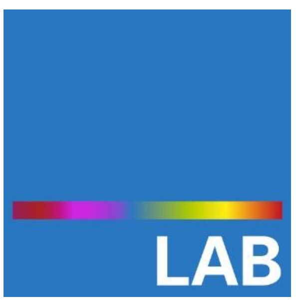
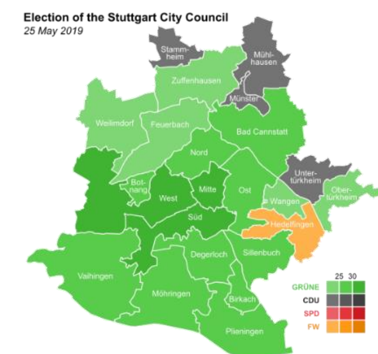
BEAMeeting Stuttgart

Technical Workshop & Discussion



Stuttgart Facts

- 5th largest city in Germany
- The name “Stuttgart” comes from “Stutengarten”
  - following the name of a stud farm (10th century)
- 400 sets of outdoor stairs
  - 20km in total if you climbed them all
- The worlds first TV tower
- Real American redwoods are growing here (Wernhagenpark)
- “Maultaschen” (swabian ravioli) were invented at the Maulbronn monestary
  - The nickname “Herrgottbscheißerle” (god deceivers) came from a monk who sneaked meat under the pastry cover, hoping that God wouldn’t notice…
- Home to the big car companies such as Mercedes Benz and Porsche
- Stuttgart has second largest mineral water reservoir in Europe
  - 14 springs, 44 million liter / day



GenISys
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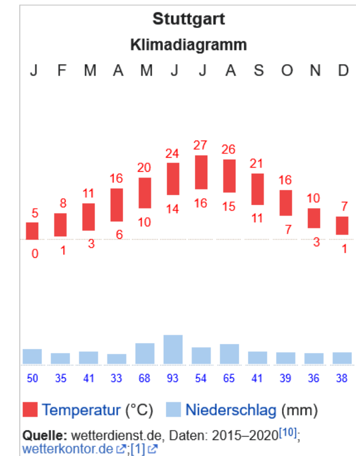
BEAMeeting in Stuttgart

- Why here – because of best weather conditions ☺
  - Least rain and moderate temperatures in April…



- Technology driven – mobility started here
  - birthplace of the petrol powered motorcar (1886)
  - Bertha Benz "advertising campaign"
    - 1888 tour from Mannheim to Pforzheim
  - The 125m long Schwabtunnel was the first tunnel a car passed through (1900)
  - F.Porsche designed the car for "everyone"
  - Diana's (princess of Wales) car is here in the museum

- Technology driven – Semiconductor and chips today

GenISys
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About GenISys

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

- Founded in 2005 in Munich
  - joined RSBG Group LAB14 in 2018
- Headquarter in Taufkirchen - Munich, Germany
  - Subsidiaries in USA, Japan and Turkey
  - Development locations in Jena, Erlangen & Urla
- Worldwide leader on proximity and process correction for electron and laser lithography processes

GenISys continues to grow while maintaining customer centric spirit!

GenISys
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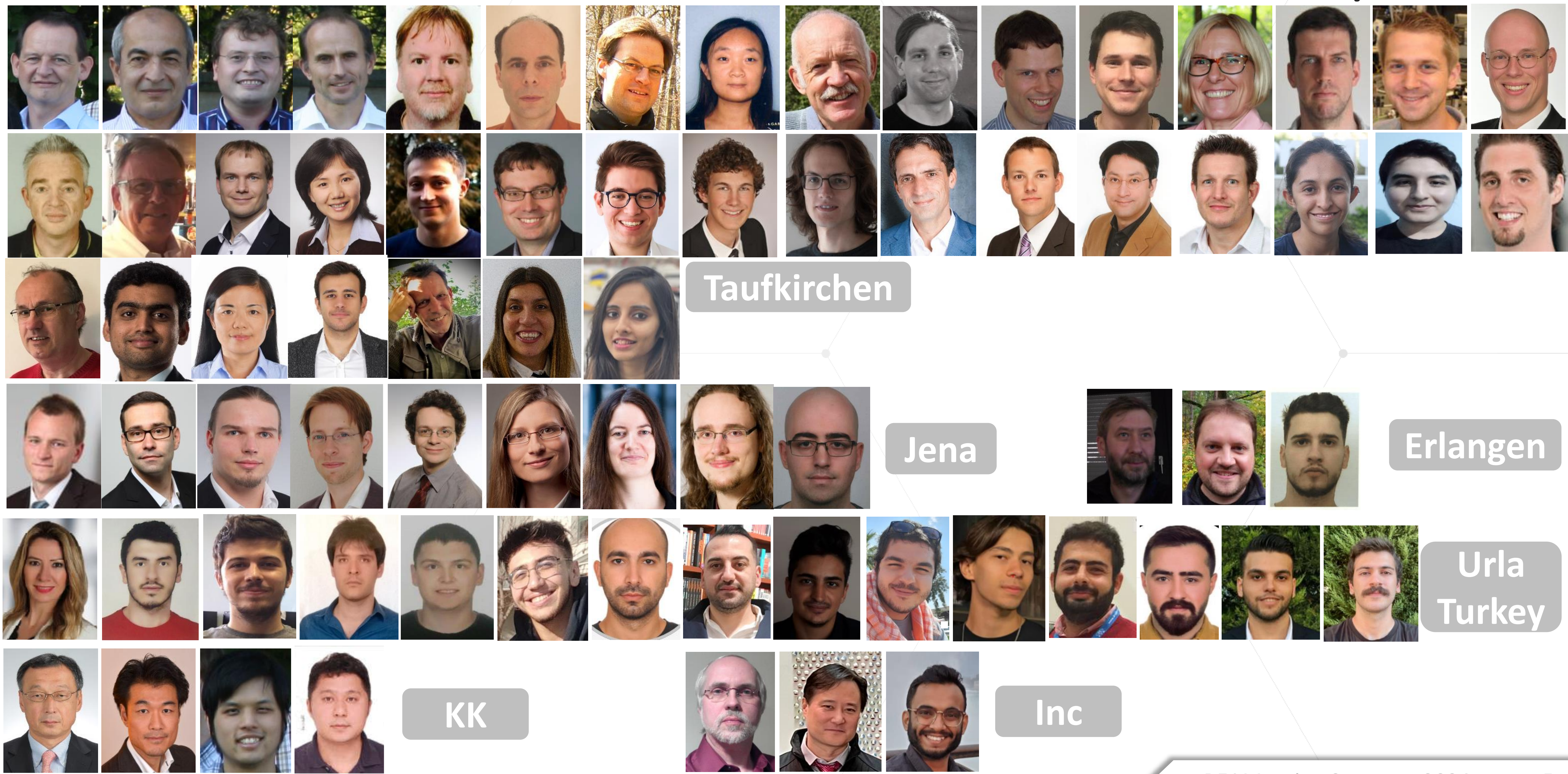
GenISys Team



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

3D lithography simulation & OPC software

- Proximity Lithography (mask aligner) & Projection Lithography (stepper / scanner)
- Electron Beam Lithography, Laser Beam Lithography

Proximity & Process Calibration software

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

Mask Production Software

- Dedicated MDP for mask house, high performance (hierarchy, parallel processing, mask process correction…)
- Special Application: Flat Panel Display, Photonic IC, non-IC

SEM Image Analysis & Metrology

- Advanced SEM metrology software for process monitoring of lithographic patterns or micro and nanostructures
- Automated layout-based image acquisition via digital interface remote control of SEM tools

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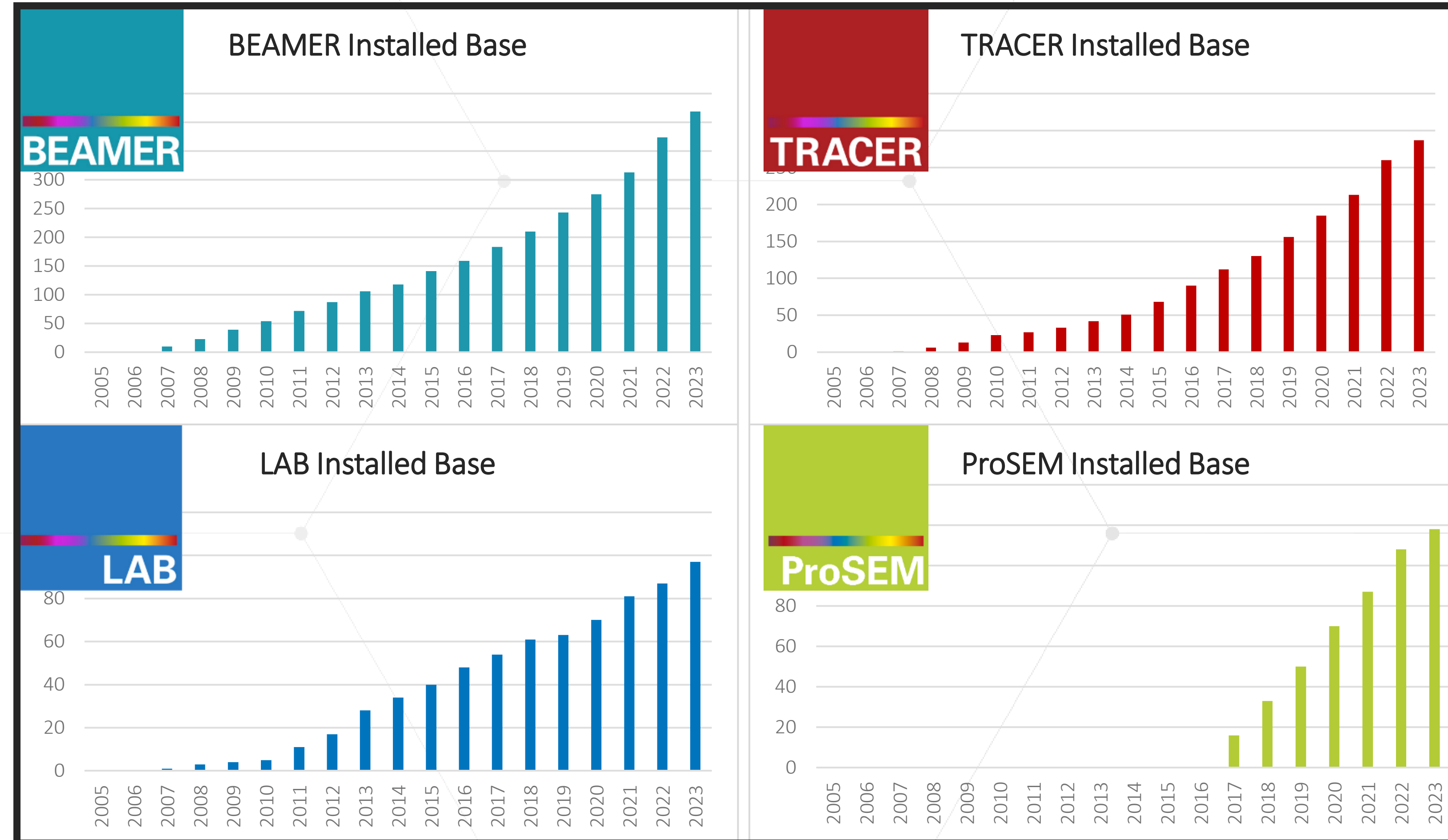
Products Installed Base 2023

