EUVL today and extension for the next generation

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Intel Corporation

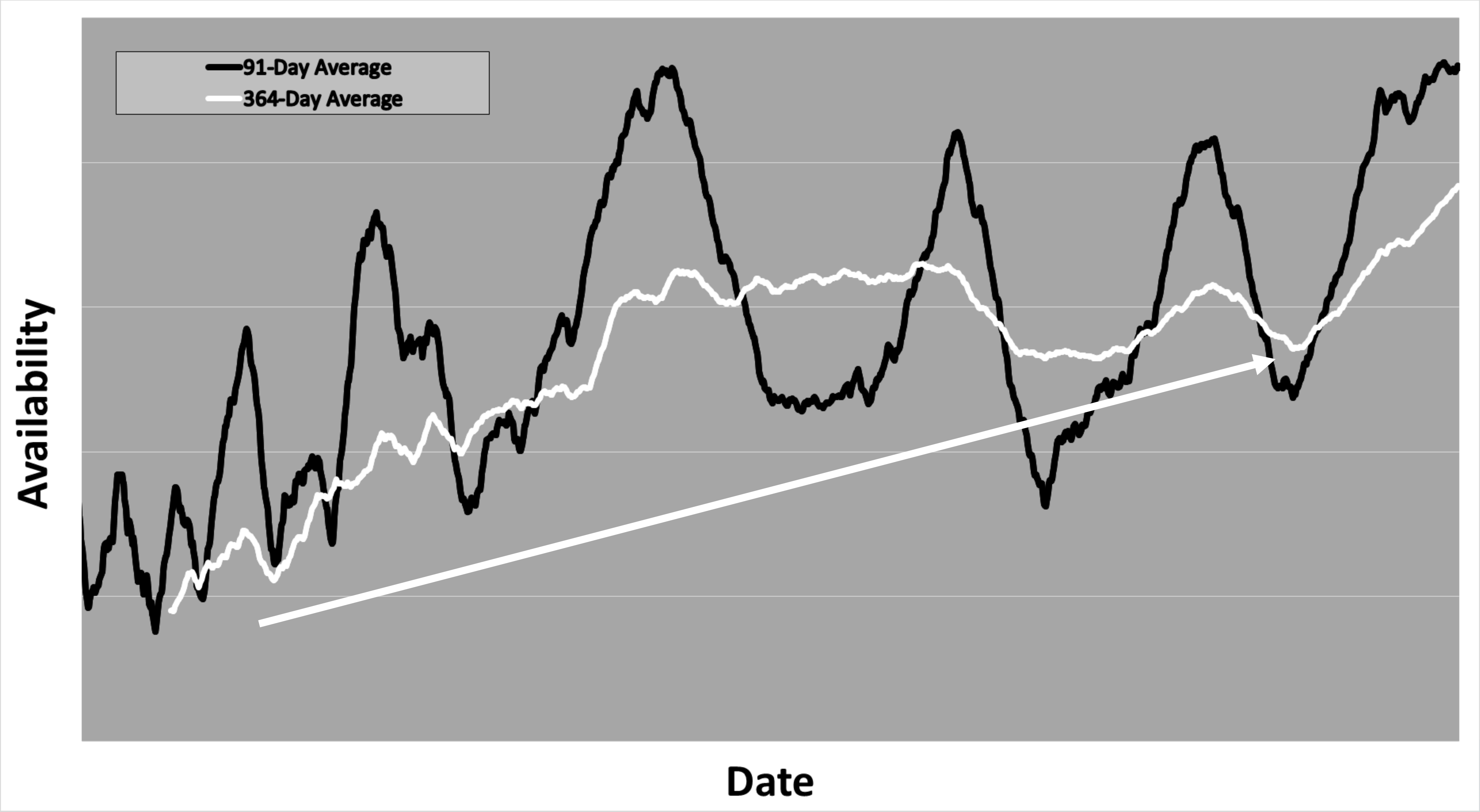
2019 International Workshop on EUV Lithography, 12 June, Berkeley, California

Outline

- Today
  - Exposure Tool
  - Reticle
  - Pellicle
  - Infrastructure
- Next-generation considerations
- Conclusion

Intel NXE combined scanner/source availability

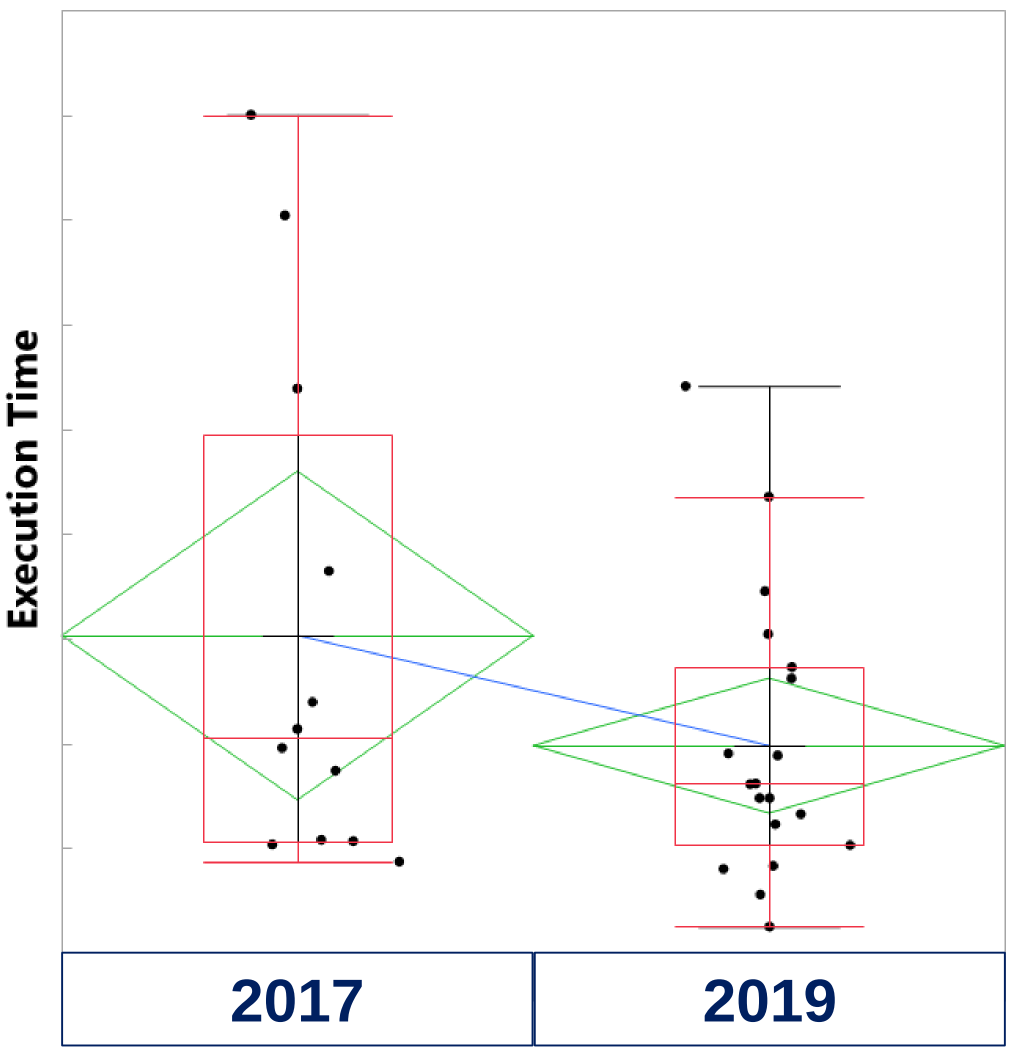
2015-present

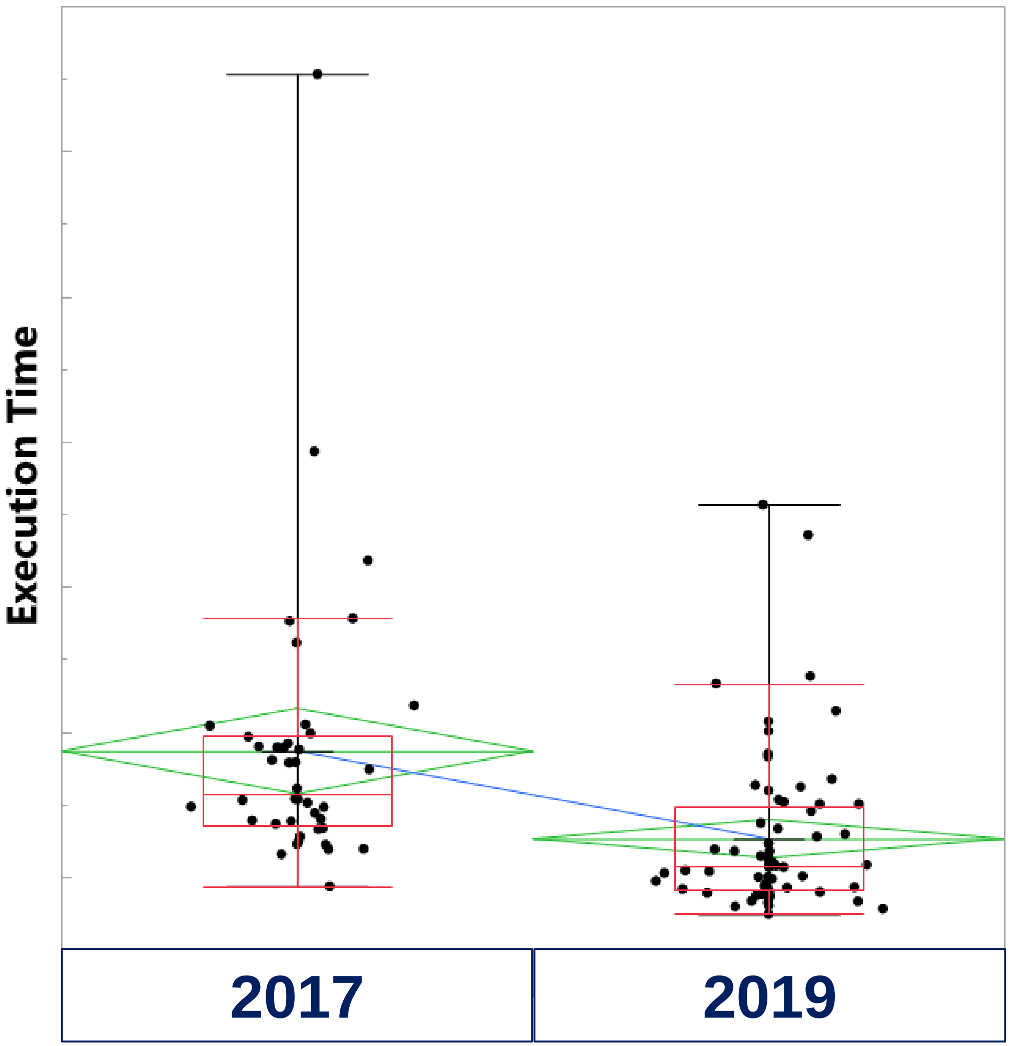


- Increased fleet size enables faster information turns
- Extended period with large perturbations
- Significant recent improvements
- Continued focus on system availability

