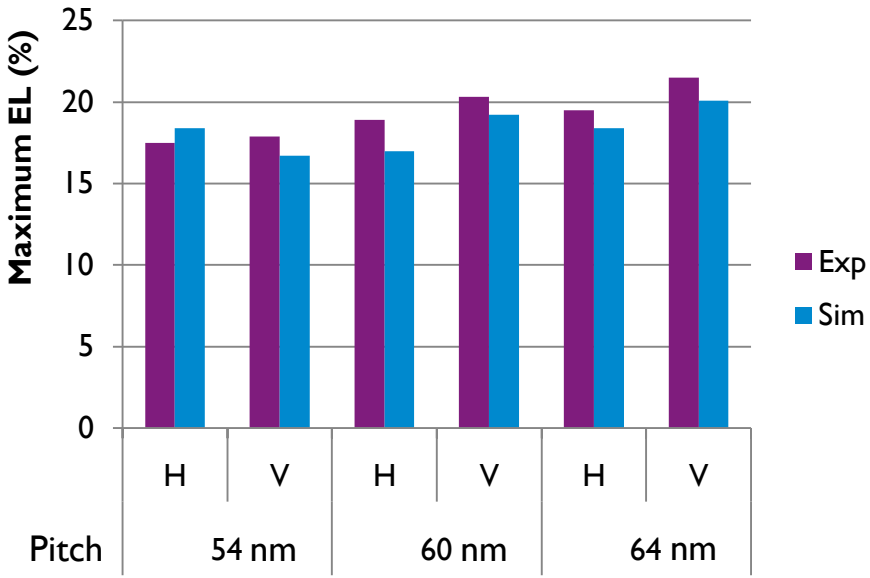


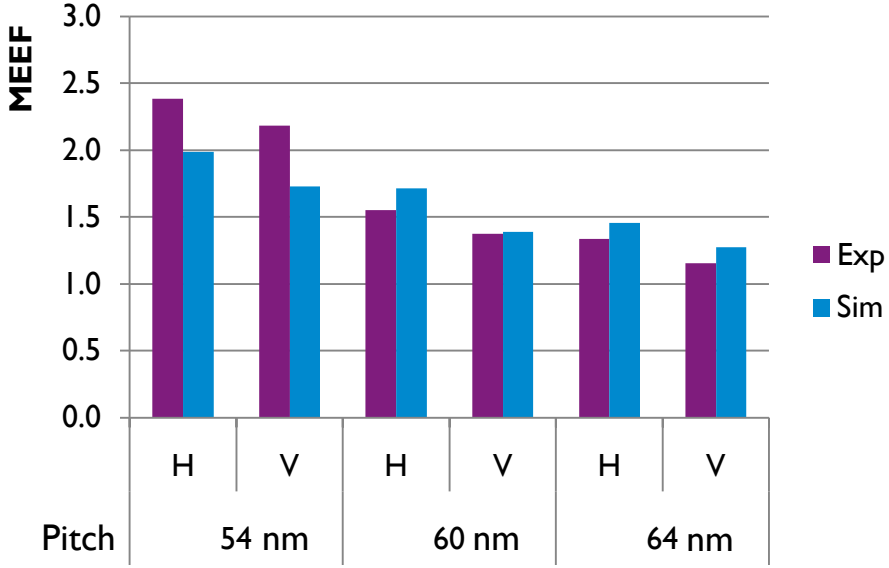
Target CD selected in Experimental Bossung center

Dot = experimental
Solid line = simulation

FULL RESIST MODEL VALIDATION

- Extracted **Exposure Latitude** and **MEEF** from experimental data and simulation
- Exposure latitude at dense pitches can be matched to within 2%
  - Note: FEM target CD at 60 and 64nm pitch were 25nm and 26nm, respectively
- MEEF increases to ~2 at 54nm pitch – well matched by model

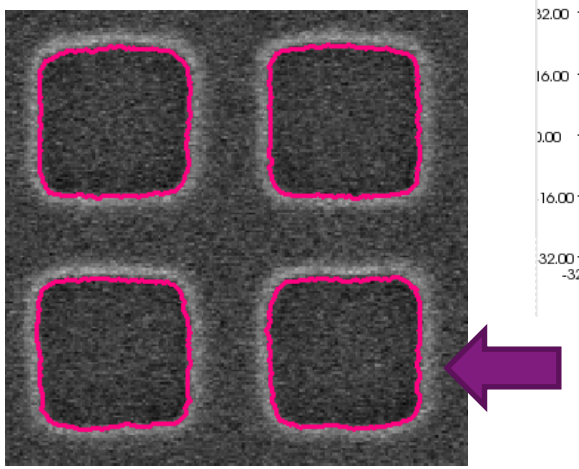




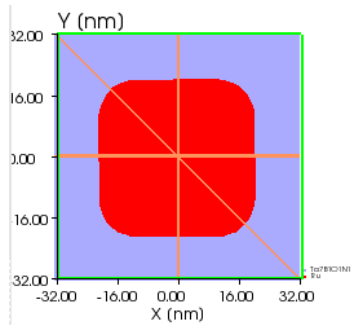
FULL RESIST MODEL VALIDATION

- Validation of resist model by 64nm pitch CH FEM measurement
- Reticle CD SEM image used as simulation input
- Good match between simulation and experiment