Growing Customer Base (>1000)

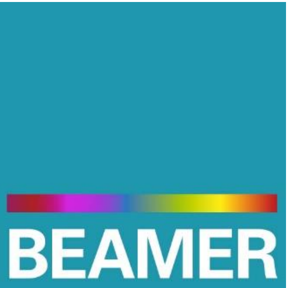
- BEAMER and TRACER
  - > 410 BEAMER installation
  - > 280 TRACER installation
- LAB Lithography Simulation
  - > 95 LAB installation
- ProSEM SEM Metrology
  - > 115 ProSEM installation



GenISys – Solution Provider

GenISys offers “more than software”:

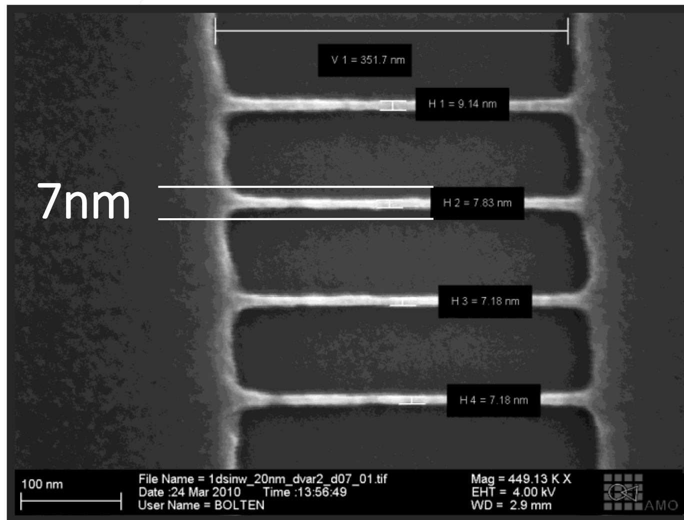
- Application support including process (~ 10 Application Engineer)
  - Process knowledge from > 200 advanced Nano-Centers
- Active user comunity beyond exposure tool
  - ~ 500 users meet at BEAMeetings worldwide
- Allways at the „spearhead“ of technology with two major releases and frequent patches per year
  - new feature, enhancements and fixes
  - all development is driven by users / equipment partners
  - fast reaction on critical issues (patch in 24 hours)



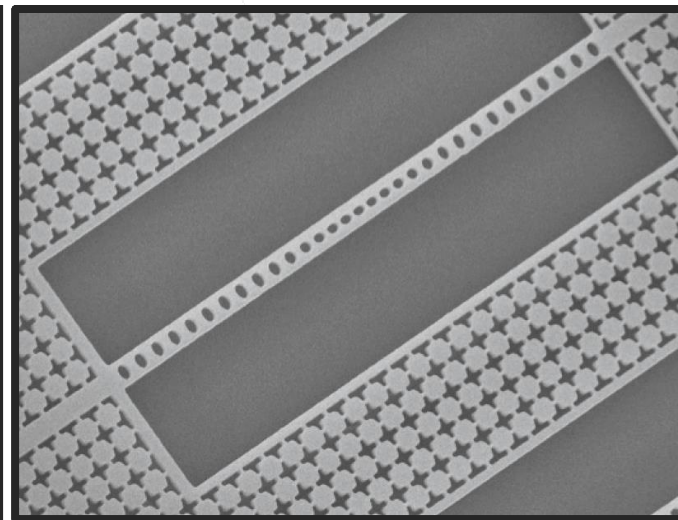
Pushing the limits …

Lithography equipment and processes need optimization to push limits of nano devices:

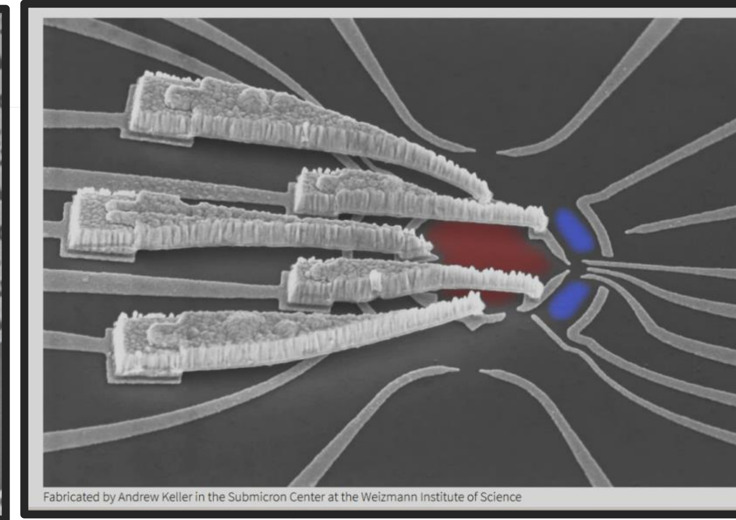
- Proximity and process effects
- Complexity of design and materials



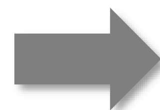
Source: AMO GmbH - Germany



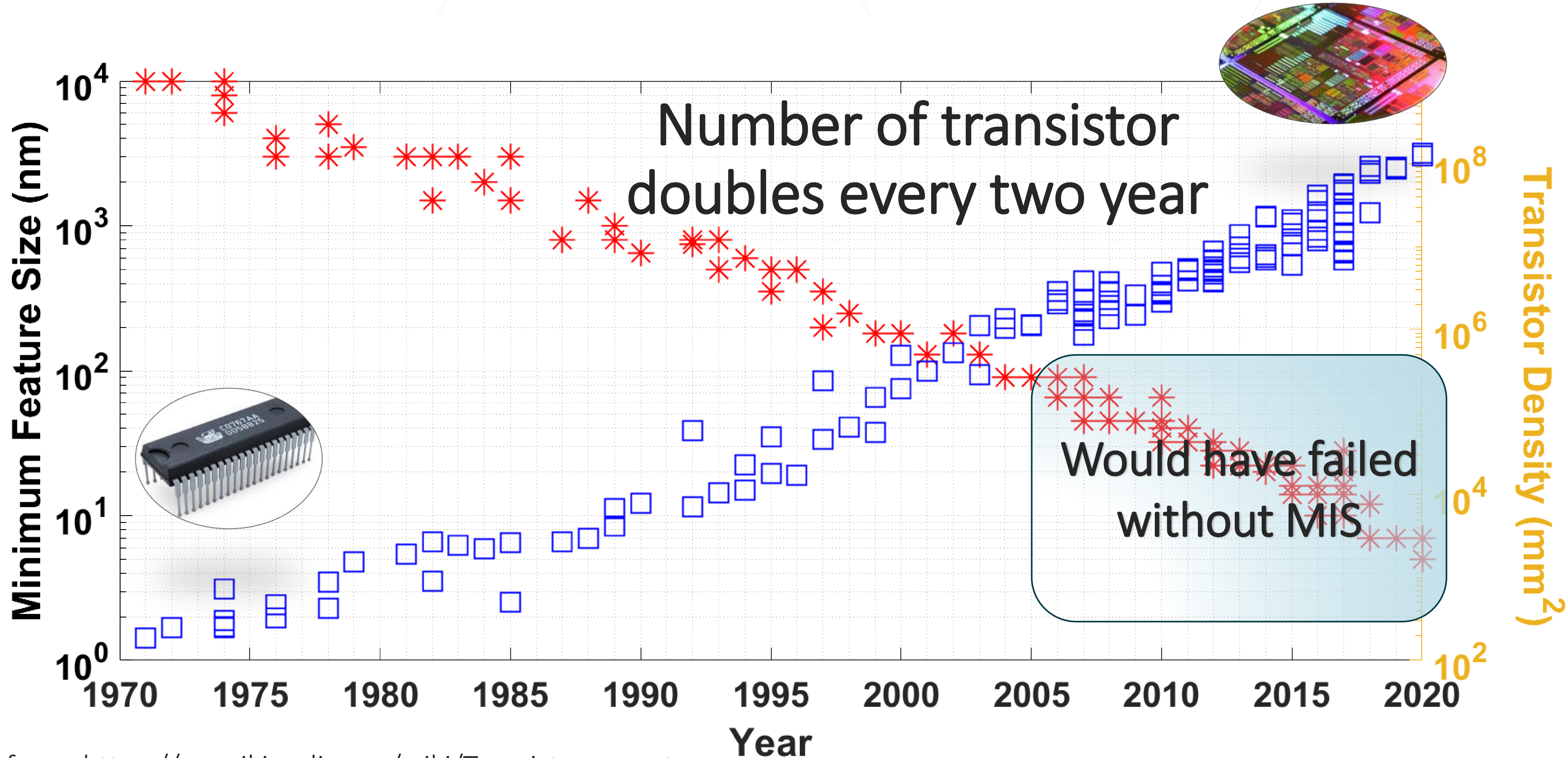
Source: NIST CNST - USA



Source: Weizmann Institute – Israel
Stanford University, USA

Improve Process  BETTER DEVICE

Moore's Law



Data from: https://en.wikipedia.org/wiki/Transistor_count

Metrology in Manufacturing

This is how
IC manufacturing
patterns...

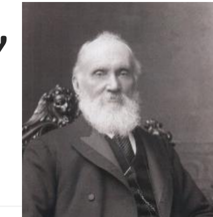
Images vendor webpages

This is how
IC manufacturing
measures...

