Understanding the impact of neighbor field flare on imaging in EUV lithography

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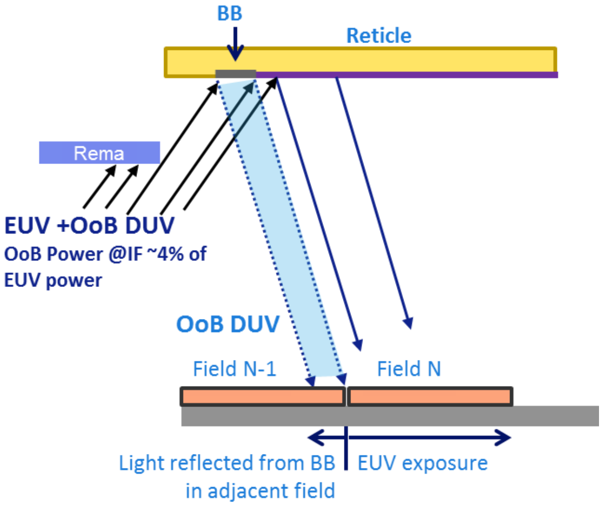
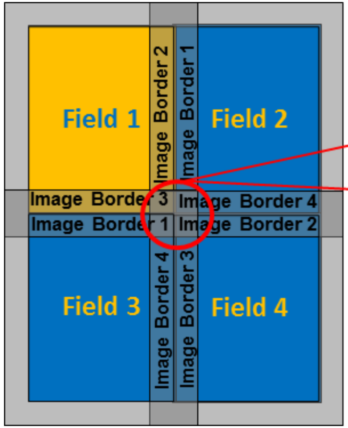
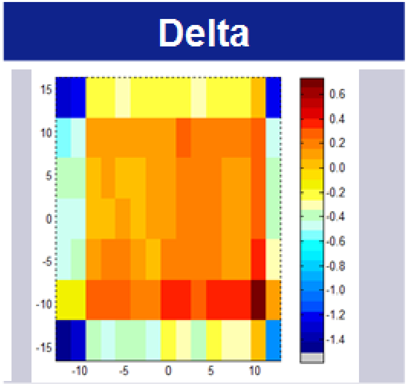
Introduction: CD impact due to butted fields





3 borders
overlap
with
Image
Field



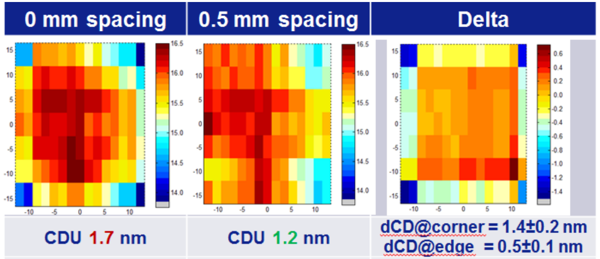
dCD@corner = 1.4±0.2 nm
dCD@edge = 0.5±0.1 nm

- E.g. CD impact is 0.5 nm at the edge and 1.4 nm in the corner
  - 16 nm dense lines, NXE:3350 ATP resist, NXE:3300 scanner

Introduction: previous status EMLC 2015

N. Davydova, Understanding of Out-of-Band DUV light in EUV Lithography, EMPLC2015

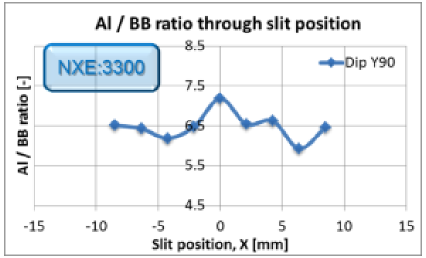
- **CD at the edges** of butted fields ***suffers from OOB DUV*** reflections from ***black border*** of the neighboring fields
- ***OOB test*** is developed to monitor OOB level
- ***OOB model*** is developed and being verified
  - ***Direct OOB*** measurements ***from black border*** are performed
  - ***CD sensitivity to OOB*** light is determined
  - ❷ Work is ongoing to improve accuracy of understanding of OOB impact on imaging
- ***Three OOB mitigation strategies***
  - ❶ ***NXE:3350 POB OOB transmission*** is reduced***: ~3x***
  - ***16 nm resist OOB sensitivity*** is reduced: ***~ 1.8x***
  - ***Improved Black Border*** is in development: ***~4x***