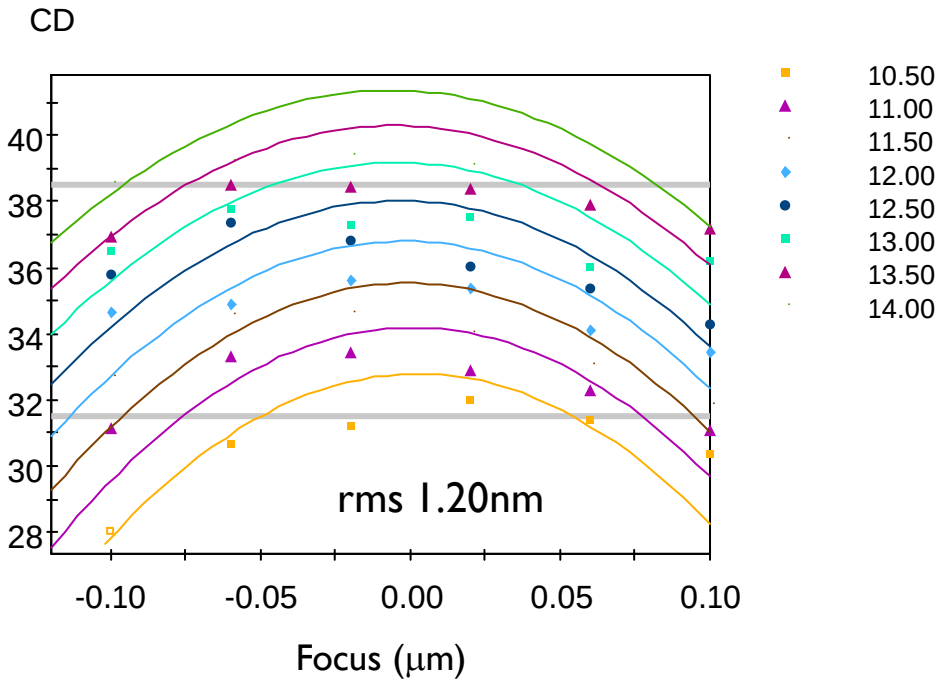
Mask CD SEM
41nm CH CD
10nm corner rounding



Simulation input



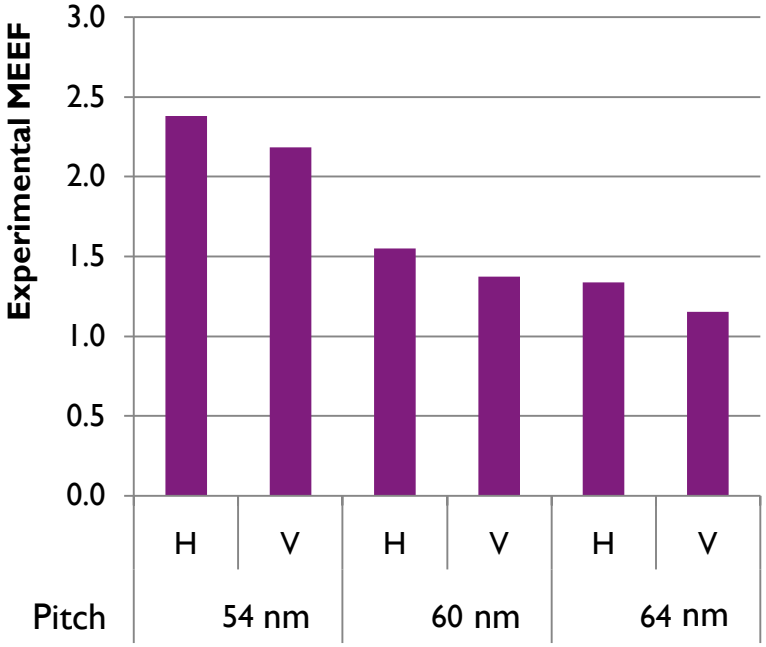
Absorber

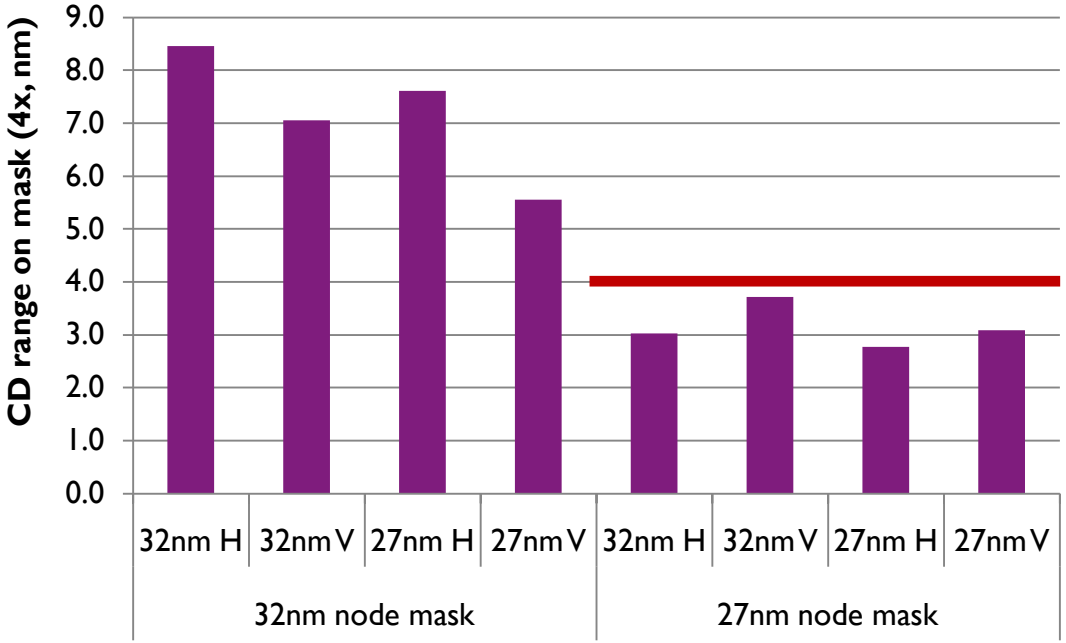


	Simulation	Experiment
Max EL	23%	27%
BE 35nm CH	11.4 mJ/cm^2	12.0 mJ/cm^2

IMPROVEMENTS REQUIRED TOWARDS 27NM LS - MASK

- Mask CD signature was clearly visible in wafer signature at 32nm LS
- At a MEEF of ~2, the 27nm LS CD mask uniformity should be:
  - <4nm at 4x
  - Controlled over the entire 33mm scan length (not only ADT field)
- New EUV masks became available that meet the <4nm CDU requirement