Image AMAT webpage

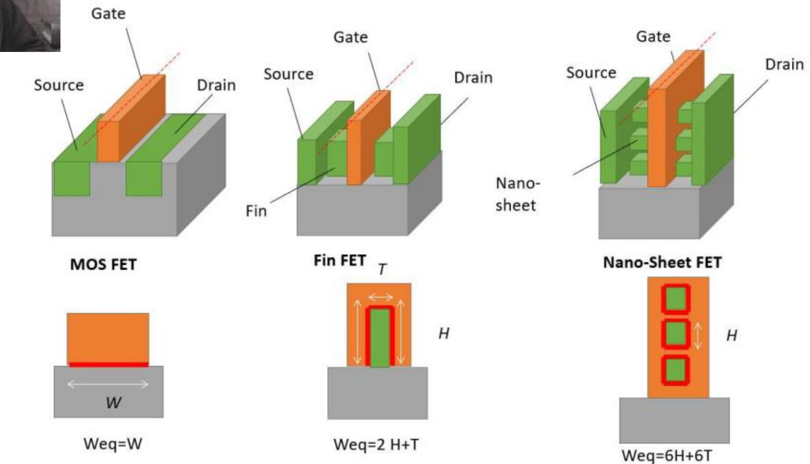
- Consistent and reliable measurements are critical for IC manufacturing
  - Fully automated, very fast, consistent using reliable algorithm
  - CDSEMs are expensive and inflexible – not affordable for most nanofabrication facilities

Metrology & Inspection (MIS)

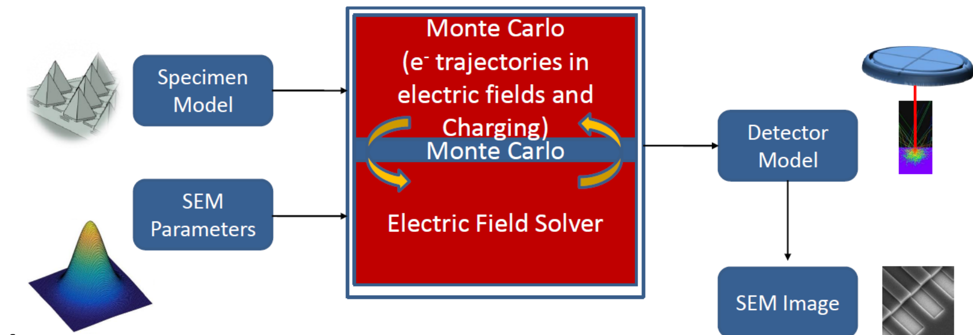


- "If you cannot measure it – you cannot improve it"
  – Lord Kelvin

- Inspection is becoming bottleneck for IC production
  - New structures need to be developed based on inspectability
  - Key enabler: computational MIS, SEM Simulation



- GenISys vSEM technology is a serious contender
  - Scattering kernels market validated
  - Charging solved in principal

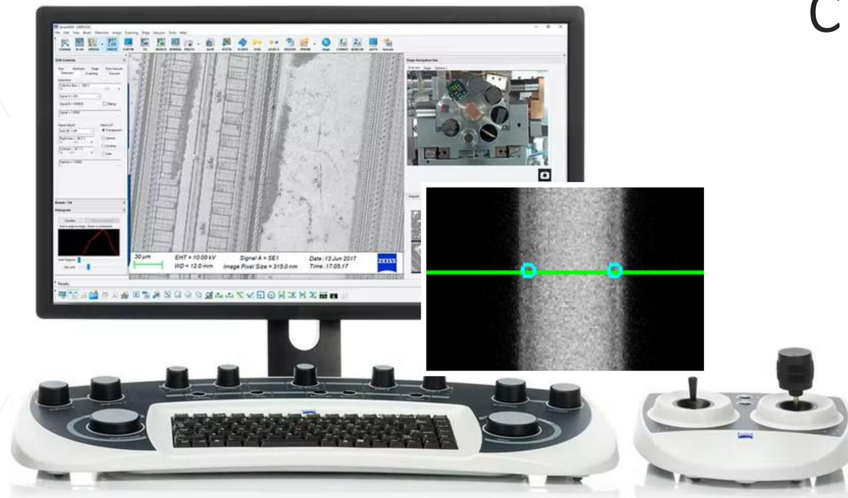


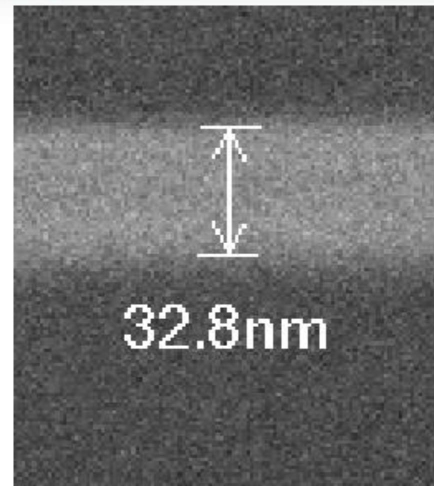
- GenISys continues to invest large resources into MIS
  - ProSEM, SEM Automation
  - Die-to-Database inspection platform
  - vSEM SEM simulation

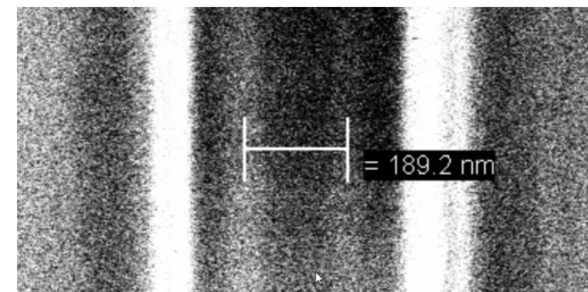
The Metrology Challenge in Nanofabrication

This is how you create nano patterns...

This is how you measure nano patterns..?







- Consistent and reliable SEM measurements are critical for process characterization
  - Hand-drawn cursors are subjective, tedious, time-consuming, inconsistent

Images vendor webpages

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Upgrade SEM to a CD-SEM by Software

This is how you measure nano patterns..?

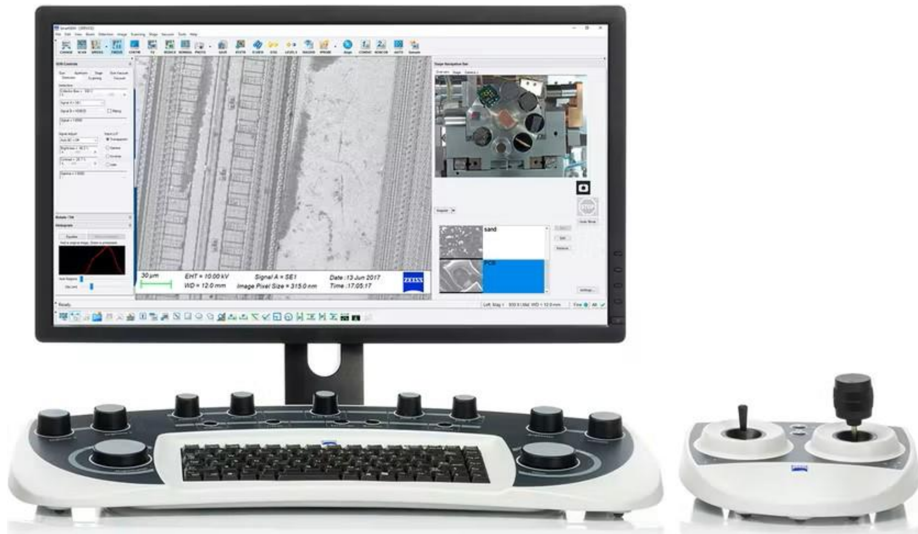


Image ZEISS webpage

Algorithm-based Easy Metrology

Advanced Pattern & Batch Processing

Aligned CAD Layout Integration

Digital Interface SEM Automation

Make „More“ out of your SEM

ProSEM — digital I/F — SEM PC — SEM

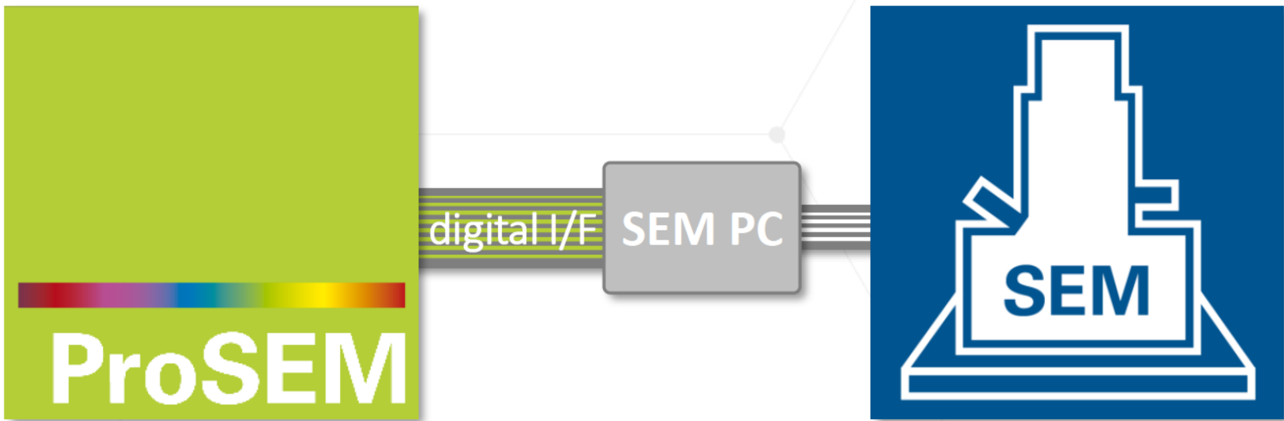
Remote control of SEM via digital PC interface