Graph courtesy S. Carson

Scheduled maintenance duration improvements


DG Action A

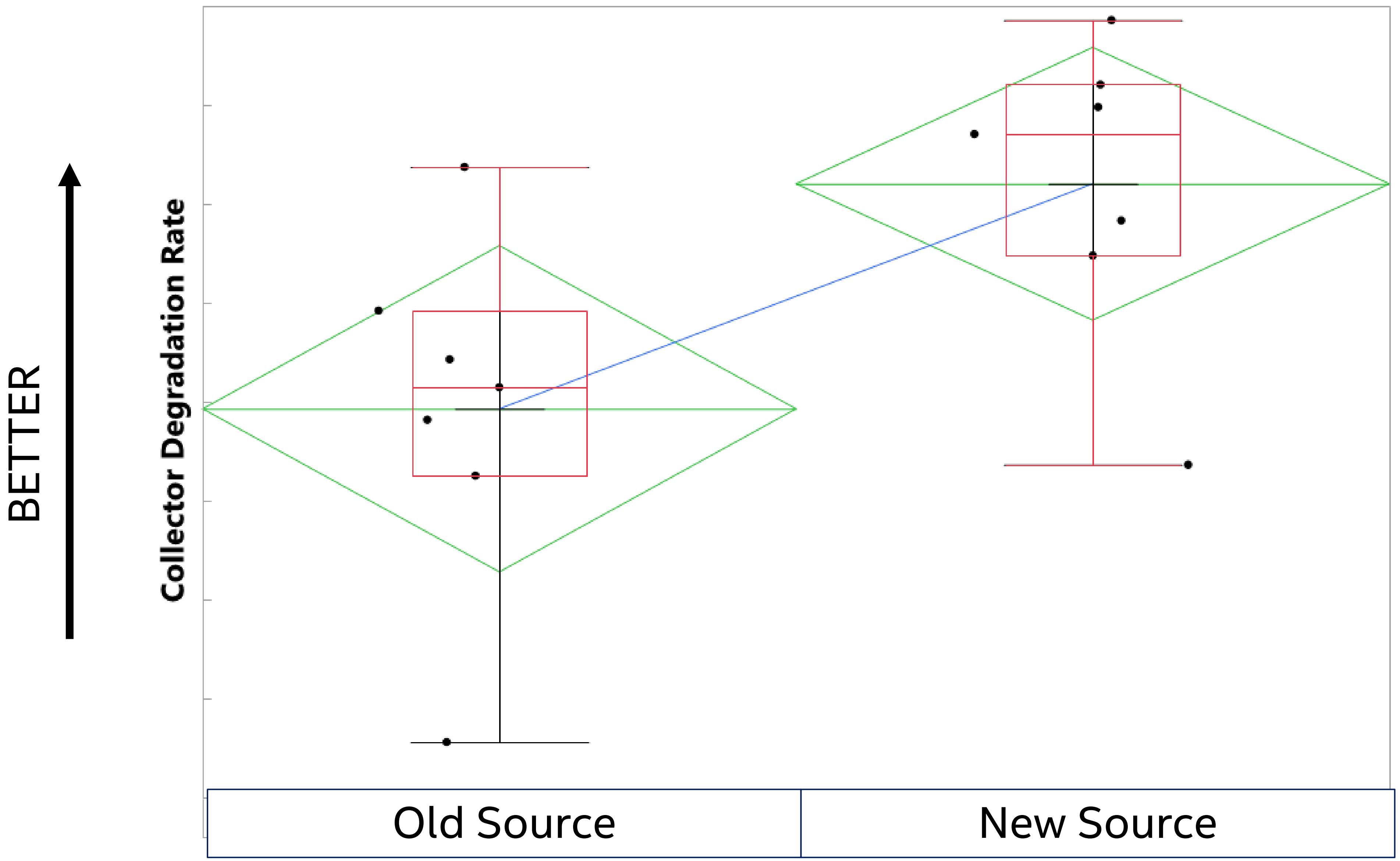

DG Action B

- Improvements in both mean and variation directly benefit system availability

- Line-of-sight to future improvements with platform upgrades

Graph courtesy S. Carson

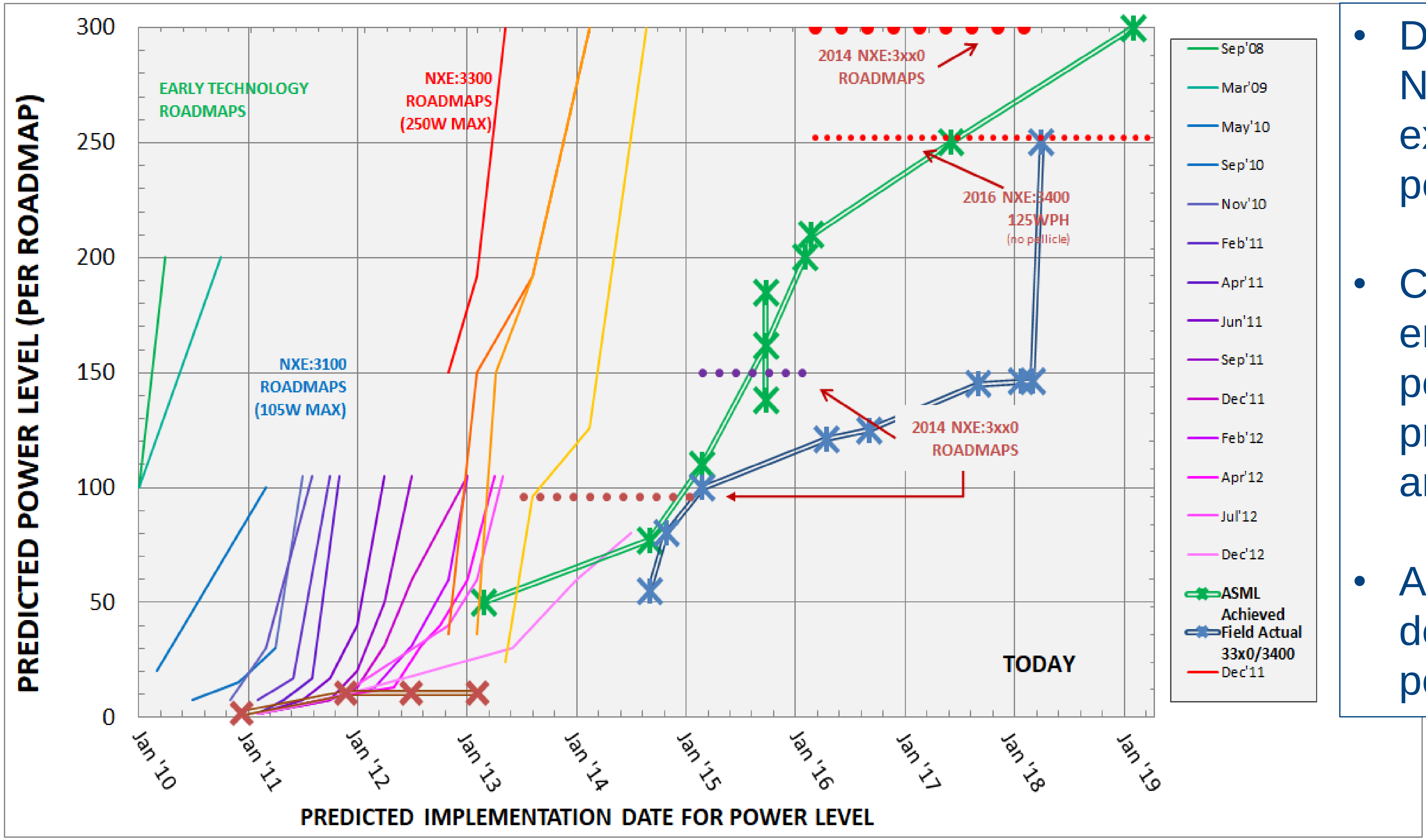
Collector lifetime improvement continues



- Clear benefit of source improvements
  - collector degradation / lifetime
  - power
- Continued focus
- Always customer demand for cleaner collector

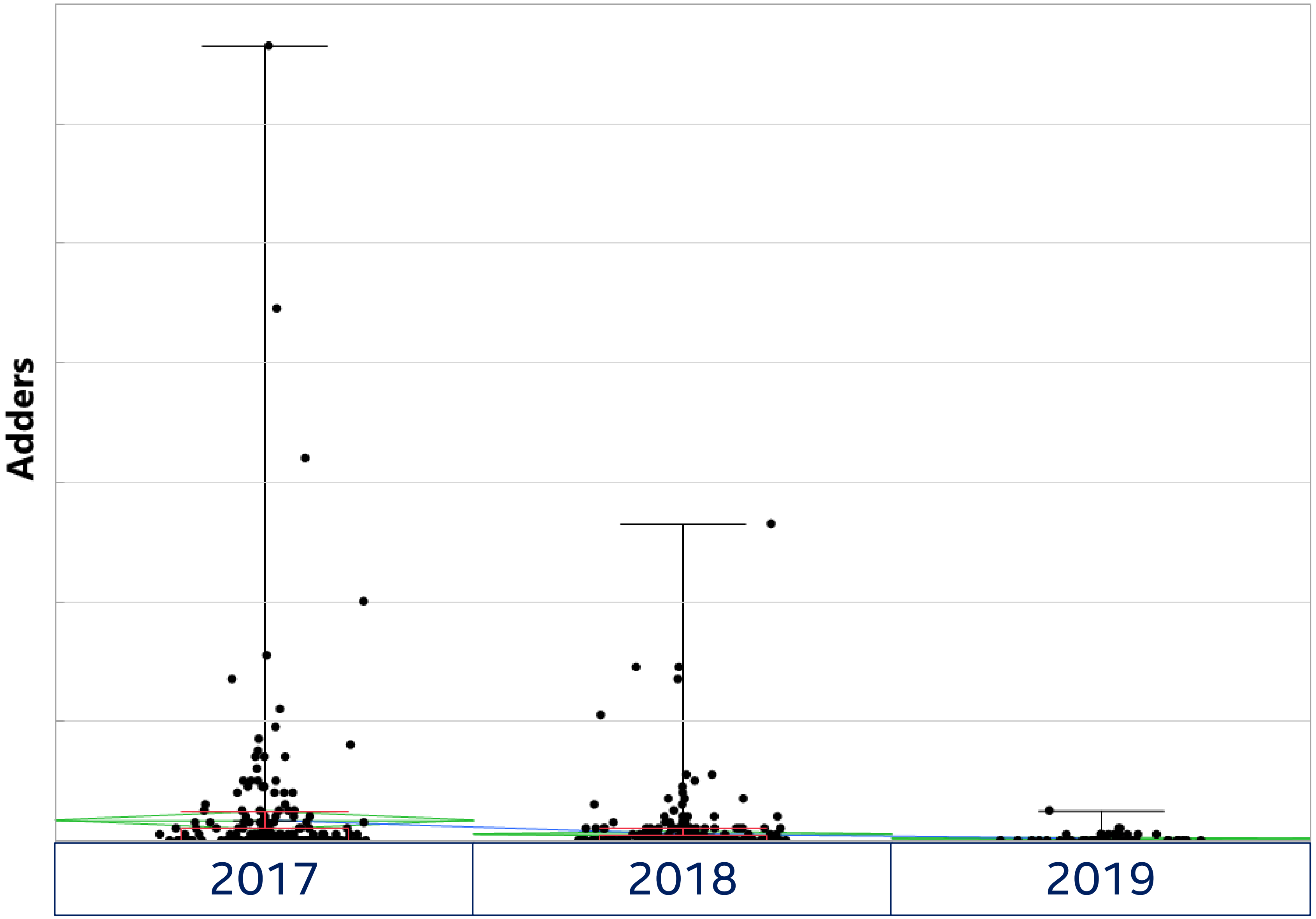
Graph courtesy S. Carson

Exposure source power meeting roadmap



- Demonstrating NXE:3400 baseline exposure source power in the field
- Continued emphasis ensuring sufficient power overhead for predictable quality and output
- Always customer demand for higher power

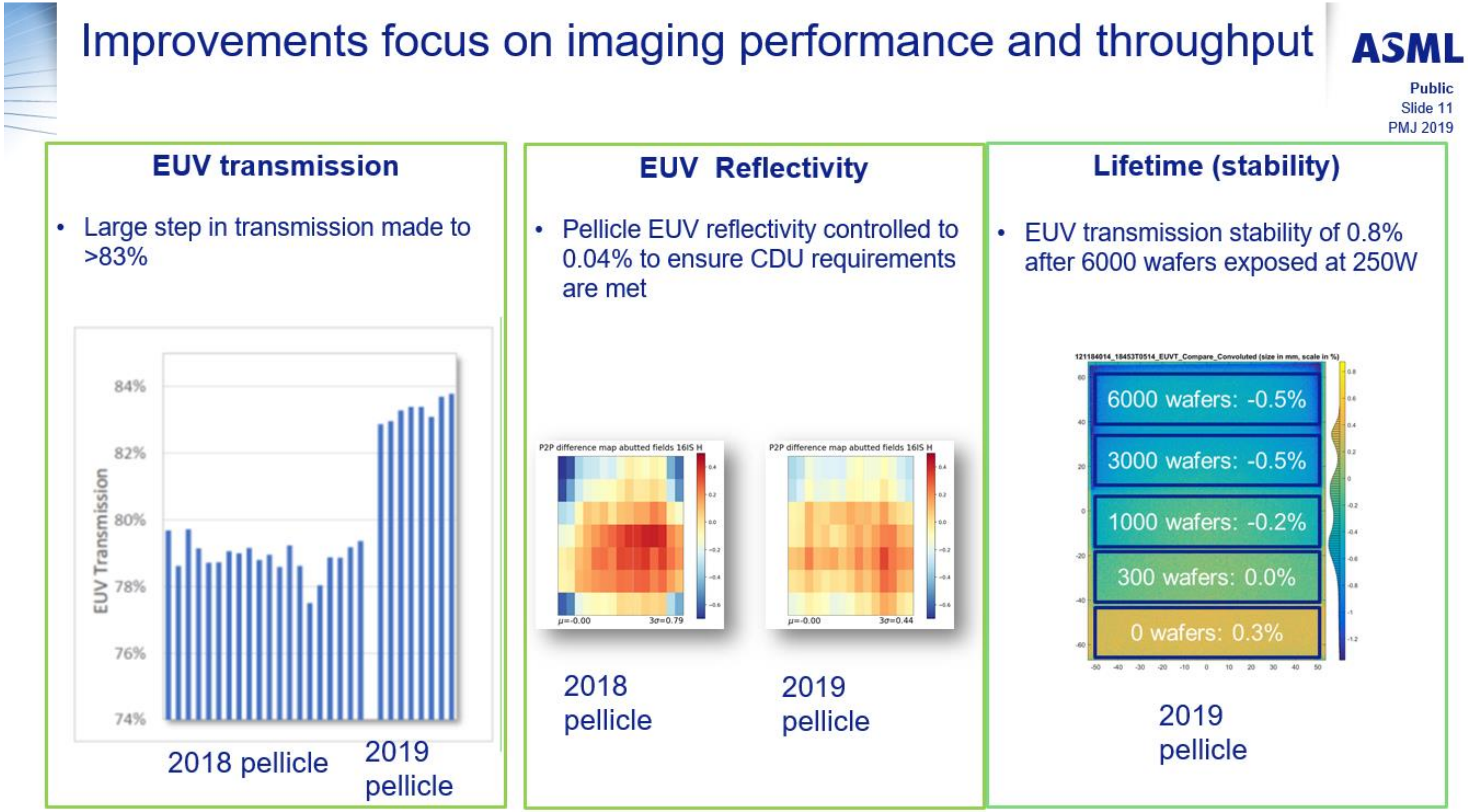
Improved Intel defectivity with platform and over time