32nm node mask CD data are for the 26 x 24mm ADT image field
27nm node mask CD data are for the 26 x 33nm NXE:3100 image field
27nm node mask CD range is upper limit – still enhanced by mask CD SEM metrology error

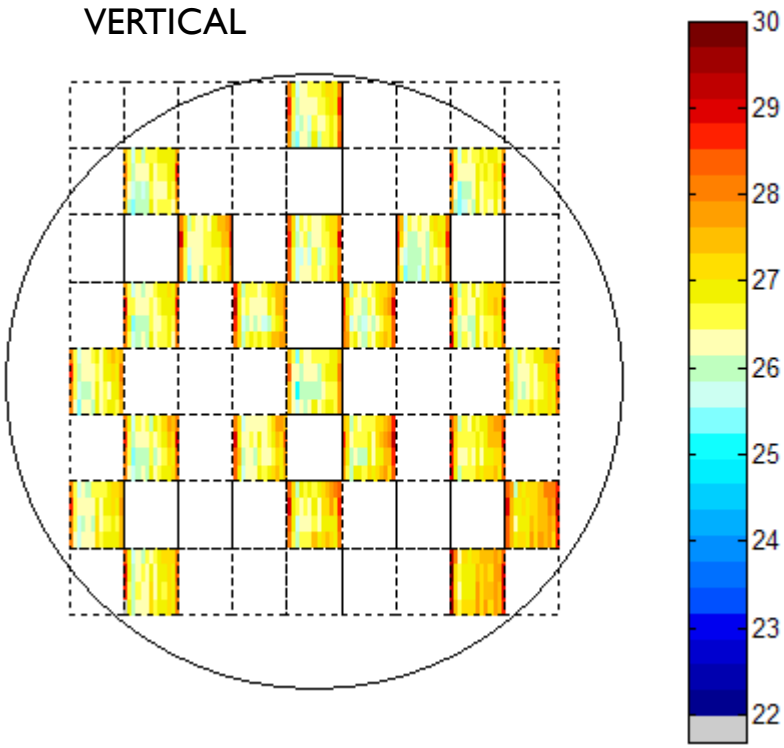
TOPPAN

27NM LS CDU – NF, ND – FULL WAFER

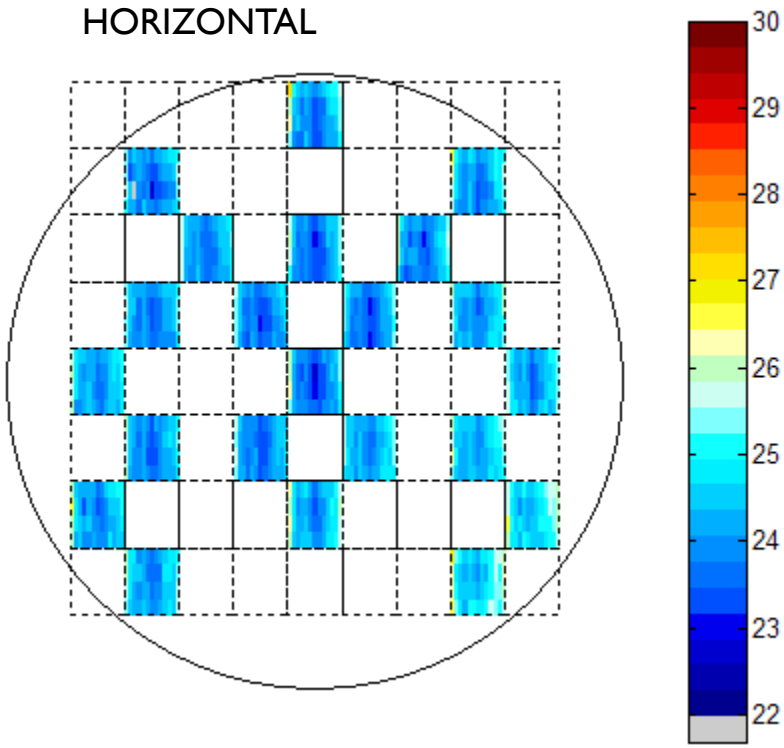
- Measurement at nominal dose (12mJ/cm²) and focus
- Measured 27nm dense lines in horizontal and vertical orientation (smaller H line CD on mask-overcompensated shadowing)
- 13 slit positions and 4 scan positions per field
- **No corrections applied to CD data for process or reticle**