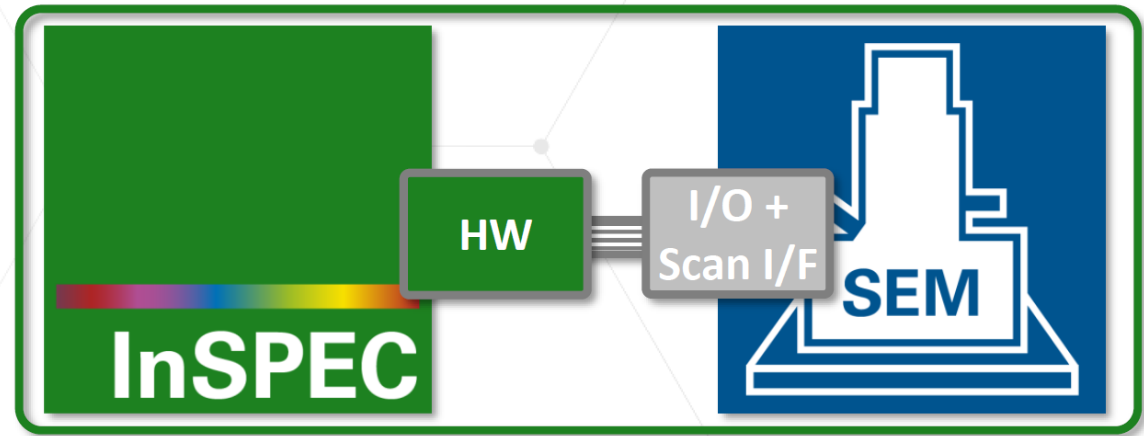
Easy to get SEM images and metrology results

Automated metrology

- Layout based metrology definition (no scripting!)
- Drive SEM stage and acquire image
- Image loading and alignment
- Apply pre-defined measurement automatically

Next level …





Remote control of SEM via digital PC interface

Easy to get SEM images and metrology results

Direct SEM control with hardware integration

Comprehensive full layout-based workflow

Integrated scanning, automation and analysis

E-Beam Process Calibration

TRACER enables to identify the optimal process point in a simple experiment

- prooven for multiple substrates (Si, SiO2, GaAs, InP, …)
- prooven for typical direct write resists (PMMA, ZEP, HSQ, …)
- demonstrated for CAR resists (both positive and negative tone)

Universal approach for process optimization of chemically amplified photoresists in electron beam lithography

Markus Greul,[a,*] Astrit Shoshi,[a] Jan Klikovits,[b] Stephan Martens,[a] Holger Sailer,[a] Olga Barahona[a], Benyamin Shnirman,[a] Leon Starz,[a] Jan Hofmann,[b] Patrick Wintrich[a]
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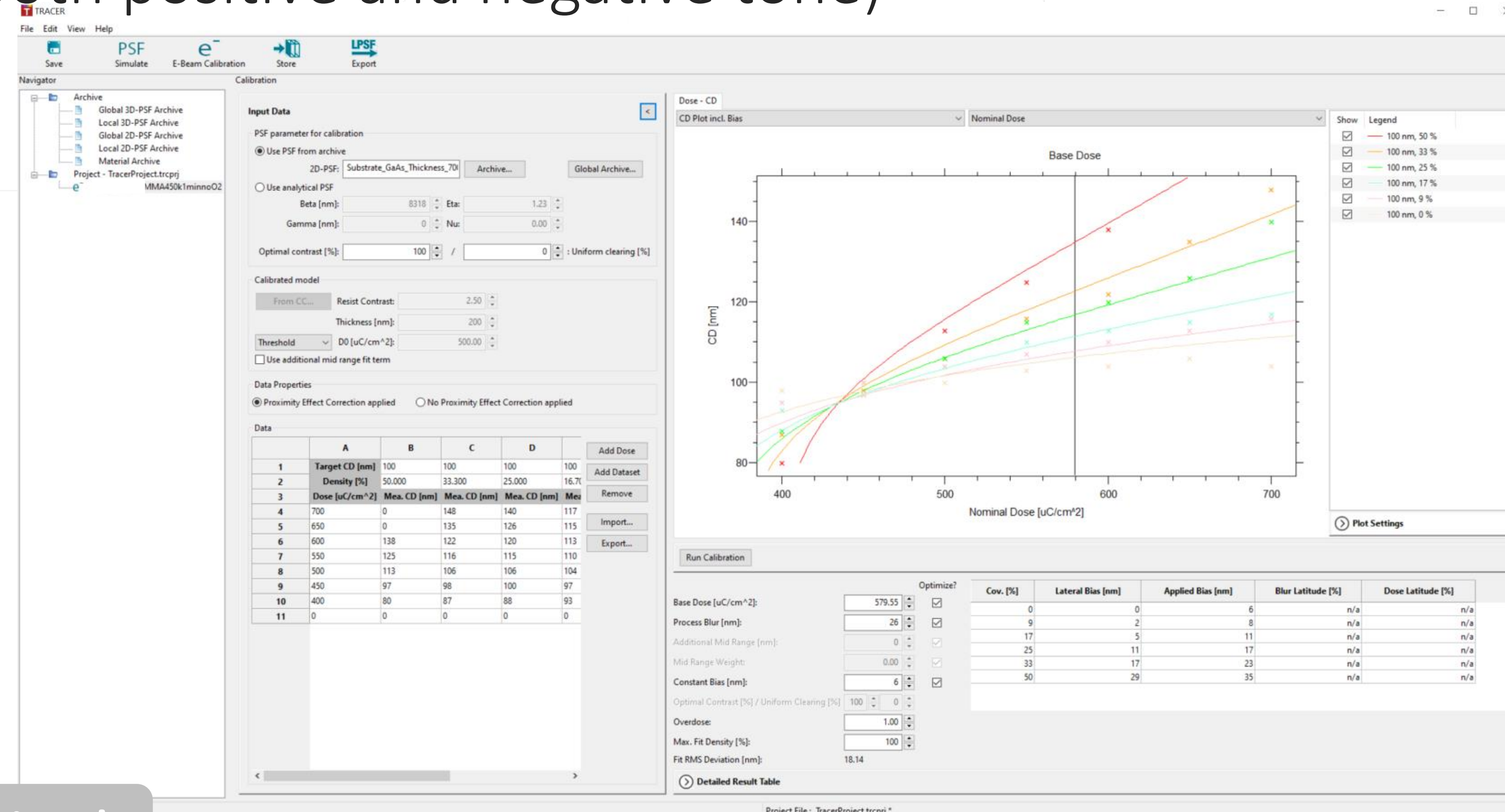
Abstract. A critical factor in the fabrication of complex nano- and microstructures with high quality and reproducibility is the determination of a suitable working point. This applies particularly to lithography, which is the basis for transferring the desired patterns onto the substrate. For this reason, the following paper presents a generic process optimization methodology that has been successfully applied to four chemically amplified positive and negative tone electron beam lithography photoresists with different sensitivities. The method is iterative and designed for best possible results with a minimum use of resources. This is accomplished by identifying the critical key factors in photoresist processing using contrast curves and determining their impact. Starting with the most influential bake parameter, the maximum effect is achieved. The method used is similar to the *Bossung*-plot procedure and aims for a maximum process window. After the bake parameters, the fundamentals of development kinetics are discussed and a method for determining an appropriate development time is presented. A mask making approach is then used to investigate the ideal exposure conditions. This includes the determination of an appropriate base dose in conjunction with proximity effect correction and sizing. The evaluation of this method is demonstrated by critical dimension linearity plots and scanning electron microscope cross sectional analysis of resist profiles. The results presented impressively demonstrate the universality of the optimization approach.

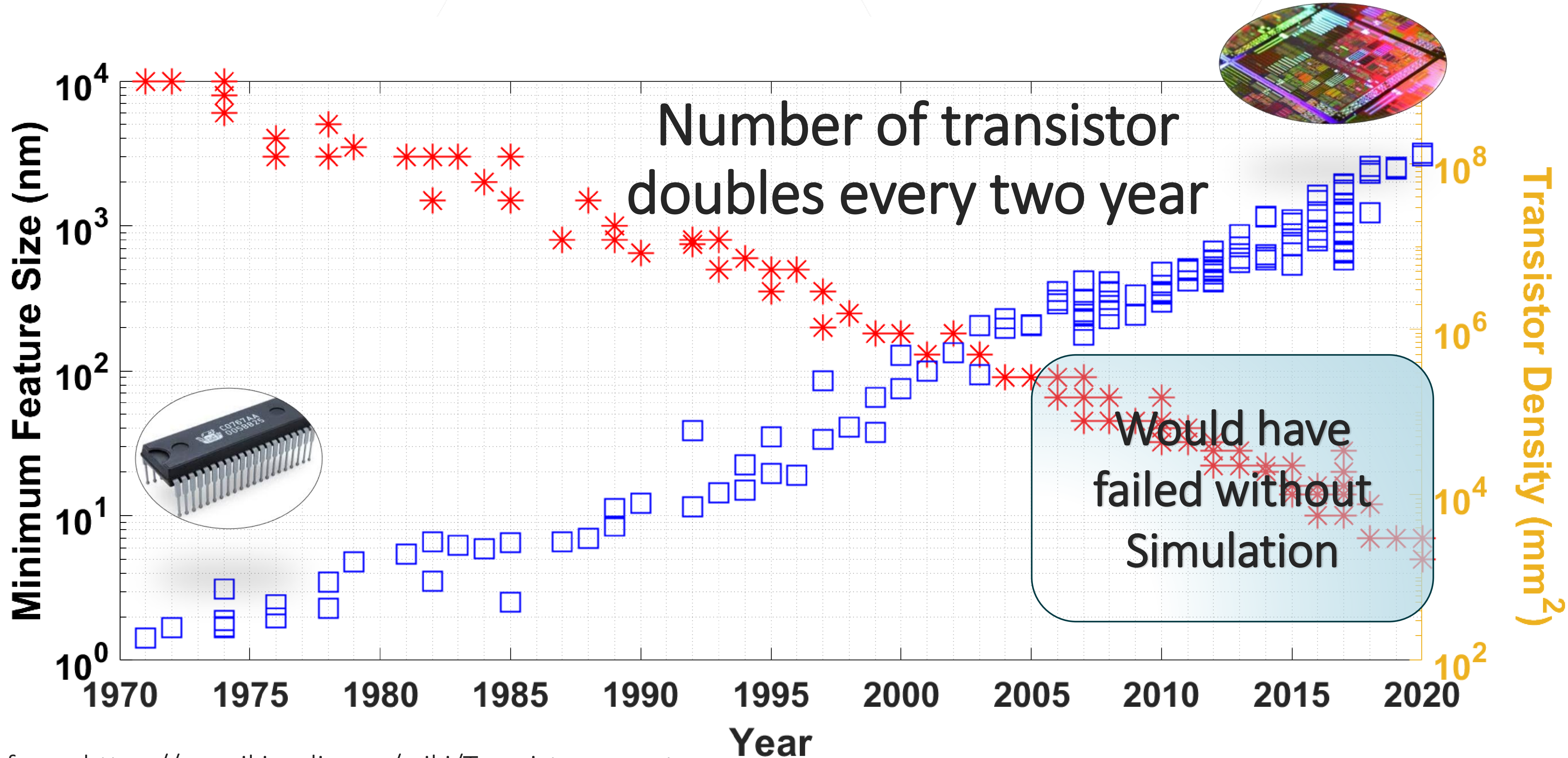
Keywords: electron beam lithography, photoresist process optimization, nano- and micro-patterning, photoresist bake, development, proximity effect correction (PEC), point spread function (PSF).