- System improvements have decreased defect levels
- Every system has shown printable reticle defect adders
- Reticle defect adder events remain unpredictable
- EUV pellicle remains necessary to ensure yield

Graph courtesy
S. Carson

Pellicle membrane progress continues



Improvements focus on imaging performance and throughput

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PMJ 2019

EUV transmission

- Large step in transmission made to >83%

2018 pellicle
2019 pellicle

EUV Reflectivity

- Pellicle EUV reflectivity controlled to 0.04% to ensure CDU requirements are met

2018 pellicle
2019 pellicle

Lifetime (stability)

- EUV transmission stability of 0.8% after 6000 wafers exposed at 250W

2019 pellicle

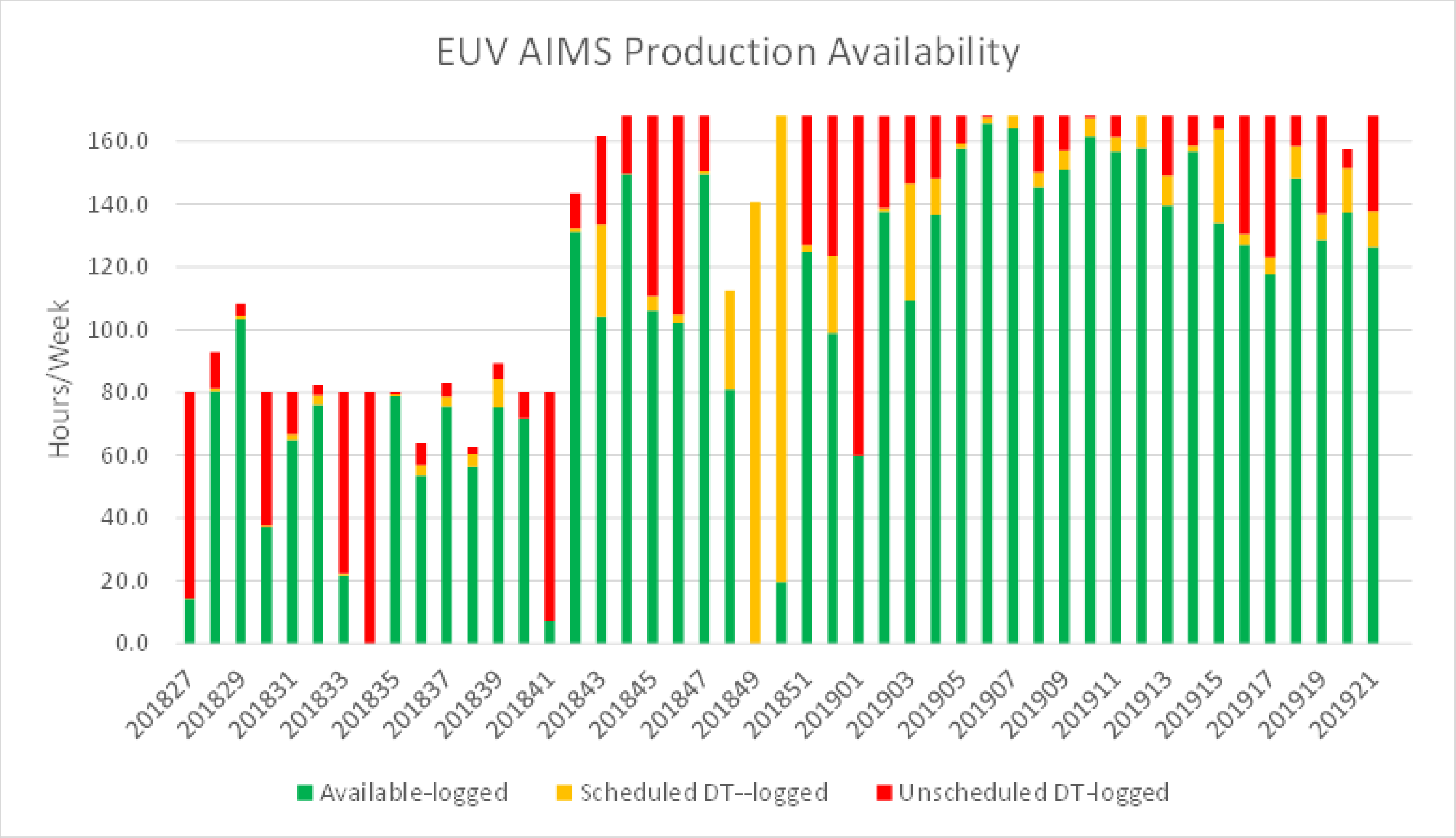
SPIE 2018 ASML / Roderik van Es

- Steady progress in pellicle membrane defects, EUV-T / EUV-R (corner CD), power resiliency, and lifetime

- Continued focus expected to deliver volumes for HVM

- Pellicle membrane must stay ahead of source power improvements

EUV AIMS meeting expectations

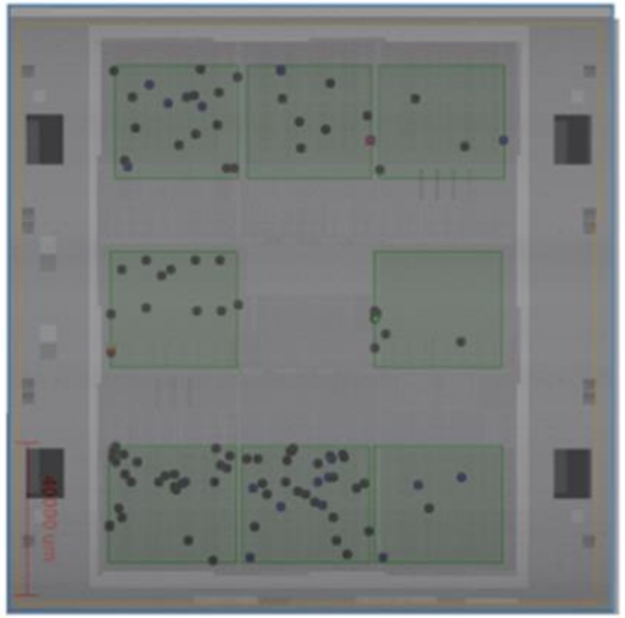


- Imaging performance confirmed
- All optical items stable and meeting targets
- Tool meeting uptime targets
- Plans in place to address leading downtime items
- Plan in place for AIMS EUV pellicle capability

Slide courtesy
LTD-IMO: F. Ghadiali

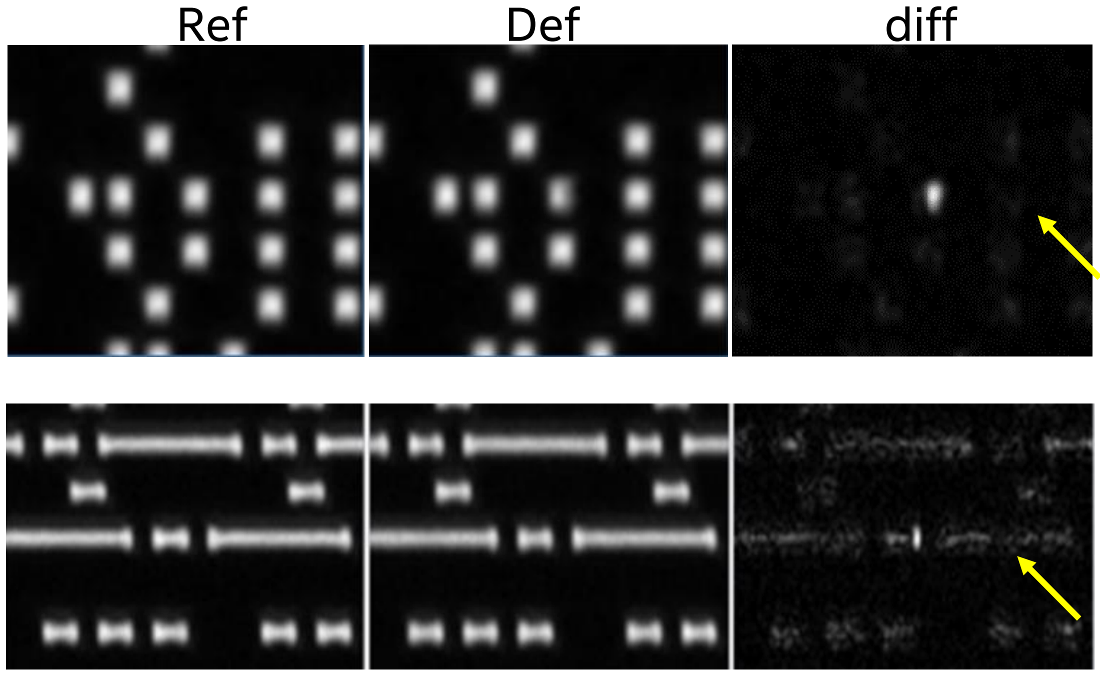
APMI operational for full mask inspection

Defect map



7nm/5nm mask

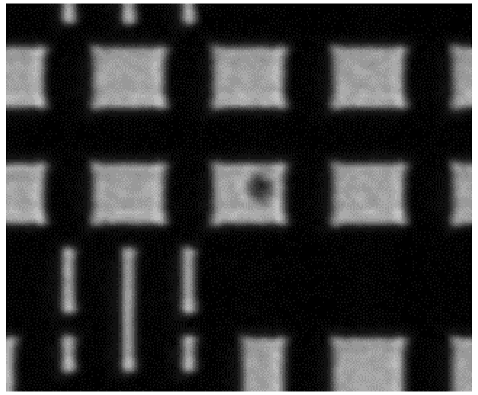
Defect samples



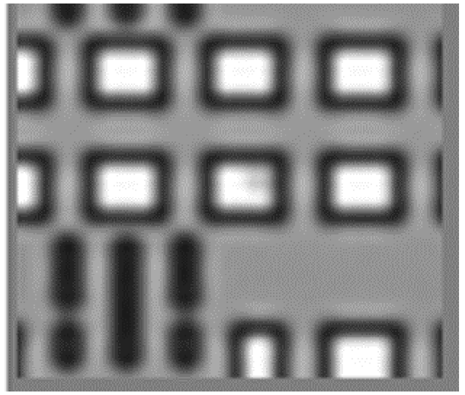
Partially blocked via

Missing OPC

EUV actinic



DUV optical



- Full-mask inspection successful
- Captured expected defects
- Resolved defect details