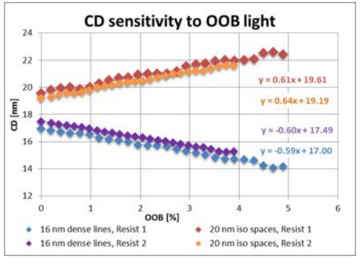

0 mm spacing | **0.5 mm spacing** | **Delta**

CDU 1.7 nm

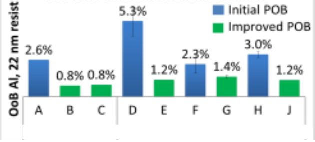
CDU 1.2 nm

dCD@corner = 1.4±0.2 nm
dCD@edge = 0.5±0.1 nm

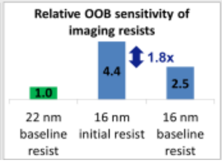




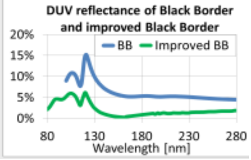
✓ Scanner POB improvement



✓ 16 nm resist OOB improvement



✓ Black Border improvement



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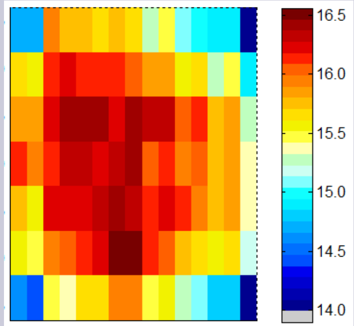
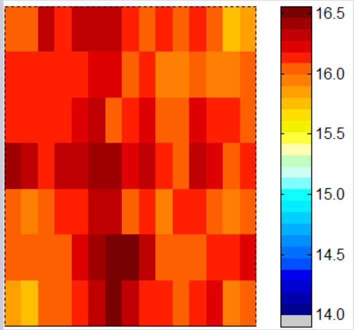
- Introduction: CD impact due to field-field effects
- Results
  - NXE:3350 improvements
  - Understanding neighbor-field impact on imaging
- Conclusions

NXE:3350: POB & ATP test improvements

Successful reduction of neighbor-field impact on 3350

NXE:3300	NXE:3350
	
CDU 1.6 > spec 1.4	CDU 0.5 < spec 1.4
dCD@corner = 1.4	dCD@corner = 0.35

- NXE:3350 POB OoB transmission reduced **~4x**
- Execute field-spacing test on 3300 and 3350
- ***0 mm vs 0.5 mm spacing → plot delta***
- ***Shows*** impact of ***nearest neighbor fields*** on imaging

- Low impact of “butted” neighbor fields on imaging for NXE:3350
- NXE:3350 ATP test introduced (0mm die spacing, 15x9 grid)

Neighbor-field impact on imaging

- **Goal:** understand impact of butted-field exposures on CD.
- **Ambition:** accurate predictive models drive ASML budgets & product solutions
- **New:**
  - Extend model to include all DUV and EUV flare contributions
  - Tachyon flare modelling
  - Lattice modules on reticle

} High resolution (50 µm) 2D CD profiles

Neighbor-field impact on imaging: model

$$\boxed{\Delta CD = \frac{dCD}{dDUV_{flare}}\left(DUV_{BB} + DUV_{REMA}\right) + \frac{dCD}{dEUV_{flare}}\left(EUV_{BB} + EUV_{REMA} + EUV_{OOF}\right)}$$

- ΔCD = CD change due to neighbor-field flare [nm]
- $\frac{dCD}{dDUV_{flare}}$ or $\frac{dCD}{dEUV_{flare}}$ = CD sensitivity due to EUV or DUV flare [nm/%]
- $$\left.\begin{matrix} DUV_{BB} \\ DUV_{REMA} \\ EUV_{BB} \\ EUV_{REMA} \\ EUV_{OOF} \end{matrix}\right\}$$ = percentage EUV or DUV due to black-border, ReMA or out-of-field flare [%]

Neighbor-field impact on imaging: model input

$$\Delta CD = \frac{dCD}{dDUV_{flare}}\left(DUV_{BB} + DUV_{REMA}\right) + \frac{dCD}{dEUV_{flare}}\left(EUV_{BB} + EUV_{REMA} + EUV_{OOF}\right)$$

🟥 Measured

🟩 Experimentally determined. E.g., 16 nm DL = **-0.6 nm/%**

🟪 Simulated. E.g.,16 nm DL = **-1.0 nm/%**

🟦 Tachyon EUV and DUV flare maps

- Scanner properties (non-standard proto configurations)

Scanner	$OoB_{Al,\ ATP\_resist}$ (%)	POB DUV transmission	REMA type
1	**1.42**	Low ‘11%’ (new coating)	MK2 **(R_{DUV} = 4%)**
2	**2.98**	High ‘47%’ (old coating)	MK3 **(R_{DUV} <0.5%)**