*Markus Greul, E-mail: greul@ims-chips.de



"Peace of Cake" with ProSEM Automation!

Moore's Law



Data from: https://en.wikipedia.org/wiki/Transistor_count

Simulation Flow

Mask Layout

Proximity

Projection

Laser

Bulk

Concentration

3D Resist

Bulk Intensity

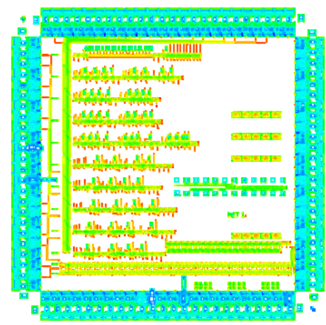
3D Resist

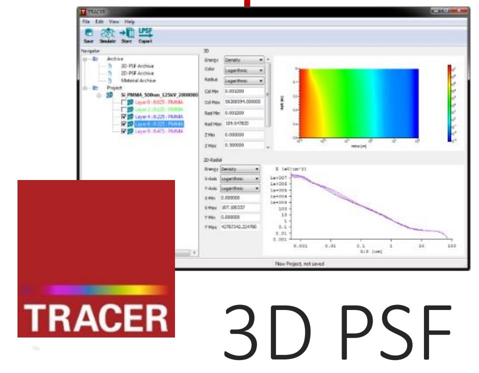
Aerial

Concentration

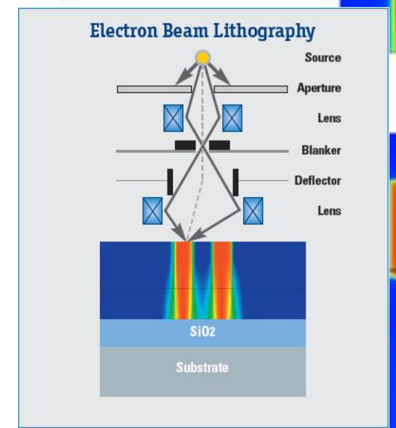
3D e-Beam Lithography Simulation

Layout

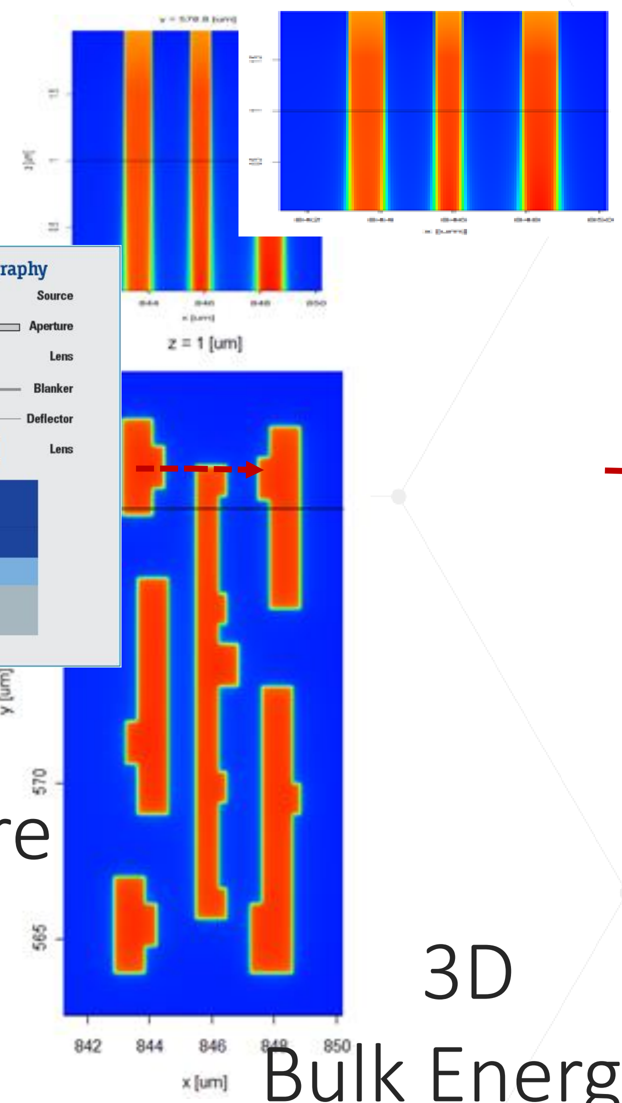




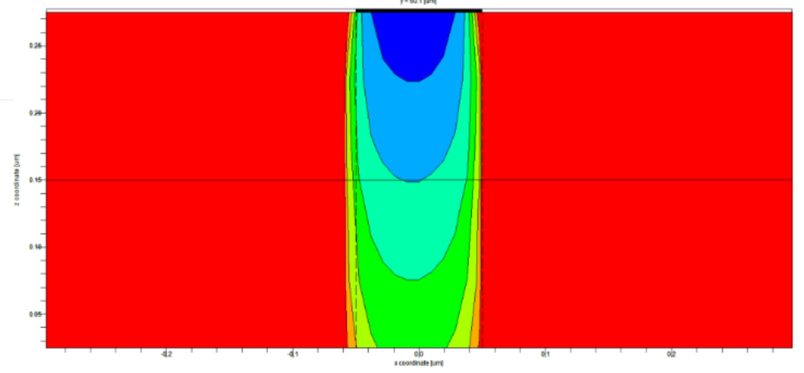
3D PSF

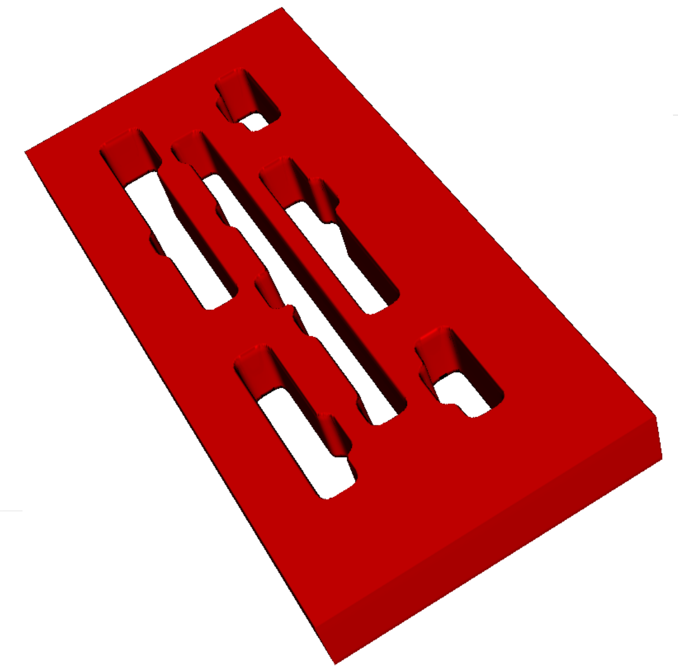


E-Beam Exposure



3D Bulk Energy





3D Resist Development

E-Beam 3DPEC & LAB (BushClover)