Slide courtesy
LTD-IMO: T. Liang

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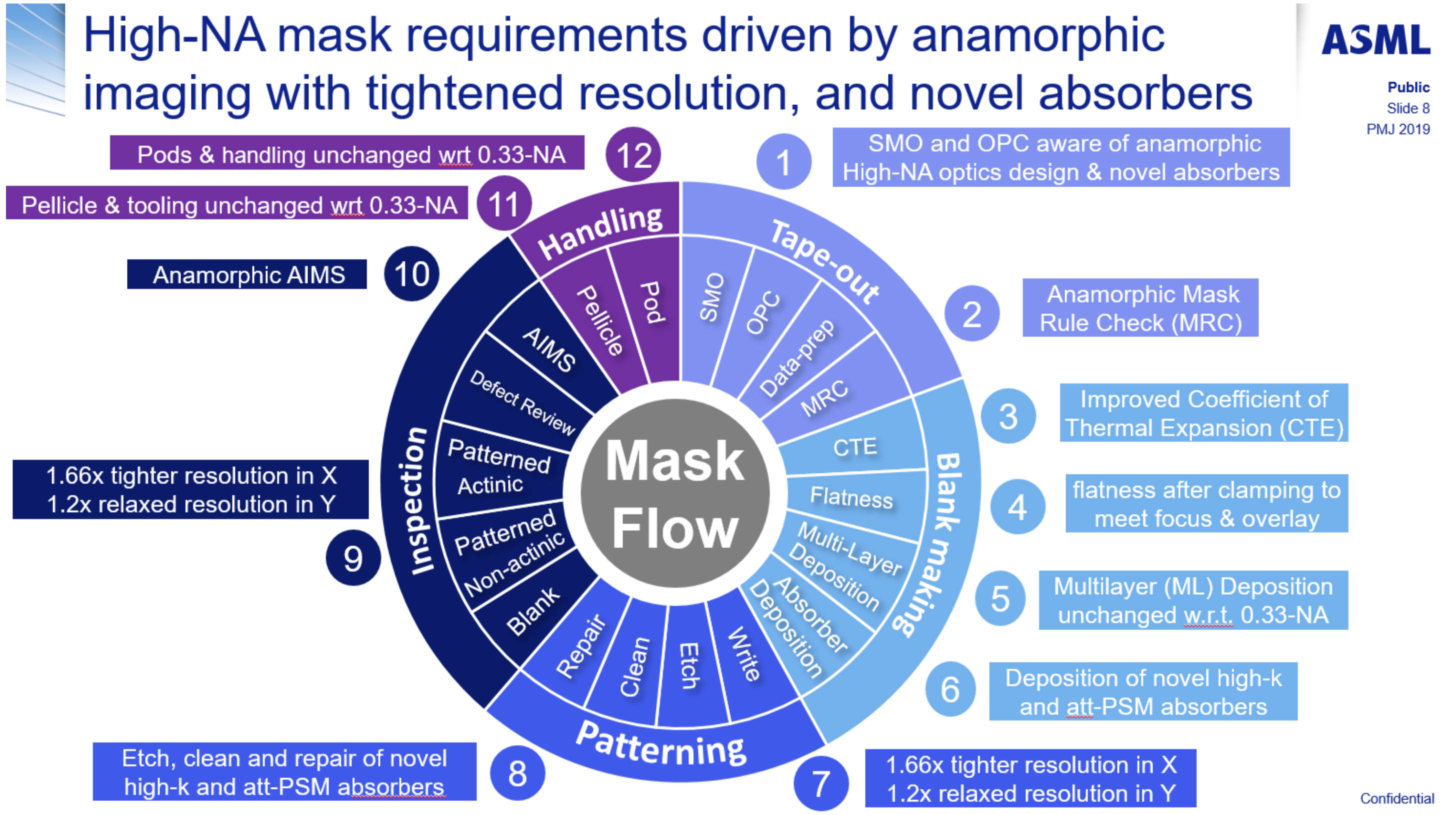
EUV 0.33NA extension & high-NA EUV



High-NA mask requirements driven by anamorphic imaging with tightened resolution, and novel absorbers

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1 SMO and OPC aware of anamorphic High-NA optics design & novel absorbers

2 Anamorphic Mask Rule Check (MRC)

3 Improved Coefficient of Thermal Expansion (CTE)

4 flatness after clamping to meet focus & overlay

5 Multilayer (ML) Deposition unchanged w.r.t. 0.33-NA

6 Deposition of novel high-k and att-PSM absorbers

7 1.66x tighter resolution in X 1.2x relaxed resolution in Y

8 Etch, clean and repair of novel high-k and att-PSM absorbers

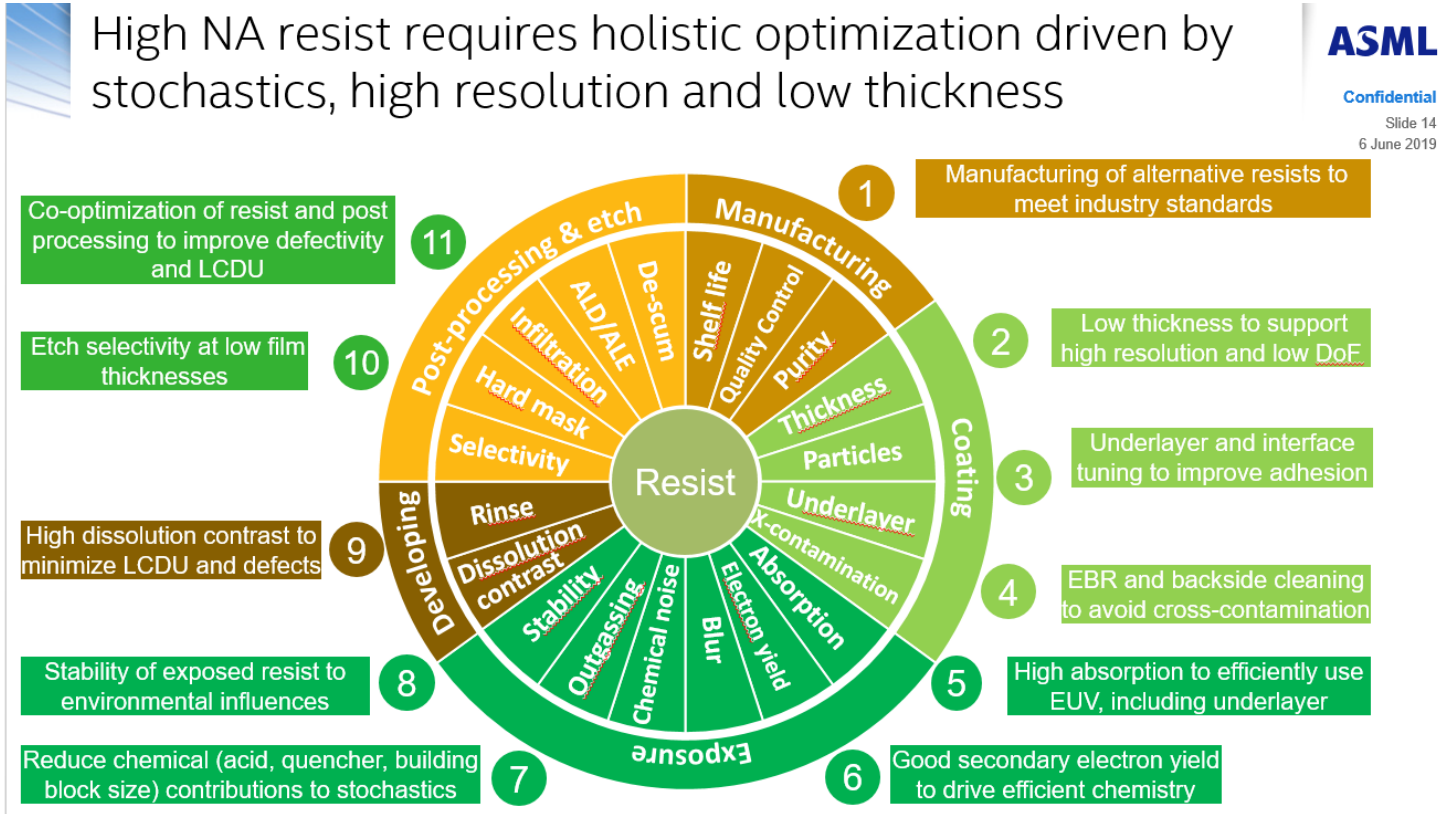
9 1.66x tighter resolution in X 1.2x relaxed resolution in Y

10 Anamorphic AIMS

11 Pellicle & tooling unchanged wrt 0.33-NA

12 Pods & handling unchanged wrt 0.33-NA

Confidential



High NA resist requires holistic optimization driven by stochastics, high resolution and low thickness

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6 June 2019

1 Manufacturing of alternative resists to meet industry standards

2 Low thickness to support high resolution and low DoF

3 Underlayer and interface tuning to improve adhesion

4 EBR and backside cleaning to avoid cross-contamination

5 High absorption to efficiently use EUV, including underlayer

6 Good secondary electron yield to drive efficient chemistry

7 Reduce chemical (acid, quencher, building block size) contributions to stochastics

8 Stability of exposed resist to environmental influences

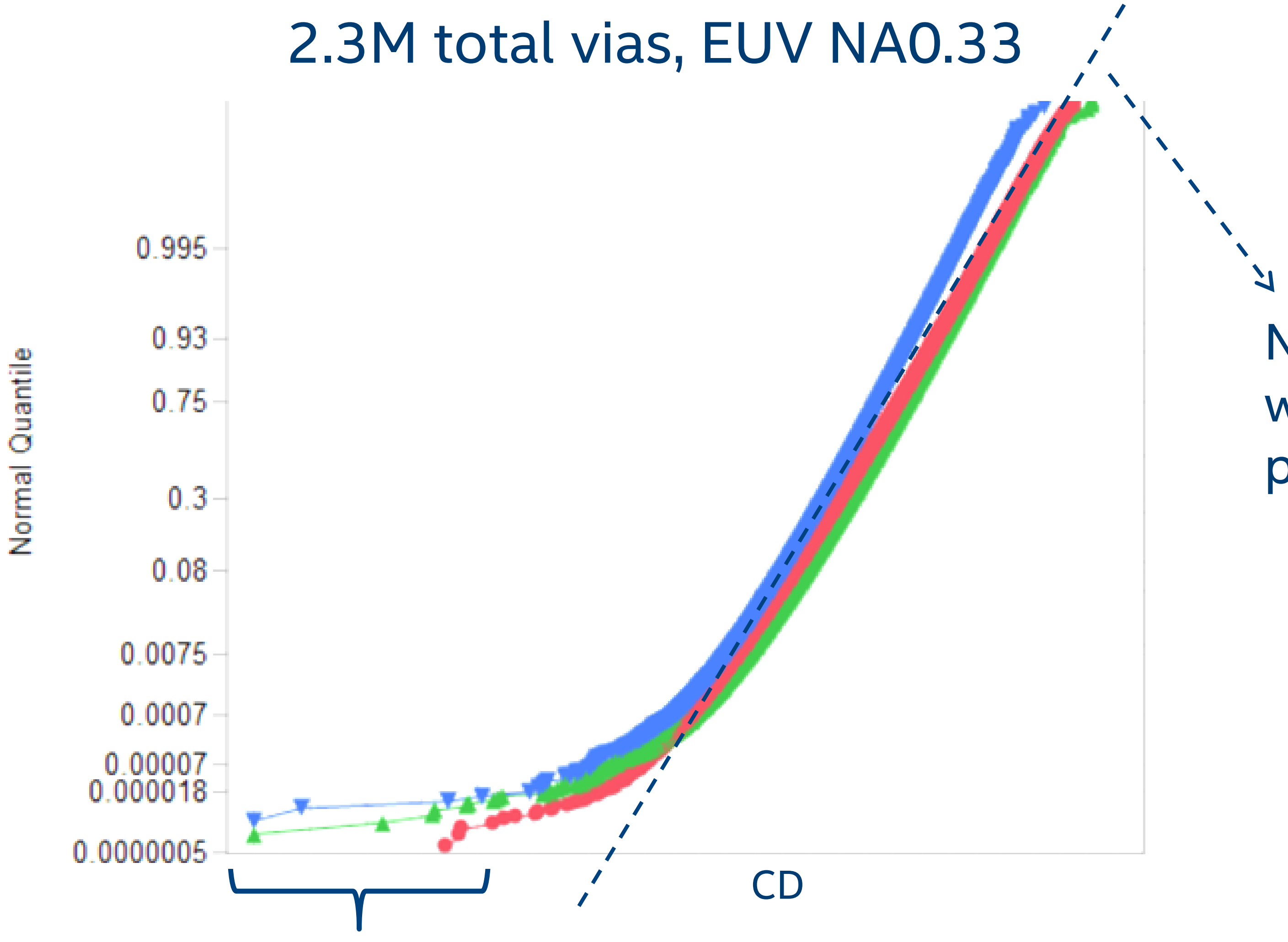
9 High dissolution contrast to minimize LCDU and defects

10 Etch selectivity at low film thicknesses

11 Co-optimization of resist and post processing to improve defectivity and LCDU

- Areas of focus for high-NA EUV are materials and masks

Example: 2.3M measured vias: Non-normal CD distribution



large local via fluctuations at ~5σ (few ppm)

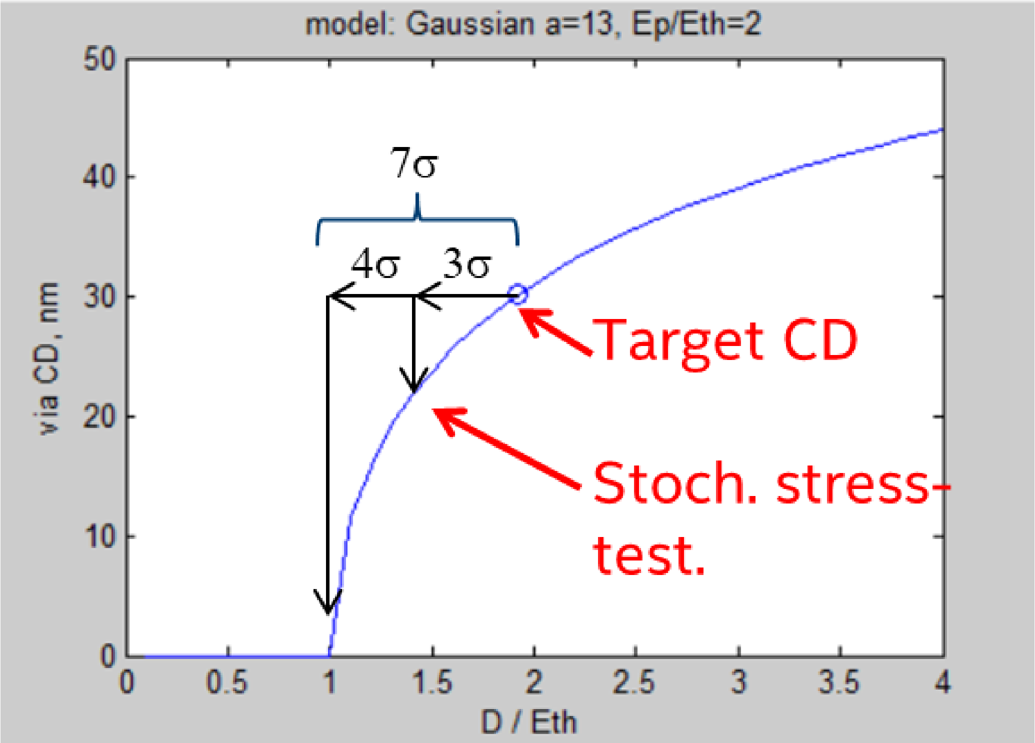
Normal distribution would be linear on this plot.

