GenISys
Advancing the Standard

APPLICATIONS

Bulk & sleeving of patterns for time writing optimisation

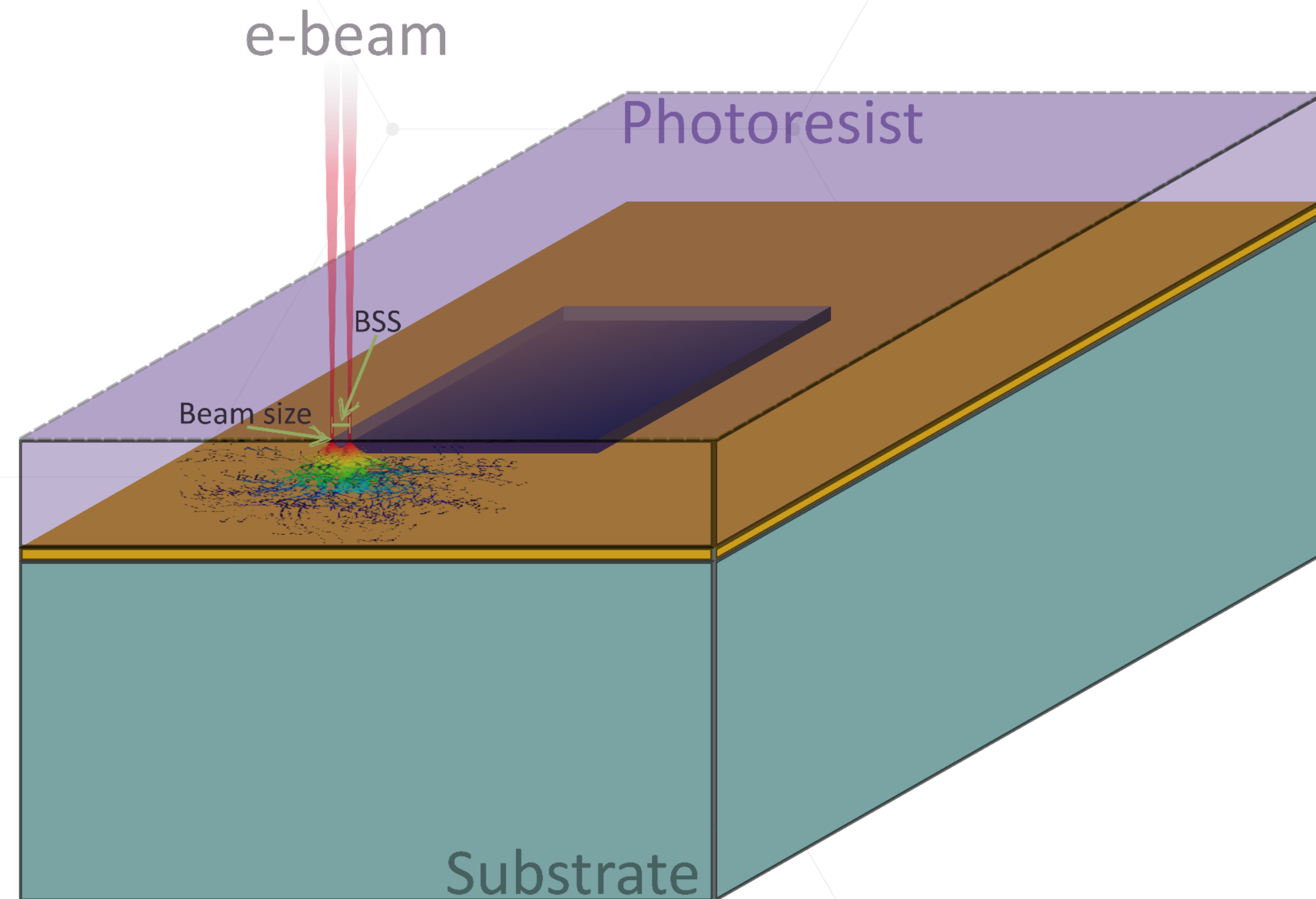
BEAMER

Outline

- Electron Beam Lithography generalities
- General exposure analysis
- Bulk and Sleeve Method
- Proximity Effect Corrections
- Summary

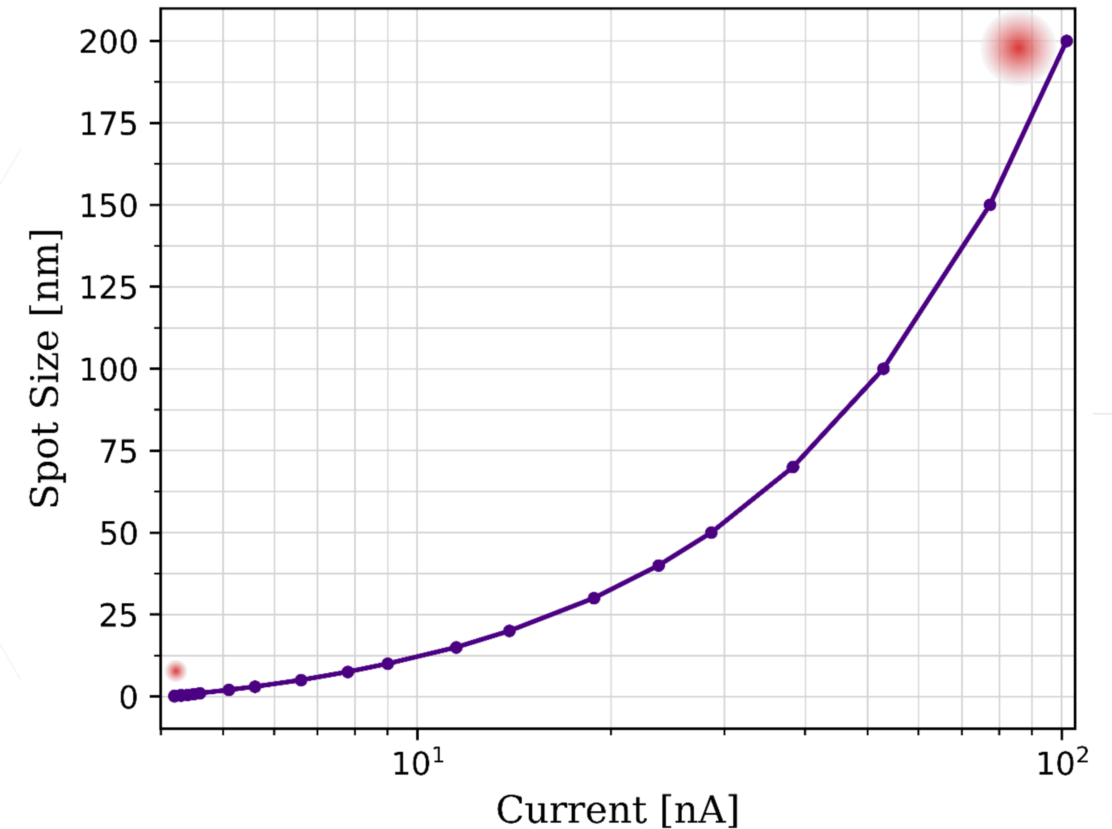
Electron-beam Exposure

- Electron-beam produces secondary electrons (SE) and back scattered electrons (BSE) when interacting with the photoresist
- Electron-beam usually is Gaussian
- Beam current ∝ Beam Size
- The resolution of exposed features will depend on:
    - Beam Size
    - Beam Step Size (BSS)
    - Photoresist sensitivity

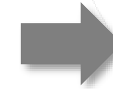


Spot size considerations

- Best exposure recommendations:
  - Image quality depends on:
    - **Pixel size**: Grid selected during data preparation
    - **Spot Size**: Selection at the beginning of the exposure (related to the current)
  - For smooth outlined shapes:
    - Spot Size should be larger than the grid by 40-60%
  - Smallest feature should be minimum 4-5 grid pixels wide when possible



Exposure Time

- The exposure time can be estimated using  $t = D\frac{A}{I}$

where
t = time [s]
D = dose [µC/cm²]
A = exposure area [cm²]
I = current [µA]

- As an example:
  - A layout of **1 cm²** exposed with a dose of **200 µC/cm²** and a current of **1 nA** requires ***56 hours*** to be completed

Why?