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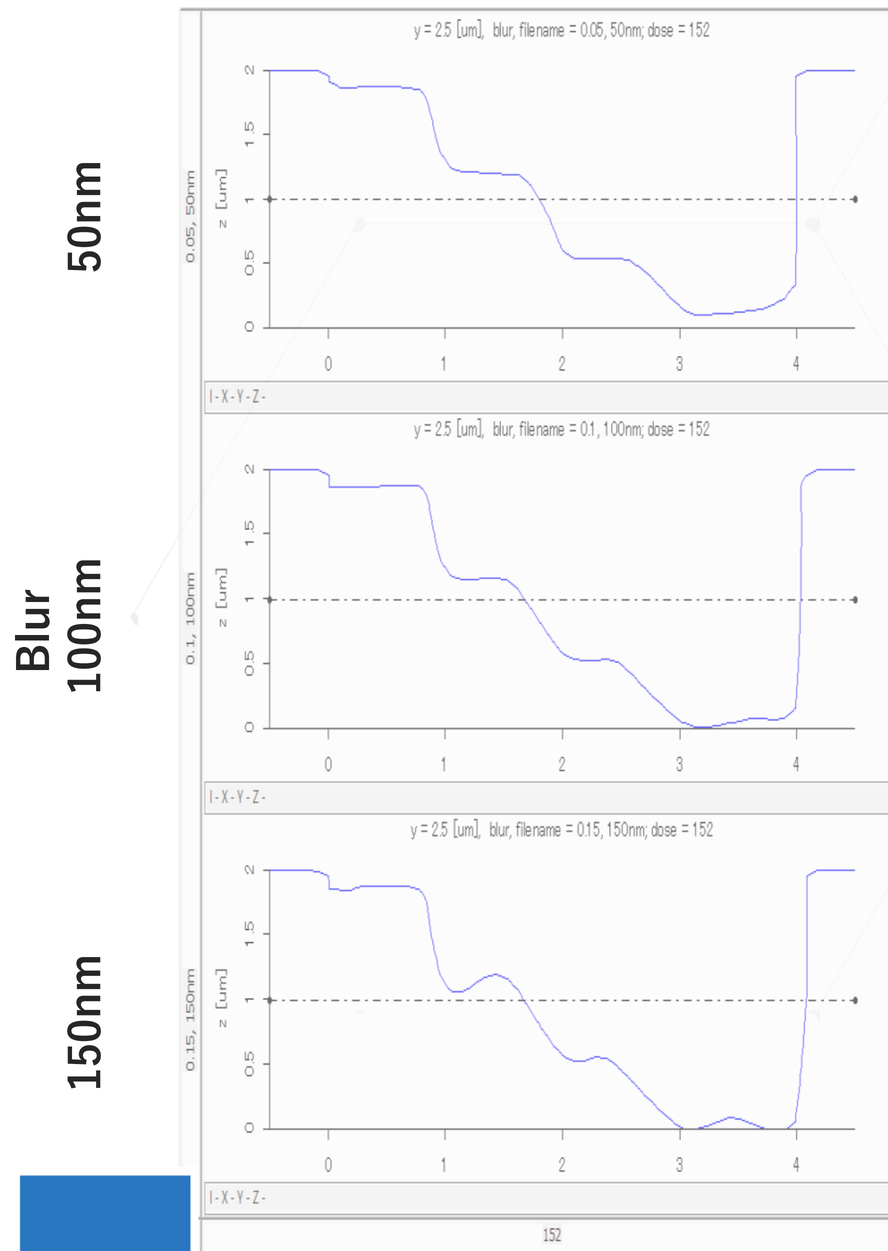
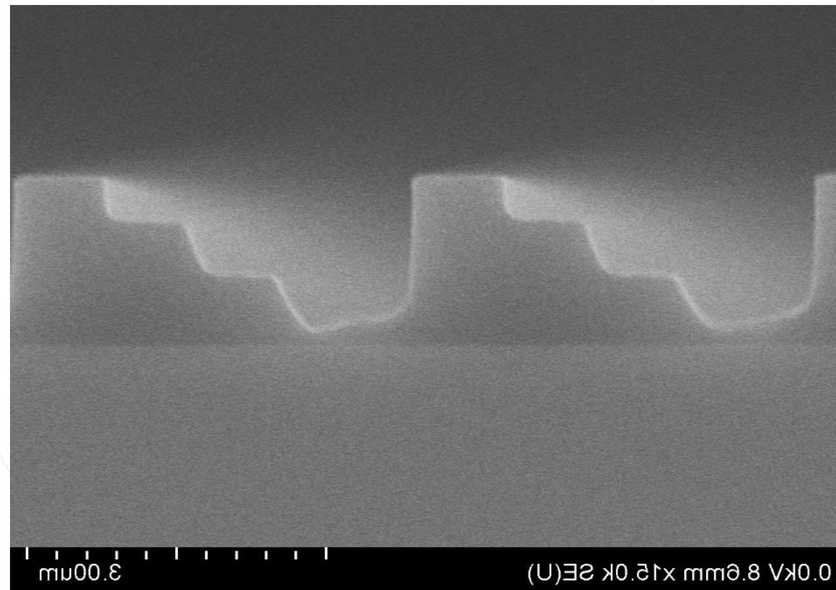
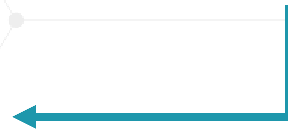


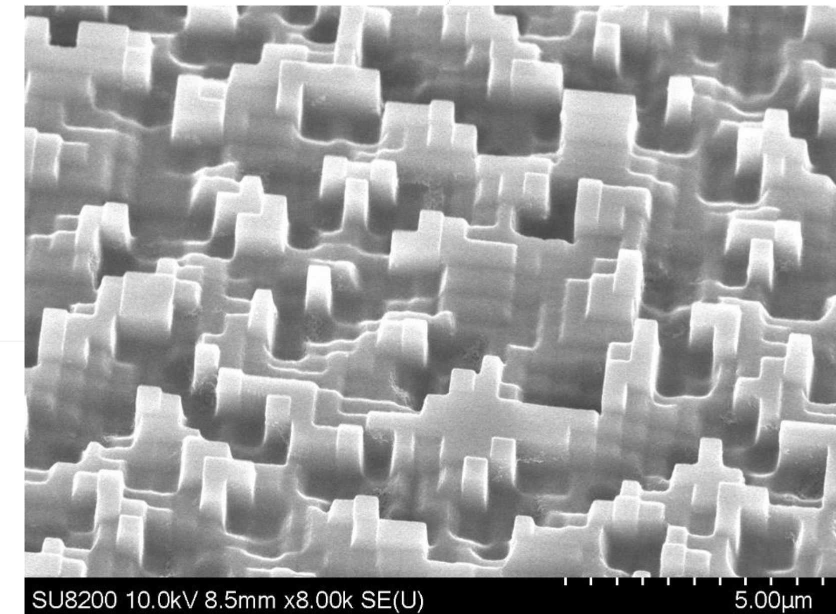
Blur
50nm
100nm
150nm

Dose 152 uC/cm2





E-Beam 3D, data prep. by BEAMER.
→ Compared with LAB simulation.

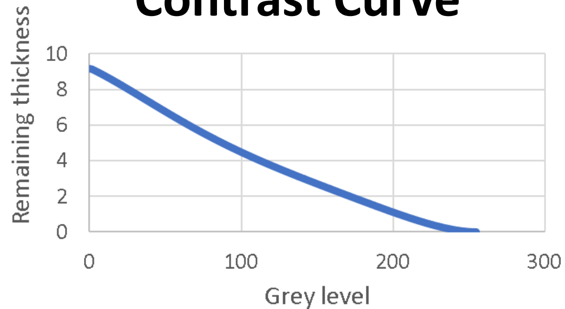


Stable results are obtained by BushClover (Mr. Nizeki)

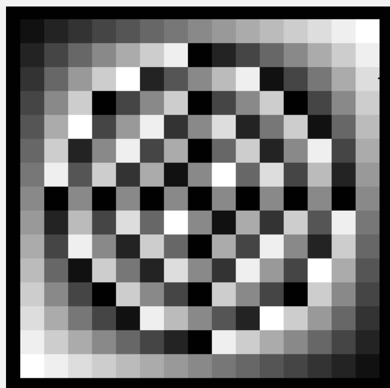
Simulation of Laser Exposure Process

Input

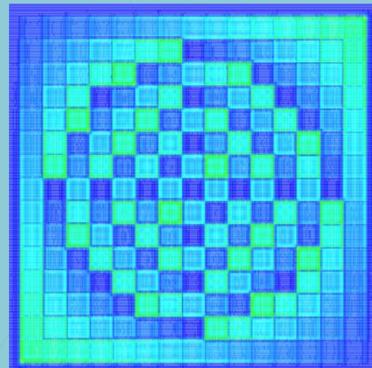
Contrast Curve



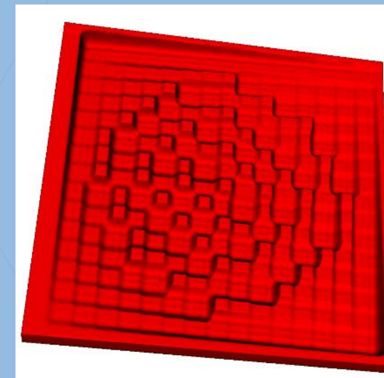
Layout



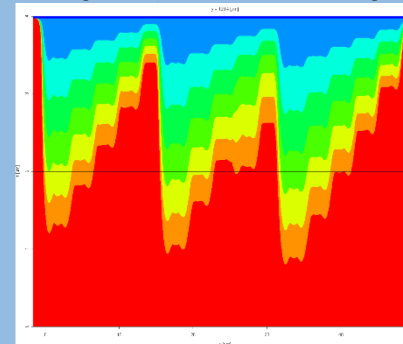
Calculated energy distribution



Simulated 3D profil (after development)



Development process (Crosssection)

