GenISys
Advancing the Standard

電子線描画におけるプロセス補正のご紹介

GenISys株式会社
アプリケーション・エンジニア 清水 諭

About GenISys

GenISys offers software solutions for optimization of micro and nano fabrication processes

Company:

- Founded in 2005, privately owned
- Headquartered in Munich, Germany
- Offices in USA-California, Japan-Tokyo
- Global Technical Support
- Fast, Flexible, Responsive

GenISys
Advancing the Standard

Products

Electron and Laser Beam Direct Write Software

- Market leader for Gaussian beam direct write systems
- Installed at most major nano-fabrication centers worldwide
- Has become a MUST for advanced e-beam lithography

Monte Carlo simulation software

- MC- Simulation of PSF for e-beam lithography modeling and correction
- Process Calibration, PSF visualization, extraction and management

3D lithography simulation software

- Proximity Lithography / Projection Lithography (stepper / scanner)
- Electron Beam Lithography
- Laser Beam Lithography (Heidelberg Instruments laser systems)

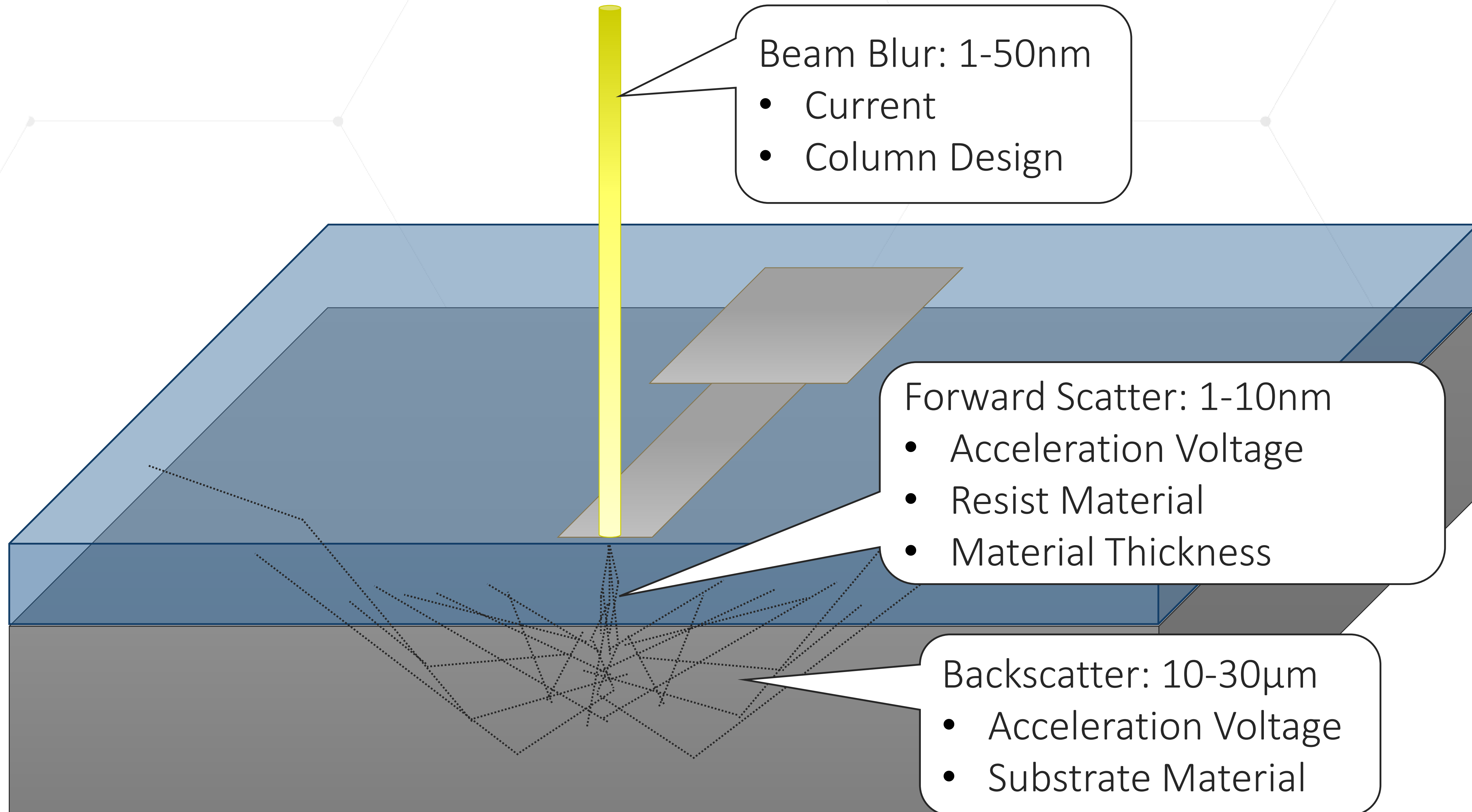
SEM Image Analysis & Metrology

- Metrology software for SEM

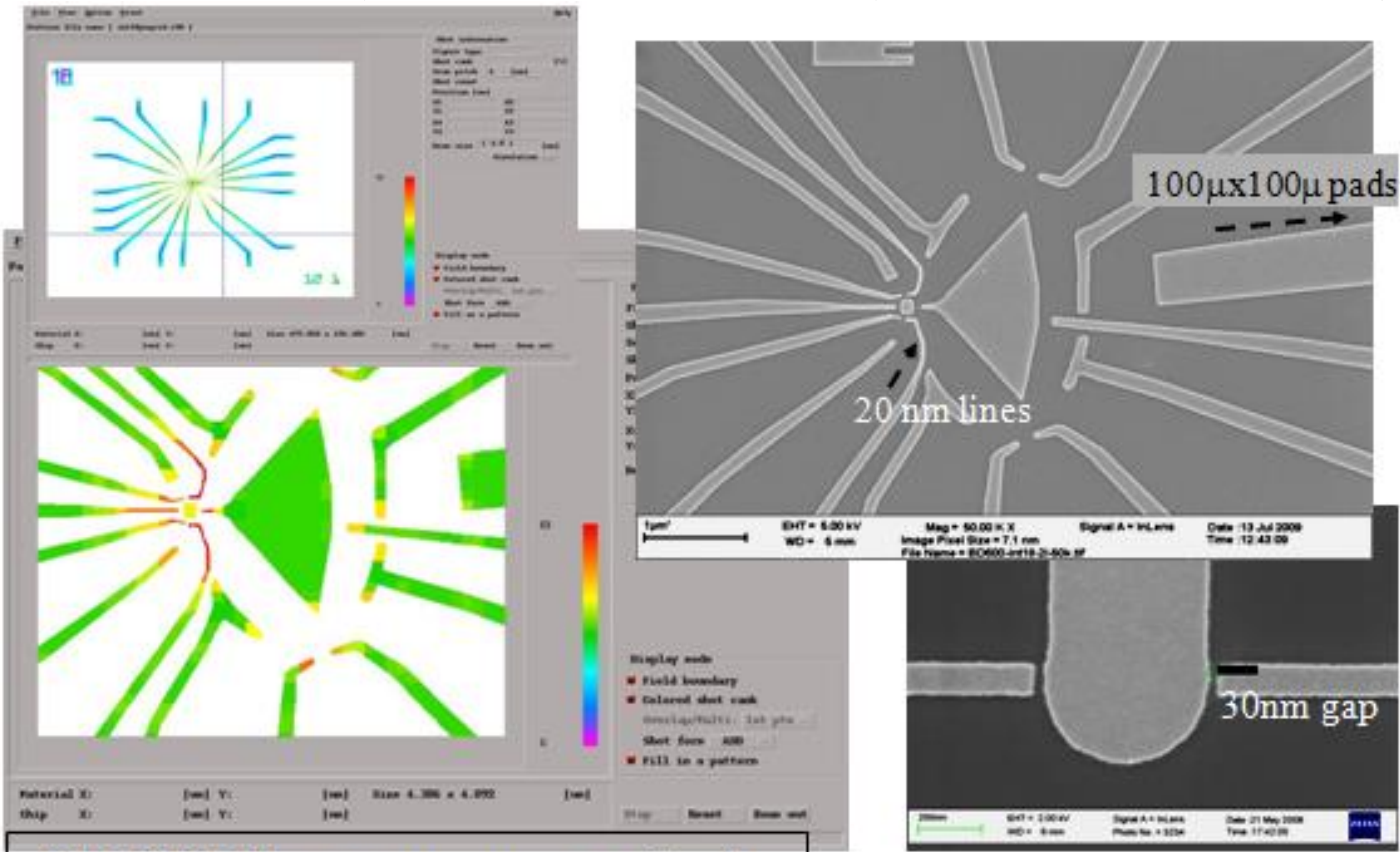
Agenda

- **Background & Model**
- Calibration
- Use Cases
- Summary

Electron Scattering



Optimized Exposure

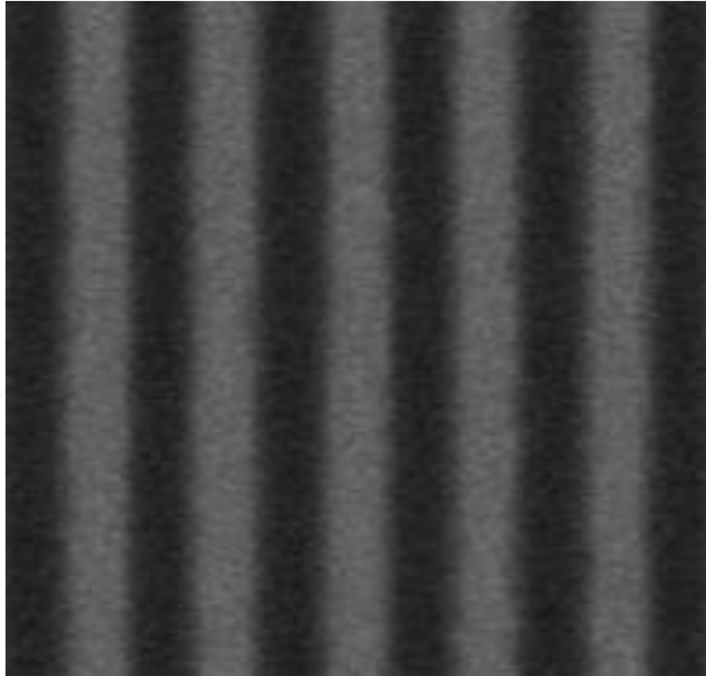


100kV Exposure on GaAs

Source: Weizmann Institute

Observation

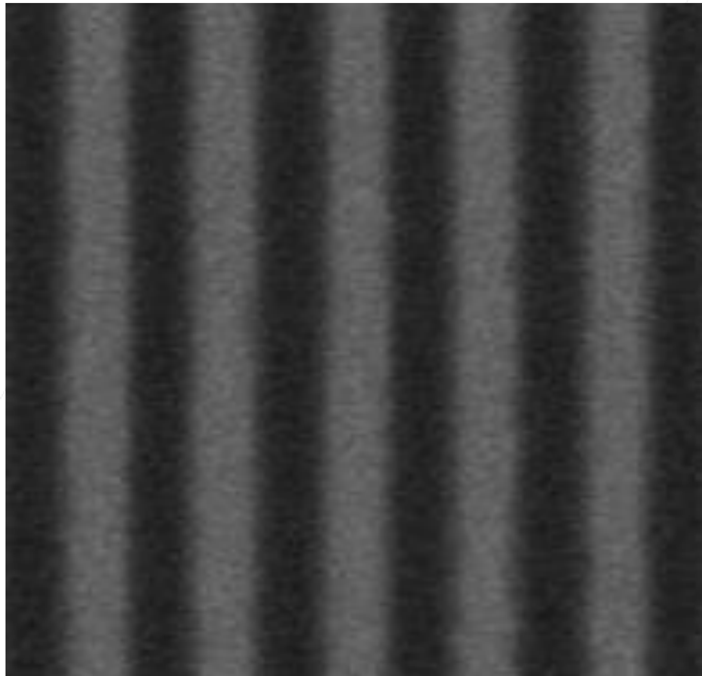
1:1 L&S



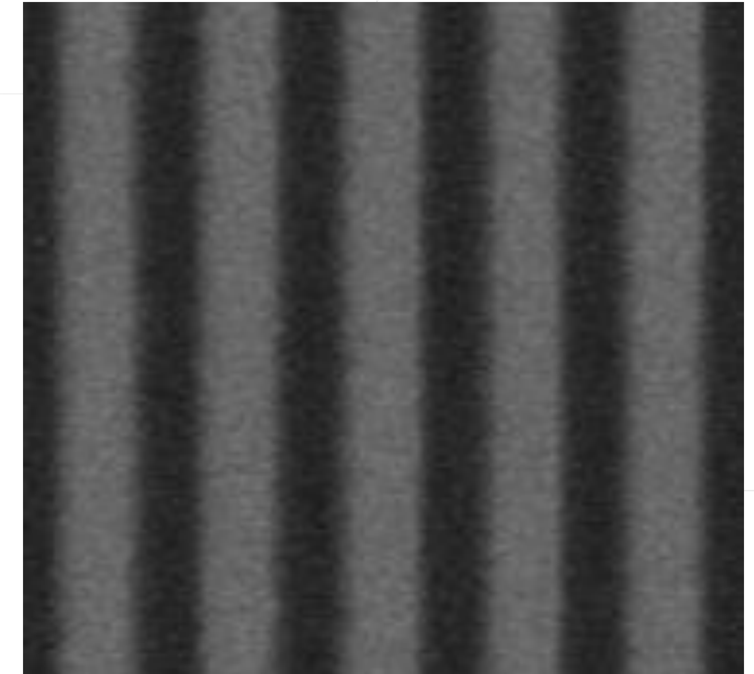
On Target CD at given Base dose
but LER is high (not well resolved)

Observation

1:1 L&S



at higher dose (+ 10uC/cm^2)