High current increases the spot size but also the CD sensitivity to dose

Why?

Low current reduces the spot size but rises exposure time

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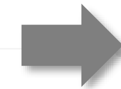
CD Sensitivity to Dose

- The CD of a structure varies depending on the Spot Size
  - For instance:
    - A 200 nm stripe at spot sizes of 4 nm and 50 nm are simulated using LAB



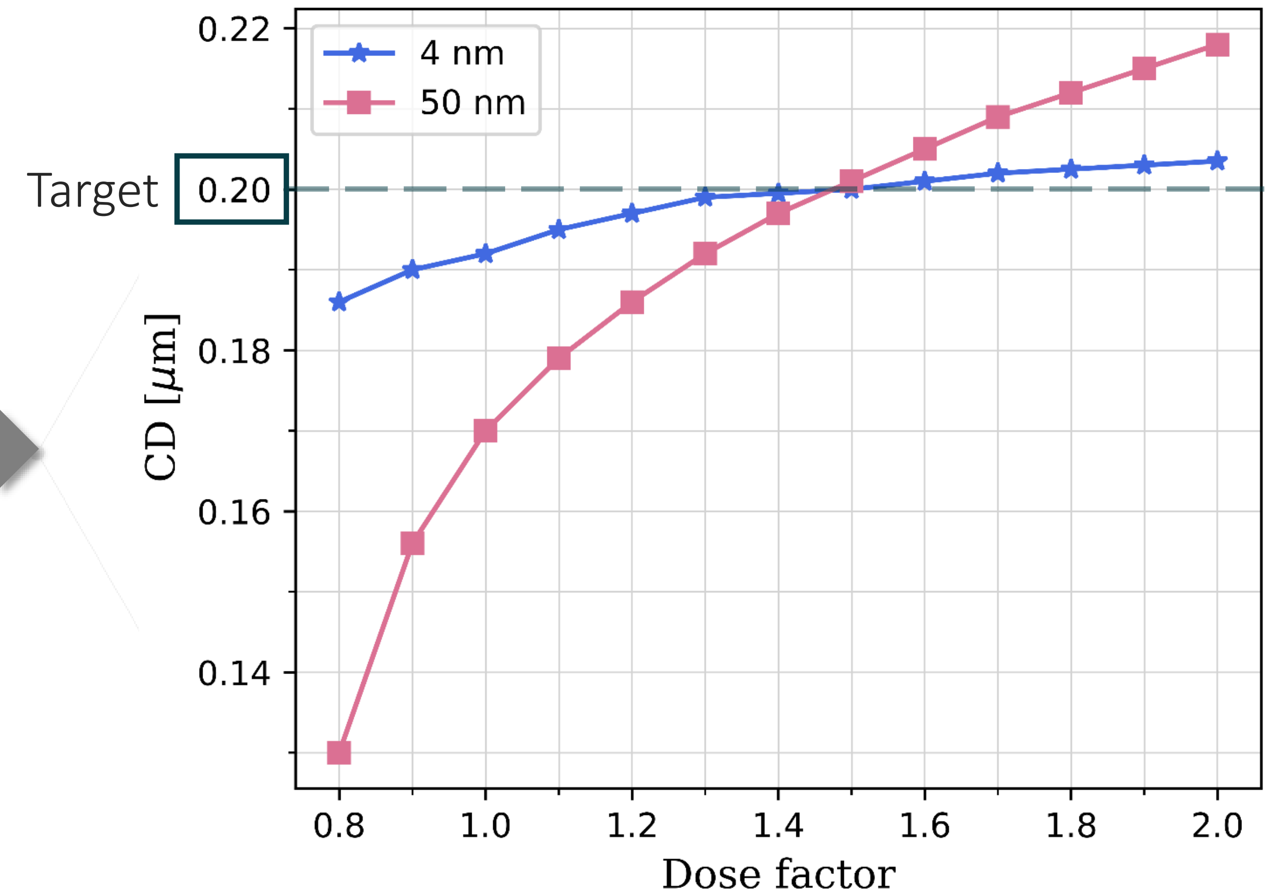
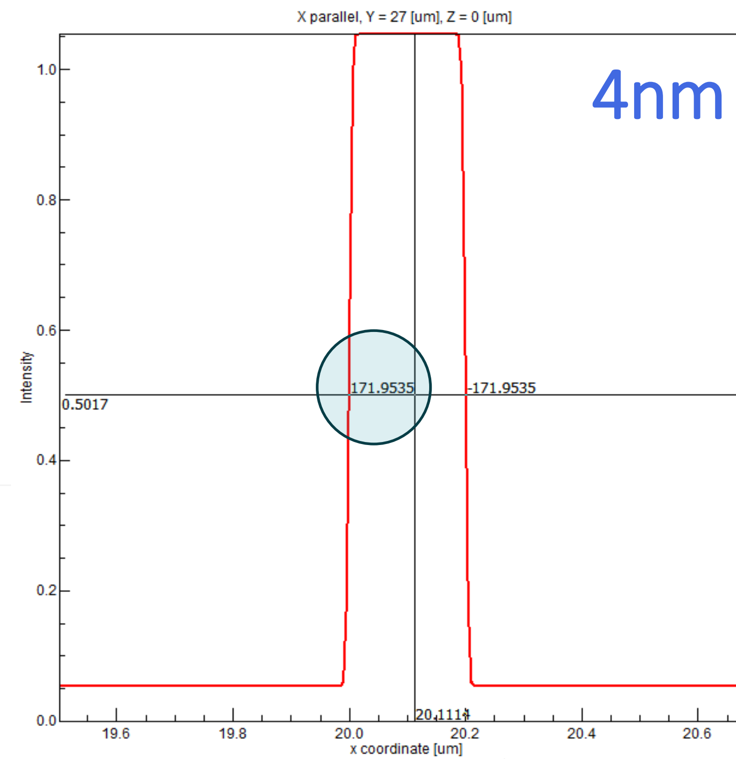


Image Log Slope

- Larger Spot Size has larger fluctuations:
  - Exposure Latitude for 4 nm is 17.2% while for 50 nm is 3.65% per nm



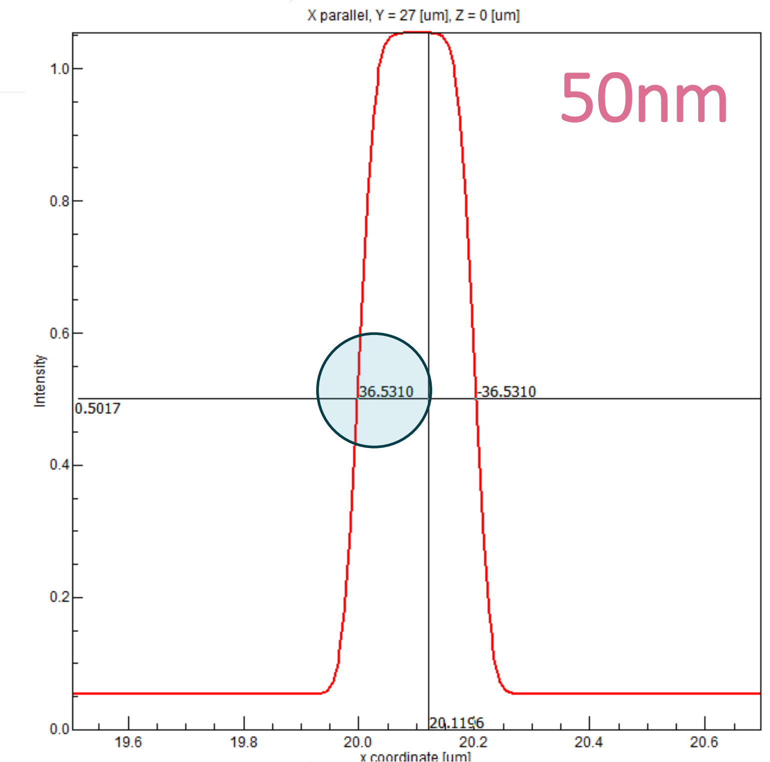


Image Log Slope (ILS) is an indicator of resist edge quality. It measures the transition from bright to dark in the image intensity