	V	H
Average CD	26.9nm	24.4nm
3 sigma	2.3nm	2.0nm
CD range	4.6nm	4.4nm

VERTICAL

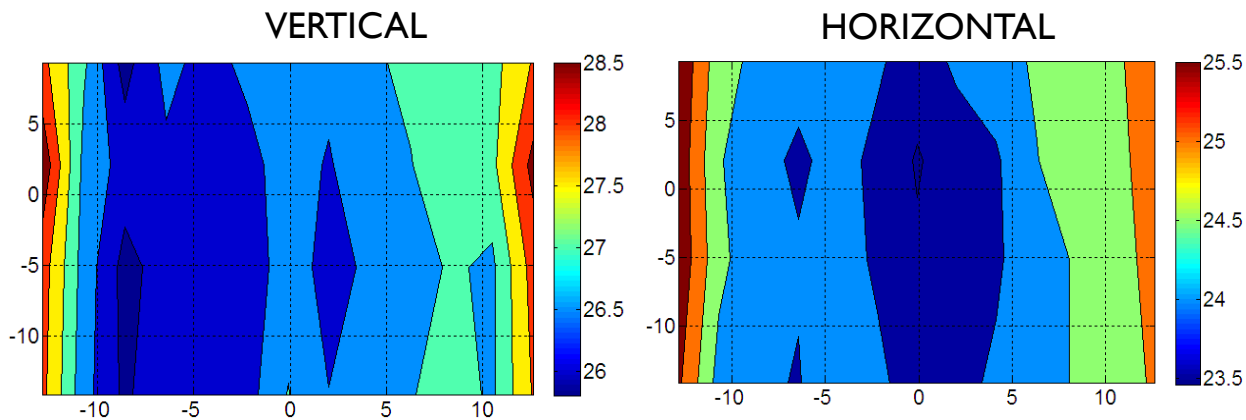


HORIZONTAL



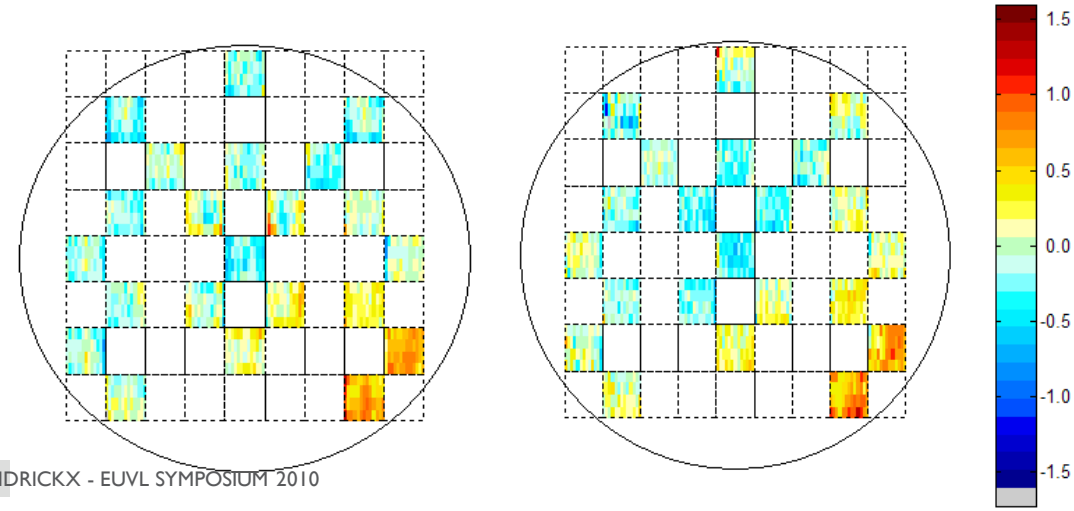
27NM LS CDU – NF, ND – FIELD & WAFER

- Separation of wafer CD fingerprint in intrafield and intrawafer contribution
- Similar CD evolution for H and V lines
- **Intrafield (IF) 3 sigma small and close to requirement of NXE3100**



No corrections for process/reticle

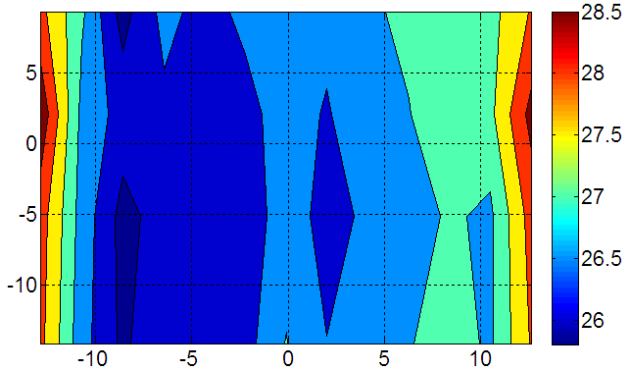
	V	H
IF 3 sigma	2.1nm	1.8nm
IF CD range	3.0nm	2.5nm
IW 3 sigma	1.0nm	1.0nm
IW CD range	2.2nm	2.5nm