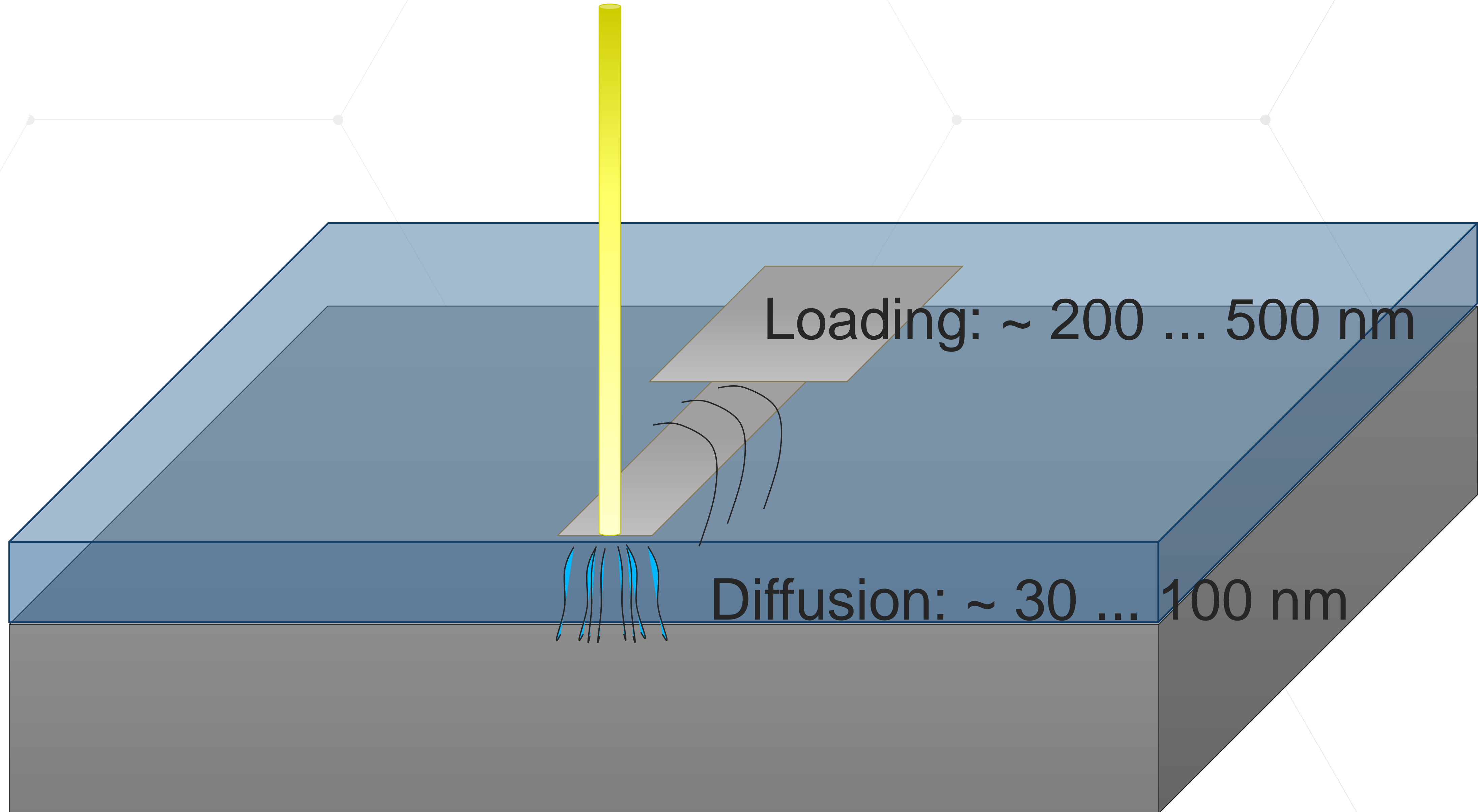
On Target CD at given Base dose
but LER is high (not well resolved)

low LER (well resolved)
but off the Target CD

Under a proper dose, compensation for the process effect is necessary

GenISys
Advancing the Standard

Process Effects



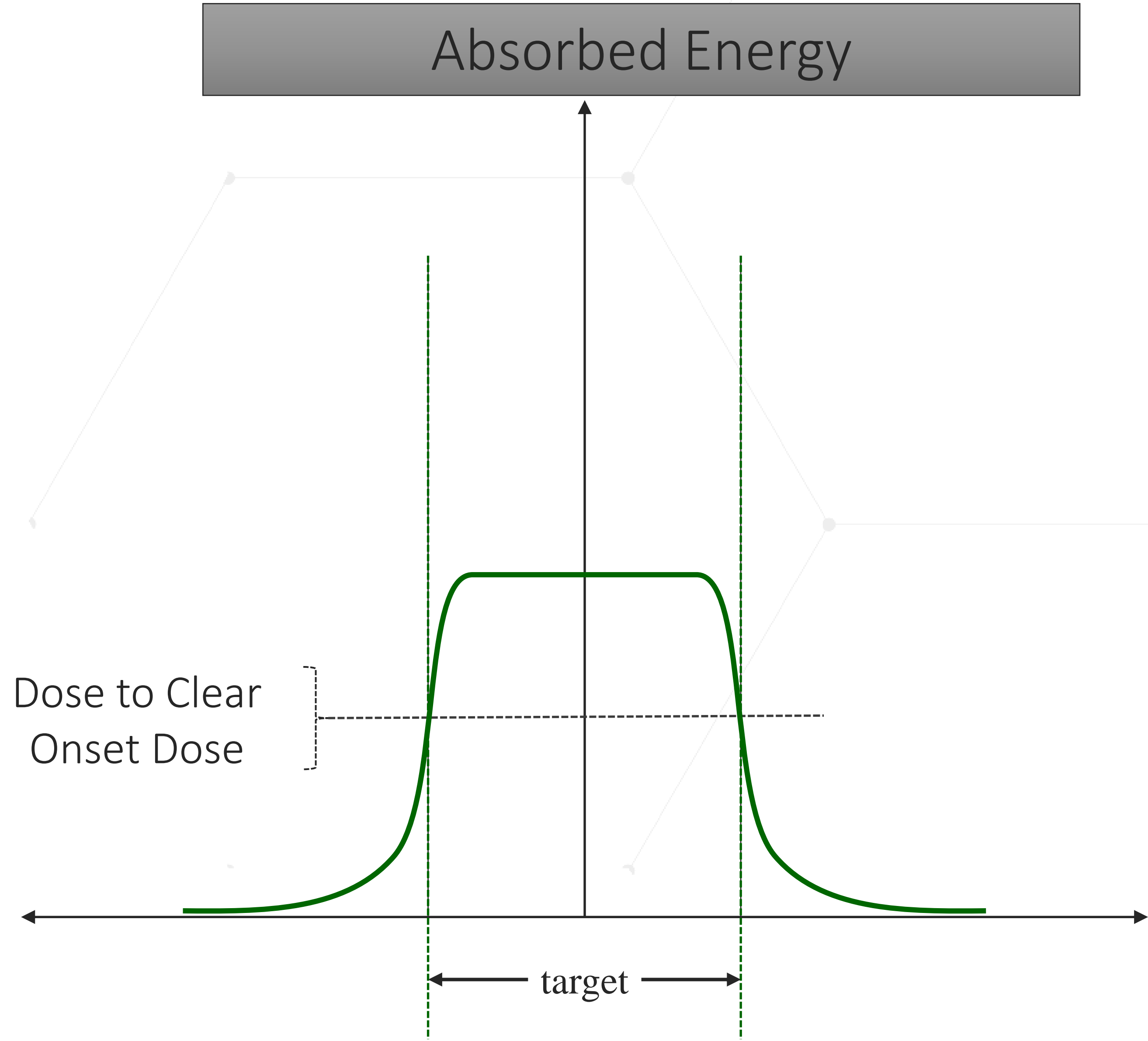
Process Blur

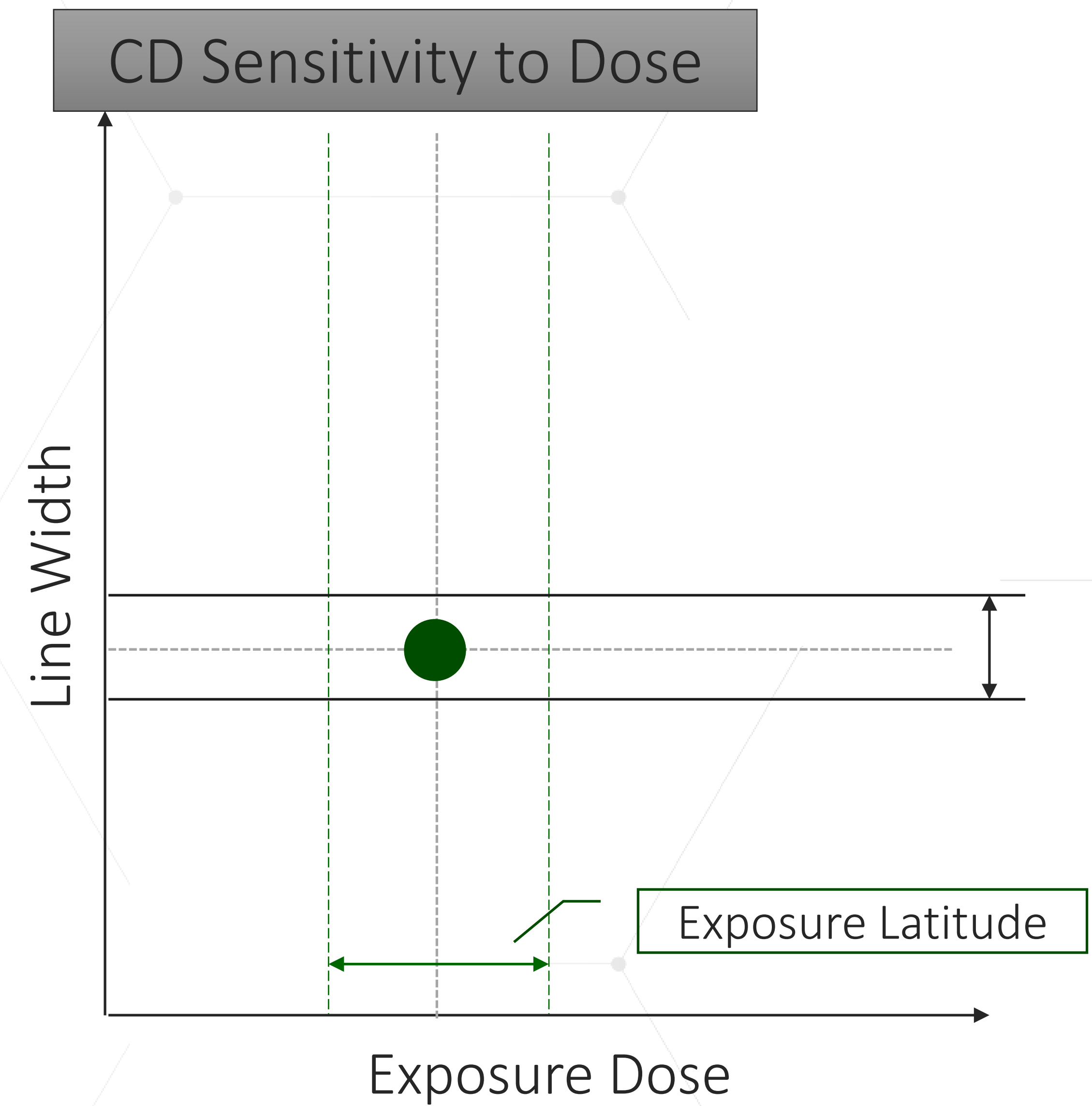
- All we can observe is convolved result of Exposure, Resist Process, Pattern Transfer and Metrology
  - $CD_{measured}$ = Exposure (CD_{Target}) ⊗ **Process** ⊗ Transfer ⊗ Metrology

- Process Blur includes contributors from
  - Spot Size, Forward Scattering, Noise, Resist Blur, Lateral development (gamma * log (D)), ...