Dose Error

- The Proximity Effect dose error can be calculated

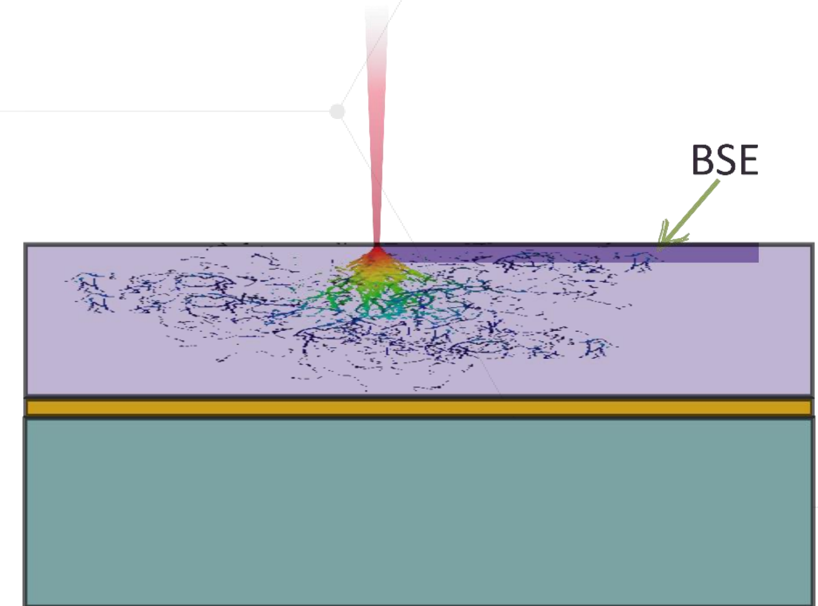
$$\text{DoseError} = \frac{\eta}{1+\eta}$$

  - For η = 0.7 the DoseError = 41%

- The difference in CD due to the Proximity-Effect-dose-error is

$$\Delta\text{CD} = 2\,\frac{\text{DoseError}}{\text{ILS}}$$

  - For a Spot Size = 4 nm → $\Delta\text{CD} = 4.8\ \text{nm}$
  - For a Spot Size = 50 nm → $\Delta\text{CD} = 22.6\ \text{nm}$



η is the energy ratio between forward-scattering electrons and back-scattering electrons (BSE)

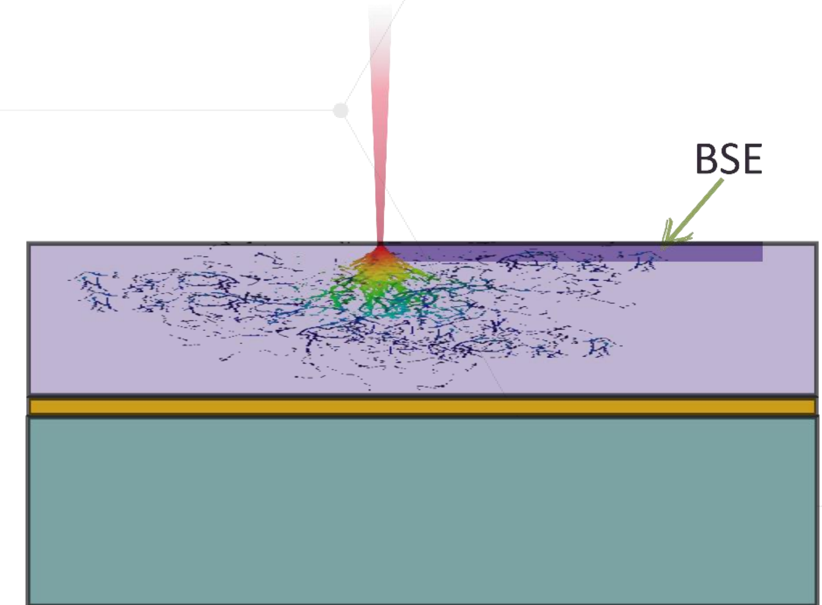
Large spots have larger errors since Proximity effect is stronger and intensifies noise:
Line Edge Roughness (LER) and **Line Width Roughness** (LWR)

Time Analysis

- Suppose the stripe is 200 nm wide and 1 µm long. The exposure dose is 500 µC/cm² and the current for the 4 nm spot is 6.1 nA while for 50 nm spot is 28.6 nA (according to relation given in slide 4) then:

➡ t(4nm) = 0.164 ms

t(50nm) = 0.035 ms

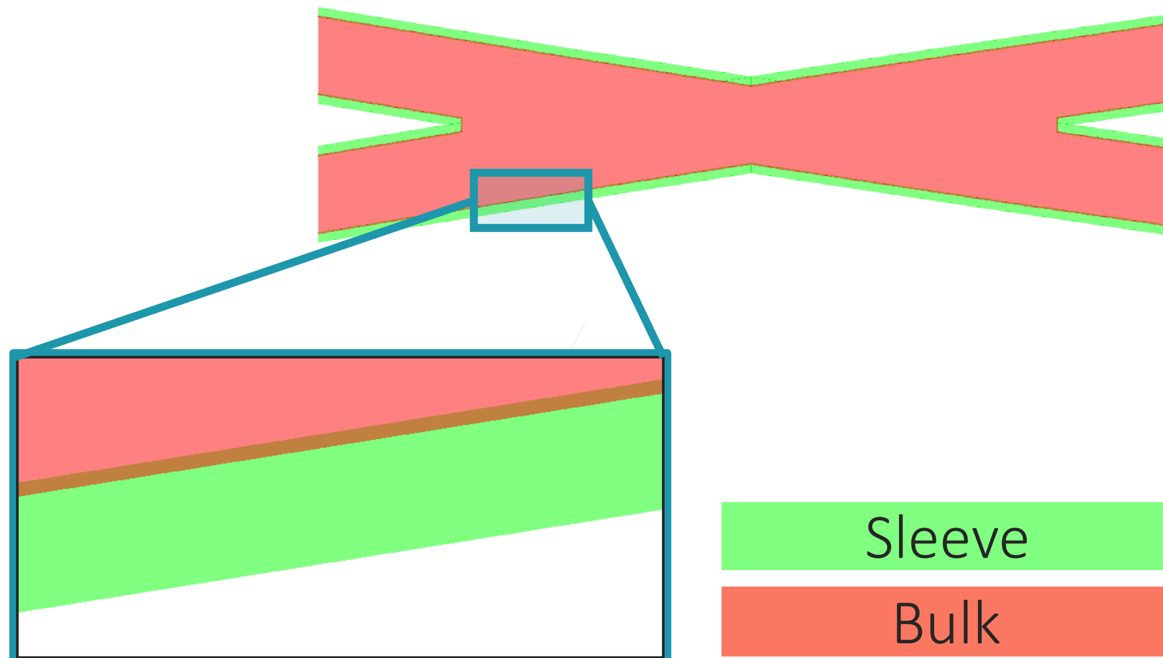


Higher current is **5 times faster**

How to get the faster exposure with the highest accuracy?