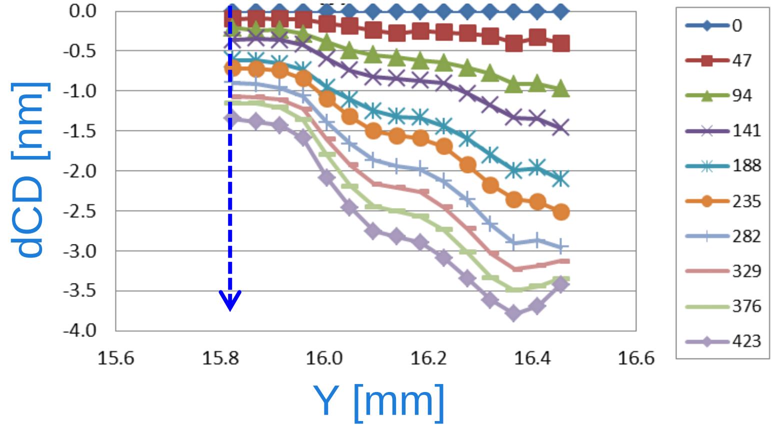
“Neighbor-field CD-sens. experiment”: method

Measurements locations (red):
50 µm resolution

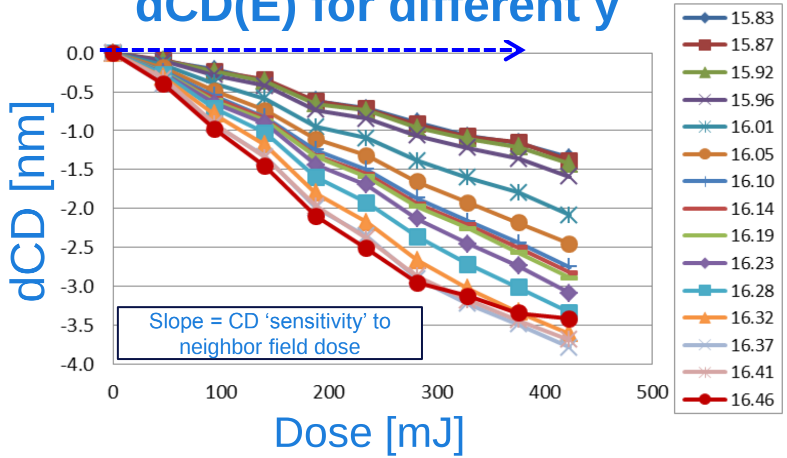
- Image field (green) is exposed @ NE (37mJ).
- Butted “neighbor-fields” are exposed at varying doses (E, 0-423mJ)
- High-density 16 nm L/S modules measured in scan and slit directions
- The CD is evaluated as a function of neighbor-field dose