- Process Bias includes contributors from
  - Lateral Development, Resist Shrinkage / Swelling, Pattern Transfer (Sidewall Angle / Footing), Metrology Offsets

Process Blur





Process Blur

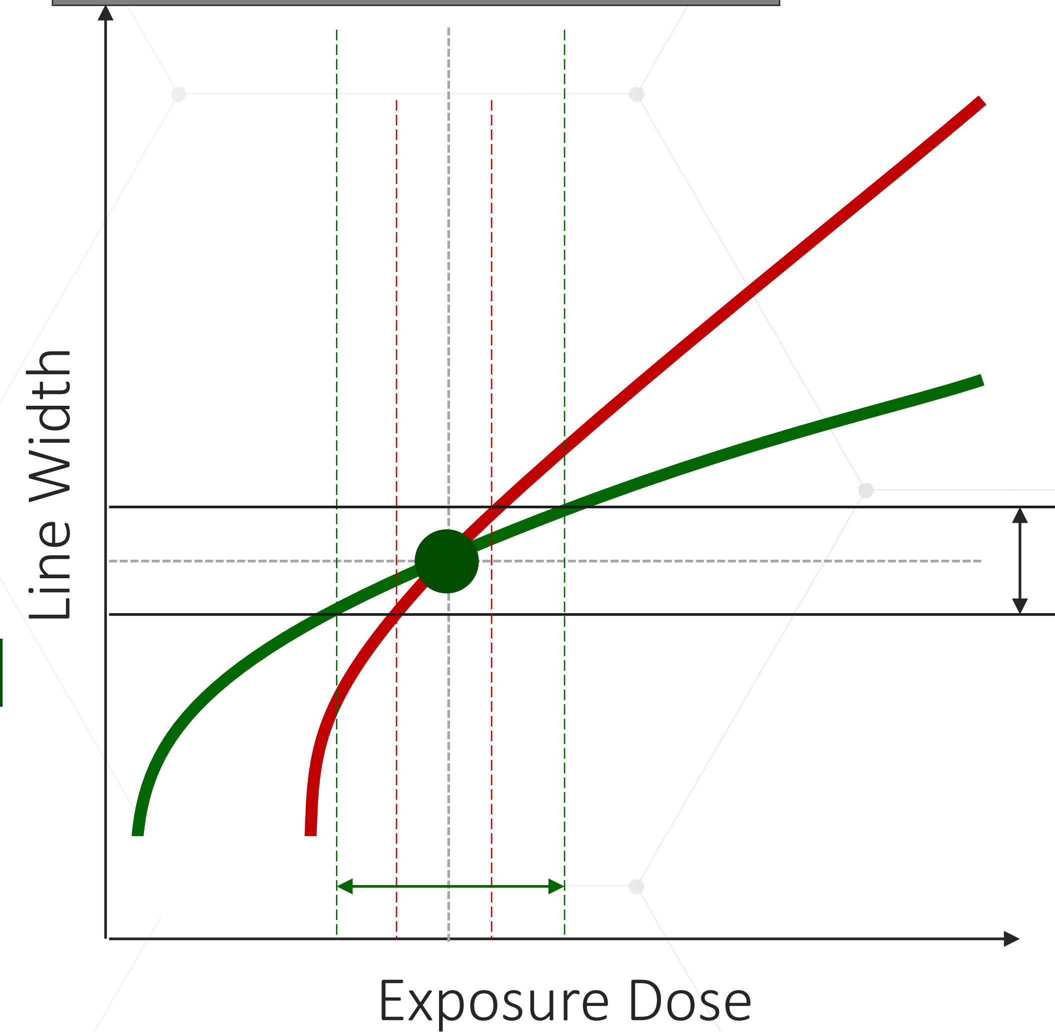
Absorbed Energy

Dose to Clear
Onset Dose

Iso-focal Point

target

CD Sensitivity to Dose



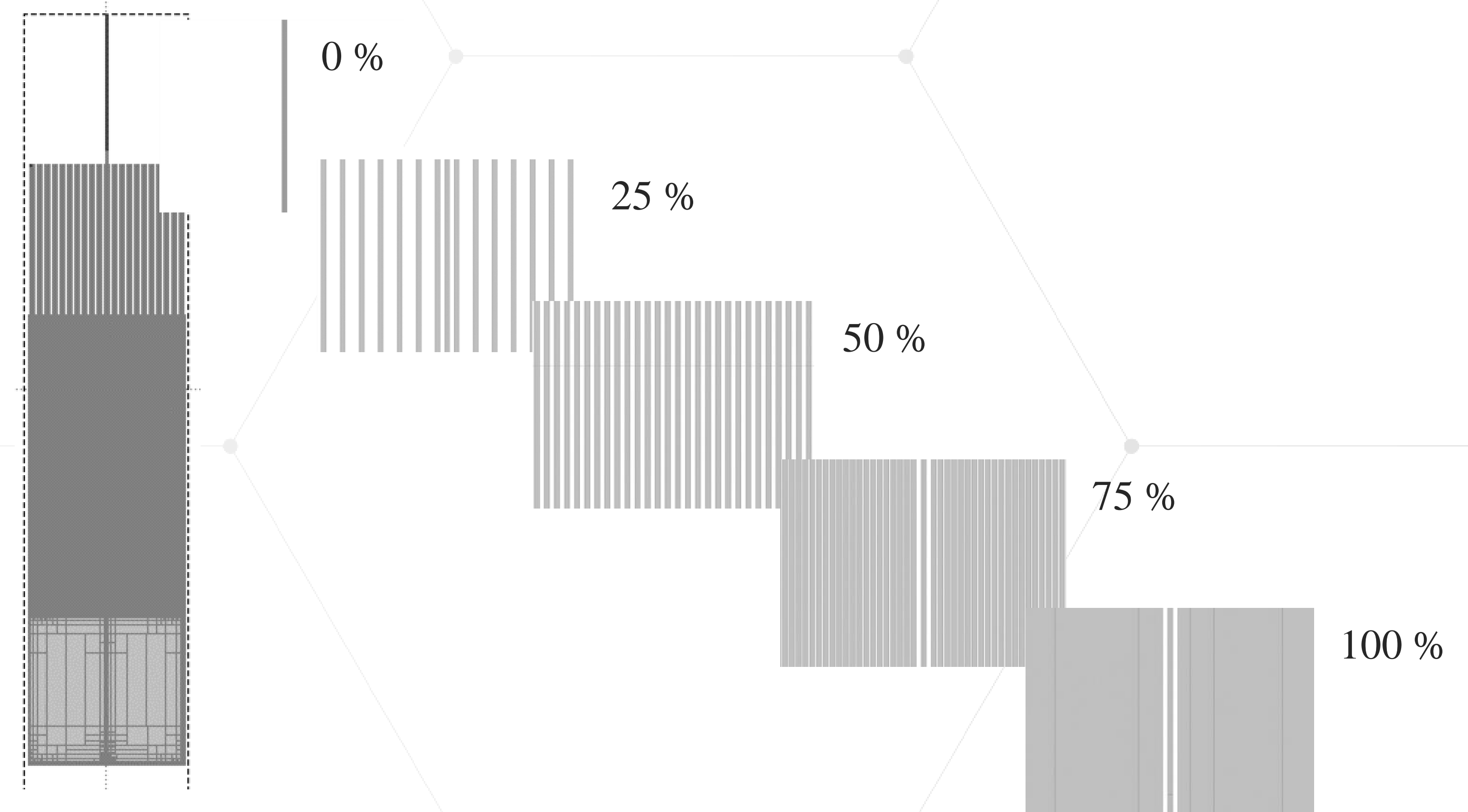
Overlay demonstrates the existance of a blur-independent line-width: the iso-focal

Agenda

- Background & Model
- **Calibration**
- Use Cases
- Summary

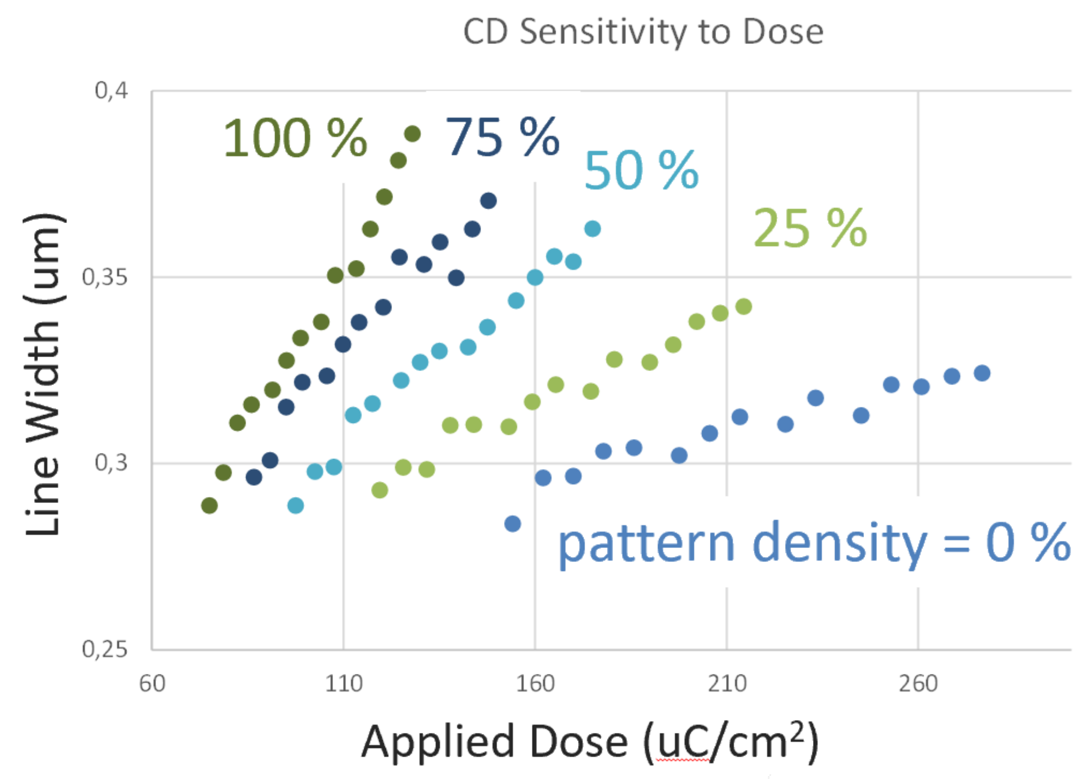
Experiment

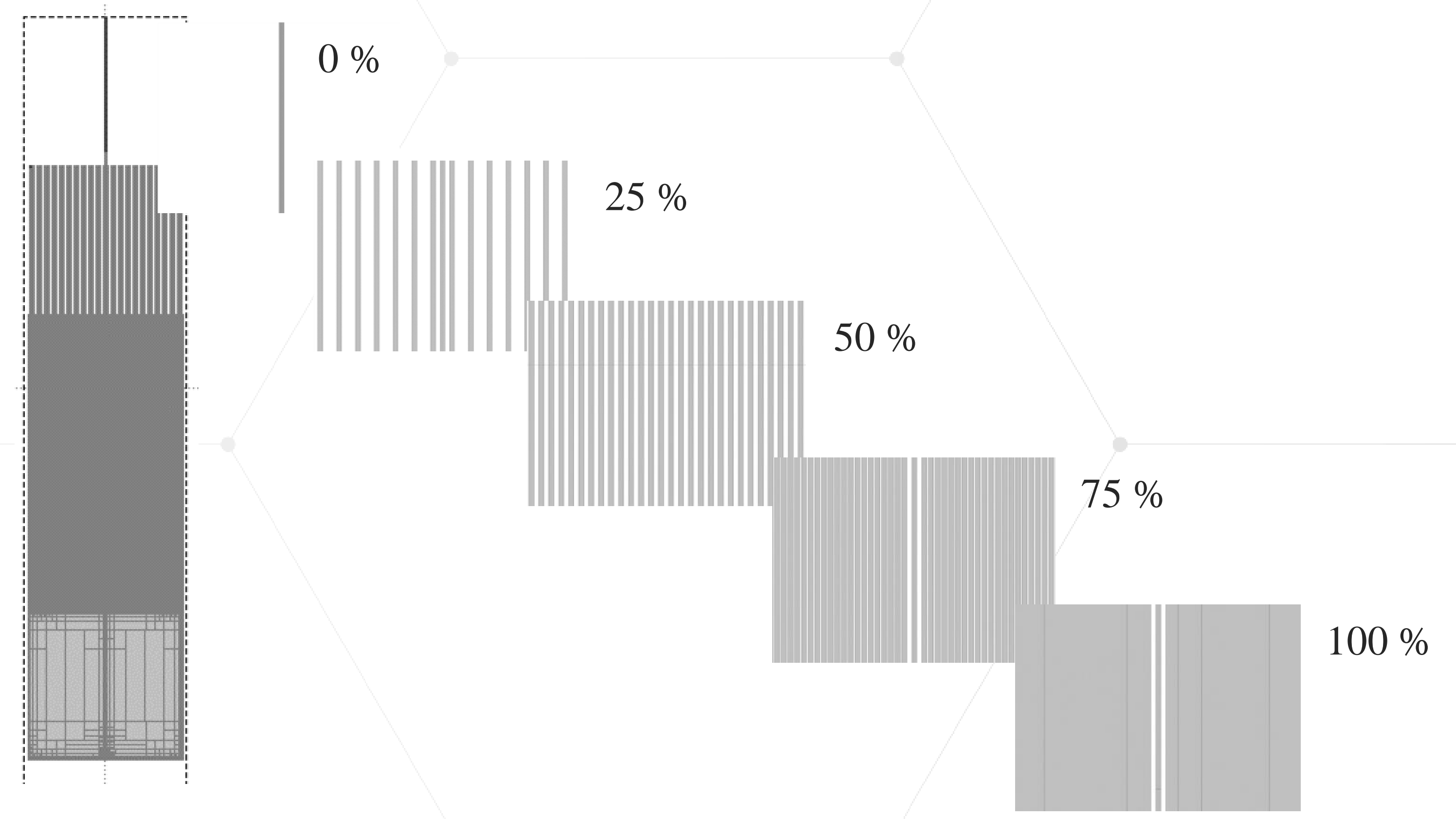
- Lines are exposed
  - at varying pattern densities
  - with Long Range Proximity Effect Collection
  - through a dose series