Solution

- Use **BEAMER** to split layout into Bulk & Sleeve regions
  - Bulk is exposed with a large beam and step size ➡ reduces exposure time
  - Sleeve is exposed with a small beam and step size ➡ increases fidelity



Note that: **Two** machine-files will be generated for the exposure

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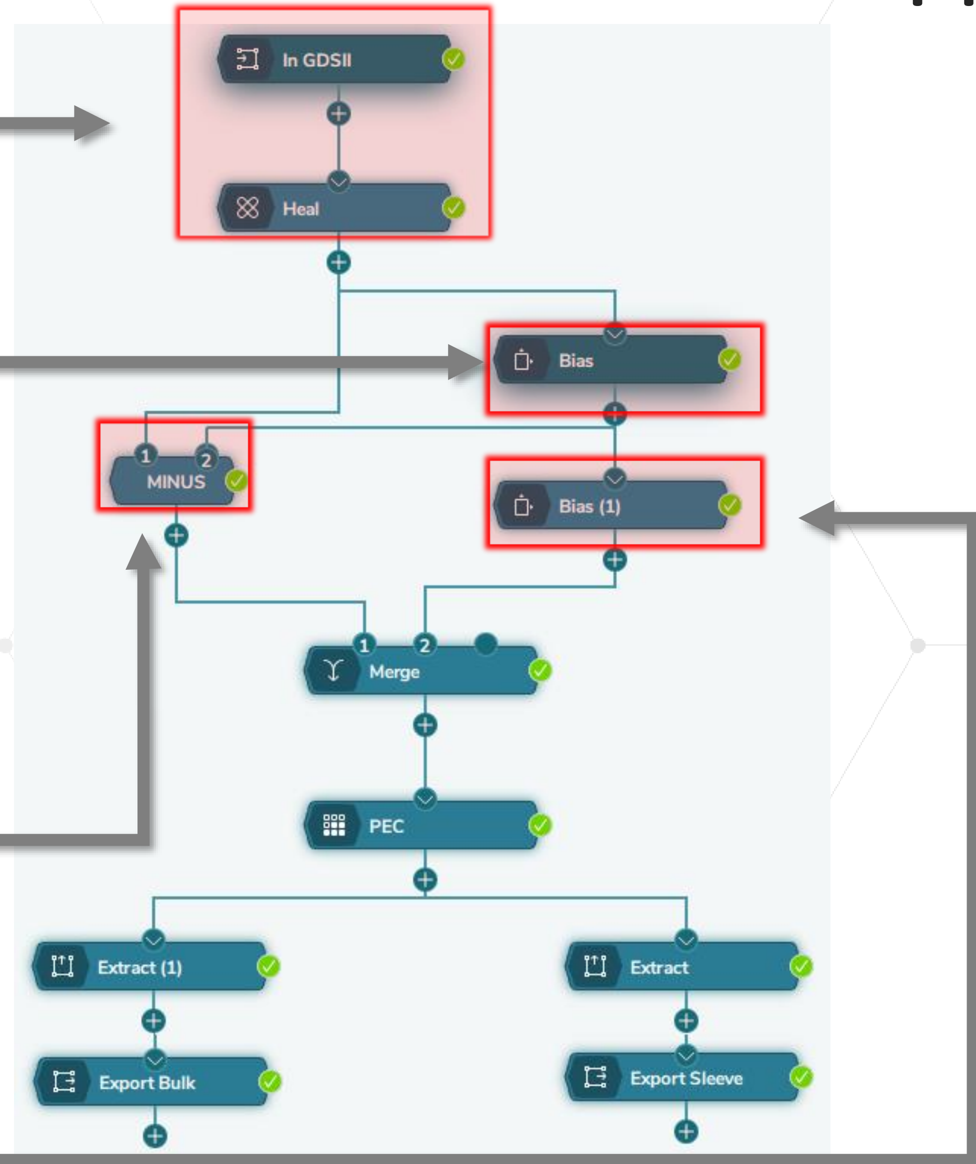
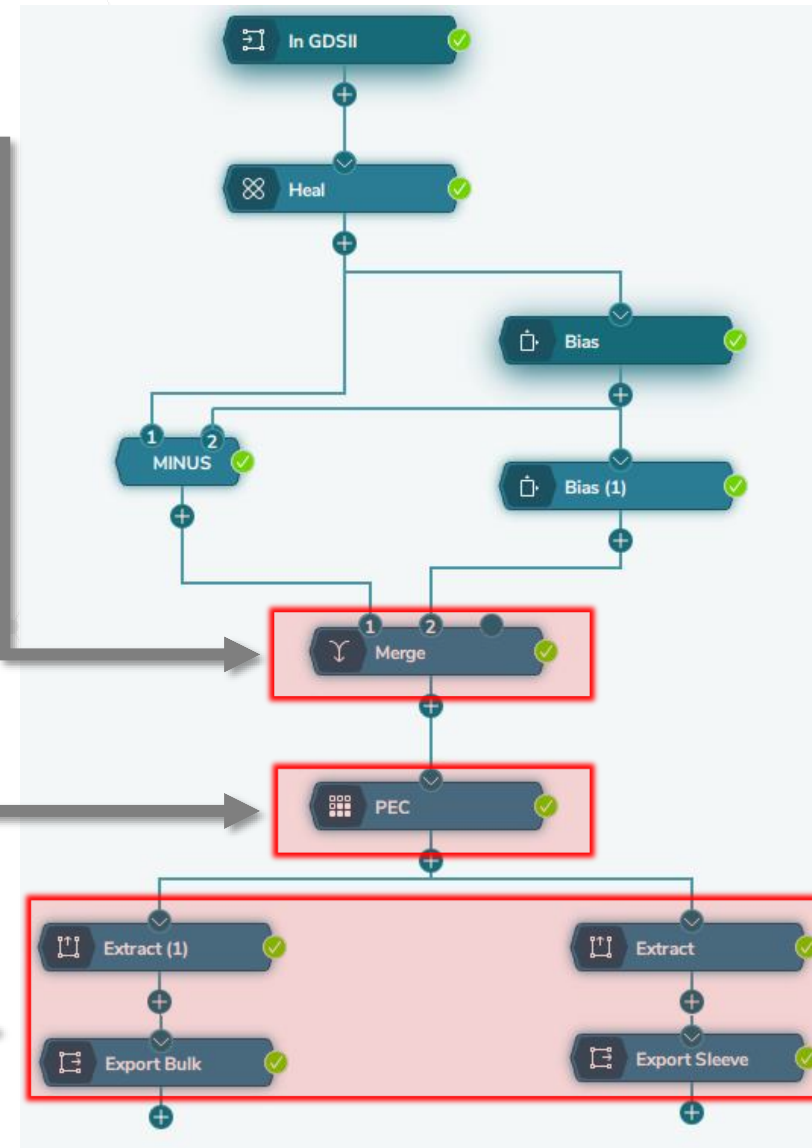
Practical

- Load and Heal
  - Import a layout and remove overlaps
- Create the bulk
  - Apply a negative bias to the layout
- Create the sleeve
  - Subtract from the original layout the bulk
- Avoiding the gap
  - Apply a positive bias to overlap the bulk and sleeve, this ensures that no gaps appear in the final exposure result