Actual in-fab on-wafer measured vias, NOT simulated results.

Source: Bristol et al., SPIE, San Jose, CA **2017**

Stochastic Stress Test

It is more physical to treat effective sensitivity as a normal distribution , NOT the CD itself



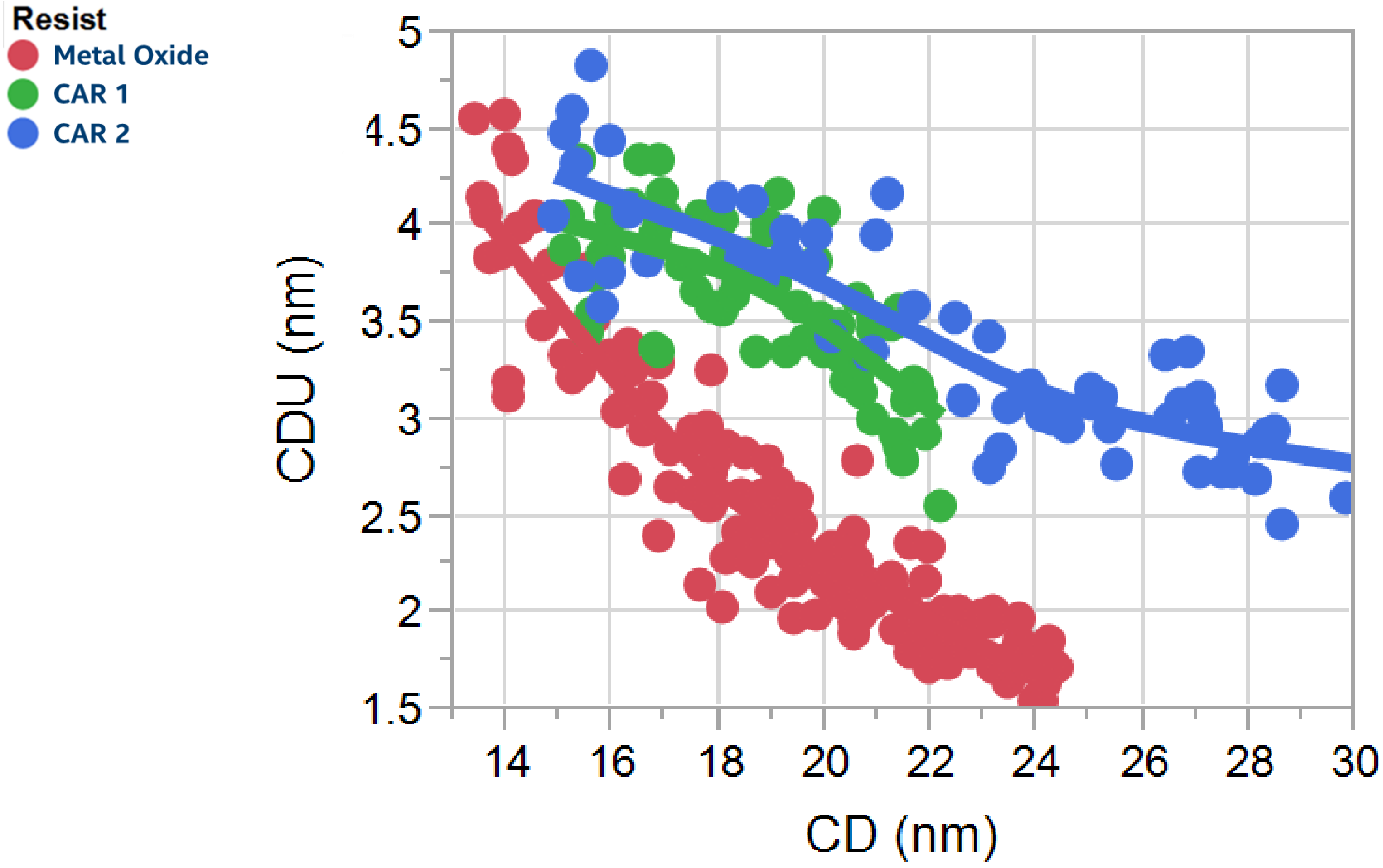
Source: Bristol et al., SPIE, San Jose, CA **2017**

Model as local sensitivity as normal distribution : (photons, electron cascade, PAG/Q distribution, etc)

Slide courtesy
R. Bristol,
F. Gstrein

- Linear extrapolation from thousands of features (3σ) is **inadequate.**
- **Better approach:** stress the system by operating off-target such that ~7σ deviations can be experimentally probed.

Metal Cluster Resists – Stochastic Stress Test



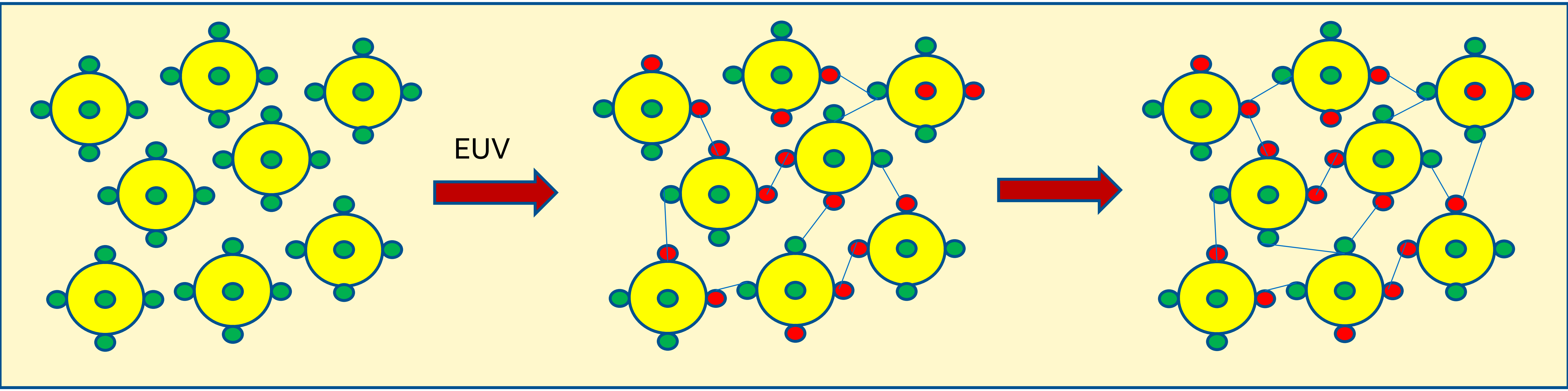
Slide courtesy
F. Gstrein

Clear CDU Improvement over CAR formulations at matched dose

Case Study 1: Metal Oxide Clusters

HfO2-based clusters

Mattson *et al Chem. Mater.* **2018**, *30*, 6198.
Hinsberg, SPIE San Jose, CA, **2016**



Cross-linking occurs during exposure

Additional cross-linking if heated.

Slide courtesy
F. Gstrein

Very different mechanism than SnOC systems, which needs high-temperature PEB and H_2O