“Neighbor-field CD-sens. experiment”: example data

dCD(y) for different E



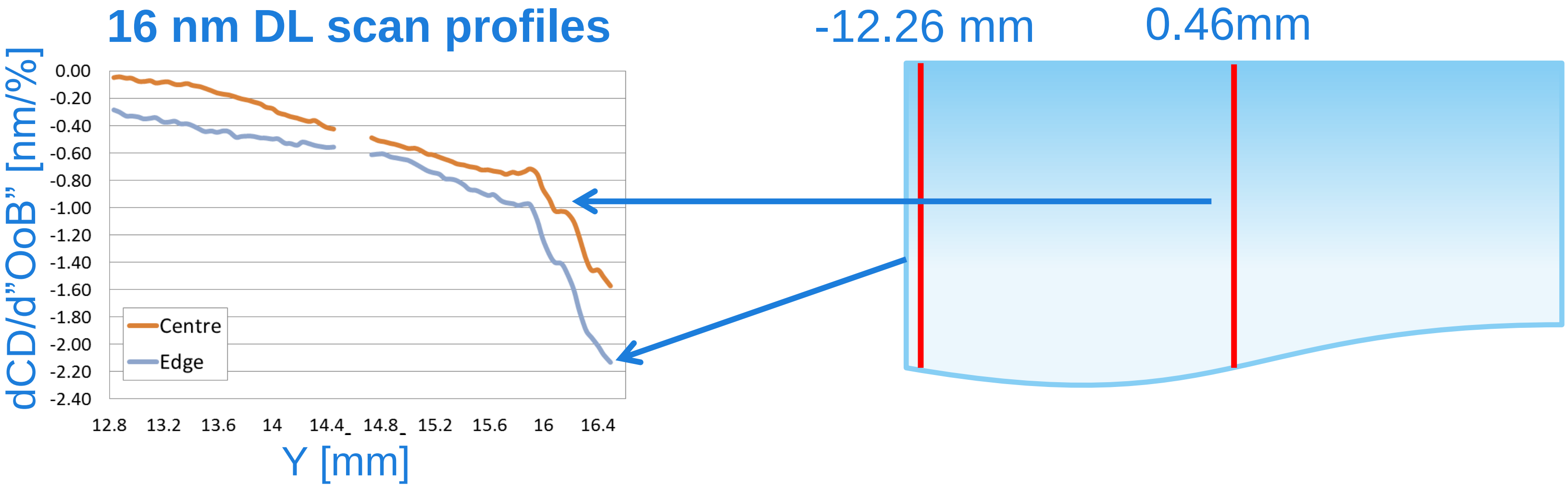
dCD(E) for different y



Slope = CD ‘sensitivity’ to neighbor field dose

- CD of image field decreases with increasing dose of neighbor fields
  - CD swing is due to ReMa penumbra (Dipole 90 Y)
- Magnitude of CD decrease depends on field position
- CD decrease as function of dose (E) can be determined per field position

“Neighbor-field CD-sens. experiment”: example result

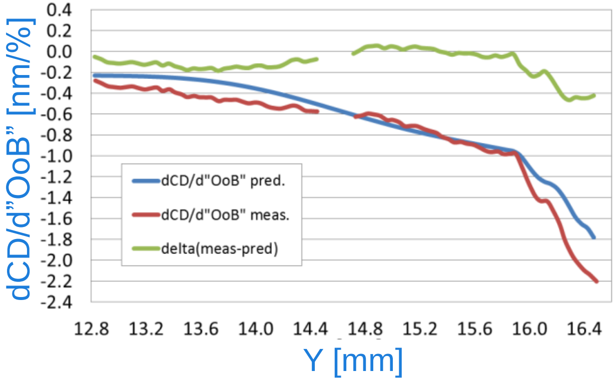


- $OoB_{BB\_nb} = OoB_{AL}/(R_{AL}/R_{BB})*(E_{neighborfield}/NE_{imagefield}) = OoB\_AL / 6.5 * (E_{neighborfield}/37)$
- CD response to flare of neighbor field is a function of scan position
- Offset between CD response at slit edge and center-field → OoB reflection from ReMa x-blade of neighbor-field
- Comparison between model and experiment for slit/scan and 2 scanners → next slides

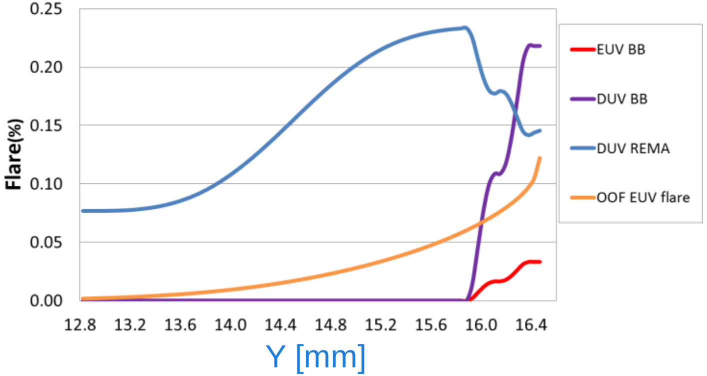
“Neighbor-field CD-sens. experiment”: model comparison