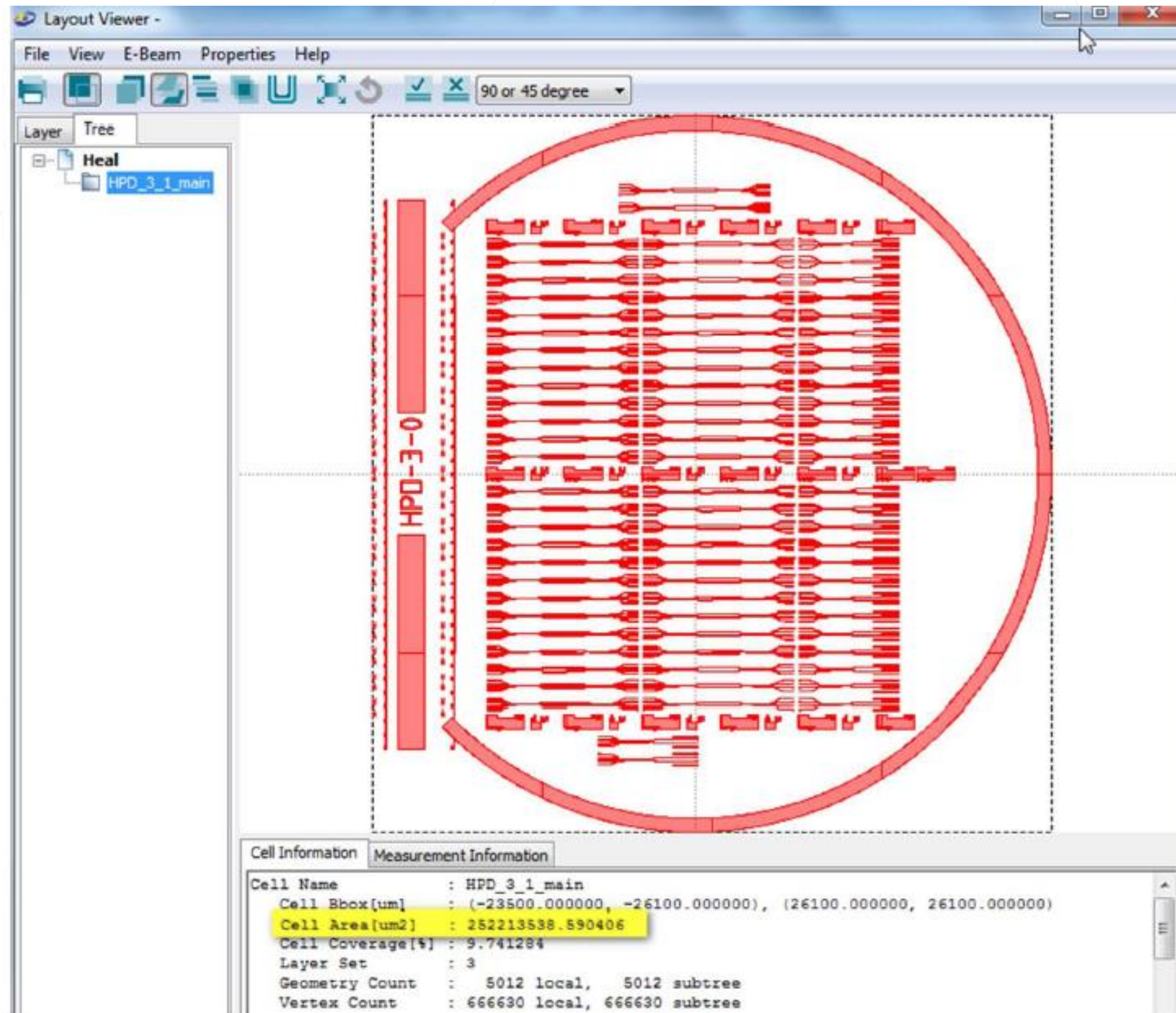


Practical

- Merge the prepared layout
  - Merging sleeve and bulk into one layout for PEC
- Performing dose correction
  - The dose correction is done on the combined bulk & sleeve layout taking their proximity into account
- Separate sleeve & bulk
  - The Extract and Export of the sleeve and the bulk allows setting different beam step sizes for each of these regions.



Example Waveguide Chip

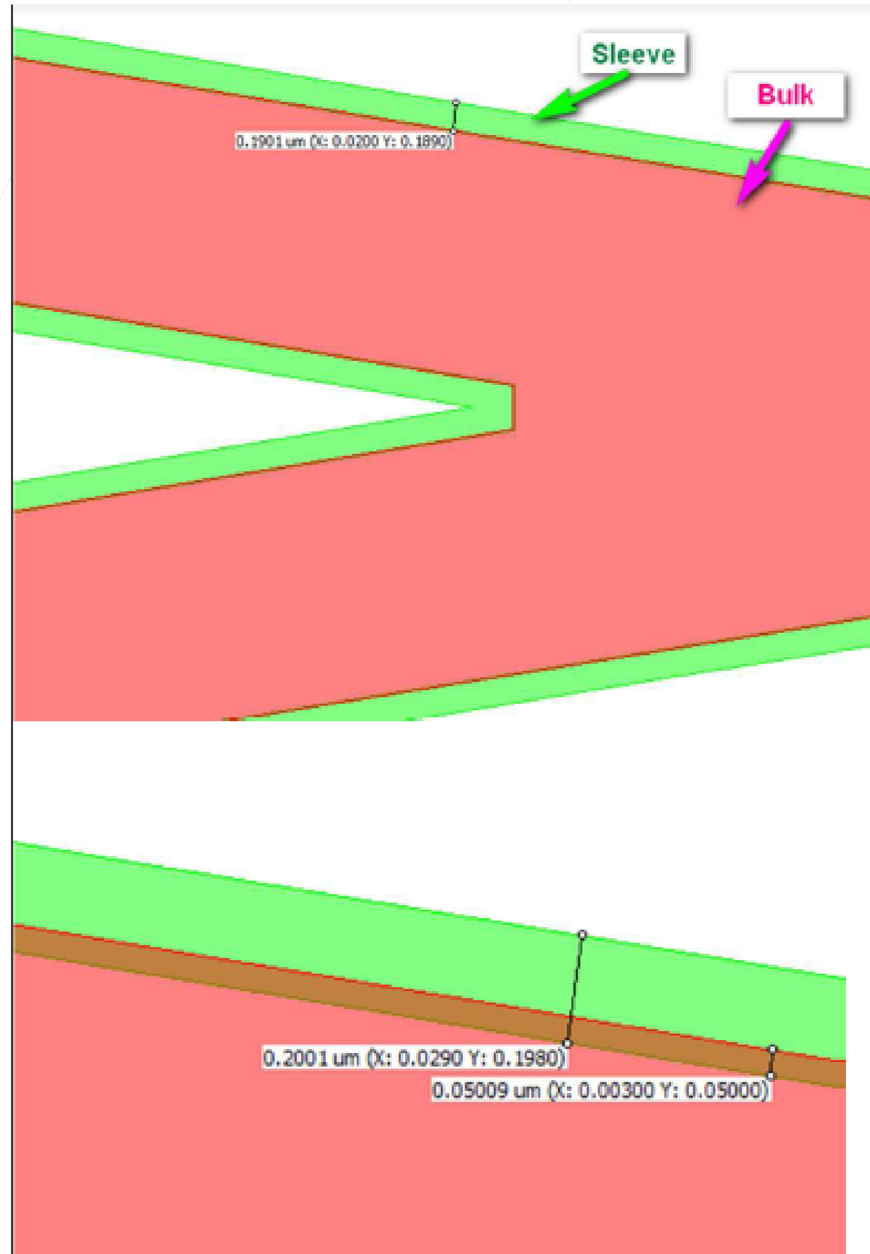


Exposure Aeria:
252213538.590406 μm^2
~ 2.5 cm^2

Asume Dose required:
$200 \mu C / cm^2$

Using 1nA for all
Exposure results in ~ 6
days writing time!