Improvement Vectors for Metal Clusters

Key Requirements

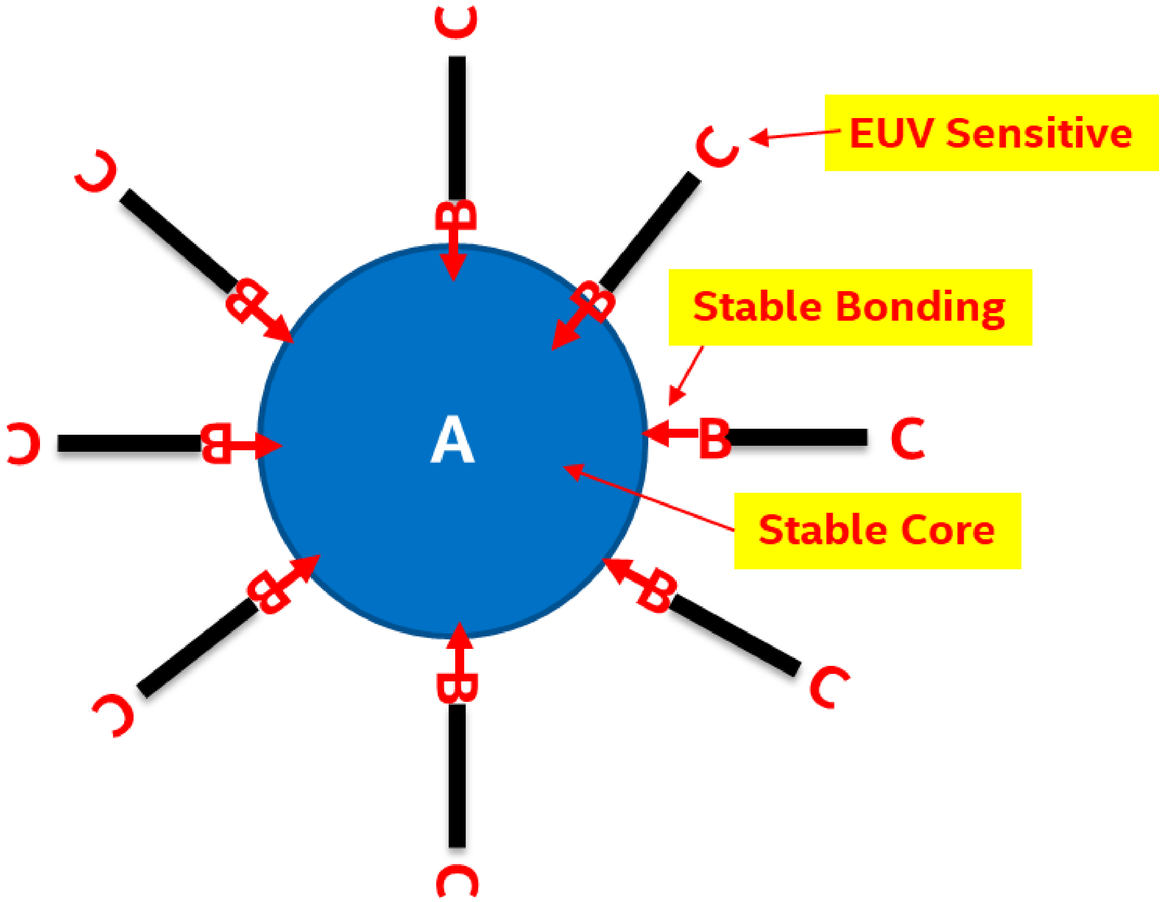
High Contrast

Single Molecule

Single Reaction Pathway

Stable

Do not waste low-energy electrons



EUV Sensitive

Stable Bonding

Stable Core

A = Metal-based Core

B = Ligand Head Group

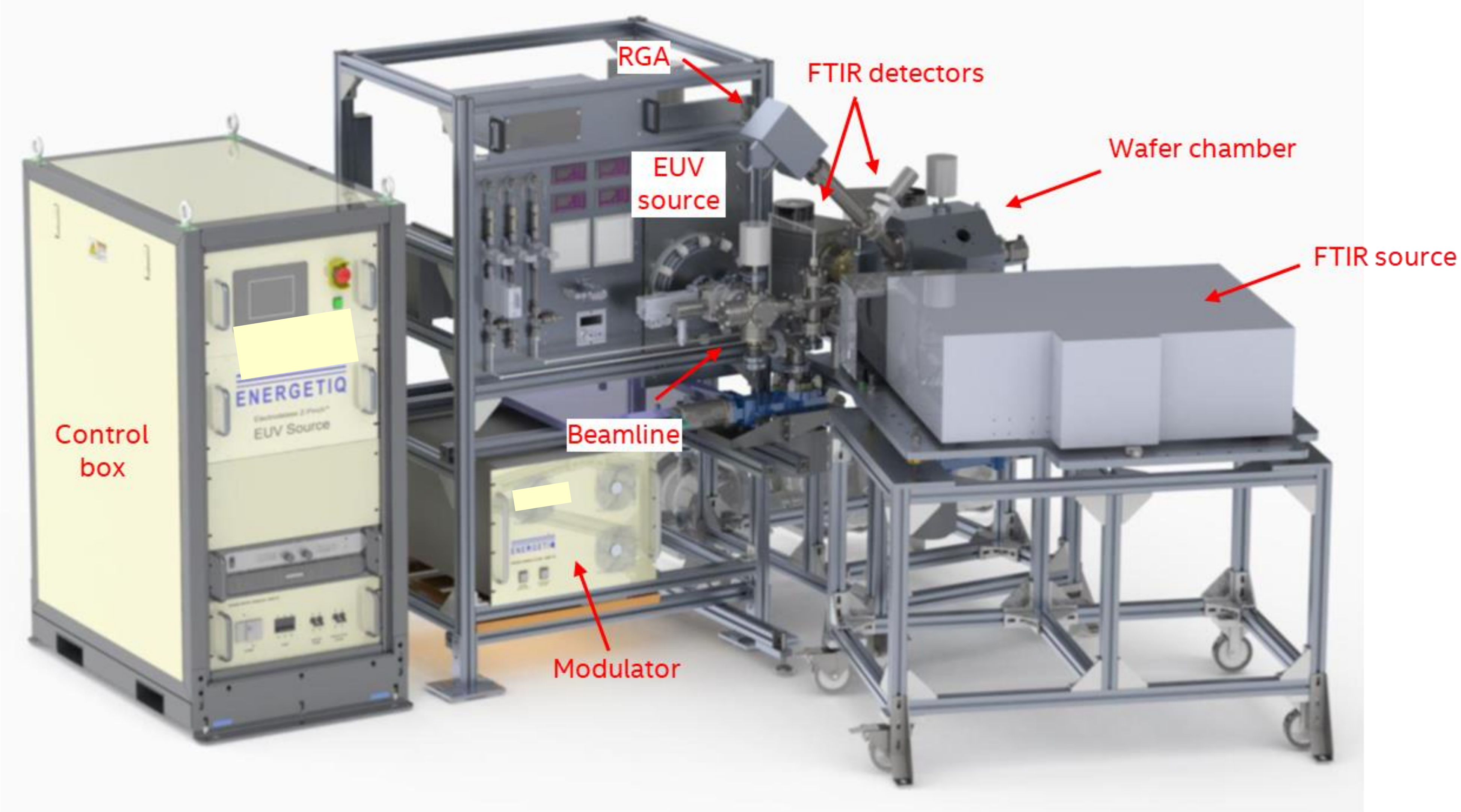
C = Ligand Tail Group

Slide courtesy
F. Gstrein

Lab EUV exposure/metrology tool is critical in making mechanism-based resist improvements

Tools for High NA EUV Resist Research:

Lab EUV Exposure Tool and Metrology Cluster



Slide courtesy
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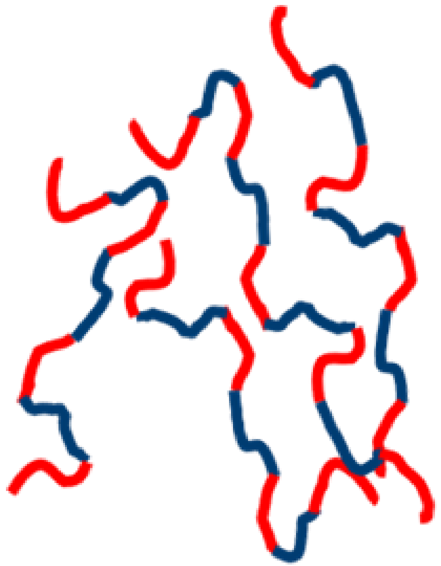
Case Study 2: Chain Scission Resists

Chemically Amplified Resists

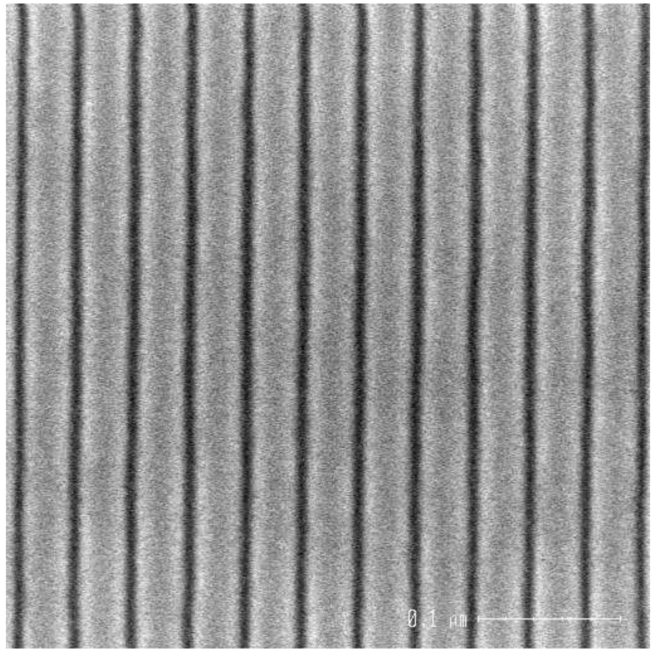
High chemical variability

Chain Scission Polymers

Much lower chemical variability



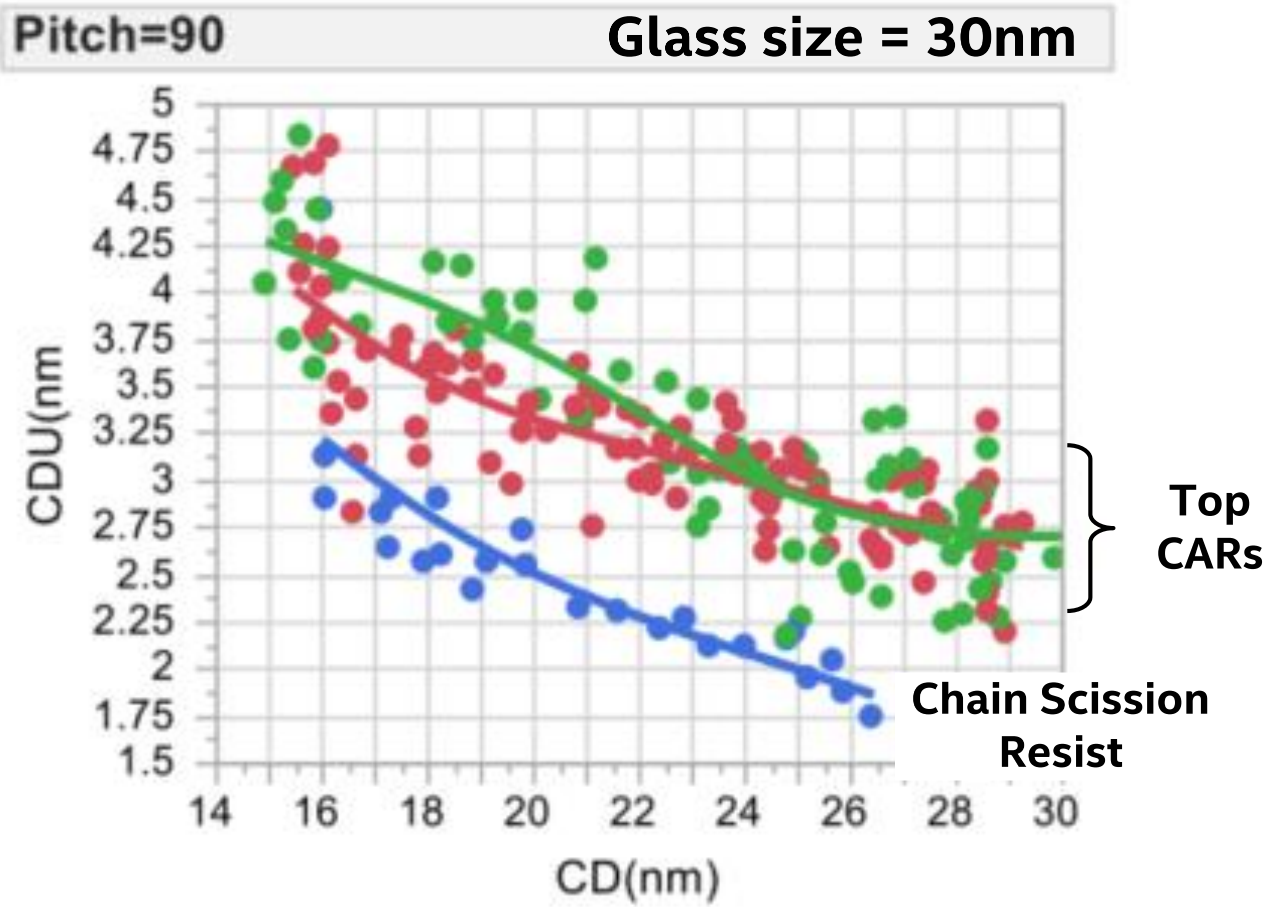
e-beam patterning

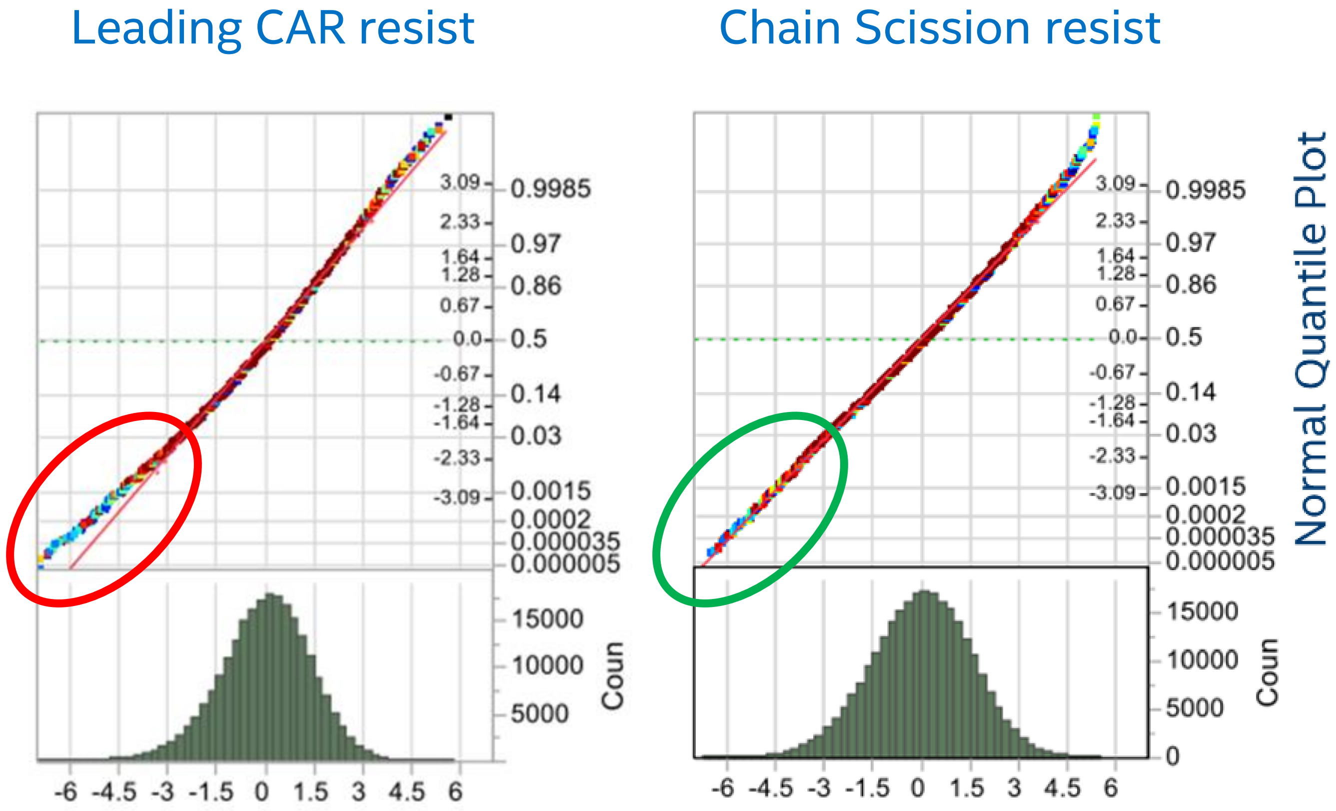


CD: 8nm Pitch: 40nm

Slide courtesy
F. Gstrein

Chain Scission Resists – Stochastic Stress Test





Slide courtesy
F. Gstrein

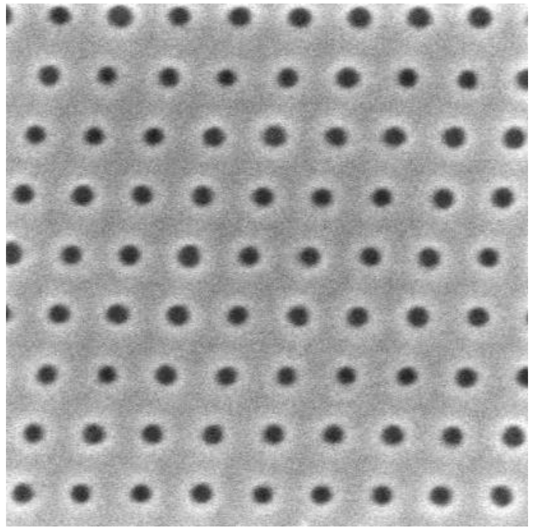
Chain Scission resists closer to normal distribution at small via sizes

