Writing Time Optimization

Outline

- Limitation of Electron Beam Lithography
- Beam Current / Beam Step Size
- PEC
- Summary

Gaussian exposure Principle

e⁻

Beam time at a position:

- Resist sensitivity
- Beam current
- Max frequency

Gaussian exposure Principle

e-

Beam time at a position:

- Resist sensitivity
- Beam current
- Max frequency

Resolution is dependent on:

- Beam size (inverse to beam current)
- Beam Step Size (Shot Pitch)

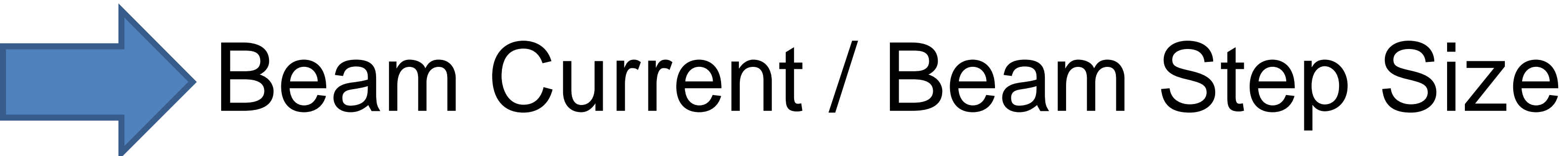
Exposure time

where
D = dose ($\mu C/cm^2$)
I = current (A)
t = time (sec)
A = exposure area (cm^2)

- Beam-on time: $t = D * A / I$
  - i.e. $D=200\mu C/cm^2$, $A=1cm^2$, $I=1nA$ leads to 56 hours beam-on time!
- Best Performance calls for large currents
  - However, this increases the spot size, and thereby the CD sensitivity to dose
- Best Accuracy calls for small currents
  - … and the write time goes to hell