Split Layout in Bulk & Sleeve



Exposure Aeria:
252213538.590406 µm²
~ 2.5 cm²

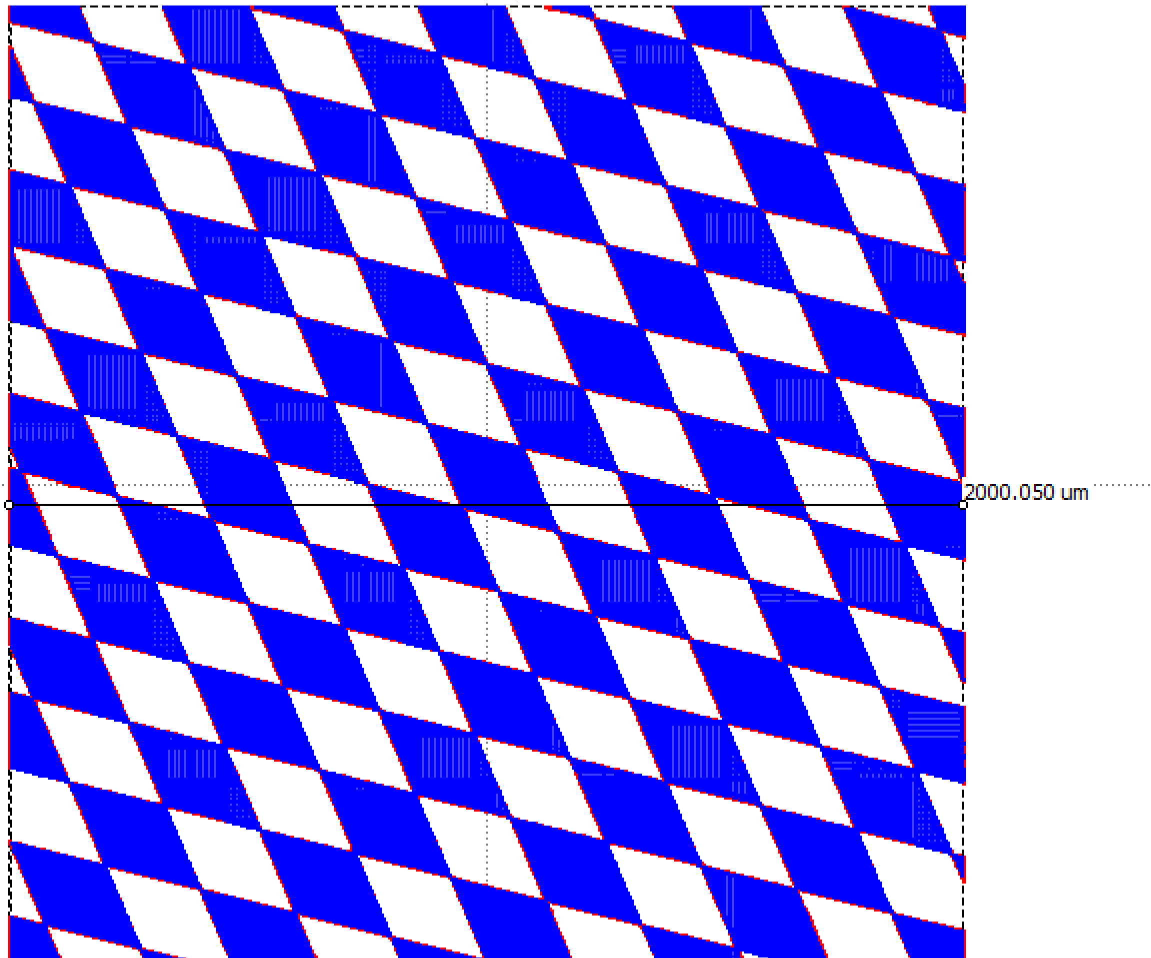
Slit Layout to **Sleeve** with area:
1115968.374040 µm²
~ 0,01 cm²
Expose with 1nA takes: ~ 30 min

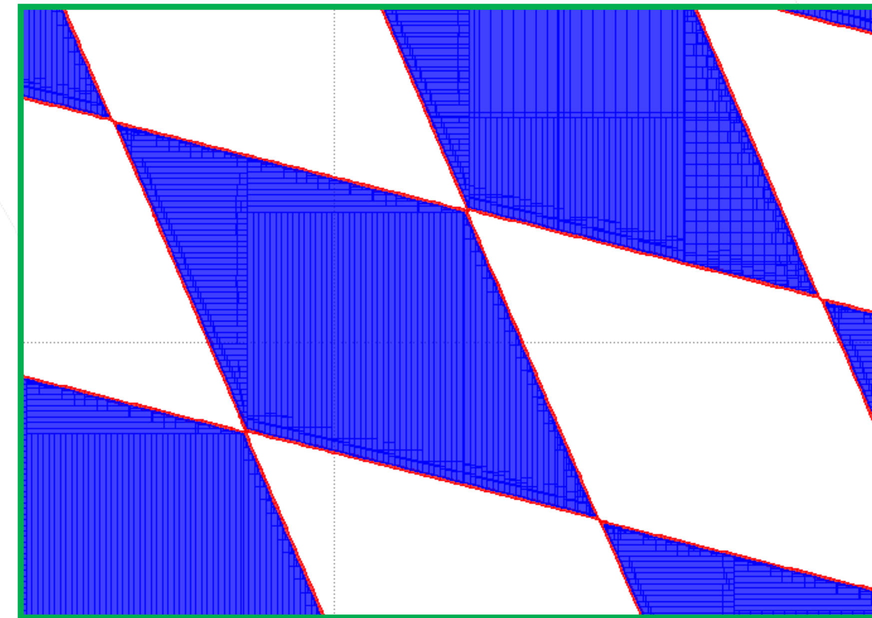
Expose Bulk with area:
251376605.100139 µm²
~ 2,5 cm²
Expose with 50nA takes 3 hours

Total exposure including
switching current takes ~ 4 hour!

Exposure test

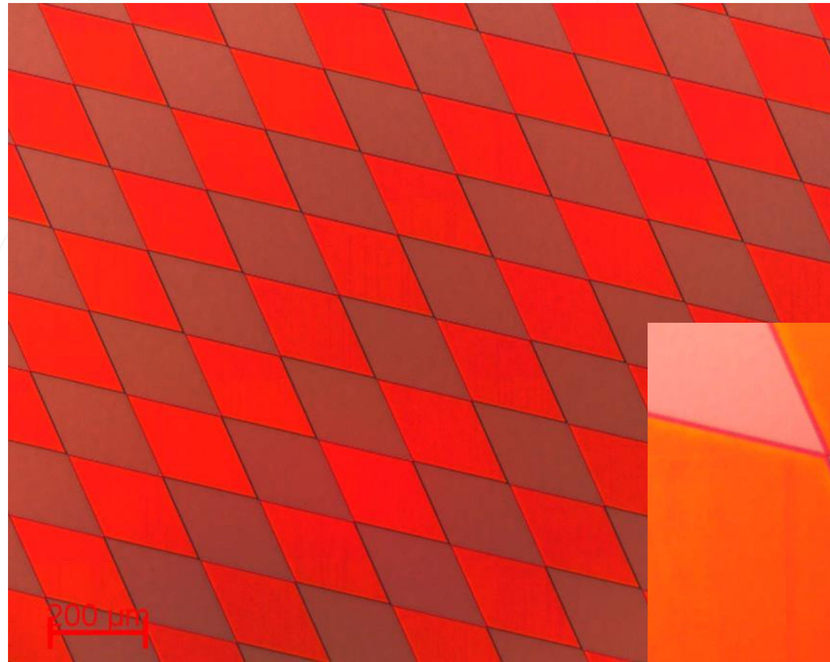
A 2000µm x 2000µm pattern was exposed using the Bulk & Sleeve method.