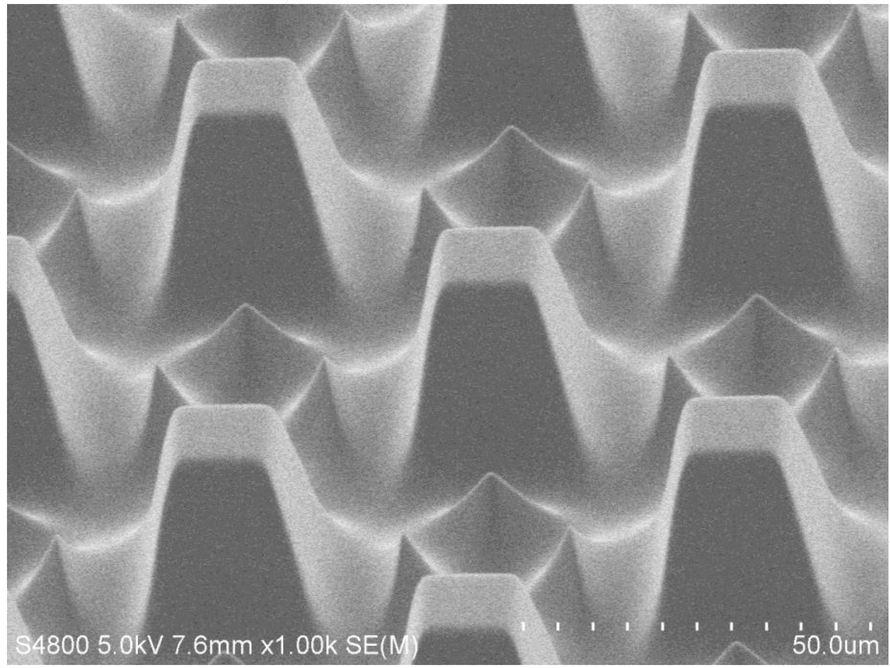


Result

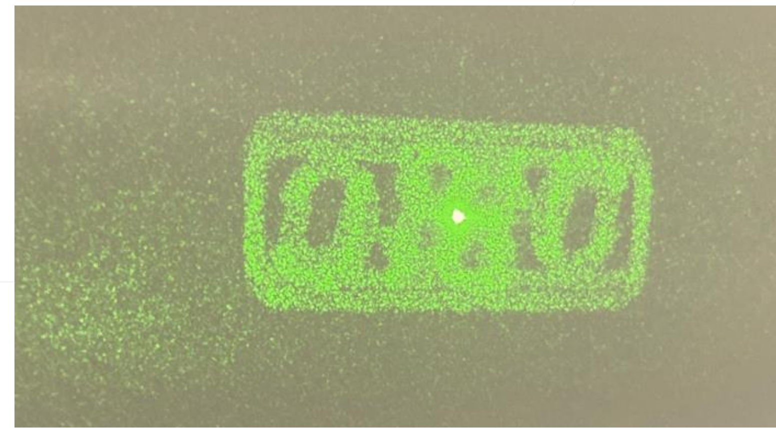
Developed sample

Laser 3DPEC

Resist : PMER P-HA 300
pre-bake: 90 ^{o}C, 6min
By BushClover

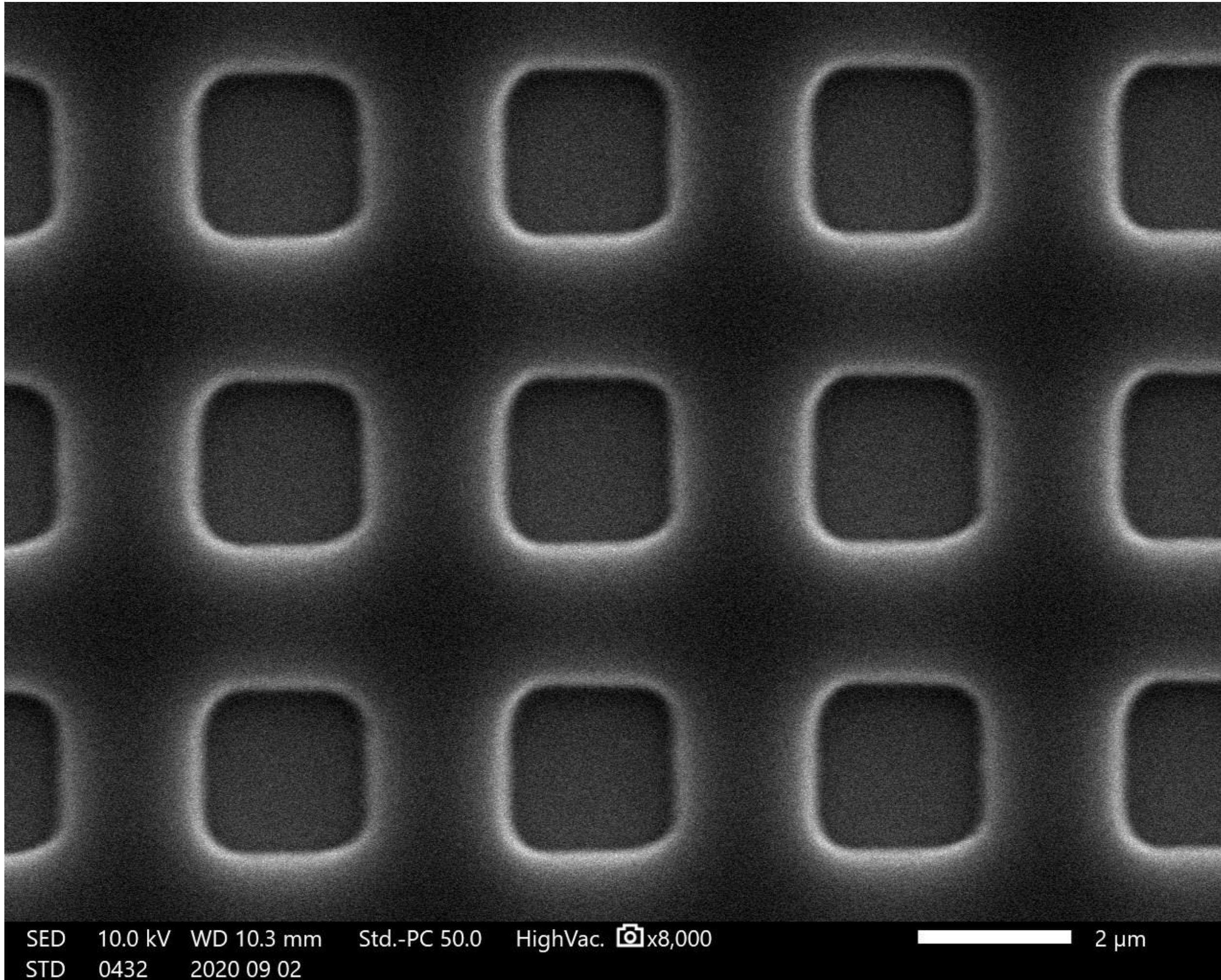


1um pixel size DOE for green laser optics.
DOE steps: ca. 200nm

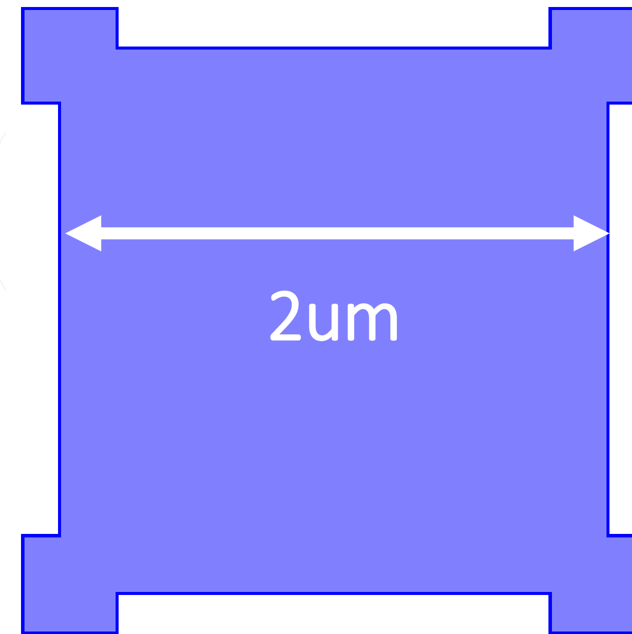


2um Square Dots

without correction



Optimize serif size & overlap influences by simulation

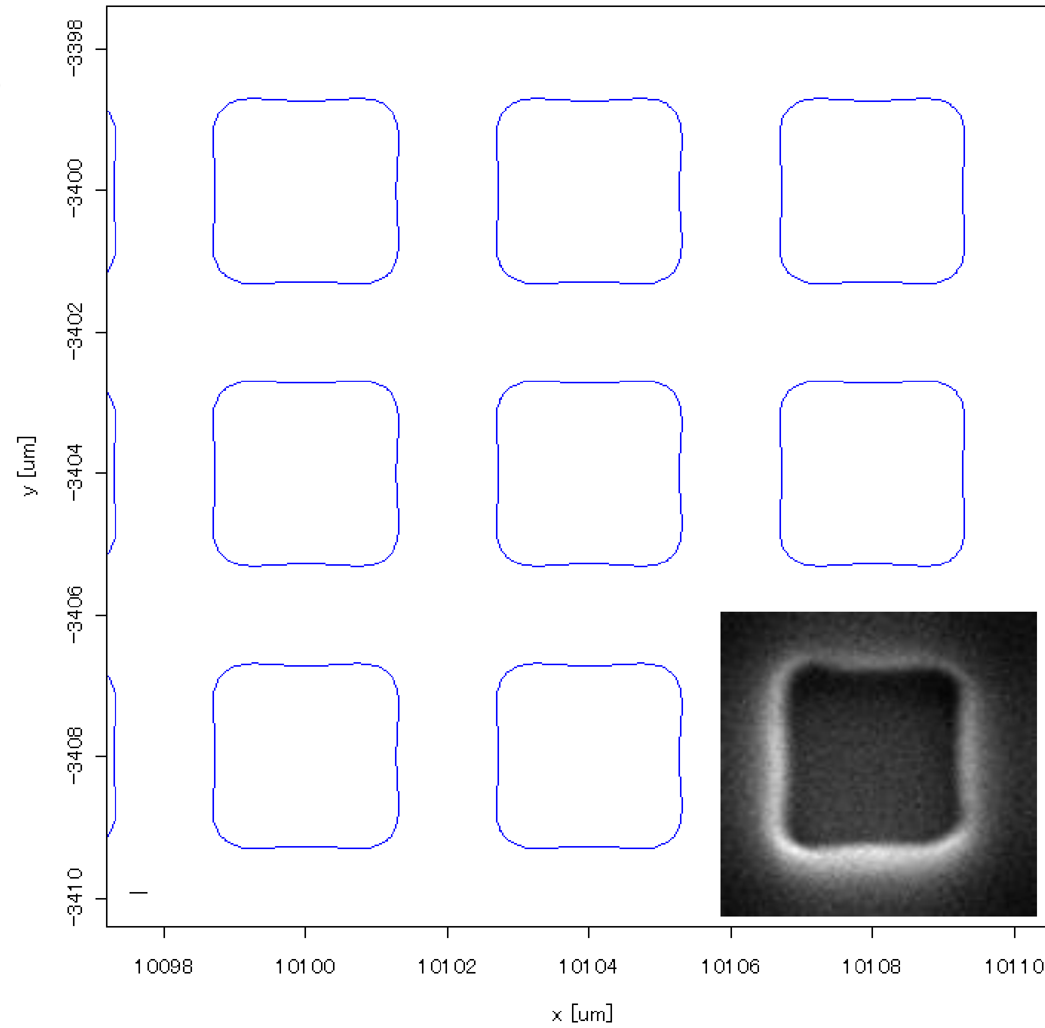


Rule-OPC

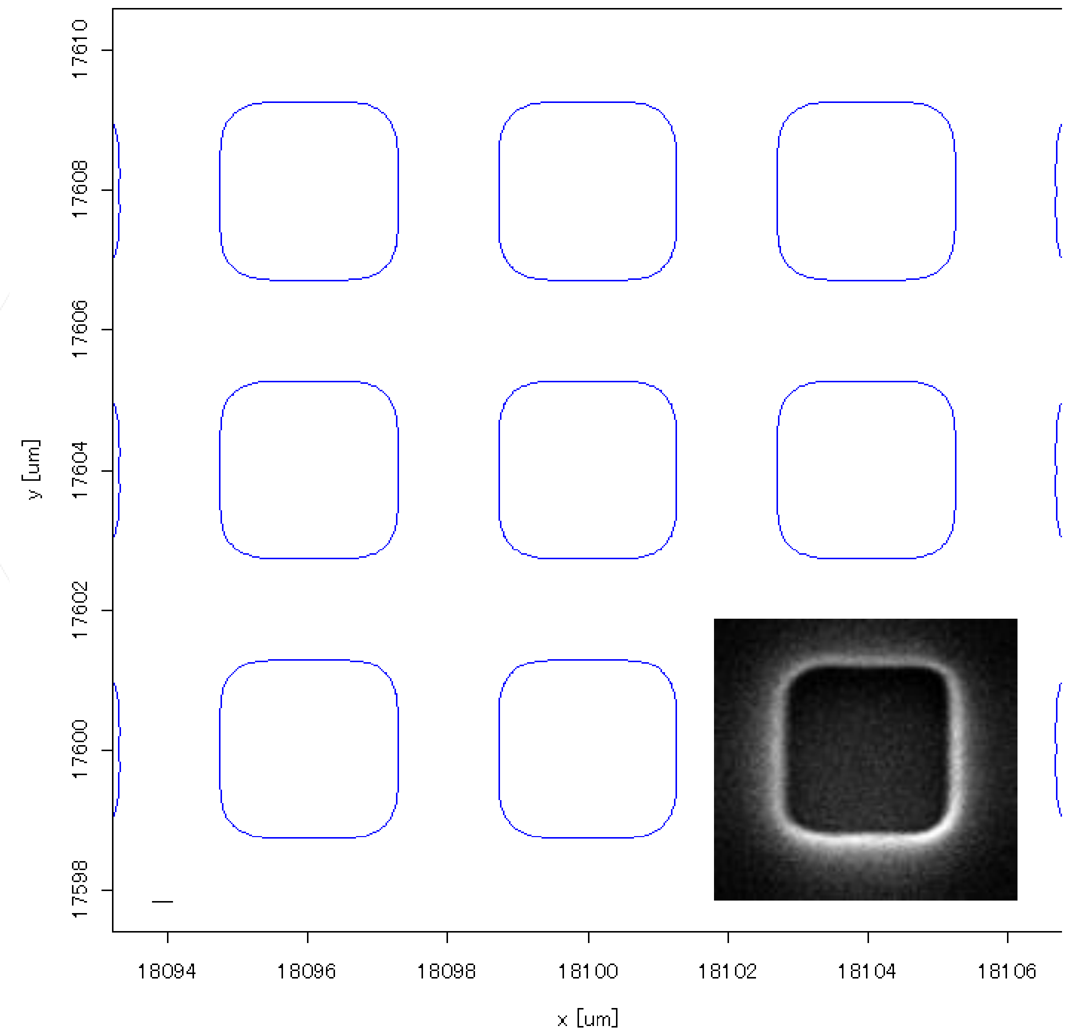
LAB Simulation : 2um Square Dots

In GDSII
Laser
Resist

350nm Serif with 60% overlap



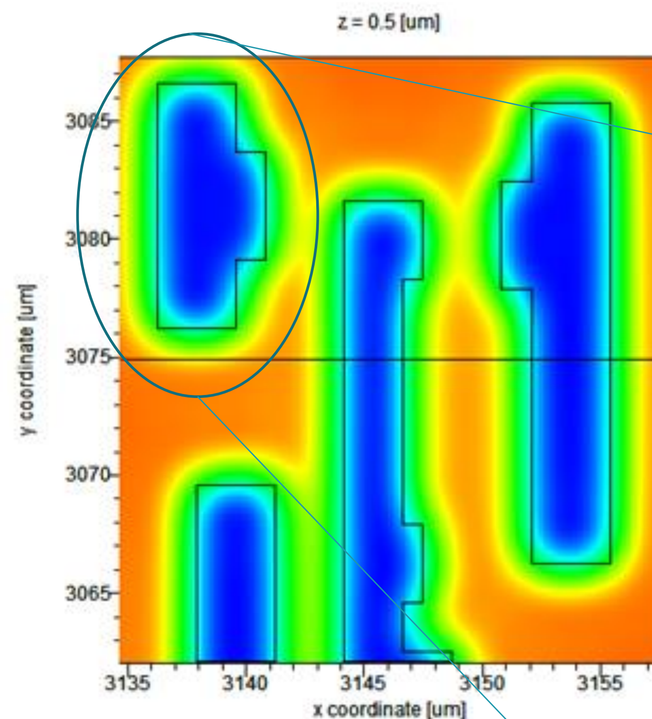
200nm Serif with 70% overlap

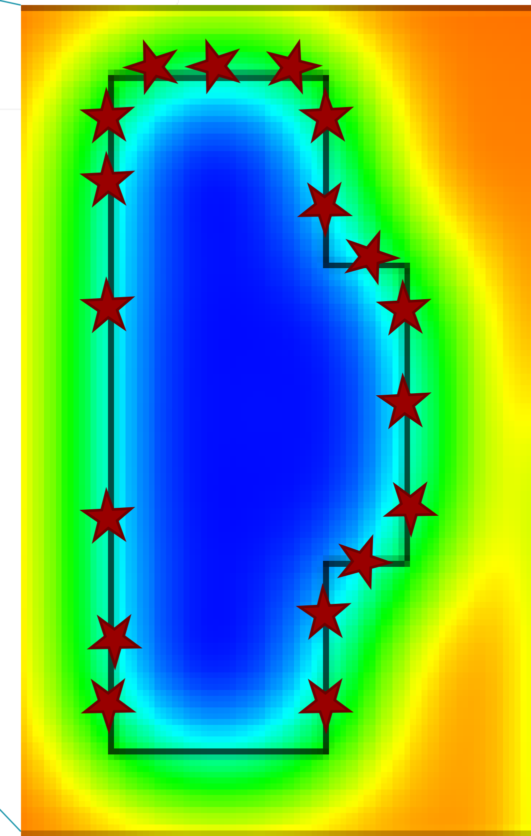


Simulation is able to predict proper serif size in advance

LAB

Model-OPC for Projection (Stepper)



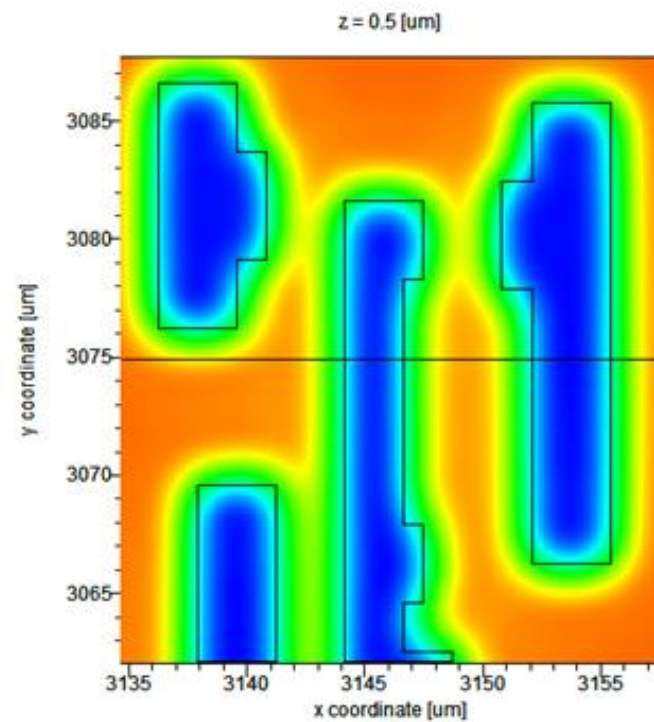


Fully automated correction:

- Iterative process
- The exposure is modelled at layout edges (fast simulation)

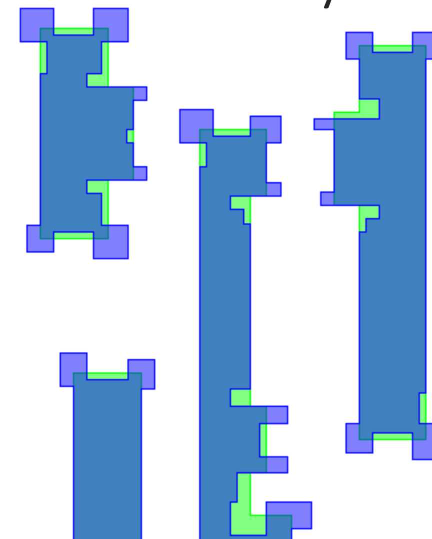
- Placing of evaluation points at layout edge
- Compare intensity level
  - at taget: no action
  - Below or above target: move edges

Model-OPC for Projection (Stepper)



Fully automated correction:

- Iterative process
- The exposure is modelled at layout edges (fast simulation), compared to target
- the layout is modified (shape correction) to compensate for mismatch
- Full layout import



GenISys is offering Full-Chip OPC for special and mature application!

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Agenda - Wednesday

Speaker	Topic	Time