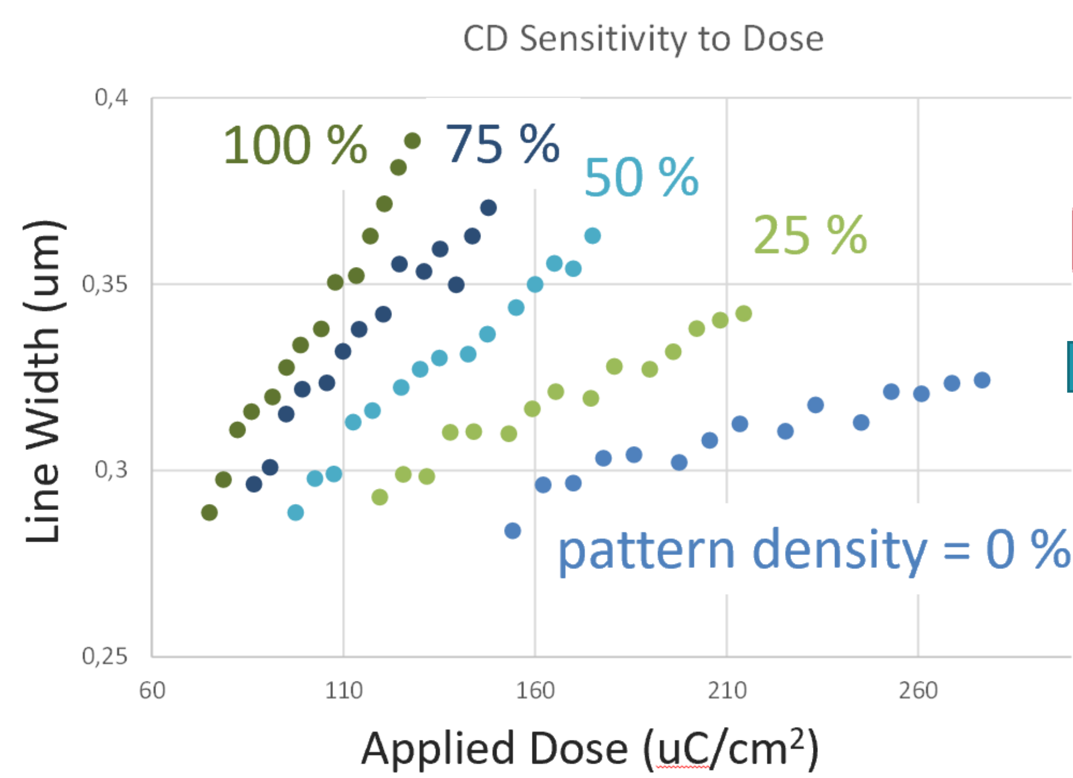
Keep in mind: we can only observe the convolved result of
$CD_{measured}$ = Exposure (CD_{Target}) ⊗ Process ⊗ Transfer ⊗ Metrology

Experiment





With or Without PEC



nm

Dose vs. CD

パターン密度100%(パッド)

50%(1:1 LS)

25%(1:3 LS)

パターン密度0%(孤立線)

700
600
300
200
100
0

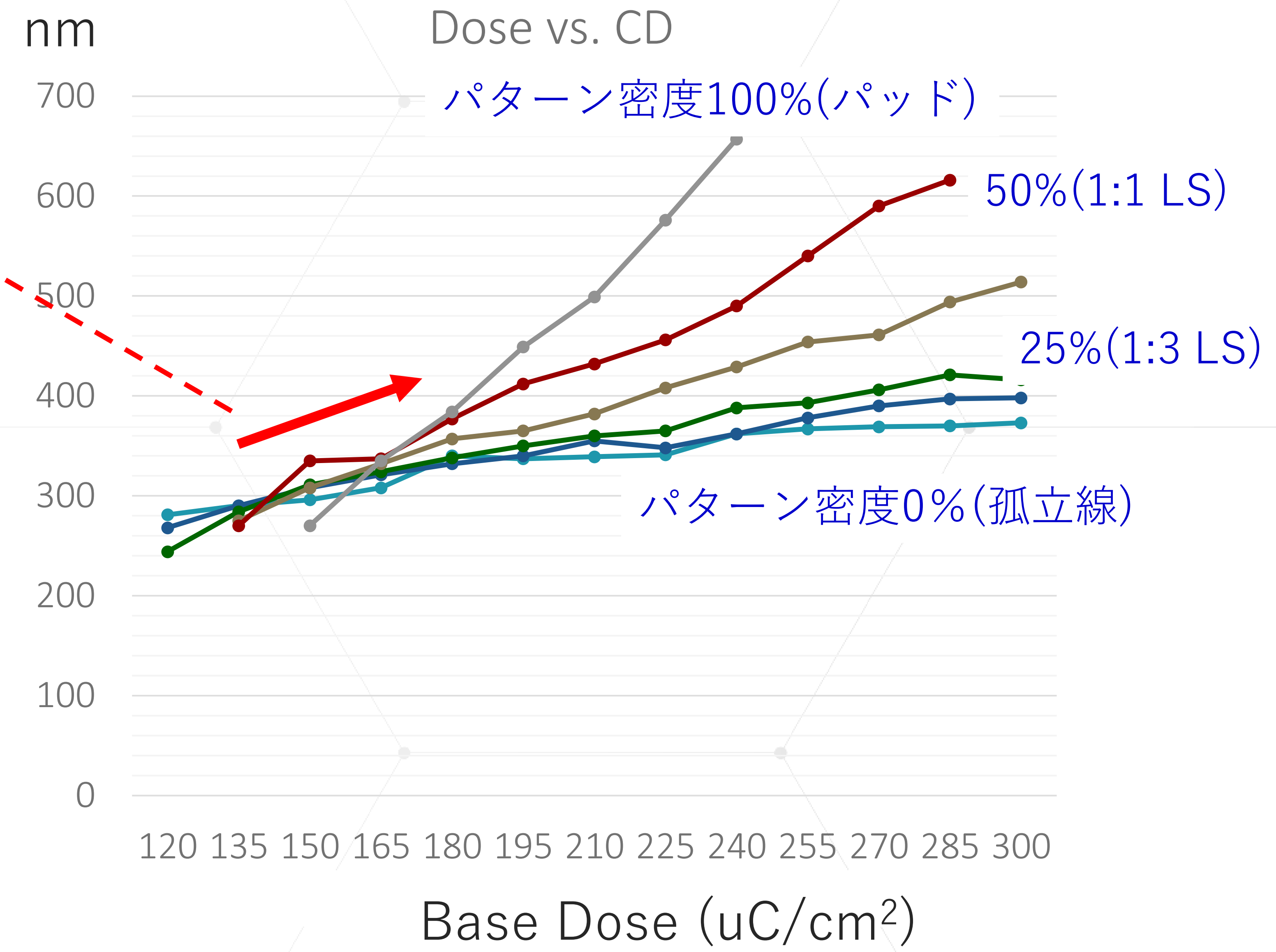
120 135 150 165 180 195 210 225 240 255 270 285 300

Base Dose (uC/cm^2)

Calibration: Process Blur

- Process Blur = 25 nm

カーブ・フィッティングから
Blur値の算出

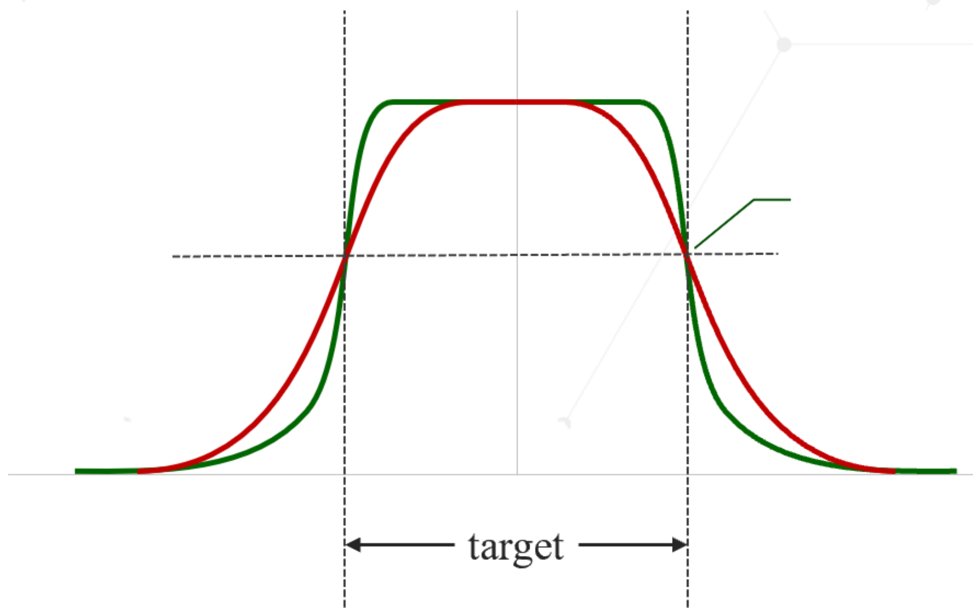


GenISys
Advancing the Standard

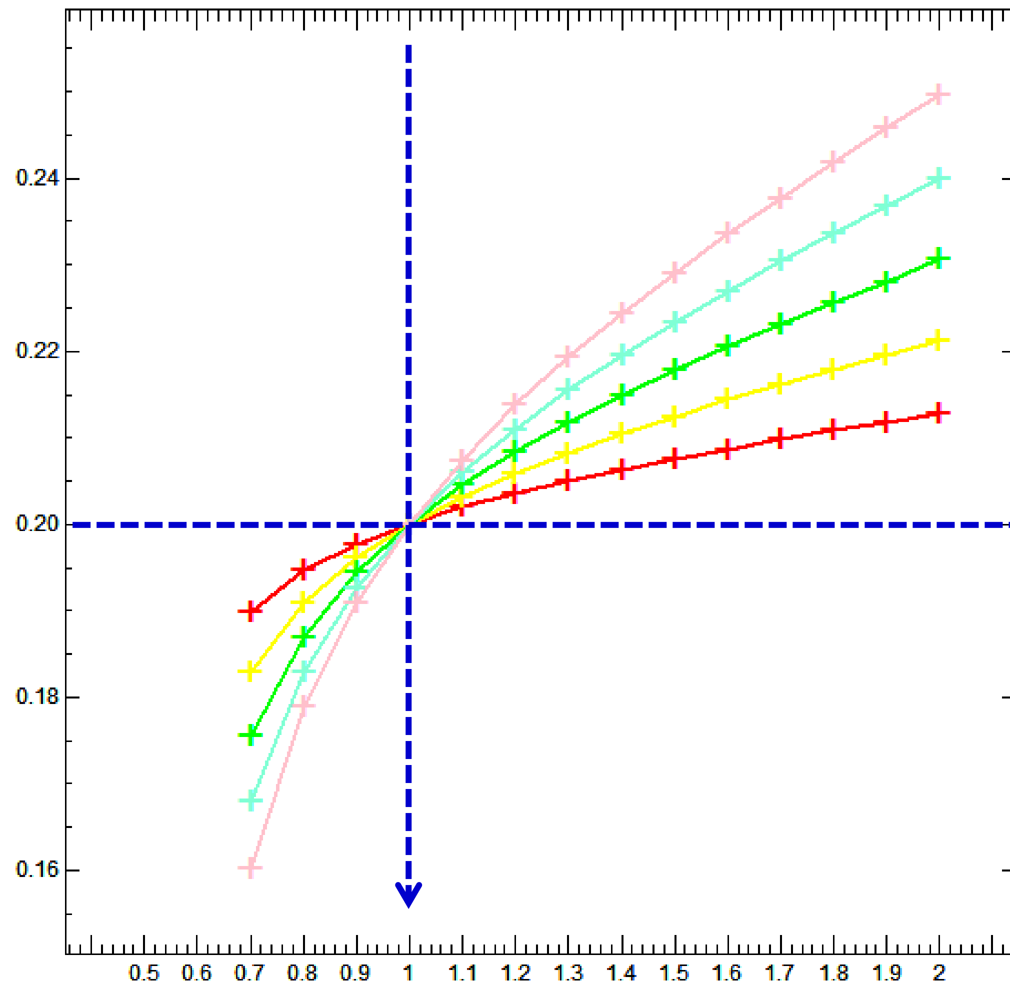
Calibration: Base Dose

- Process Blur = 25 nm
- Base Dose = 165 μC/cm²

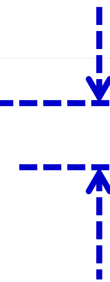
右図クロスポイントから
基準ドーズの算出

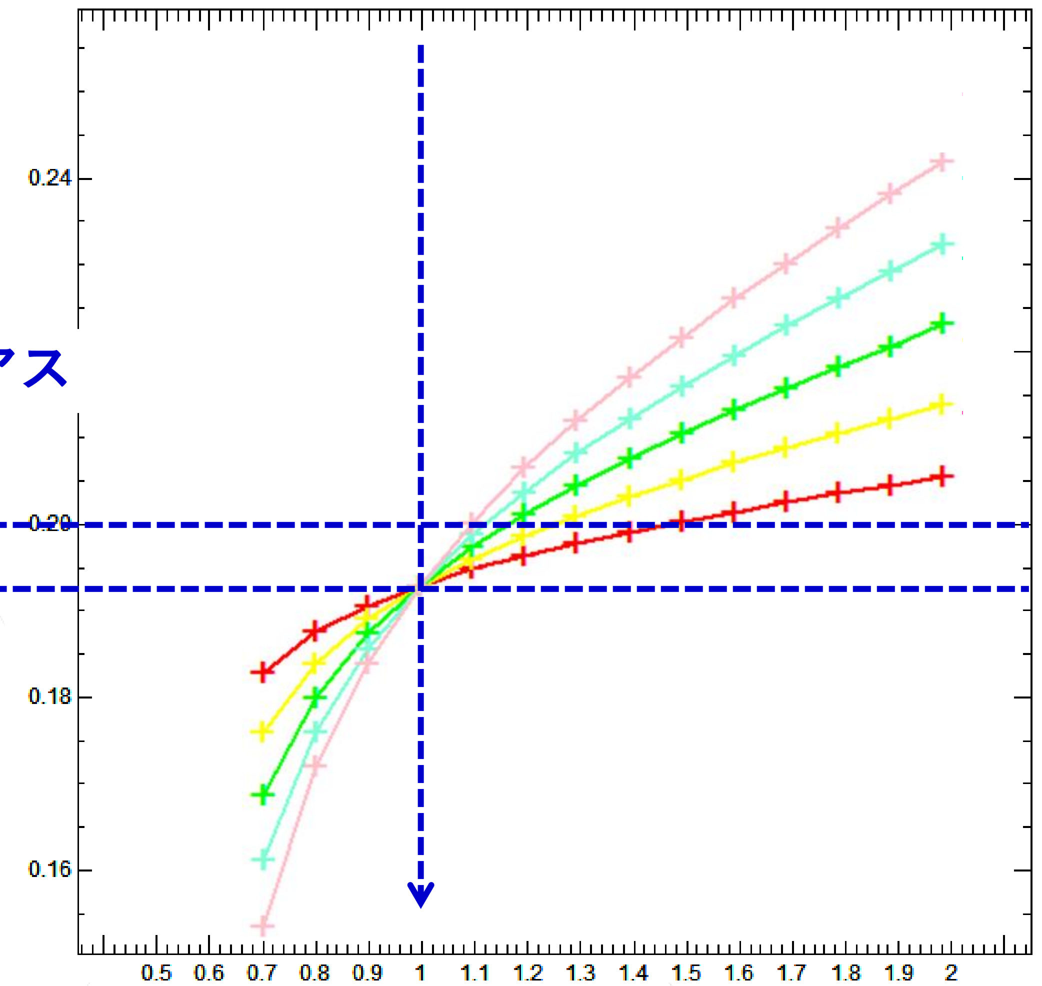


Iso Focal Point (Cross Point)