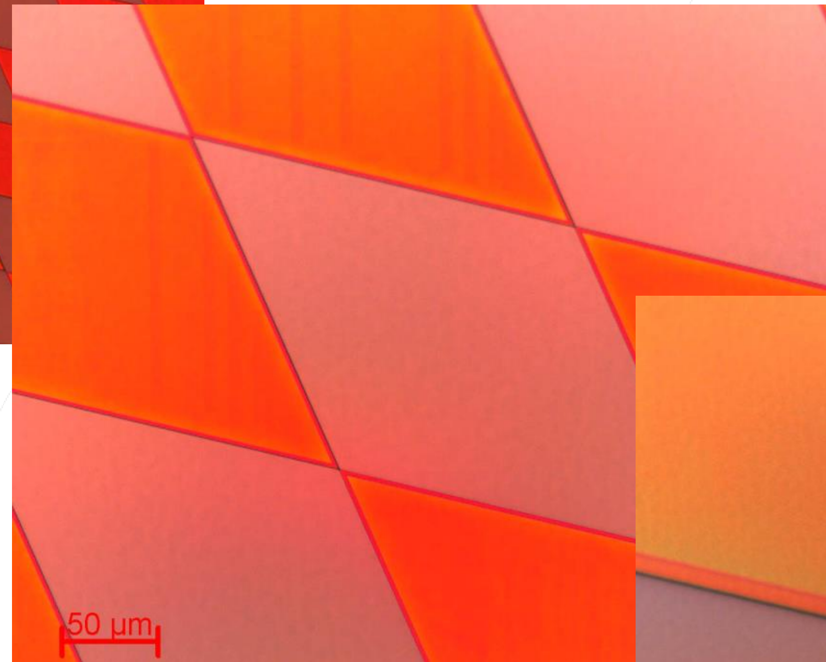


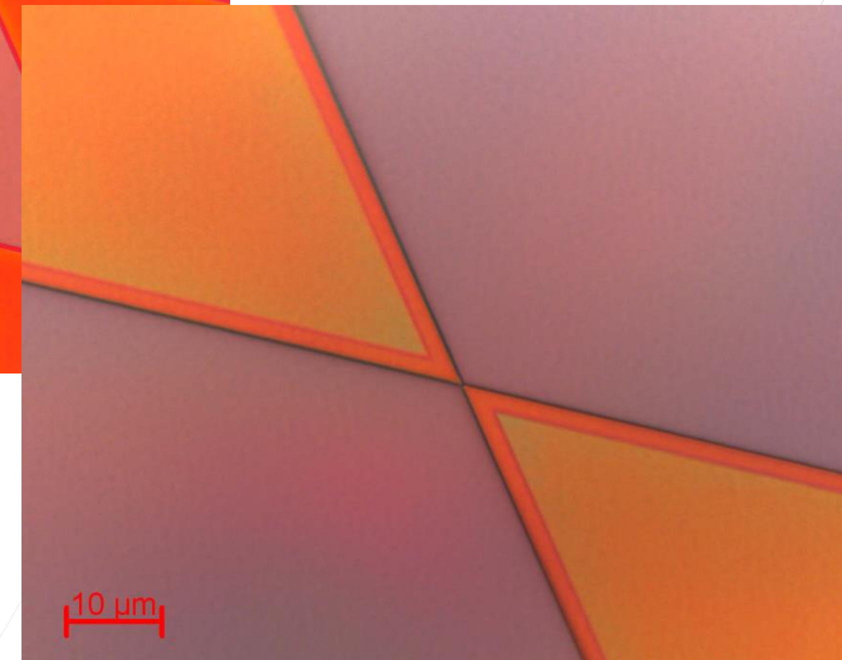


Exposure results

Exposure at Fraunhofer HHI – Berlin
Stack definition:
SAL601H on chromium/quartz mask blank
System: Vistec EBPG5000plus @ 50kV







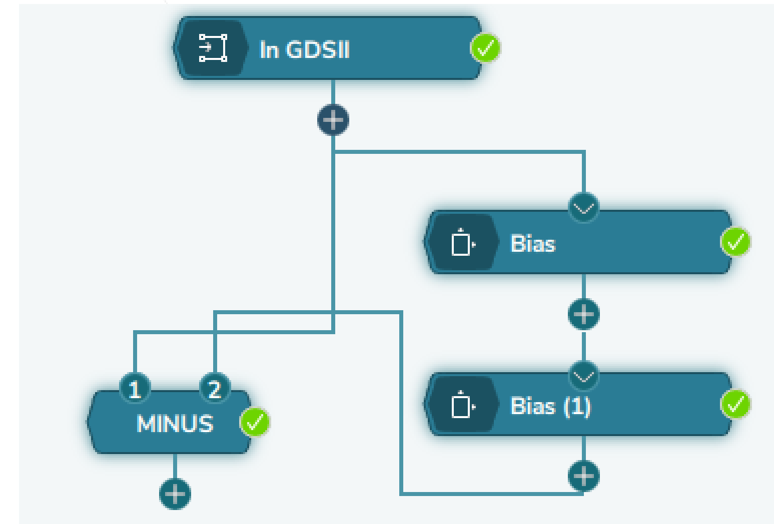
Conditions:
bulk:
100nm resol, 20na cur, 10uC, 2xmultipass, 16.7MHz
sleeve:
25nm resol, 2na cur, 10uC, 2xmultipass, 30.6MHz

Result

- Pattern exposure time without Bulk & Sleeve was about 2hours 30 Minutes
- Using Bulk & Sleeve with the PEC process reduced the time to about 25 minutes
- The Bulk & Sleeve was 6 times faster
- Keep in mind: we used two different exposure files so beam switching, calibration and such occur twice. This adds up and reduce the theoretical maximum gain.

Alternatives

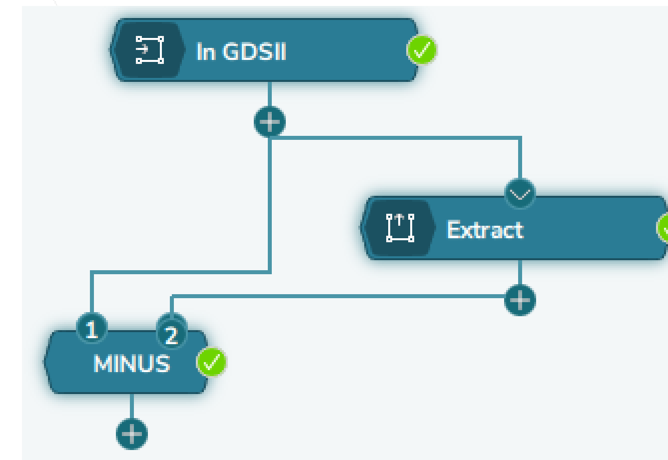
- Coarse - Fine Split



< 1µm

> 1µm

- Extract critical region or layer



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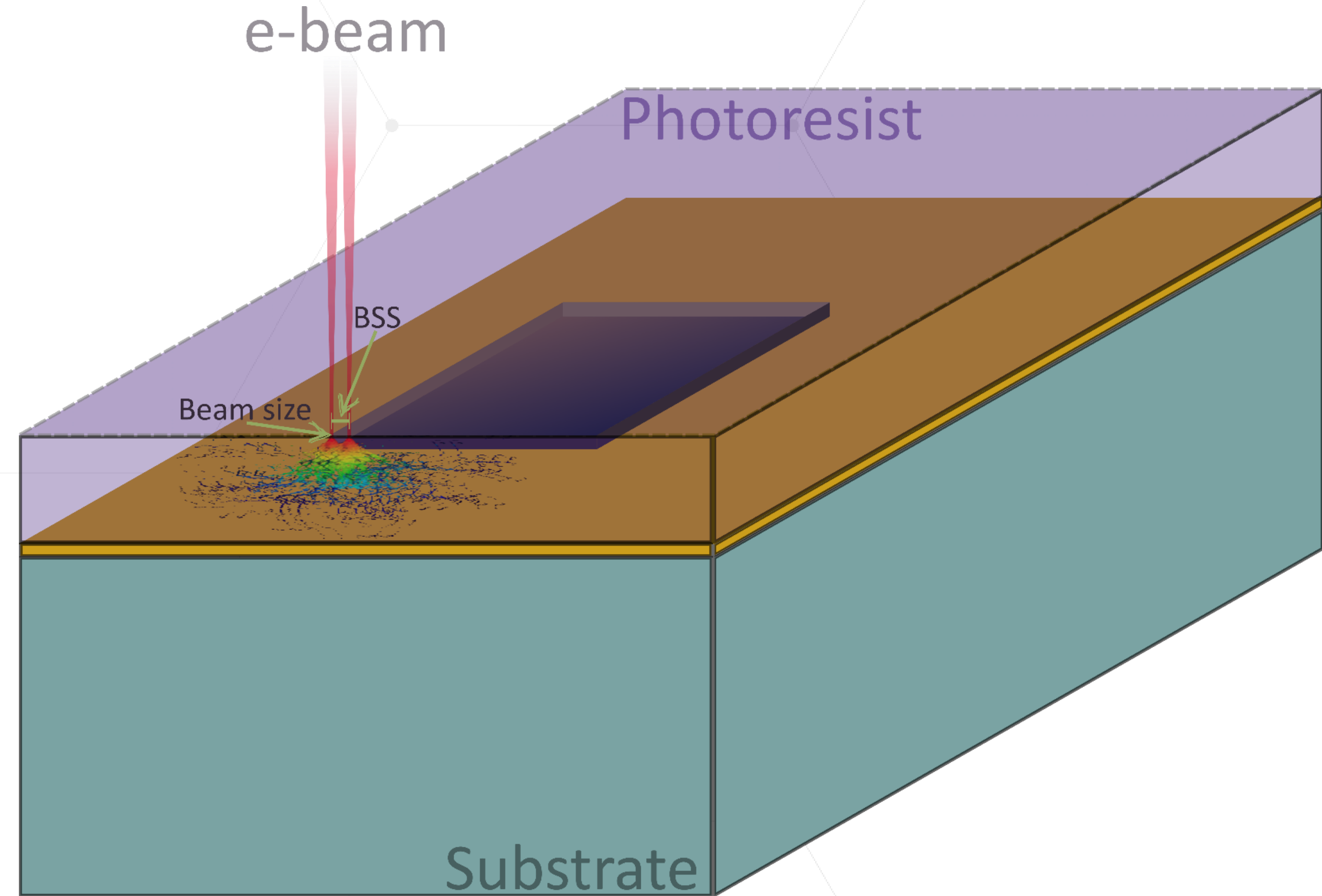
Electron Scattering Effect