Nezih Ünal / Uli Hofmann GenISys	Welcome & GenISys Update	13:00
Julian Hartbaum IMS	Introduction IMS Chips	13:20
Markus Greul IMS	Optimizing chemically amplified photoresist processes in electron beam lithography	13:30
Jan Klikovits GenISys	TRACER calibration for chemically amplified photoresists	14:00
Kevin Anthony Hofhuis Paul Scherrer Institut	Grayscale lithography in HSQ and the application of dose gradient shapes	14:20
	Coffee Break & IMS Tour	14:40
Dr. Cathelijn van Nisselroy Heidelberg Instruments Nano AG	Towards automation and parallelization in thermal scanning probe lithography with the NanoFrazor	15:30
Anirudh Peyyety GenISys	Application Use Cases of ProSEM	16:00
Sven Bauerdick GenISys	Automated Layout-based SEM Metrology with ProSEM and InSPEC Discussion MIS	16:30
	Closing	17:30
Relexa Waldhotel Schatten Stuttgart	**Champagne reception**	18:00
	Dinner	19:00

Agenda - Thursday

Speaker	Topic	Time
Jing Becker GenISys	Loops, Variables, Functions	9:00
Holger Sailer IMS	Resolution optimization optical lithography	9:30
Nadia Chahir University of Twente	Proximity effect correction for e-Beam fabrication of Aluminum Oxide waveguides	10:00
	Coffee Break	10:30
Jürgen Weis MPI	Nanostructuring Lab at the MPI for Solid State Research	11:00
Thomas Michels GenISys	BEAMER Update Development Roadmap and Discussion	11:30
Max-Planck-Institut	**MPI Tour**	12:00
Max-Planck-Institut Cafeteria	**Lunch at MPI**	13:15
	Open Discussion and User Workshops* With Coffee	14:00
	Closing	16:30

GenISys
Advancing the Standard

Thank You!

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