Outline

- Limitation of Electron Beam Lithography

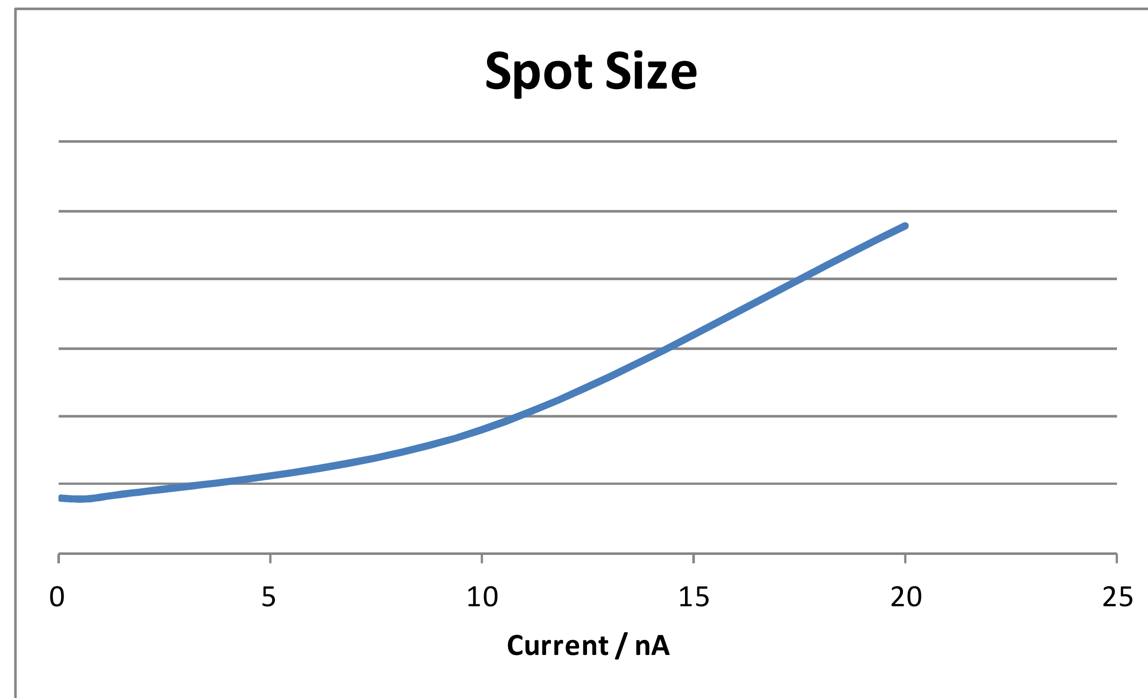


Beam Current / Beam Step Size

- PEC

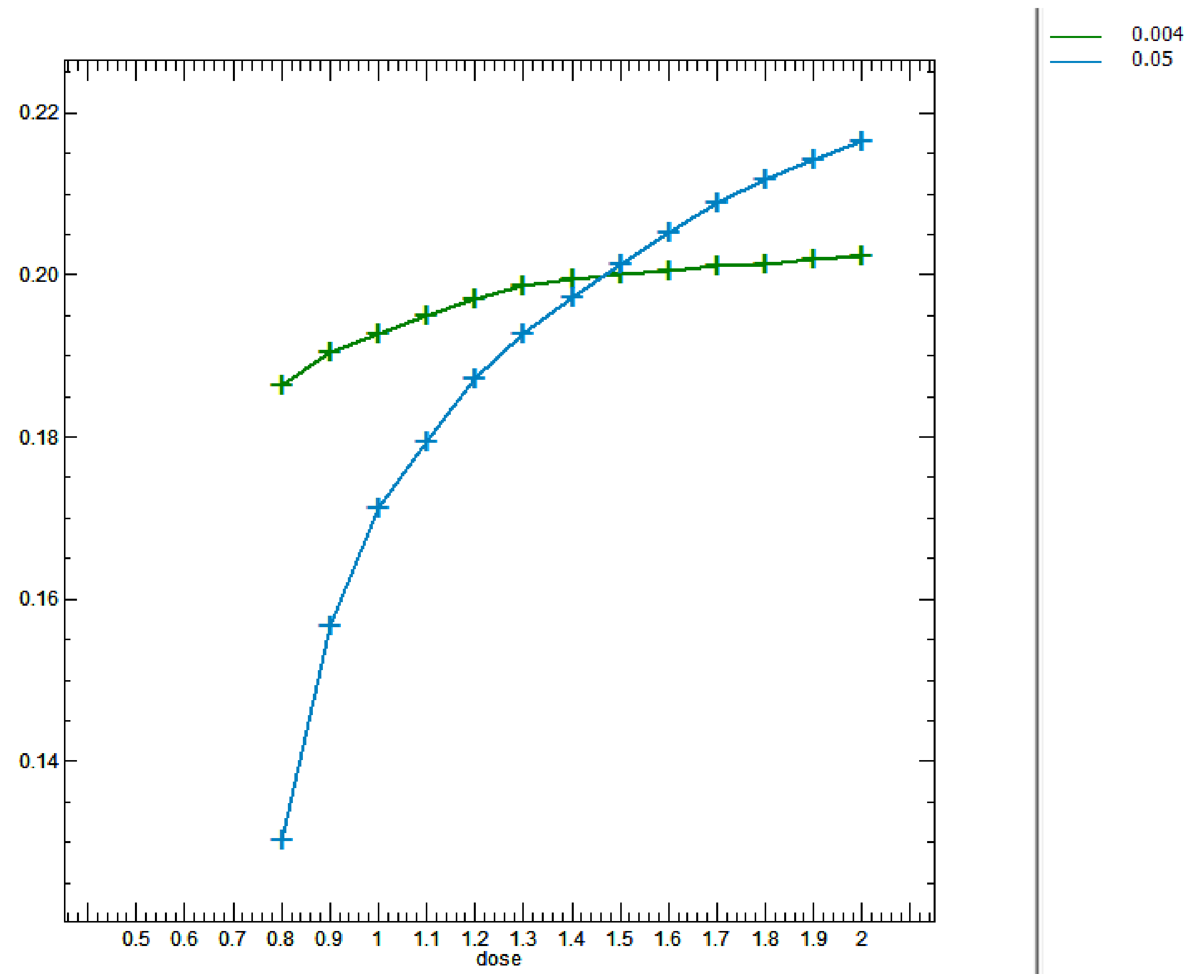