Better CDU at all CDs but convoluted by need for higher dose

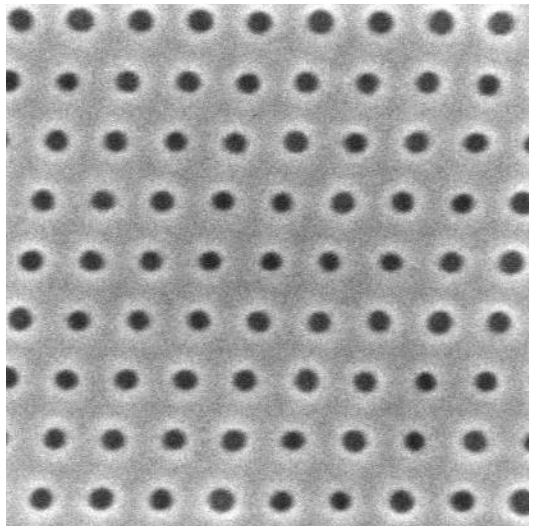
Chain Scission Resists – Ultimate Resolution (MET 5)

MET5

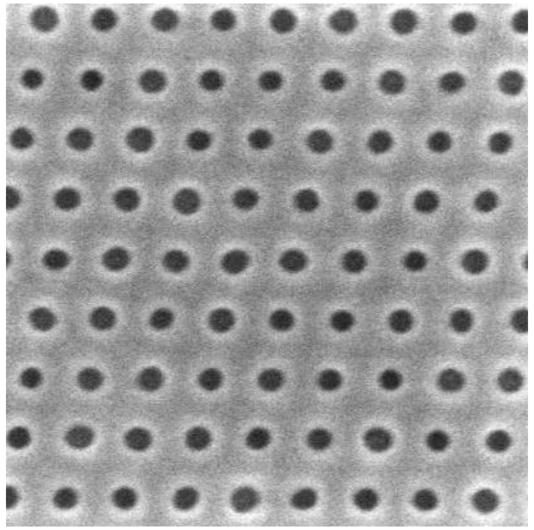
Impressive resolution



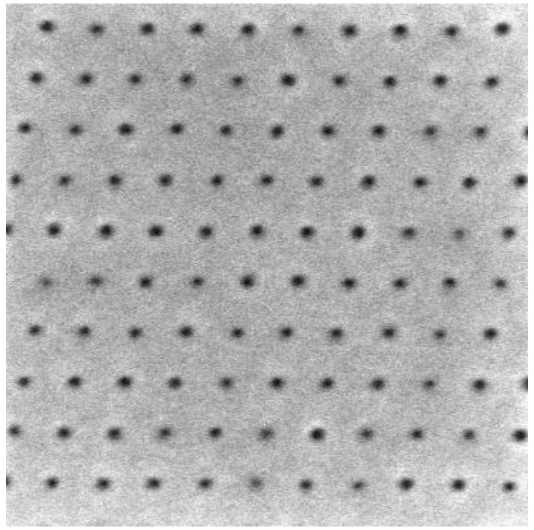
CD: 16 nm



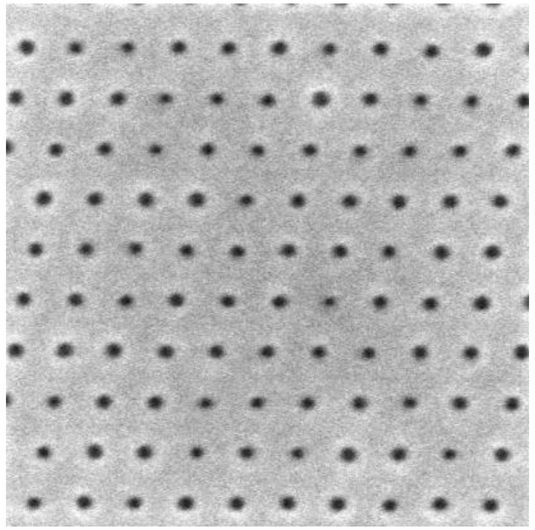
CD: 18 nm



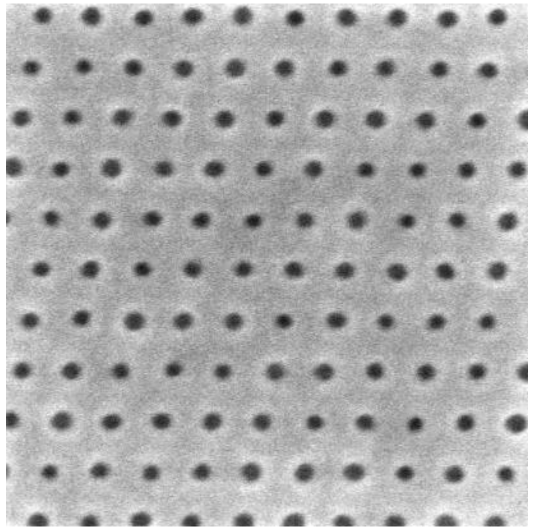
CD: 20 nm



CD: 11 nm



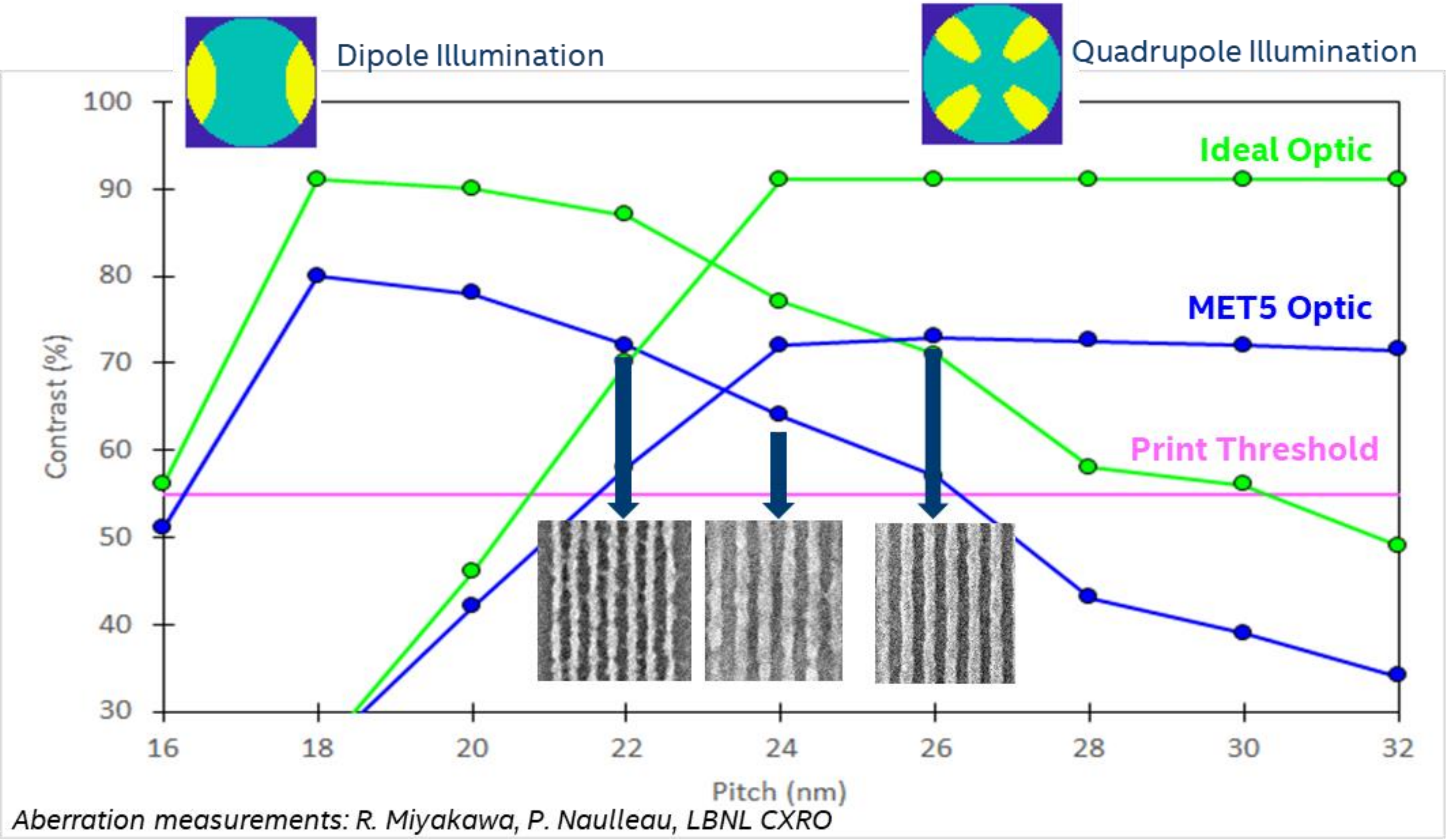
CD: 12 nm



CD: 14 nm

Slide courtesy F. Gstrein

Tools for High NA EUV Resist Research: MET - 5



Aberration measurements: R. Miyakawa, P. Naulleau, LBNL CXRO

Slide courtesy
F. Gstrein

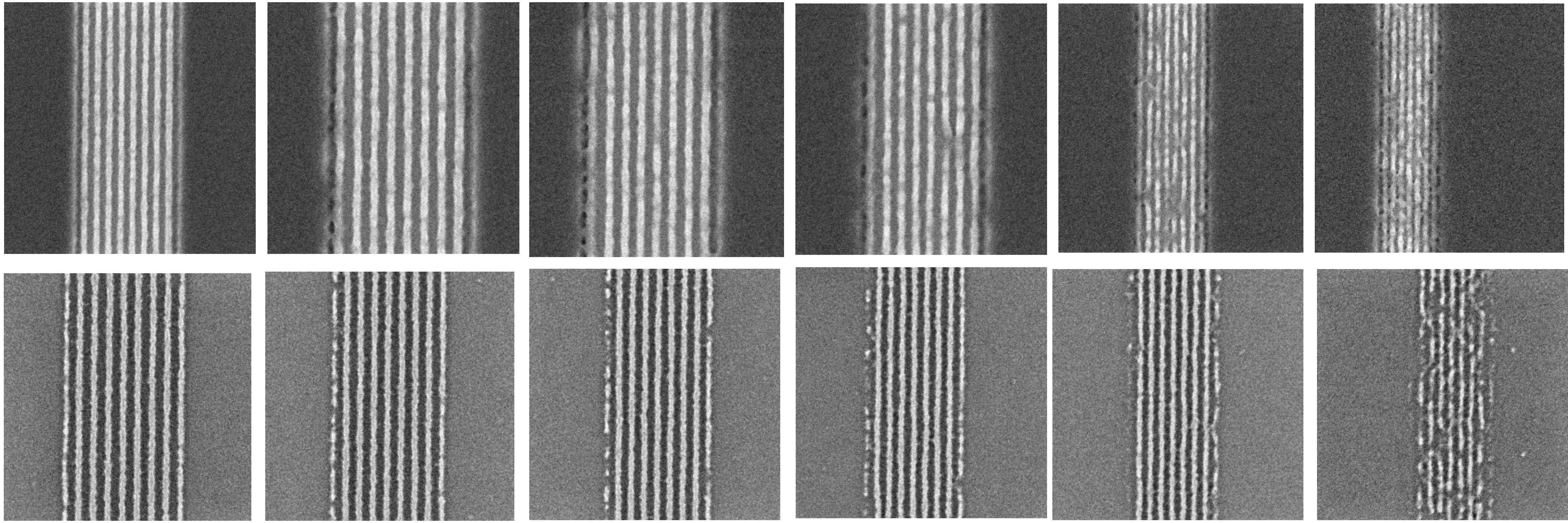
METs are resist limited and NOT tool limited