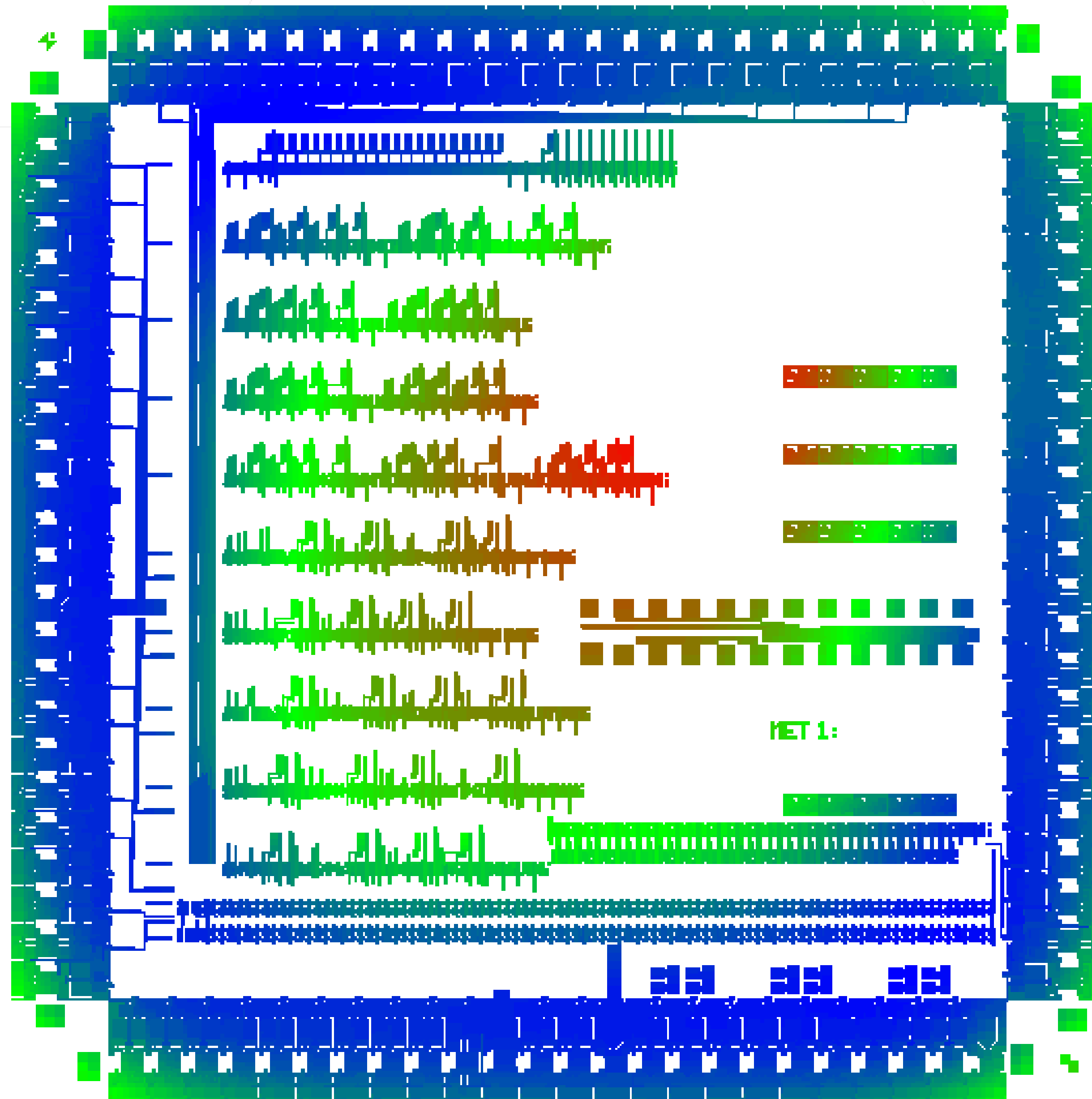
Beam blur **1- 50 nm**
- Beam current
- Beam source

Back scattering **10 – 30 µm**
- Acceleration voltage
- Substrate material

Forward scattering **1 – 10 nm**
- Acceleration voltage
- Resist material
- Resist thickness



Density Dependent Dose

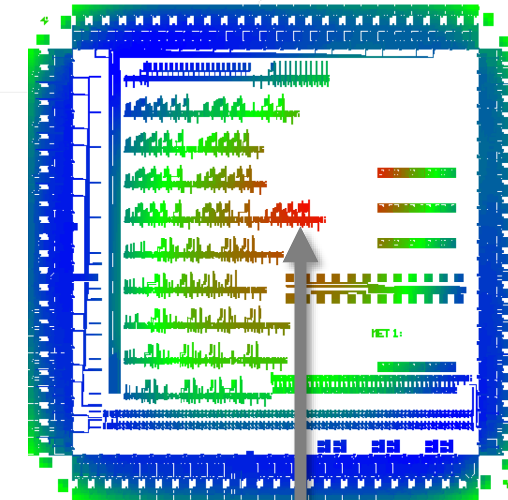


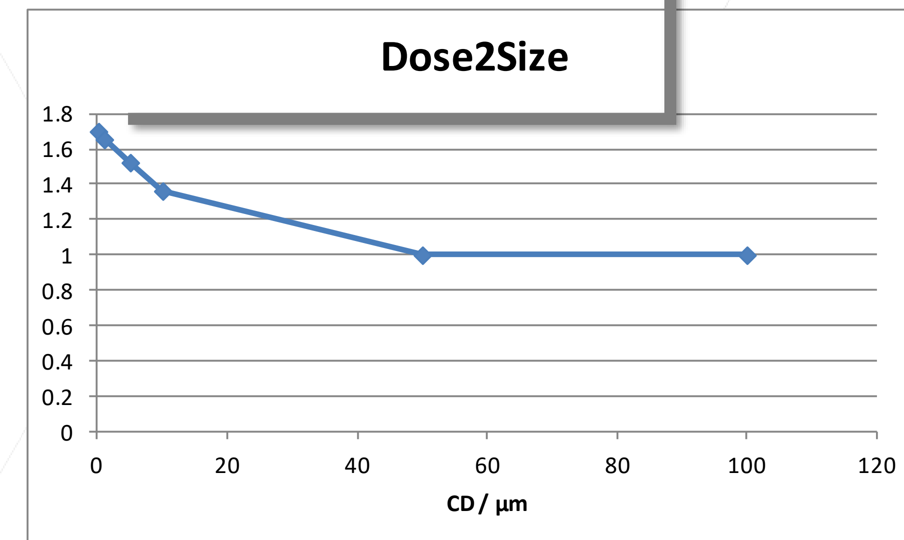
PEC Benefits

- Improves accuracy, since iso-dense dose error is removed

- Improves write time
  - Without PEC, entire pattern has to be written at Dose-to-Size for small isolated pattern
  - Saves up to 50% write time in case 80% of the pattern consists of large features
  - Normalizes Dose

    No need for dose variation





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- If write time is an issue, use Bulk-sleeve and PEC
- Significant write time reductions through
  - Bulk-Sleeve - up to 90%
  - PEC – up to 50%
- Significant accuracy improvements through
  - Bulk-Sleeve
  - PEC

Thank You!

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