パターンバイアス

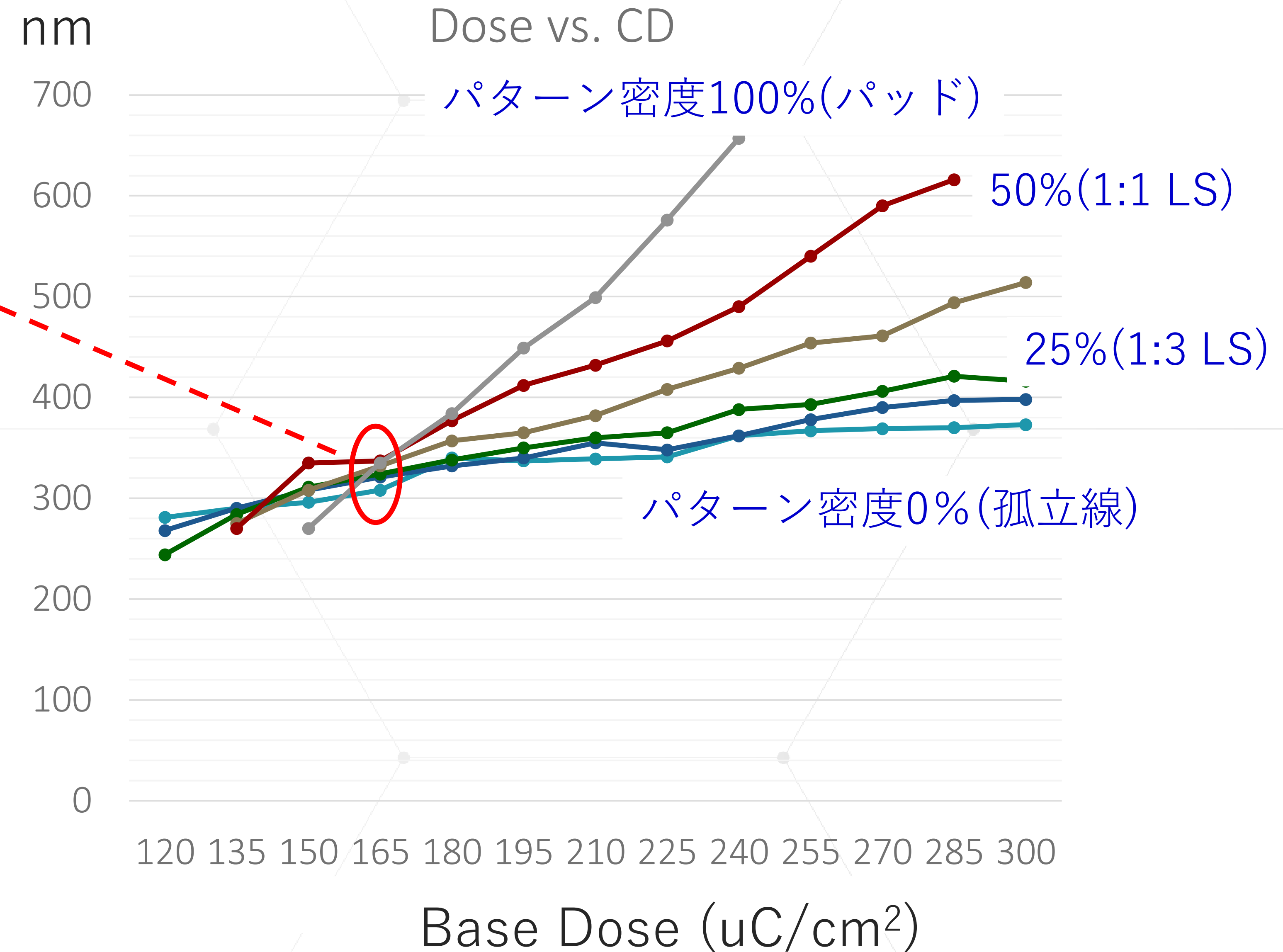




Calibration: Global Bias

- Process Blur = 25 nm
- Base Dose = 165 µC/cm²
- Global Bias = -20 nm

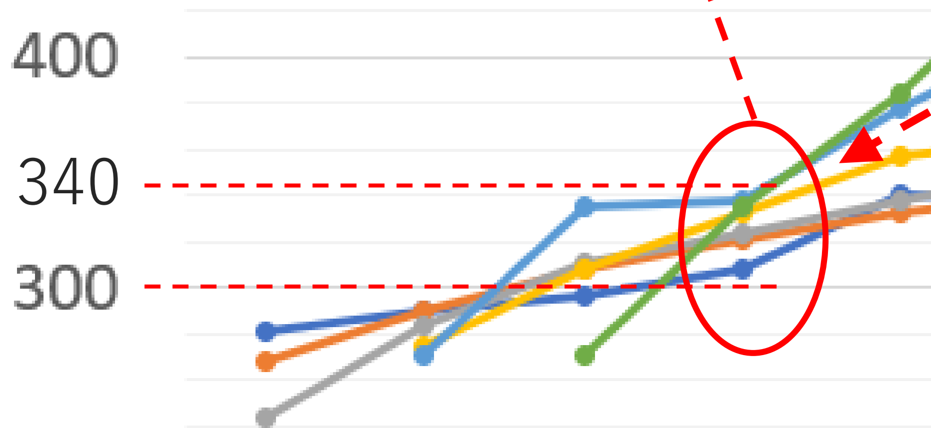
クロスポイントにおける1:1 L&S幅と設計値との差分を全体バイアス値として設定。



Calibration: Lateral Development

- Process Blur = 25 nm
- Base Dose = 165 μC/cm²
- Global Bias = -20 nm
- Lateral Bias
  - iso line (0%) = 4 nm
  - 1:3 (25%) = 18 nm
  - 1:1 (50%) = 29 nm
  - large Pad (99%) = 40 nm

更にパターン密度ごとの細かな差分を横方向現像補正値として設定



Dose vs. CD

nm

700
600
500
400
300
200
100
0

パターン密度100%(パッド)
50%(1:1 LS)
25%(1:3 LS)
パターン密度0%(孤立線)

120 135 150 165 180 195 210 225 240 255 270 285 300

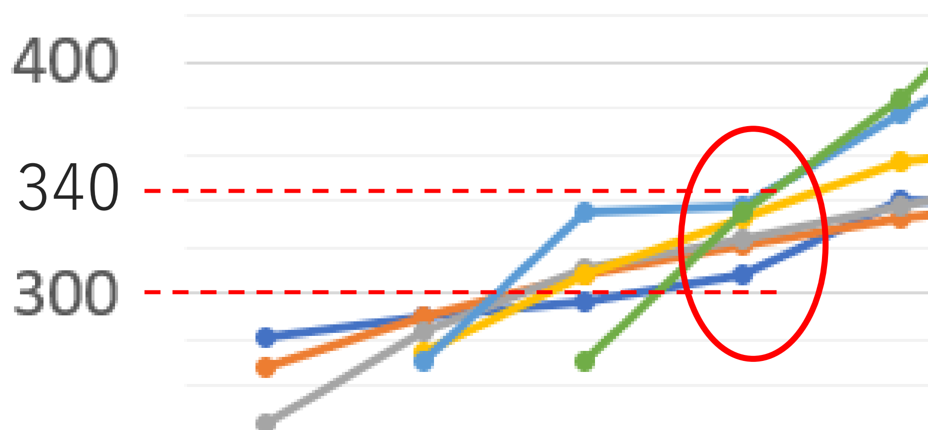
Base Dose (uC/cm²)

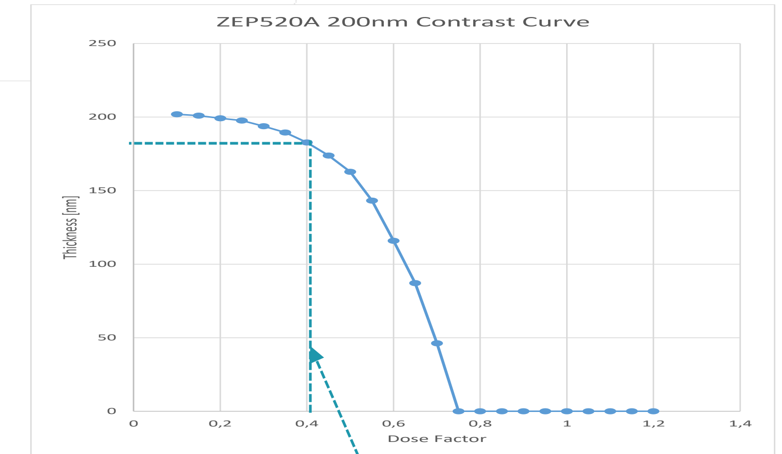
GenISys
Advancing the Standard

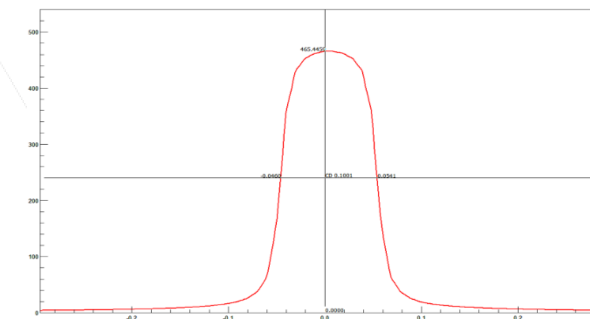
Calibration: Lateral Development

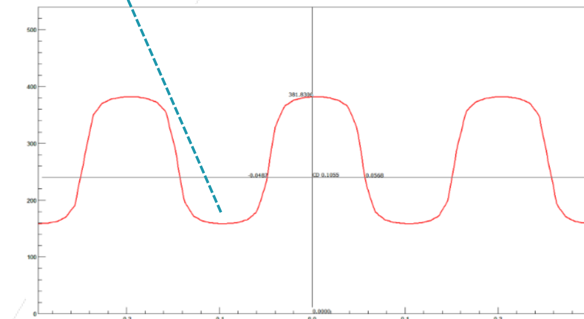
- Process Blur = 25 nm
- Base Dose = 165 μC/cm²
- Global Bias = -20 nm
- Lateral Bias
  - iso line (0%) = 4 nm
  - 1:3 (25%) = 18 nm
  - 1:1 (50%) = 29 nm
  - large Pad (99%) = 40 nm

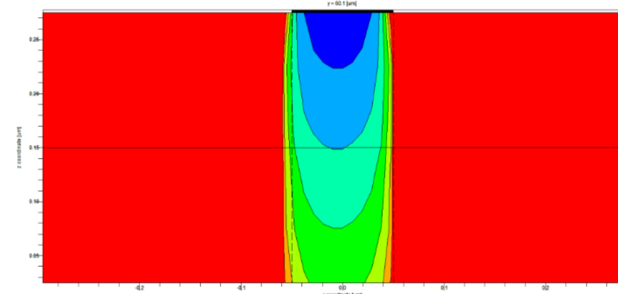
クロスポイントに幅が出来る原因の一つとして「横方向現像」を提案しています。周囲のパターン密度が異なることで、該当パターンエッジでのエネルギーコントラストが変わり得る、との観点からになります。レジスト感度（γ）にも左右されます。

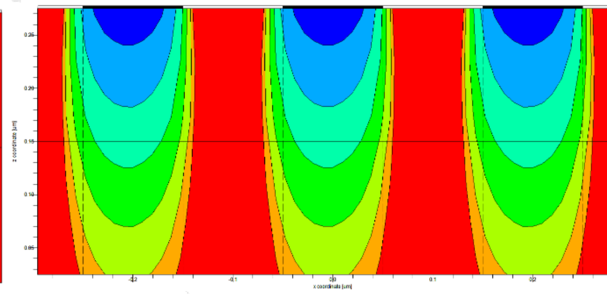






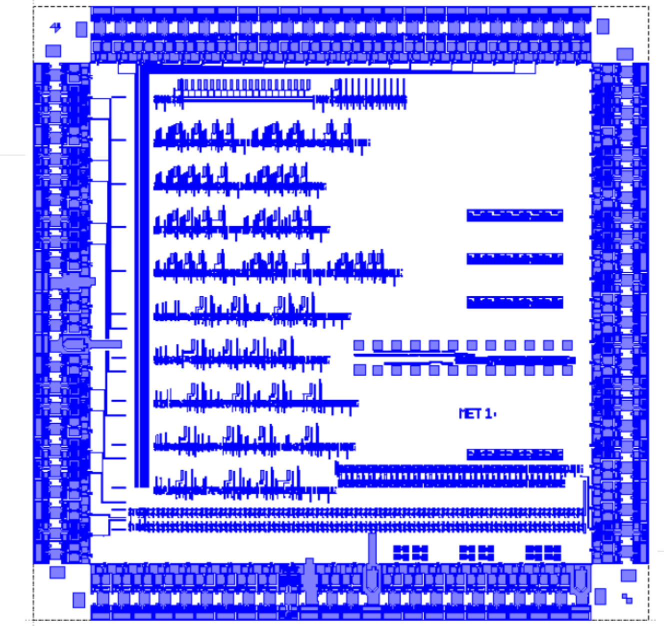


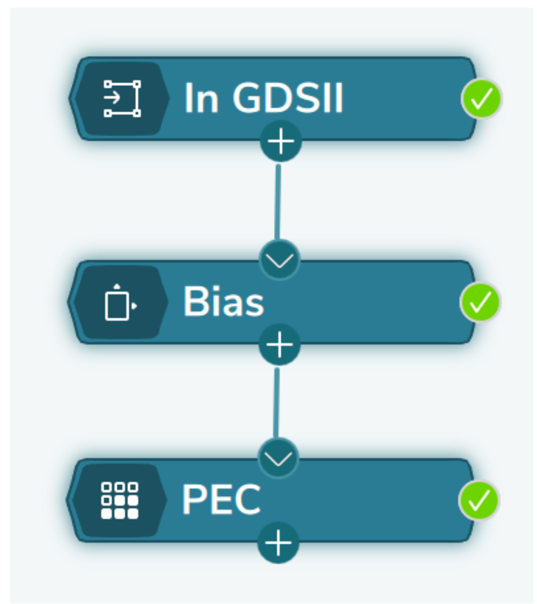




BEAMER Correction

- Process Blur = 25 nm
- Base Dose = 165 µC/cm²
- Global Bias = -20 nm
- Lateral Bias
    - iso line (0%) = 4 nm
    - 1:3 (25%) = 18 nm
    - 1:1 (50%) = 29 nm
    - large Pad (99%) = 40 nm