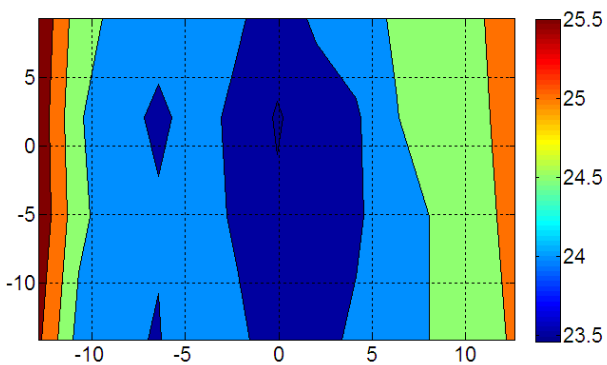
27NM LS CDU – NF, ND – INTRAFIELD

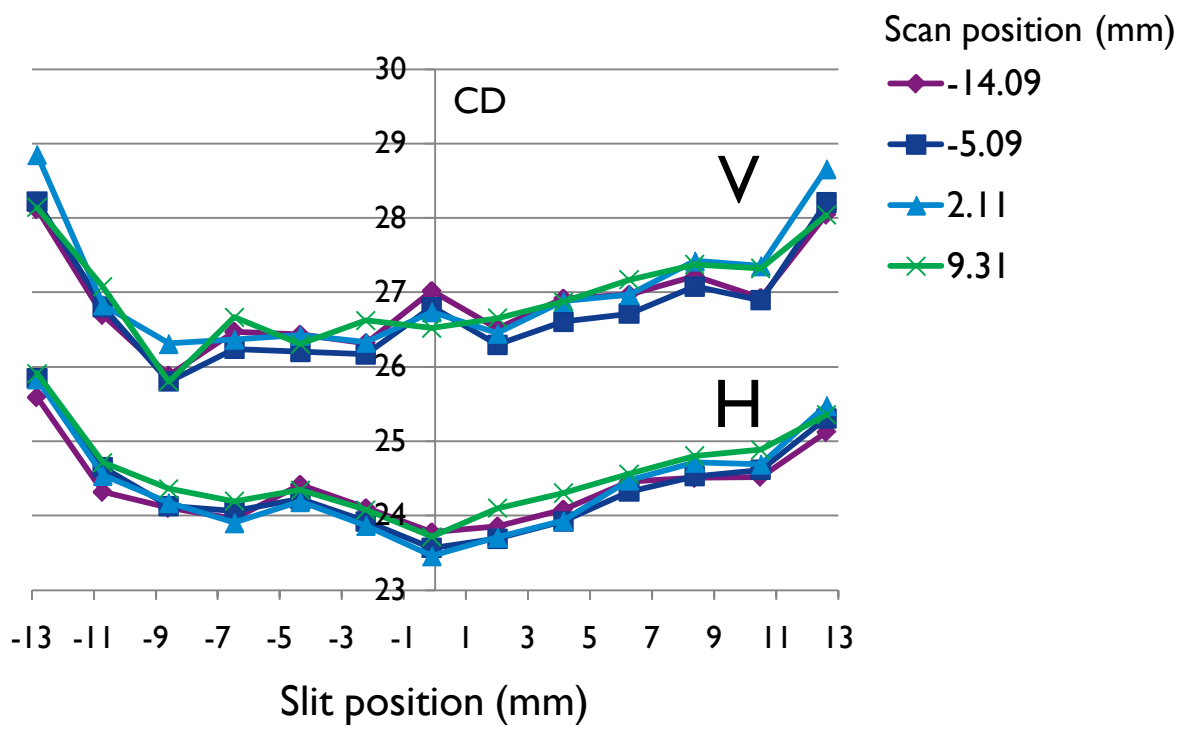
- Separation of intrafield CD fingerprint in slit and scan contribution
- Similar CD evolution for H and V lines
- CD range in scan direction: 0.3nm, CD range in slit direction: 2.4nm