Sensitivity profiles are well predicted

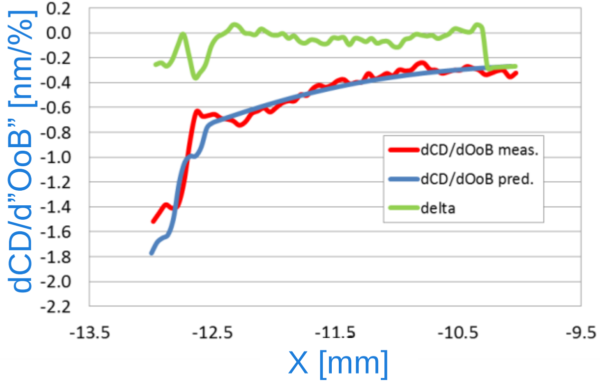
dCD/dOoB: top field edge



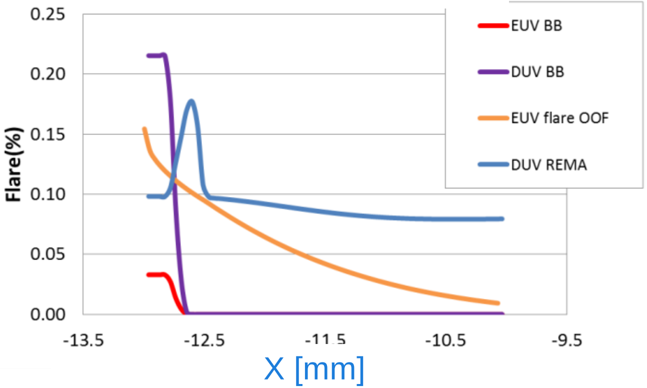
Flare: top field edge



dCD/dOoB: left field edge



Flare: left field edge



- Max CD prediction error is <0.4nm/% (~22%)
- $\mathrm{DUV}_{\mathrm{ReMa}}$, $\mathrm{DUV}_{\mathrm{BB}}$ and $\mathrm{EUV}_{\mathrm{OoF}}$ dominate

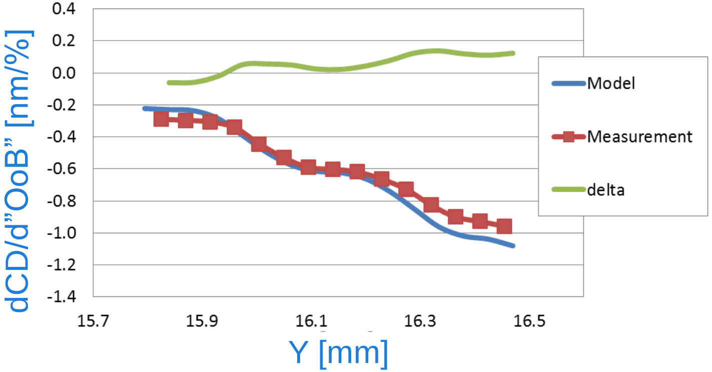
Scanner config:

- *OoB = 1.42%*
- *REMA(MK2).*
- *Scan @ X = -12.24 mm*
- *Slit @ Y = 14.69 mm*

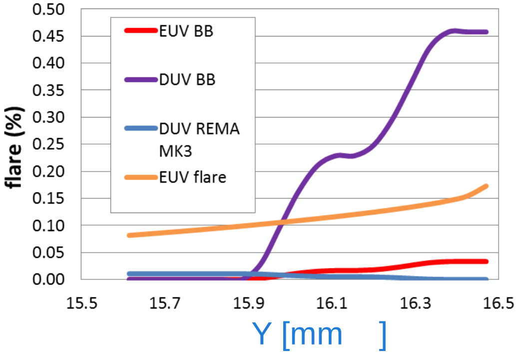
"Neighbor-field CD-sens. experiment": model comparison