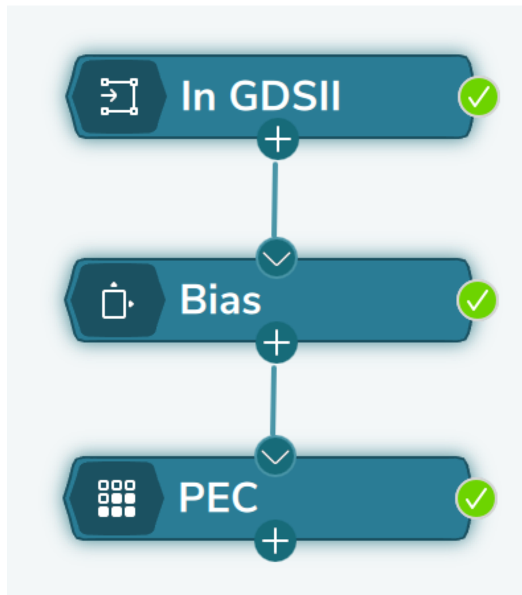




BEAMER Correction

- Process Blur = 25 nm
- Base Dose = 165 µC/cm²
- Global Bias = -20 nm
- Lateral Bias

  iso line (0%) = 4 nm
  1:3 (25%) = 18 nm
  1:1 (50%) = 29 nm
  large Pad (99%) = 40 nm



Proximity Effect Correction

Configure Quick A...

General
Accuracy
Advanced
Comment

Correction Layer Selection
Layer(s)
*

PSF Representation
Archive | Gaussian Approx... | Numerical PSF

Layers: ; Resists: PMMA 100 nm; Energy [kV]: 100;

Archive... | Global Archive... | View Comment...

Effective Short Range Blur ...
0.025

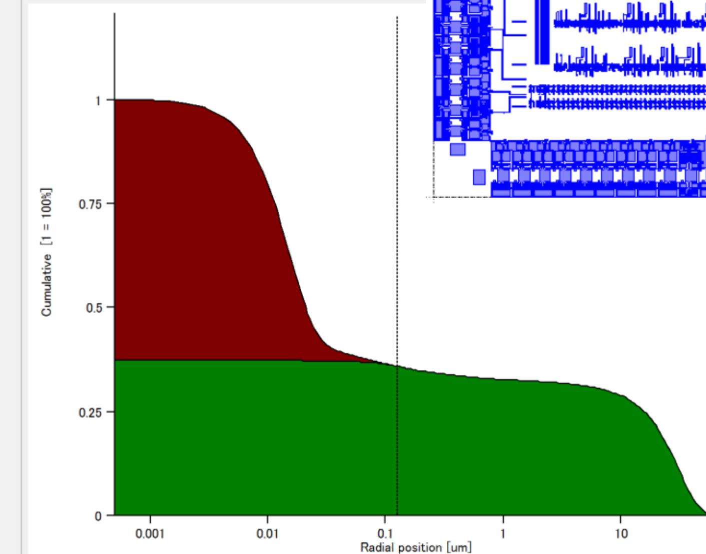
Add Gamma [um] 1.000000
Nue 0.100000

Include Short Range Correction

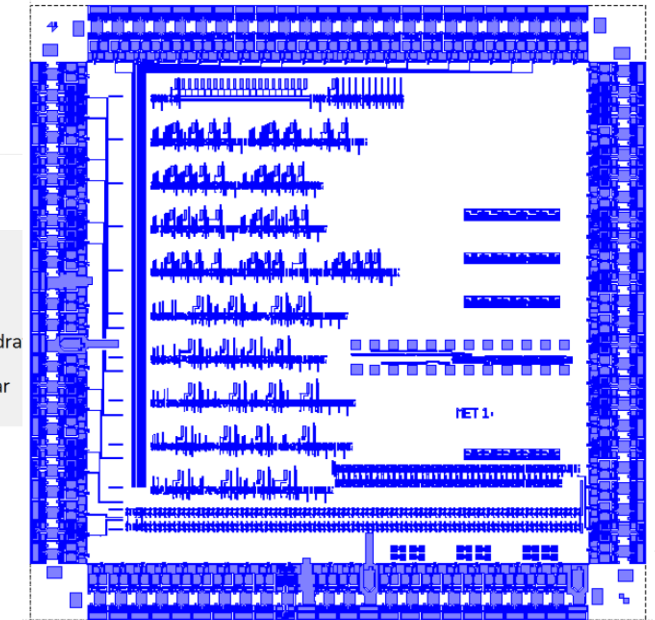
Lateral Development Parameters...

OK Cancel

Show Energy Density
Show Cumulative Radial Energy
Behaviour X-Axis: Logarithmic Quadra
Behaviour Y-Axis: Logarithmic Linear



Separation at 0.1253 um.
No additional Separation necessary.
Additional Information:
Min. layout independent LR dose factor = 0.7294



BEAMER Correction

- Process Blur = 25 nm
- Base Dose = 165 µC/cm²
- Global Bias = -20 nm
- Lateral Bias
  - iso line (0%) = 4 nm
  - 1:3 (25%) = 18 nm
  - 1:1 (50%) = 29 nm
  - large Pad (99%) = 40 nm

Effective Short Range Blur...
0.025

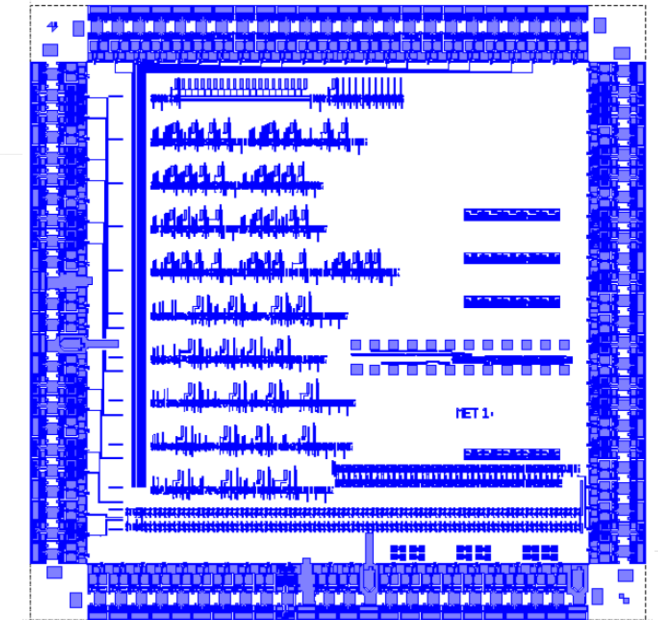
Bias [um]
-0.02

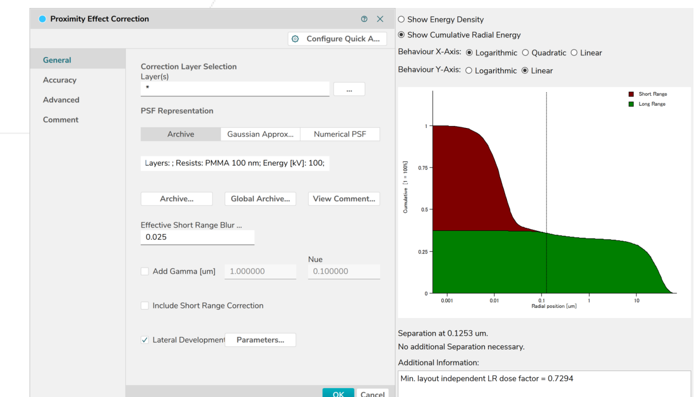
Lateral Developme Parameters...

Lateral Dev. Correction Parameters

PSF-density [-]	Bias [um]
0	-0.004
0.25	-0.018
0.5	-0.029

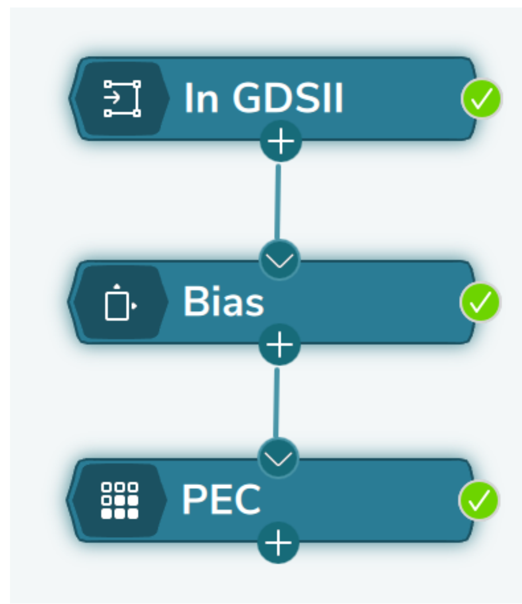
In GDSII
Bias
PEC

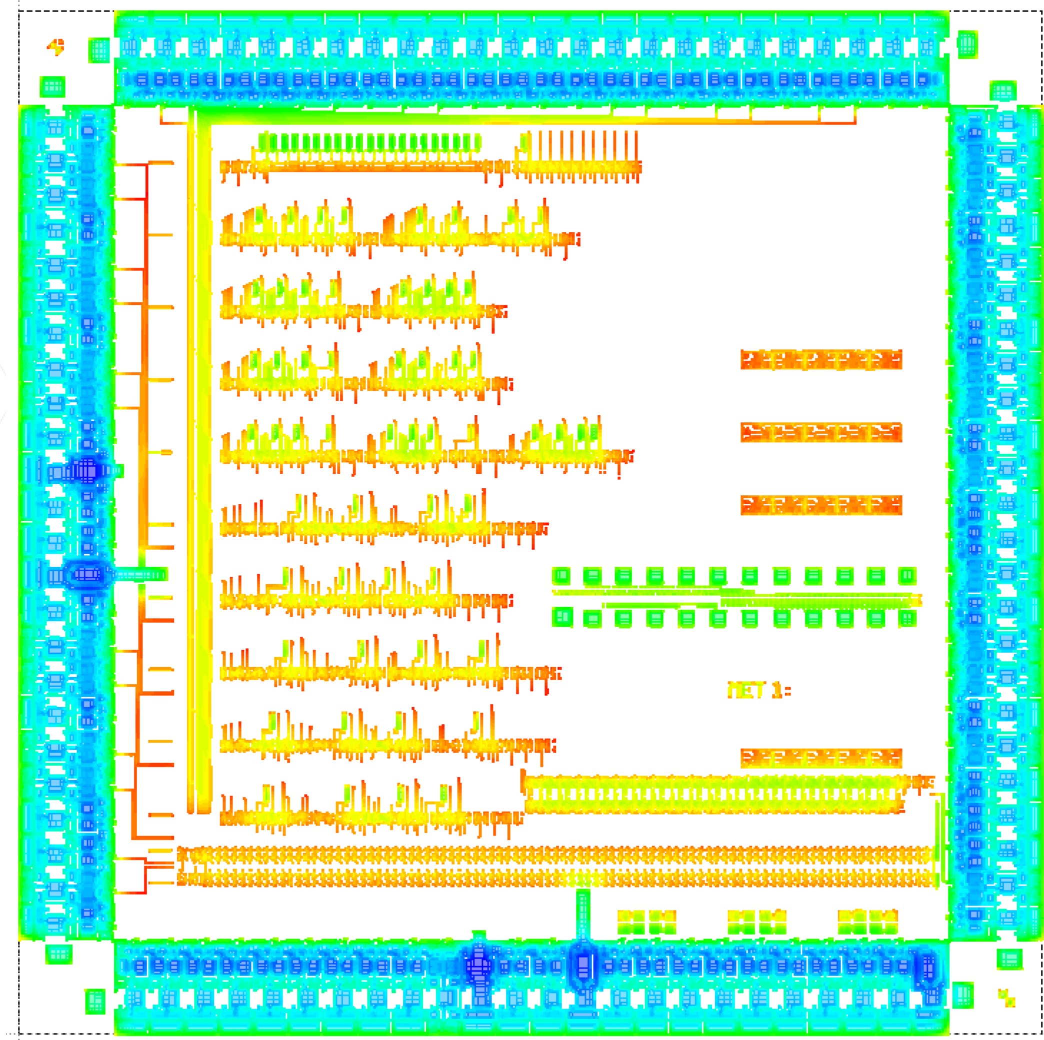




BEAMER Correction

- Process Blur = 25 nm
- Base Dose = 165 µC/cm²
- Global Bias = -20 nm
- Lateral Bias
  - iso line (0%) = 4 nm
  - 1:3 (25%) = 18 nm
  - 1:1 (50%) = 29 nm
  - large Pad (99%) = 40 nm





Agenda

- Background & Model
- Calibration
- **Use Cases**
  - **Weizmann Institute of Science**
  - Univ. Queensland
- Summary

Weizmann Inst. of Science, Diana Mahalu et al.