- Summary

Spot size / current relationship



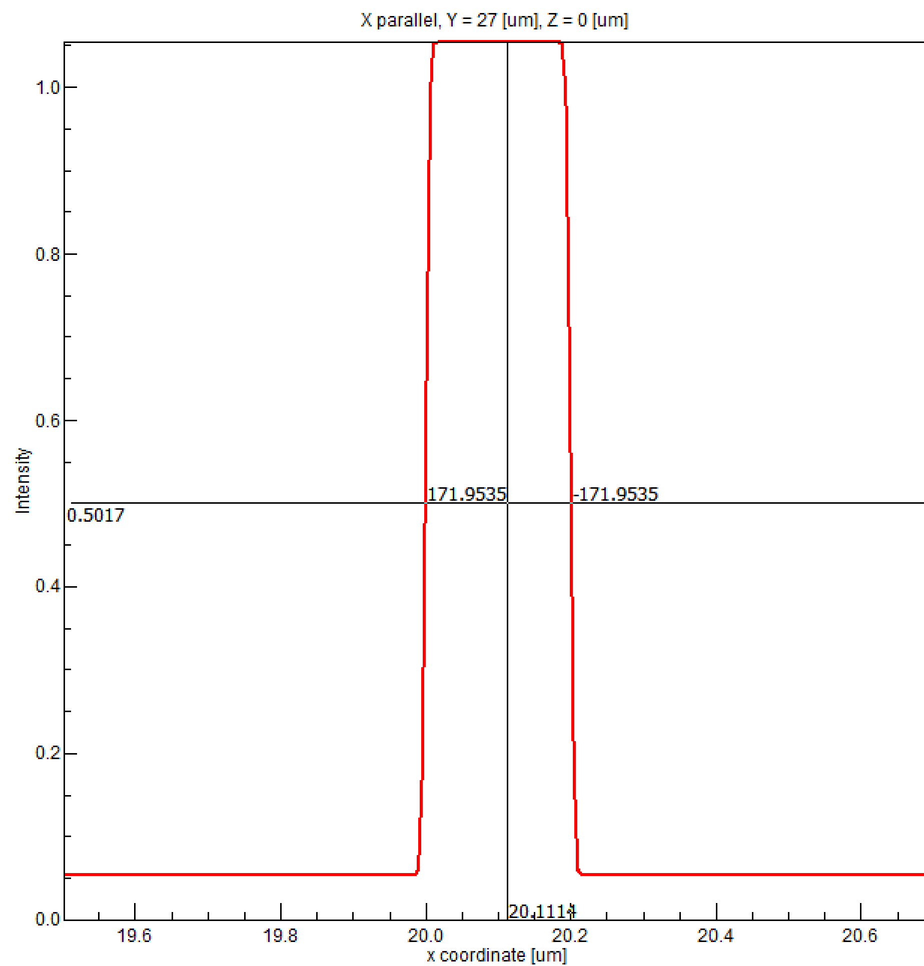
- Spot size increases at larger beam currents