DUV reflected from ReMa Mk3 is negligible

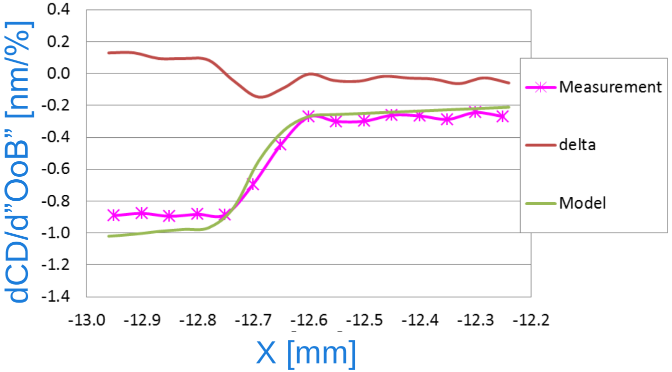
dCD/dOoB: top field edge



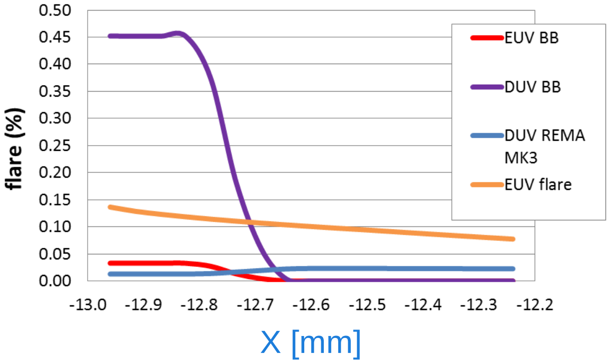
Flare: top field edge



dCD/dOoB: left field edge



Flare: left field edge



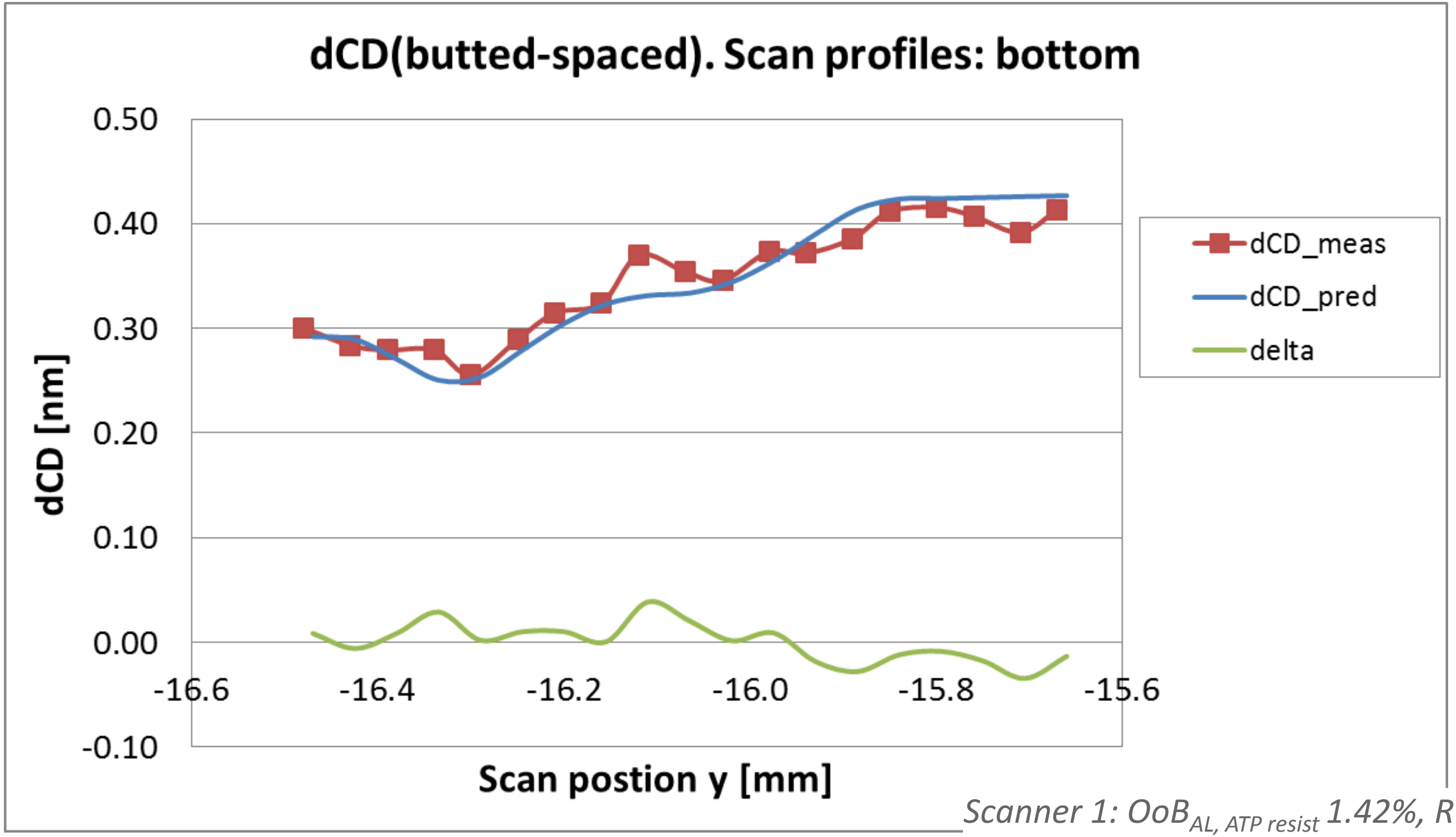
- Max prediction error is <0.14nm/% (~14%)
- Main contributors: DUV BB and EUV flare

Scanner config:

- *OoB = 2.98%*
- *REMA(MK3).*
- *Scan @ X = -12.24 mm*
- *Slit @ Y = 14.69 mm*

"Field spacing experiment": model comparison

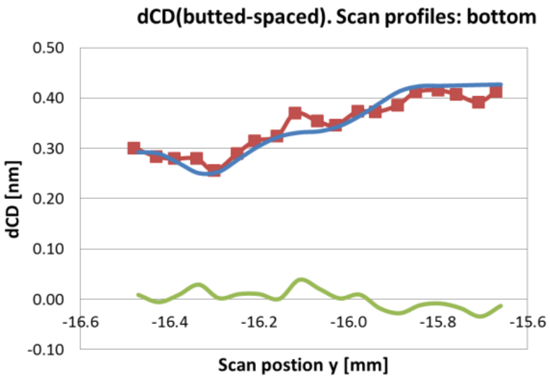
CD profiles are well predicted

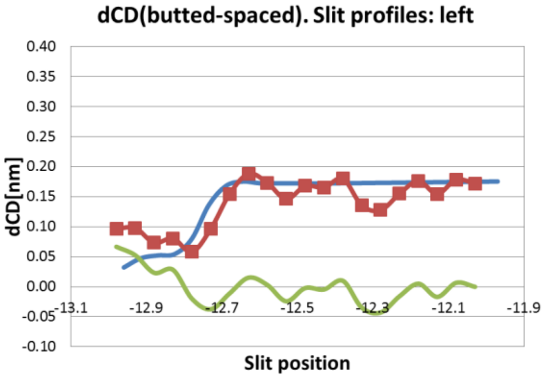


Scanner 1: OoB$_{AL, ATP\ resist}$ 1.42%, REMA = MK2

“Field spacing experiment”: model comparison

CD profiles are well predicted



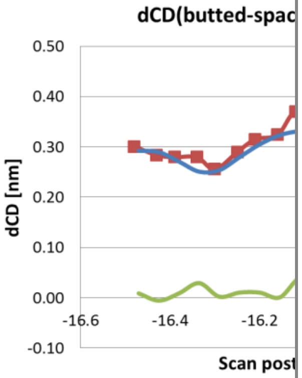


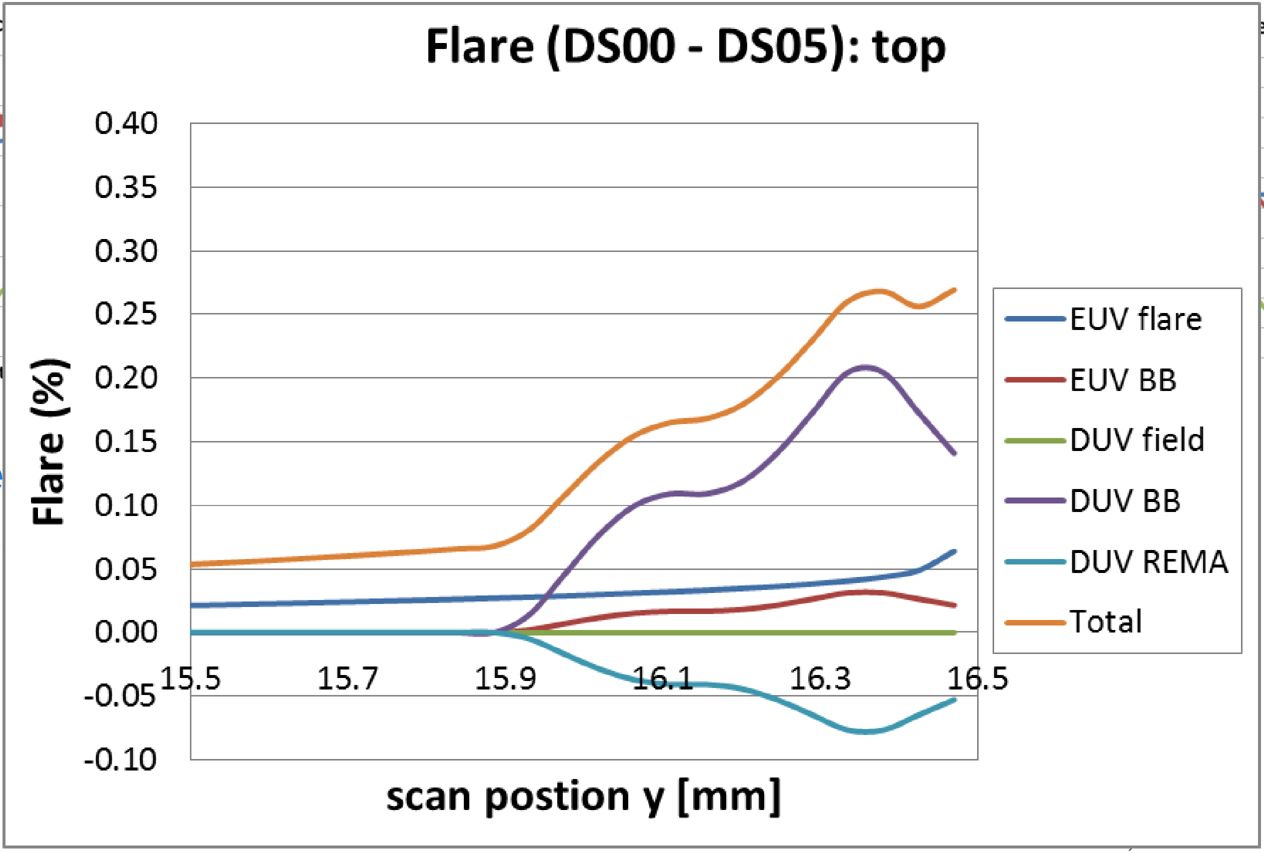
- ΔCD profiles are well reproduced by prediction
- Max ΔCD error is <0.05nm (compared to a dCD of ~0.25nm: 20%)