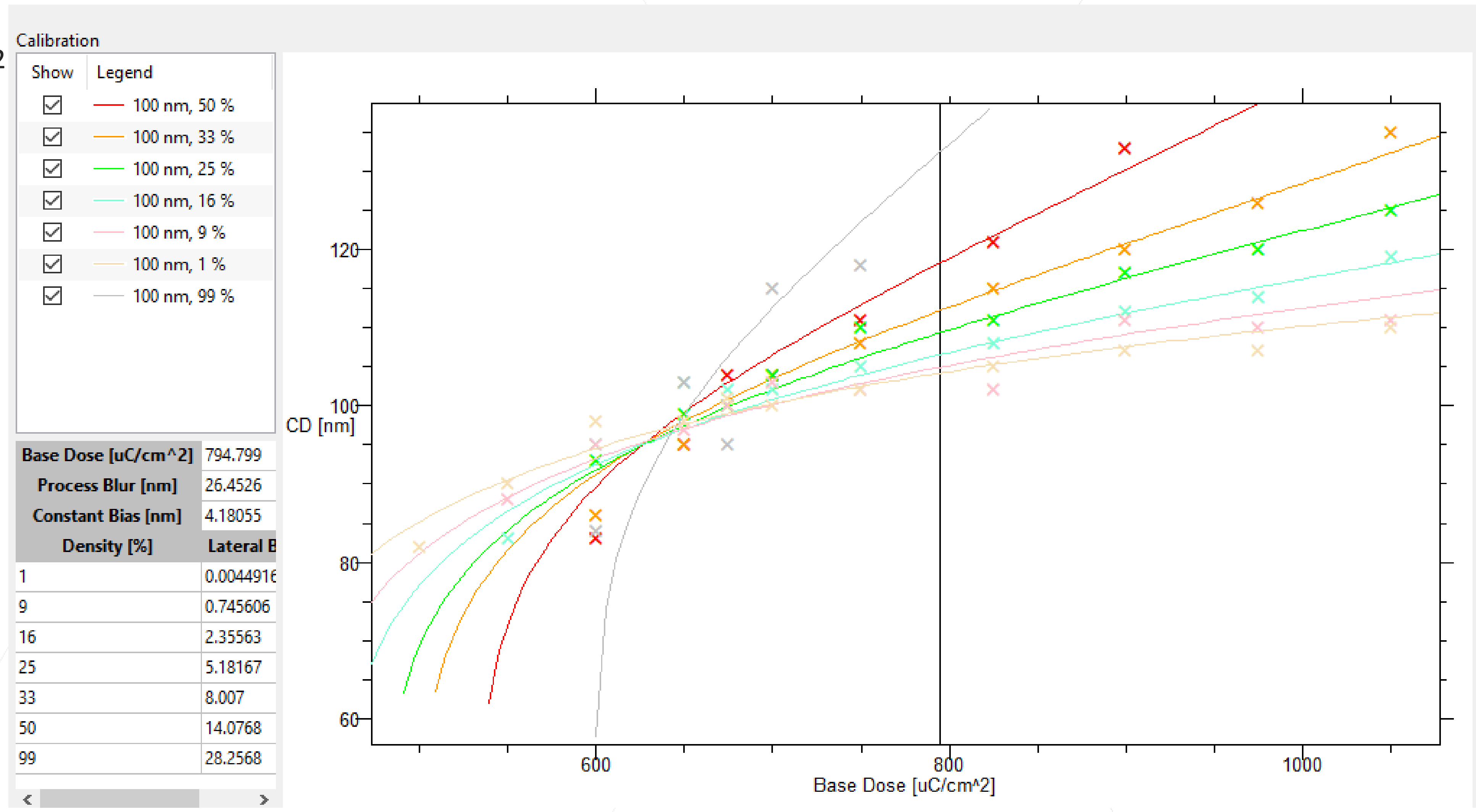
- Calibration of Process Data resulted in
  - Base Dose = 795 µC/cm²
  - Process Blur = 26 nm
  - Bias

    Bias (0%) = 4 nm

    Bias (25%) = 9 nm

    Bias (50%) = 18 nm

    Bias (99%) = 32 nm



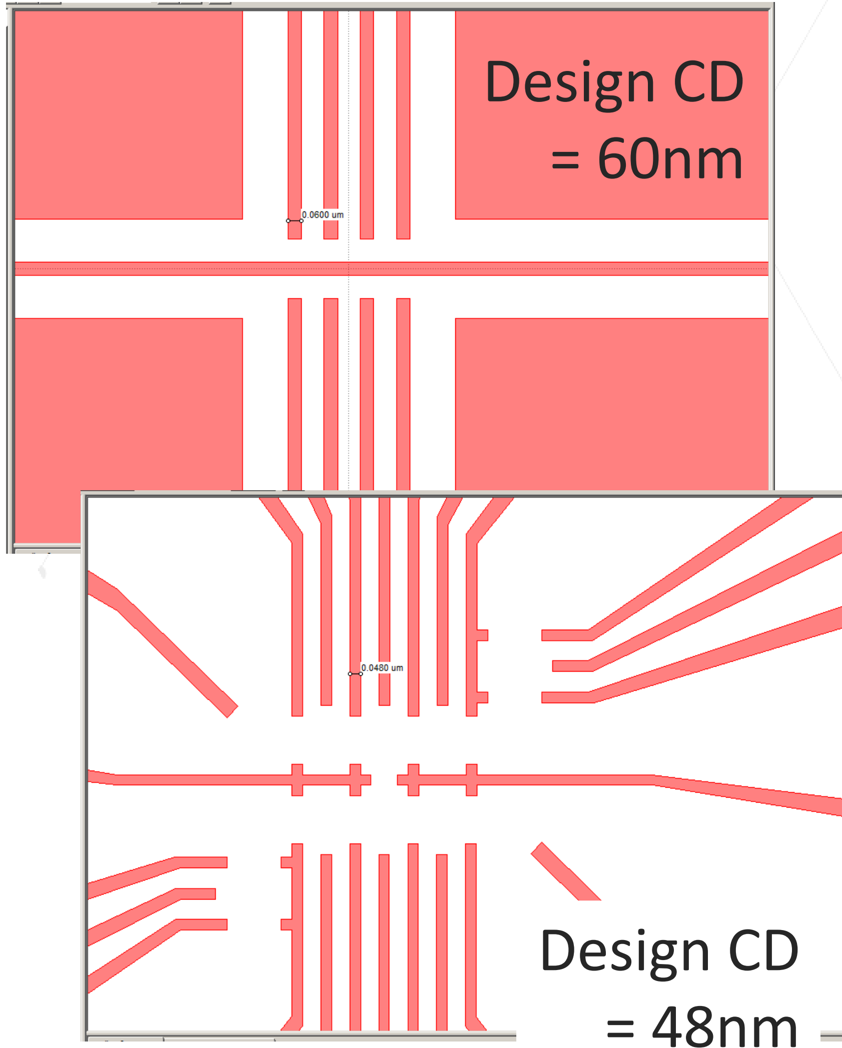
Base Dose [uC/cm^2]	794.799
Process Blur [nm]	26.4526
Constant Bias [nm]	4.18055
Density [%]	Lateral B
1	0.0044916
9	0.745606
16	2.35563
25	5.18167
33	8.007
50	14.0768
99	28.2568

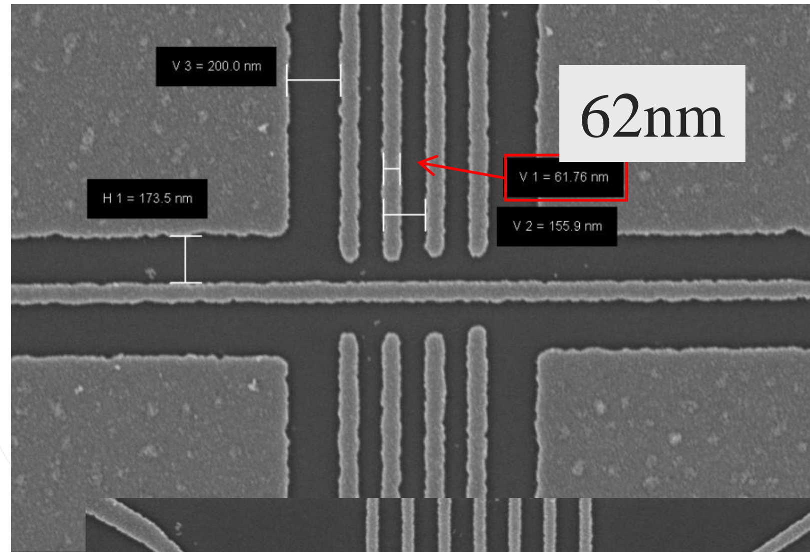
Source:

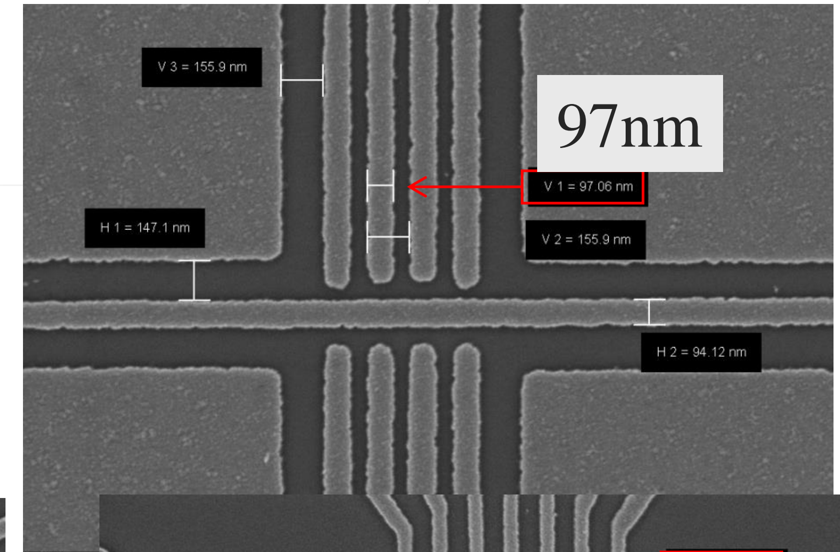
מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

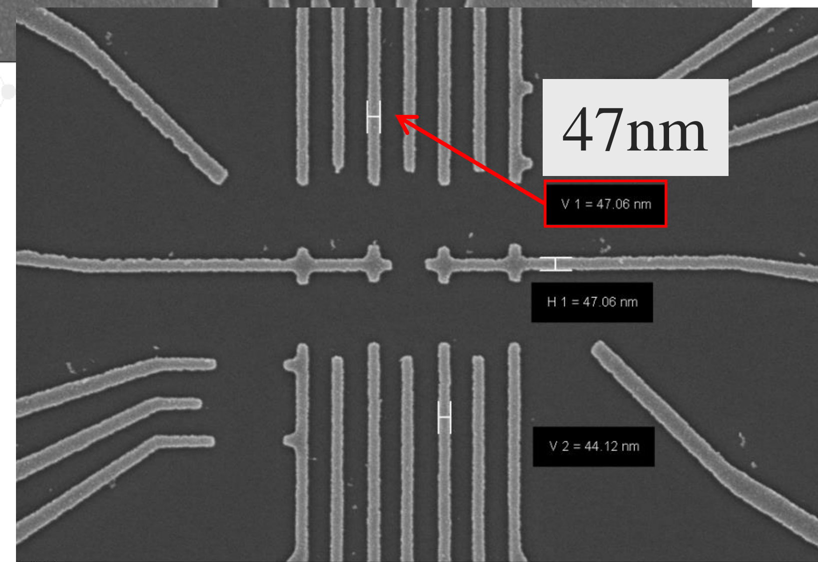
GenISys
Advancing the Standard

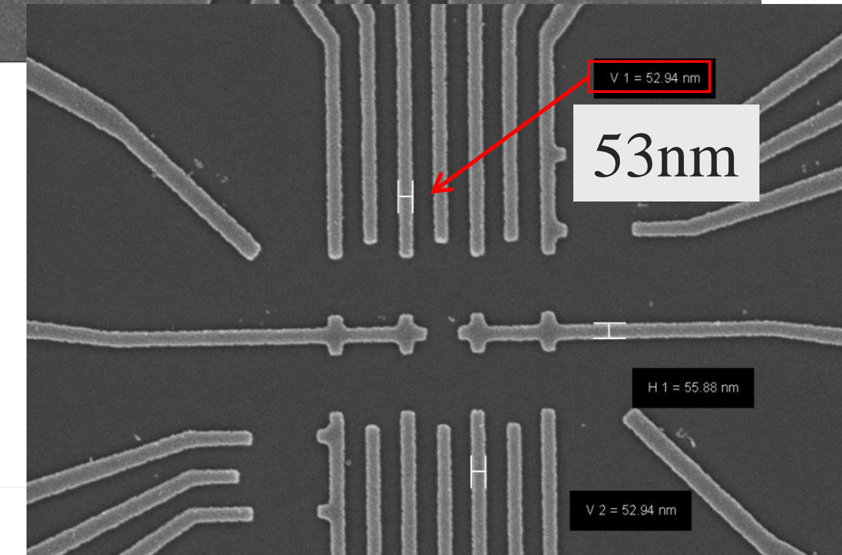
Weizmann Inst. of Science, Diana Mahalu et al.