Ack.: Kloster

Quadrupole Illumination MET

Contrast limit
ASML NXE 3350
Dipole

Contrast limit with
0.5 NA quad
illumination



32 nm pitch
30 nm pitch
28 nm pitch
26 nm pitch
24 nm pitch
22 nm pitch

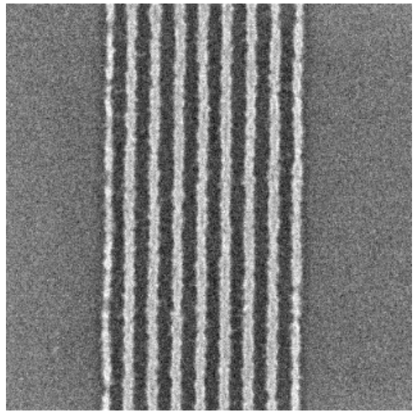
CAR

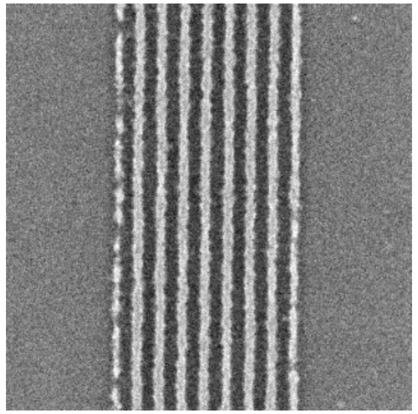
Non-CAR

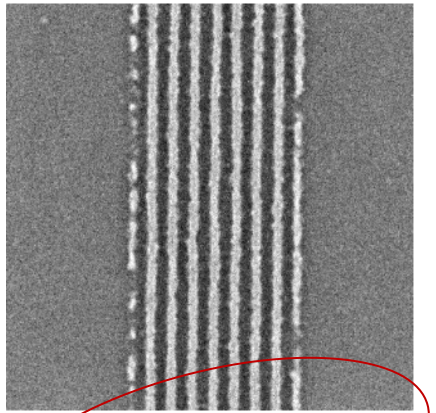
Ack.: Kloster

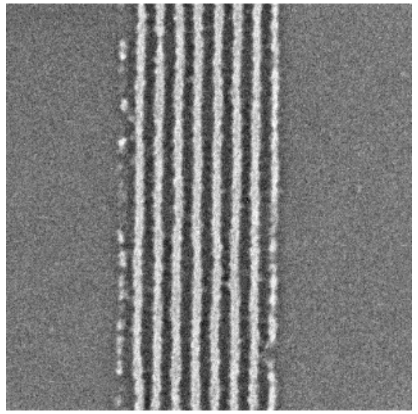
Non-CAR – Ultimate resolution MET

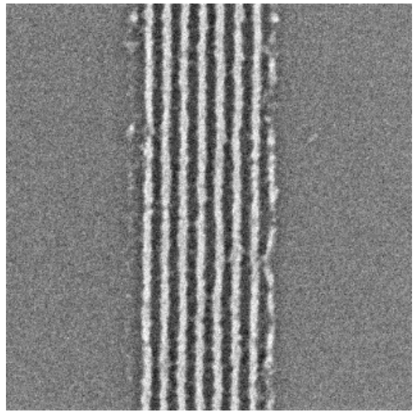
QUAD. PERFORMANCE

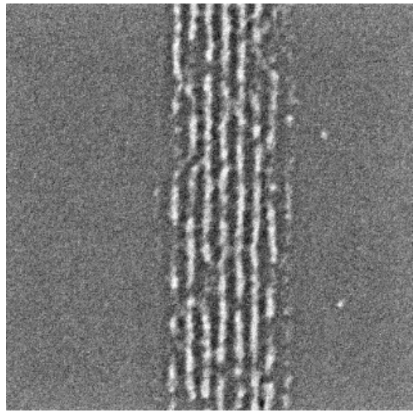

32 nm pitch


30 nm pitch

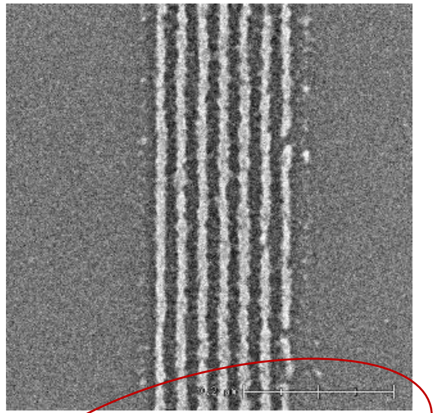

28 nm pitch

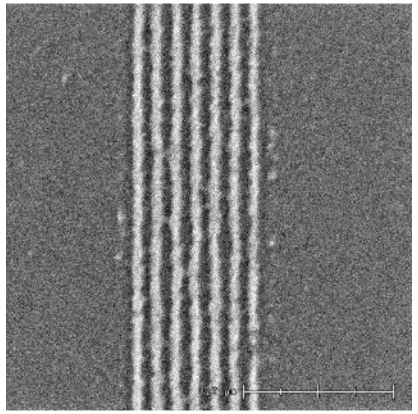

26 nm pitch

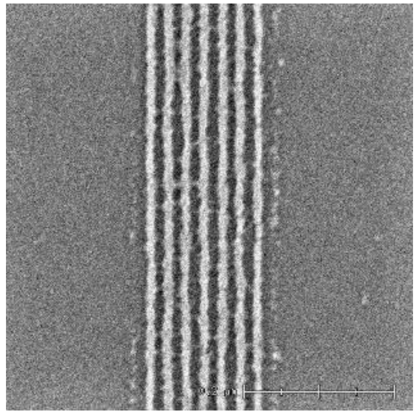

24 nm pitch

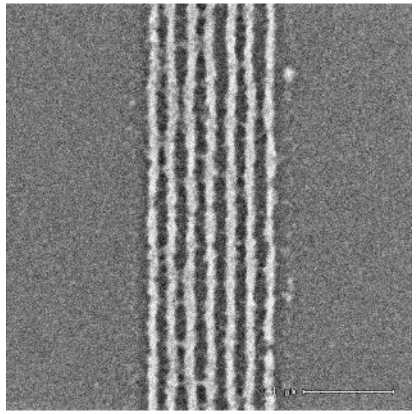

22 nm pitch

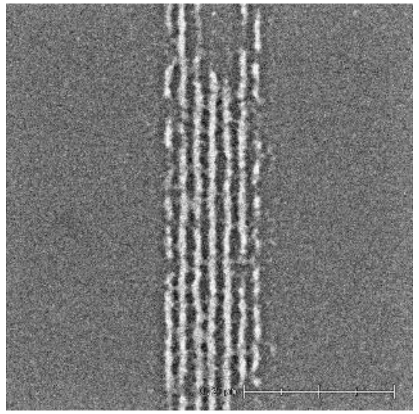
DIPOLE PERFORMANCE


28 nm pitch

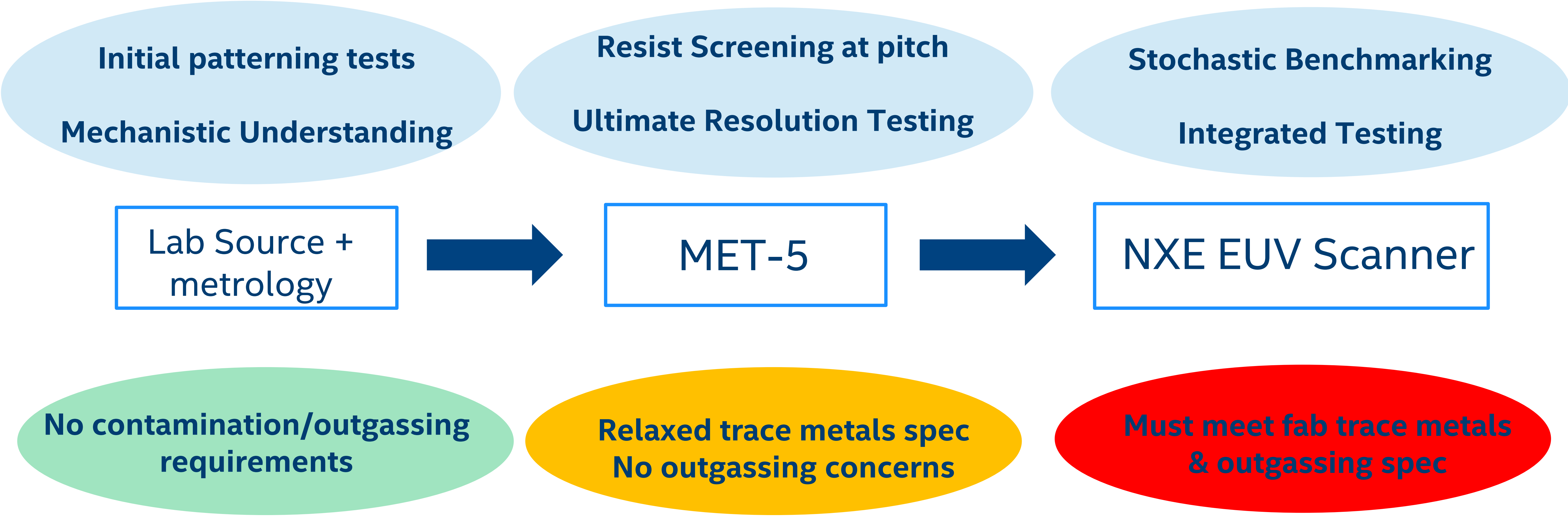

26 nm pitch


24 nm pitch


22 nm pitch


20 nm pitch

Resist Evaluation Flow



Initial patterning tests

Mechanistic Understanding

Resist Screening at pitch

Ultimate Resolution Testing

Stochastic Benchmarking

Integrated Testing

Lab Source + metrology → MET-5 → NXE EUV Scanner

No contamination/outgassing requirements

Relaxed trace metals spec
No outgassing concerns

Must meet fab trace metals & outgassing spec

Next-generation materials

1) **The industry needs high-NA EUV.** If high-NA tools were available today, we would use them.

2) **Novel resists are a critical enabler for high-NA EUV.** Novel resists need to have low stochastic-variation and high EUV- absorbance.

3) **High-NA EUV screening tools for resist evaluation are available.** Challenge to resist suppliers and academia is to provide novel resists and better utilize these expensive research tools.

4) **Chain scission resists and metal cluster resists are promising new platforms** based on stochastic stress tests. More work based on in-depth mechanistic understanding is needed.

5) **New metrology tools to study resist mechanisms are available.** We encourage resist suppliers and academia to use them and are willing to share our best-known-methods.

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EUV infrastructure readiness snapshot: 0.33NA extension and 0.5NA

0.33NA		0.5NA	
Today	Exten.		
🟩	🟨	🟥	**EUV resist:** CAR capable for introduction. Stochastics driving process window for 0.33NA extension and 0.5NA. Need fundamental understanding of electron/ion/photon interaction with materials. Suppliers must have access to EUV photons and appropriate metrology.
🟩	🟨	🟥	**EUV blank quality:** Capable for introduction. 0.33NA extension and 0.5NA require standards for front-side/back-side flatness, CTE, defectivity
🟩	🟨	🟨	**Actinic Blank Inspection (ABI): 0.33NA**: Ready for qualification of HVM quality blanks at introduction. **0.5NA**: need to ensure metrology capability/timing
🟩	🟩	🟩	**Mask pattern:** write capability for 0.33NA extension and 0.5NA – may need curvilinear
🟩	🟨	🟨	**E-beam Mask Inspection: 0.33NA:** In use for low volume production. Need TPT increase
🟩	🟩	🟨	**AIMS Mask Inspection: 0.33NA:** NXE:3400 illumination emulation underway; **0.5NA:** work needed
🟨	🟨	🟥	**Pellicle: 0.33NA /0.5NA:** increased sensitivity to smaller defects. Improvement needed re. power resiliency, transmission, EUV-R, uniformity. Opportunity for industry participation.
🟩	🟩	🟨	**Actinic Patterned Mask Inspection (APMI): 0.33NA/0.5NA:** Feature sizes drive need for actinic inspection in mask shop and fab.
🟩	🟩	🟨	**Mask backside defect inspection / clean:** expect tighter requirements for mask backside contamination

🟩 Technical and commercial solution exists. Proof of concept demonstrated, HVM availability is eminent

🟨 Technical path exist. Proof of concept or Commercialization path needed

🟥 No technical path or requirements are unknown

Conclusion

- Combined scanner/source availability continues to improve
    - Exposure source remains largest contributor to tool downtime
- Exposure source power meeting 250W roadmap and demonstrated in field systems
- Scanner defectivity levels improved with introduction of NXE:3400
    - Every system has demonstrated printable defects resulting from fall-on particles
    - Need remains for EUV pellicle and associated infrastructure / support
- Progress has been made in pellicle and membrane material development, but continued improvement necessary for increasing transmission, withstanding increased source power, and extending lifetime
- EUV AIMS system meeting expectations
- APMI operational for full mask inspection
- Next-generation considerations include material stochastics and thermal effects: recommend standards
- Need to consider stochastics for decreasing feature sizes and high NA: need to understand the interaction of EUV radiation with resist and design resist materials for stochastics

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Markus Kuhn
Curt Ward
Sam Sivakumar
Guojing Zhang
Jeff Farnsworth
Sang Lee

Backup