VERTICAL



HORIZONTAL

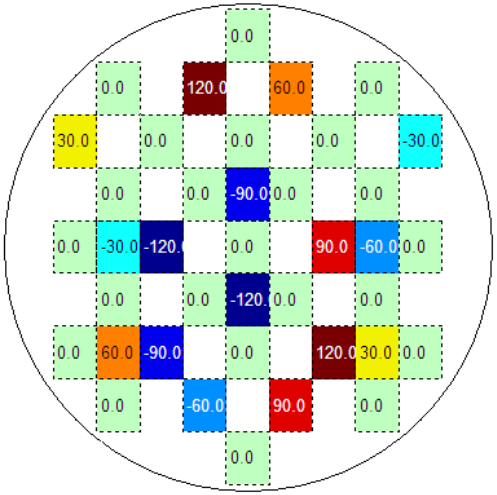


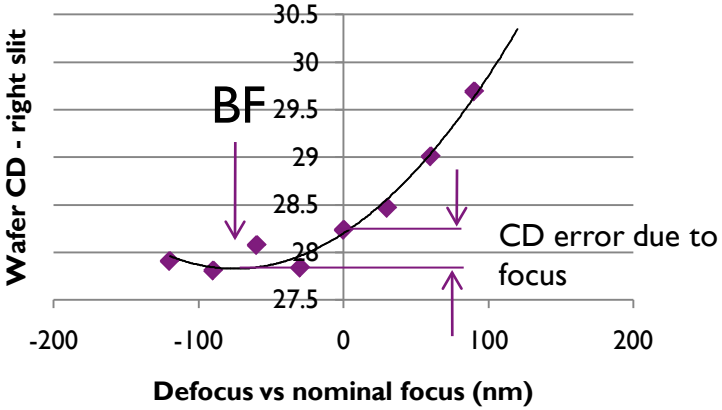


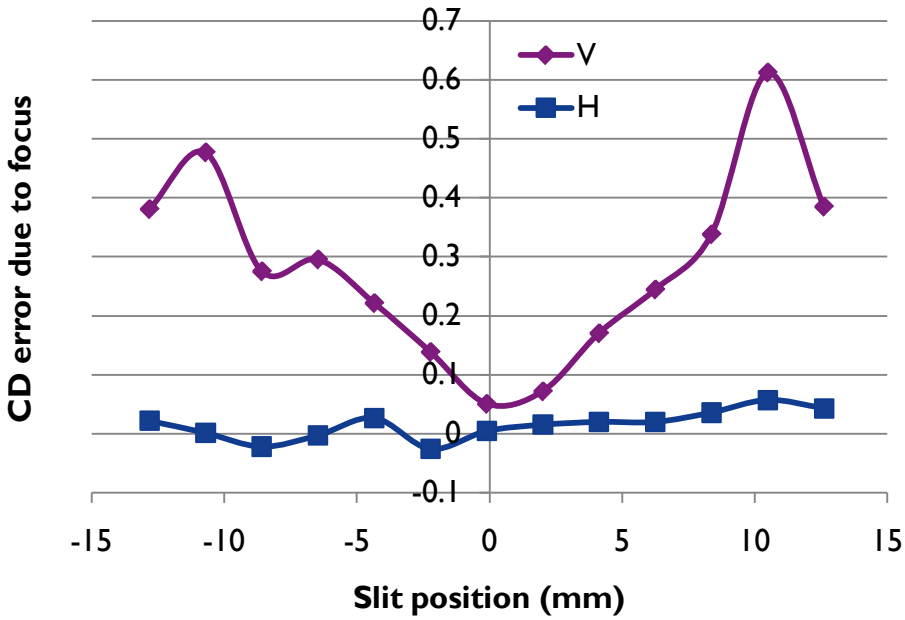
CD evolution along scan limited to 0.3nm

27NM LS CDU – NF, ND – INTRAFIELD

- Fields were printed in defocus to measure CD vs. focus for every field position
- Contribution of focus to CD evolution along scan is limited to ~0.6nm for V



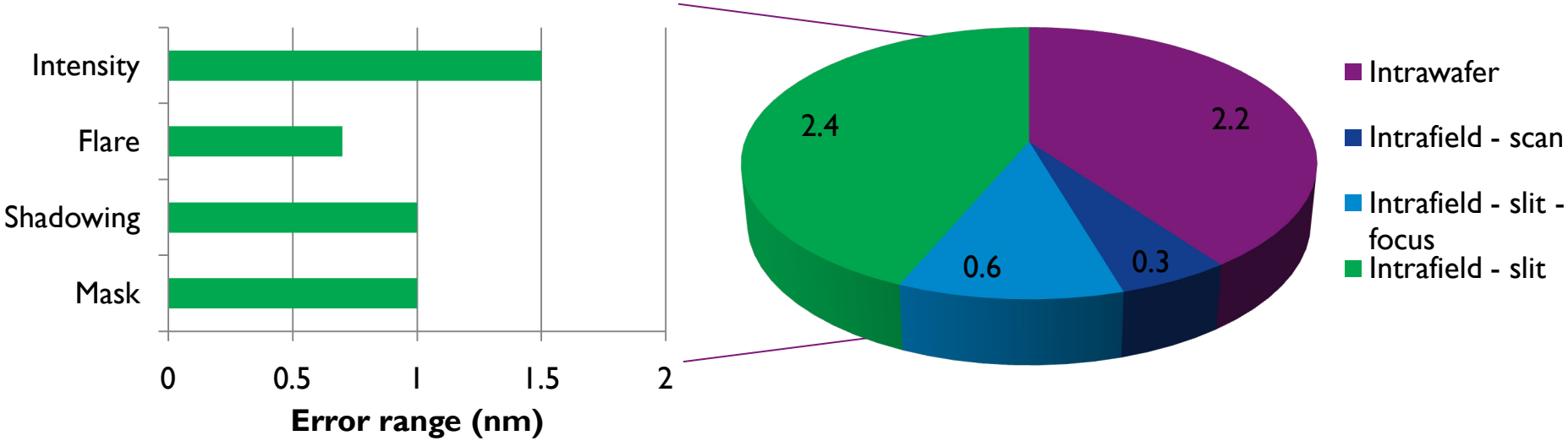




Impact of intrafield focus error <0.6nm CD along slit

27NM LS CDU – NF, ND – INTRAFIELD

- 2.4nm remaining slit signature: 4 contributions



Effect	Error range	Wafer CD error range
Intensity uniformity	5%	1.5nm
Intrafield flare	0.5%	0.7nm
Shadowing		1.0nm
Mask CD error	2nm CD at 4X	1nm