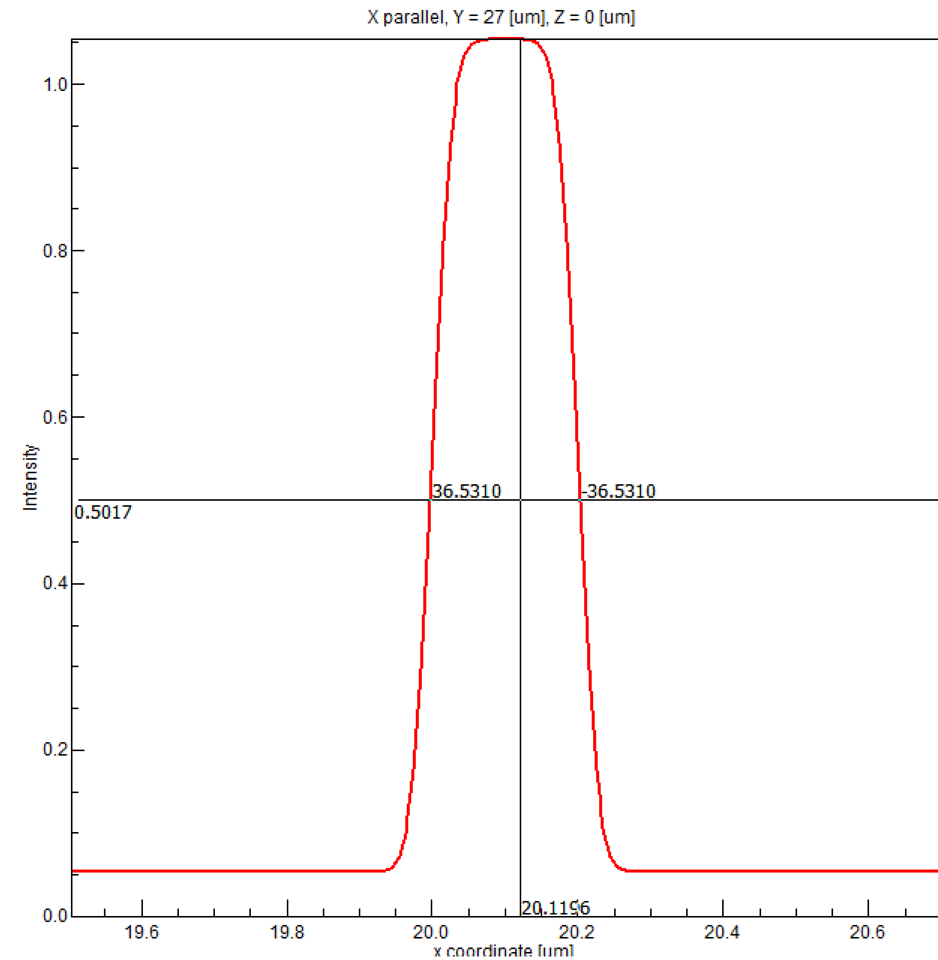
CD Sensitivity to Dose



- CD Sensitivity to Dose depends on spot size
  - 200nm line at spot sizes of 4nm and 50nm

ILS and why this impacts the CD





- Exposure Latitude 17.2 %/nm vs 3.65%/nm
  - -> Larger spot will show dose fluctuations more clearly

Dose Error Examples

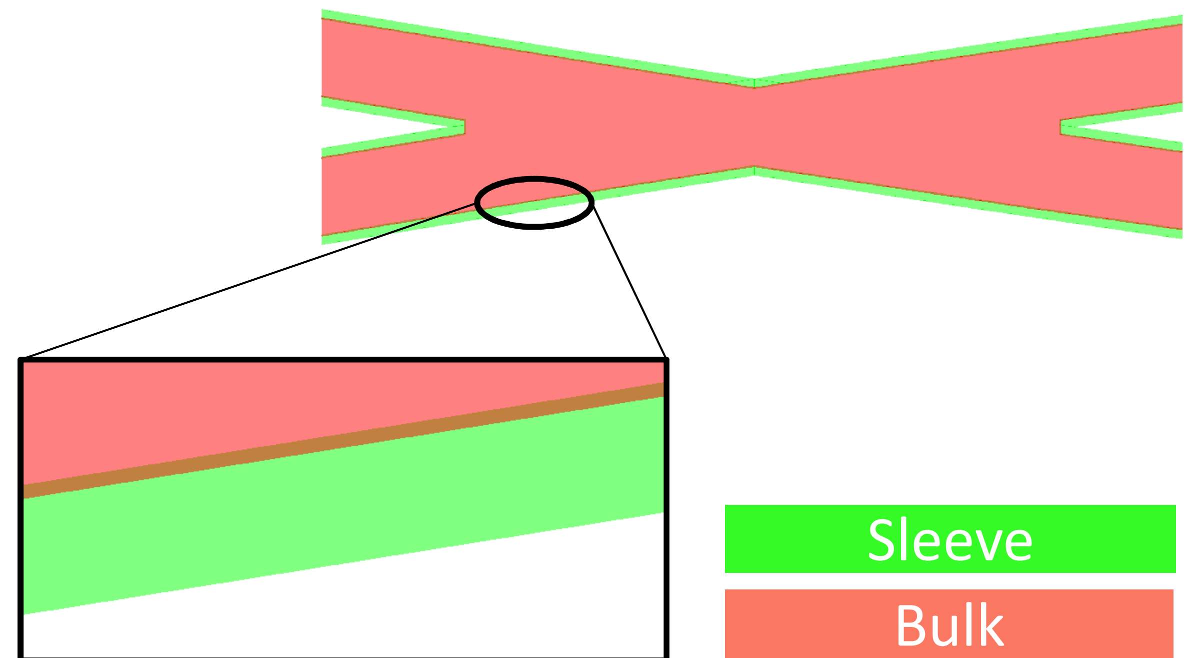
- Larger spot “magnifies” dose errors
  - Noise shows up stronger -> LER, LWR
  - Proximity Effect shows up stronger

- ΔCD = 22nm (50nm spot) vs. 4.6nm (4nm spot)
  - Proximity effect maximum dose error is $\eta/(1+\eta)$
  - For $\eta=0.7$, the maximum dose error is 41%
  - $\Delta CD = 2 * DoseError / ILS$