Process Corrected

No process corrected

Source:
מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

- Excellent Results on different layouts at different densities

Agenda

- Background & Model
- Calibration
- **Use Cases**
  - Weizmann Institute of Science
  - **Univ. Queensland**
- Summary

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

Our project goals – an *automated metrology workflow*

- Develop a **complete and automated** workflow for design, lithography correction (TRACER, BEAMER), fabrication, characterisation (ProSEM), and analysis
- Feed analysis results back into TRACER to optimise EBL parameters for **minimising line-edge-roughness** (LER)

3

Elliot Cheng, Daniel Peace, Zach Degnan
Centre for Microscopy and Microanalysis (CMM)
The University of Queensland, Brisbane, Australia

Univ. Queensland, *Elliot Cheng et al.*

University Solution for Metrology Automation

Concept Simulation

Electronic Design Automation (EDA)

Lithography Correction & Optimisation (PEC)

Nanofabrication (EBL/Etching)

GDStoSEM

AutoSEM

Customised software scripts

TRACER Calibration file

SEMET

Device Characterisations

Batch Data Analysis

Batch Image Analysis

ProSEM

Automated SEM Imaging

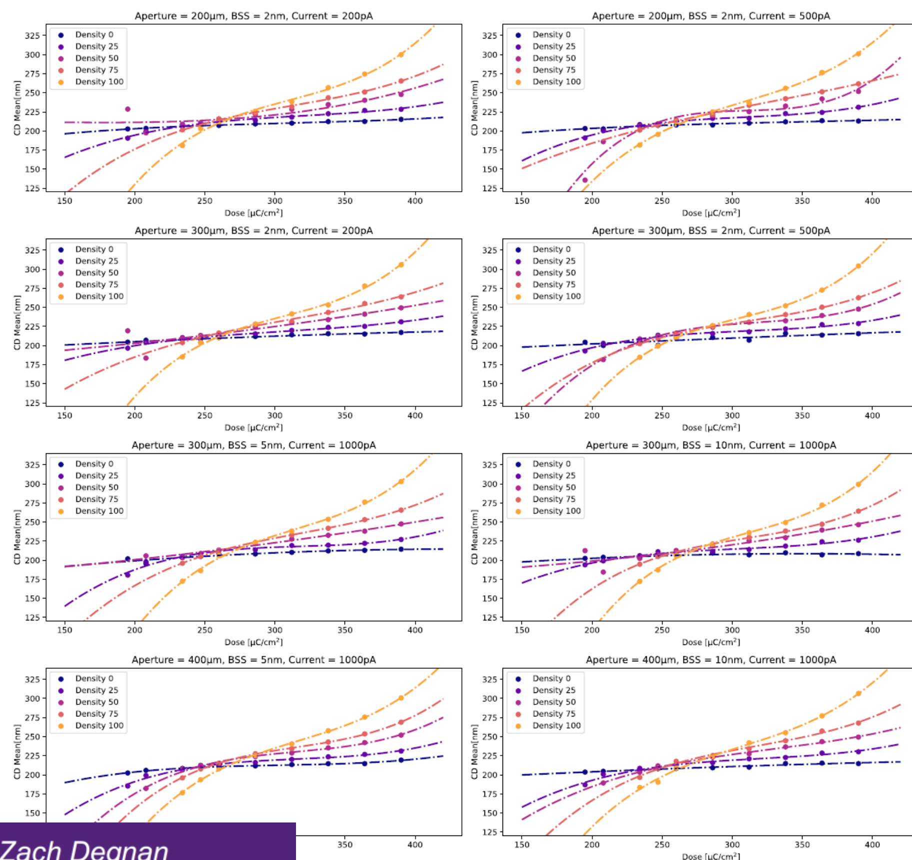
Elliot Cheng, Daniel Peace, Zach Degnan
Centre for Microscopy and Microanalysis (CMM)
The University of Queensland, Brisbane, Australia

Univ. Queensland, *Elliot Cheng et al.*

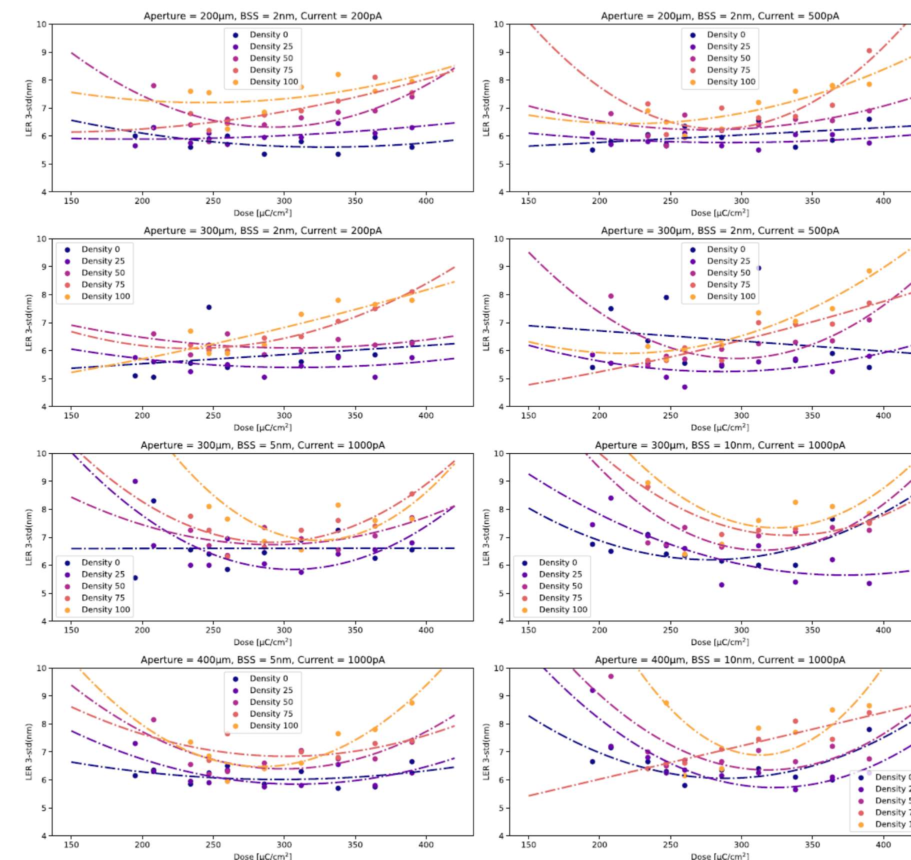
THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

CD/LER Summary: ARP6200 on SOI – target CD 200nm

ARP6200: Dose vs CD Mean[nm]



ARP6200: Dose vs LER 3-std(nm)



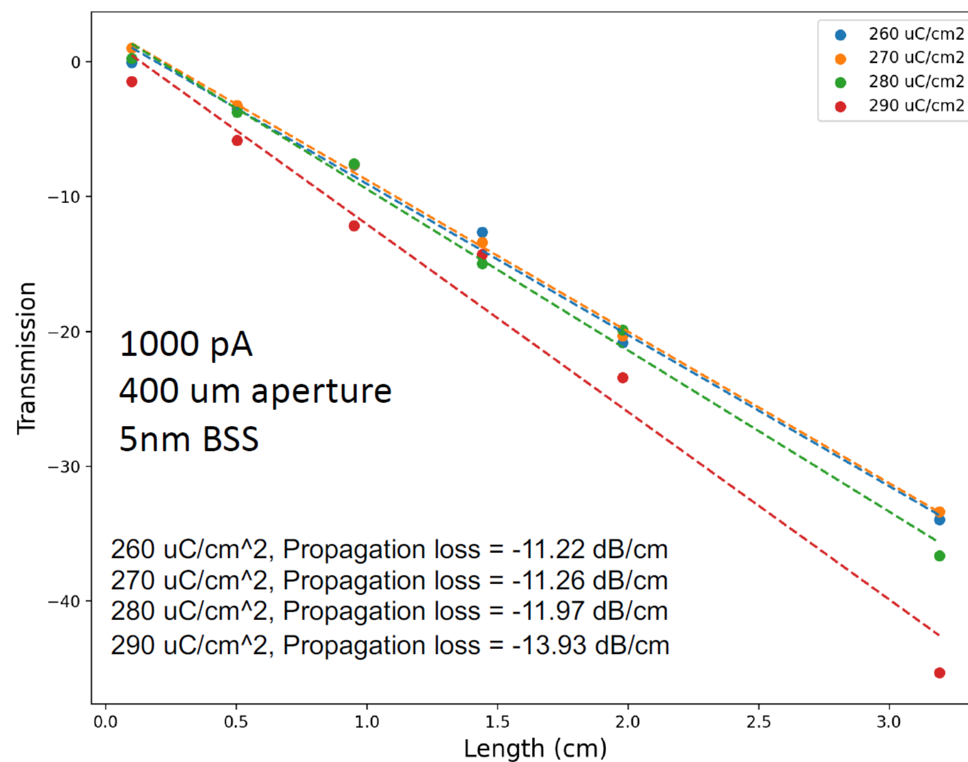
Elliot Cheng, Daniel Peace, Zach Degnan
Centre for Microscopy and Microanalysis (CMM)
The University of Queensland, Brisbane, Australia

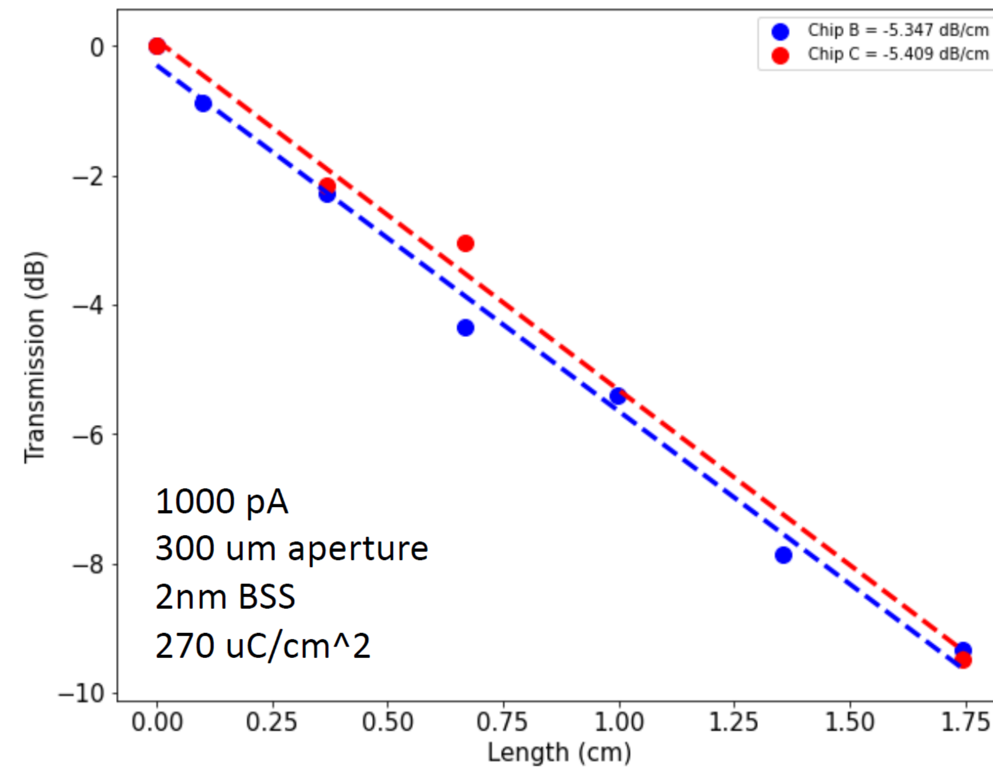
Univ. Queensland, *Elliot Cheng et al.*

The University Of Queensland
Australia

EBL Writing Strategy + Large Data Analysis + Etch Recipe

61% improvement on the ARP6200 on SOI using optimal beam parameters from LER study





Elliot Cheng, Daniel Peace, Zach Degnan
Centre for Microscopy and Microanalysis (CMM)
The University of Queensland, Brisbane, Australia

Agenda

- Background & Model
- Calibration
- Use Cases
- **Summary**

GenISys
Advancing the Standard

Summary

- 近接効果補正 → 電子線散乱モデルによる補正
- プロセス補正 → 上記以外の擾乱要因の補正

1) 現像条件、化学反応、レジスト解像度、装置振動、SEM観測精度
→ Beam Blurとしての取り扱い
2) クロスポイントを基準ドーズとして選択
→ 擾乱要因（Blur）に依らず、設計線幅が得られやすい
3) クロスポイントにおける設計線幅からのずれ
→ 設計値バイアス（パターン・バイアス）として補正
4) クロスポイント領域内でのパターン密度ごとの微小な線幅のずれ
→ 横方向現像成分としてパターン密度ごとに個々に補正

Join Us!

Position Overview

We are looking for a highly motivated Applications Engineer for the GenISys Japan team to support sales and adoption of GenISys' products. Topics can be on lithography corrections, process simulation, and layout optimization as well as advanced SEM-based image analysis, metrology, and inspection. Cooperation with tool vendors or working on related instruments is an important part in both cases. We are offering a varied and exciting position in a unique environment of nanoscience and leading-edge nanotechnology serving international communities. You will be part of and receive second line support from a team of innovative, results-oriented, and self-dependent experts.

About GenISys

GenISys has become a global market leader in the field of electron-beam lithography software and is expanding to related markets of lithography and metrology. Our team combines deep technical expertise in layout data processing, image analysis, physical modelling, and measurement algorithms with world-class software engineering and nanofabrication knowledge for development and production.

Job Opening

GenISys

www.genisys-gmbh.de

Global Headquarters
GenISys GmbH
Eschenstr. 66
D-82024 Taufkirchen, Germany
Phone: +49-89-3309197-60
Fax: +49-89-3309197-61
sales@genisys-gmbh.com

Asia Pacific & Japan
GenISys K.K.
Tokyo Japan
Phone: +81-3-6423-0611
ap@genisys-gmbh.com

North America
GenISys Inc.
Santa Clara, California, USA
Phone: +1-408-353-3951
usa@genisys-gmbh.com