27NM LS – WEEKLY MONITOR

Resist

- 27nm POR coated to 50nm resist thickness

Reticle

- 32nm reticle – first wafers
- 27nm reticle – as soon as available

Exposure in-line

- Focus: -20nm
- Exposure dose: 12.0mJ/cm2

Intrafield CDU

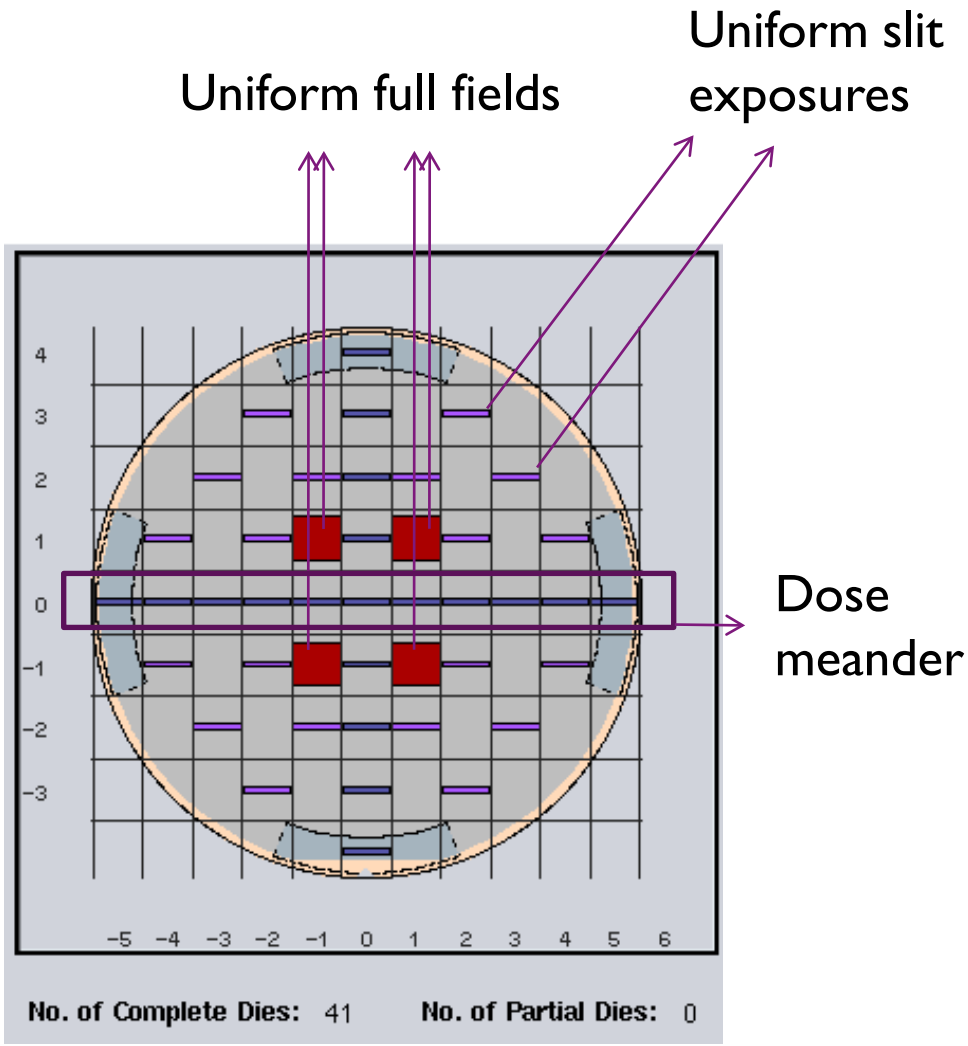
- 4 full fields
- 26x24mm^2 field size
- 7x5 intrafield sampling