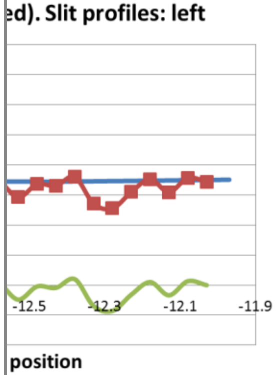
Scanner 1: OoB$_{AL,\ ATP\ resist}$ *1.42%, REMA = MK2*

“Field spacing experiment”: model comparison

CD profiles are well predicted





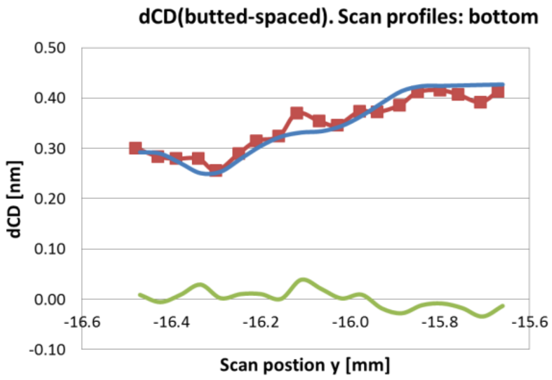


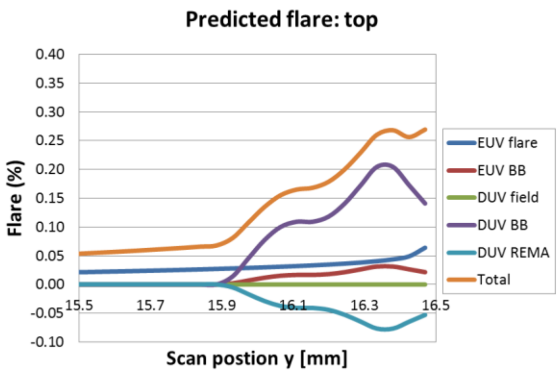
- ΔCD profile
- Max ΔCD e

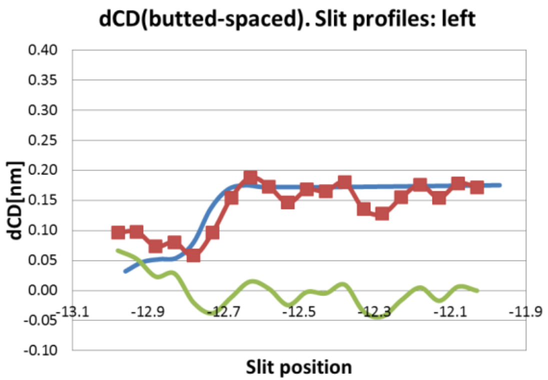
.42%, REMA = MK2

“Field spacing experiment”: model comparison

CD profiles are well predicted


dCD(butted-spaced). Scan profiles: bottom


Predicted flare: top


dCD(butted-spaced). Slit profiles: left

- ΔCD profiles are well reproduced by prediction
- Max ΔCD error is <0.05nm (compared to a dCD of ~0.25nm: 20%)
- The combined effects of all flare contributors (EUV, DUV) are required to reconstruct the measured CD profile
    - DUV reflections from BB and REMA, together with an OOF EUV flare component are dominant.

Scanner 1: OoB$_{AL,\ ATP\ resist}$ *1.42%, REMA = MK2*

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Conclusions

- NXE:3350 ATP test introduced (0mm die spacing, 15x9 grid)
- NXE:3350 reduction of neighbor-field impact realized:
  - POB ~3x
  - New Mk3 ReMa supresses DUV >4x to a negligible level
  - 1.4 nm → 0.35 nm dCD @ corner
- CD impact of neighbor-field flare modelled with accuracy ~20%
- Tachyon flare maps support this
- All flare contributors (EUV + DUV) required to correctly predict impact

Predictive capability sufficient to drive ASML budgets & product solutions

ASML