Across wafer CDU

Dose meander

Metrology

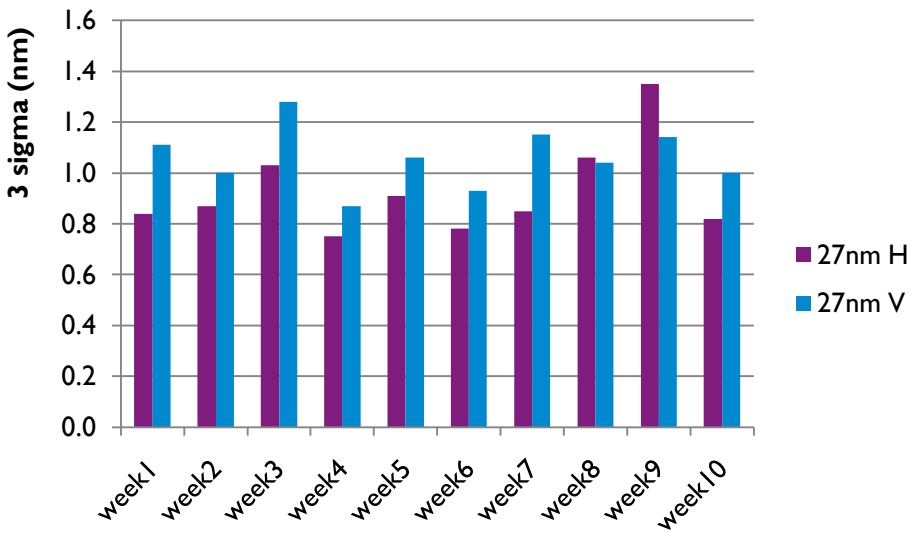
- CD-SEM: Hitachi CG-4000



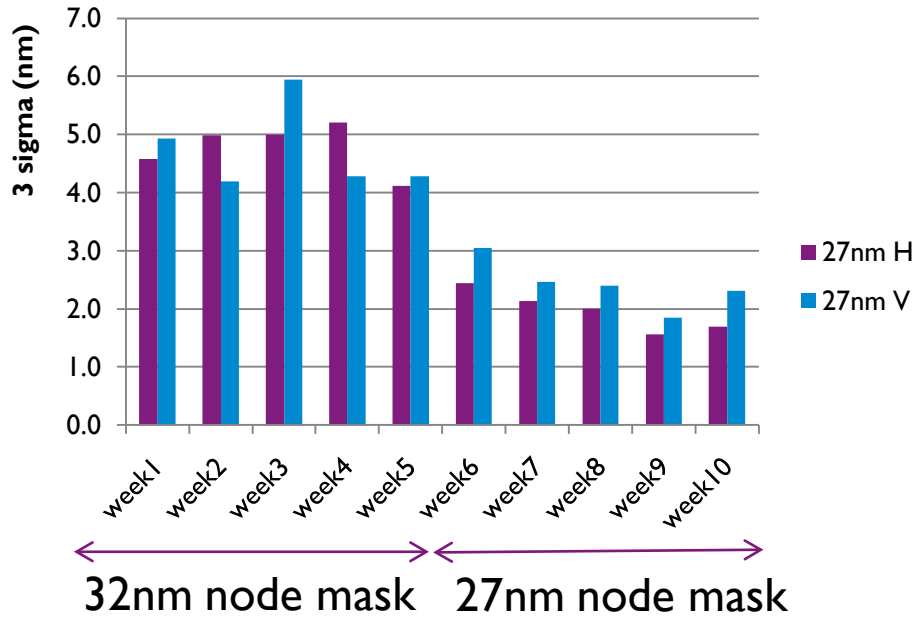
27NM LS – WEEKLY MONITOR

- **27nm LS** were printed on a weekly basis using imec daily monitor layout

Intrawafer 3 sigma



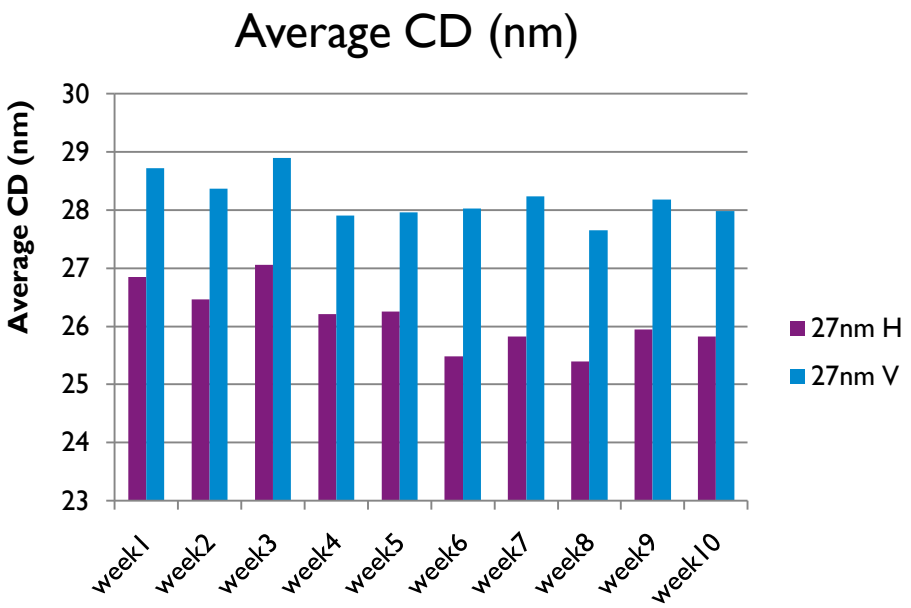
Intrafield 3 sigma

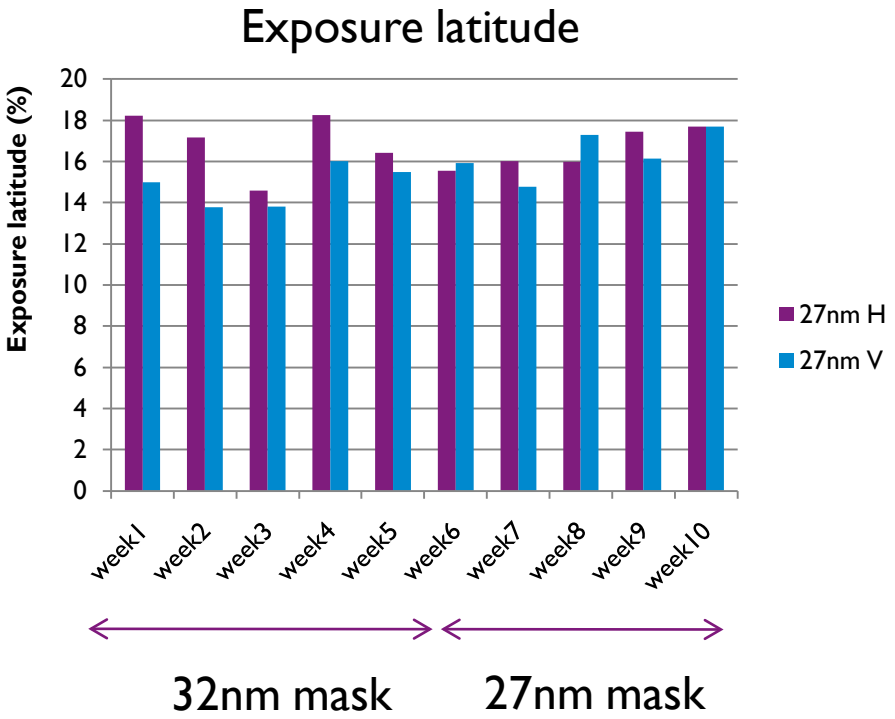


- Intrawafer 3 sigma values consistent at 1nm 3sigma
- Intrafield 3 sigma shows clear improvement through use of new mask
- Good 27nm LS performance demonstrated for several weeks

27NM LS – WEEKLY MONITOR

- 27nm LS were printed on a weekly basis using imec daily monitor layout





- Average CD stable to within 1nm
- Exposure latitude ~16-17%
- Good 27nm LS performance can be repeated from week to week

CONCLUSION

- Two major improvements in EUV have allowed 27nm LS imaging performance on the EUVADT at NXE3100 requirements
  - Resist process: 17% EL and 200nm DOF at 27nm LS
  - Photomask: Mask uniformity of 2-3nm at 4x demonstrated
- Weekly exposures demonstrate sufficient process stability over a 10-week period and give confidence for NXE:3100 POR
- Predictive resistmodel is available for rigorous simulation
- Further improvements can be expected, for better CD control:
  - **TEL Lithius™Pro™-EUV track** will improve process control vs. ACT12
    - More than 50% improvement in PEB contribution to CDU expected
  - **NXE:3100** will also offer better intrafield CD uniformity
    - Smaller CD focus sensitivity at 27nm LS (0.8 sigma)
    - Smaller flare level and flare variation across slit
    - Smaller intensity variation across slit (<2%)

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  - 27nm mask manufacturing
  - Matt Lamantia
- Imec
  - Mieke Goethals
  - Ardavan Niroomand (Micron assignee at imec)

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