Solution

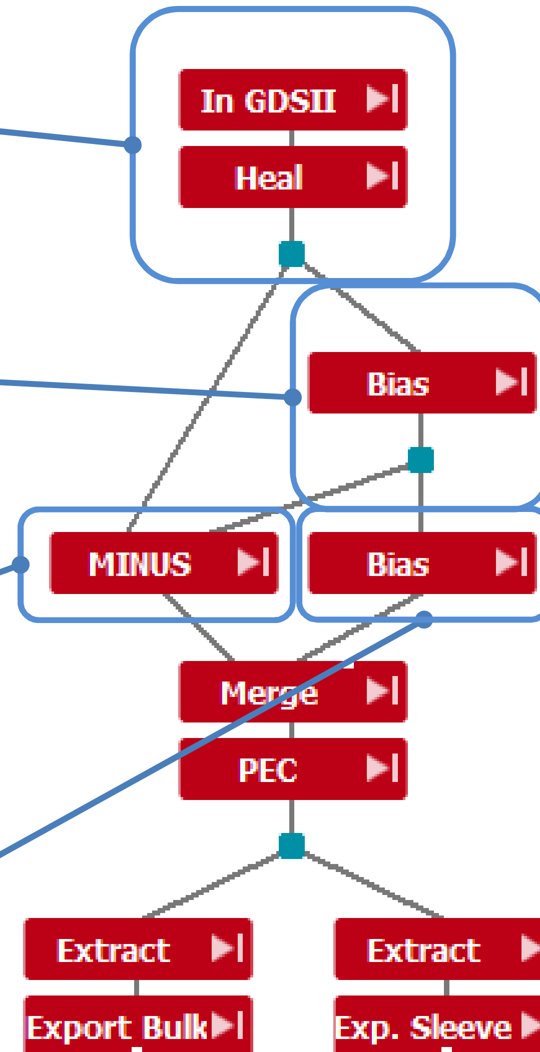
- Split layout to Bulk & Sleeve with core part (bulk) of the layout written with a large beam and step size and sleeve that is written with a small beam and step size.

- Two machine files will be generated for the exposure.



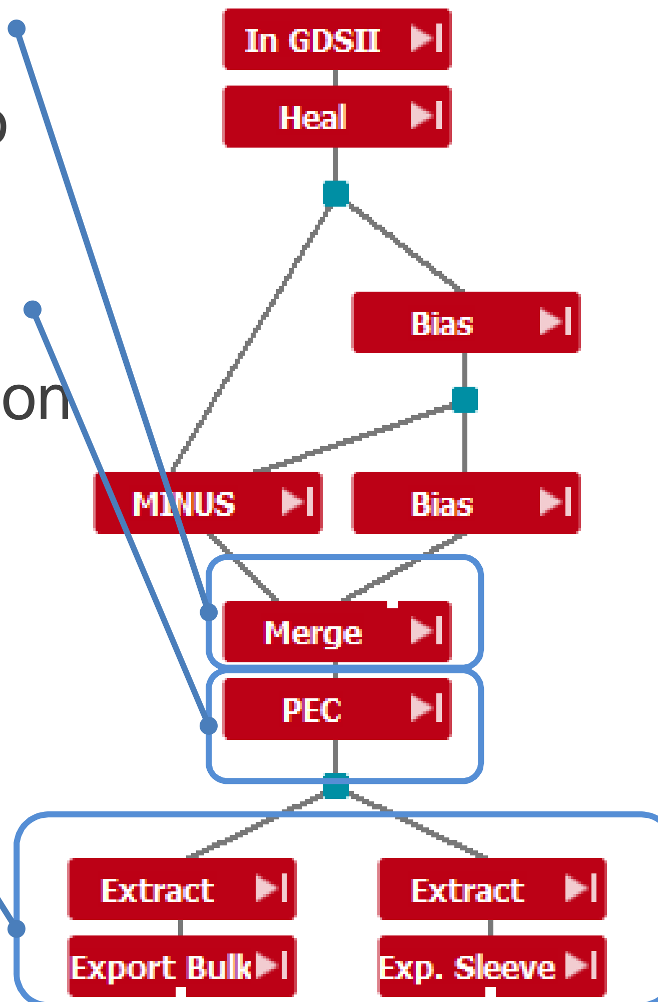
Practical

- Load and Heal
  - Provide a layout and remove any overlaps
- Create the bulk
  - Negatively bias the layout and create the bulk part
- Create the sleeve
  - Subtract from the original layout the bulk to get the sleeve
- Avoiding the gap
  - An one beam step size large overlap on the bulk will ensure that no openings appear in the final exposure result

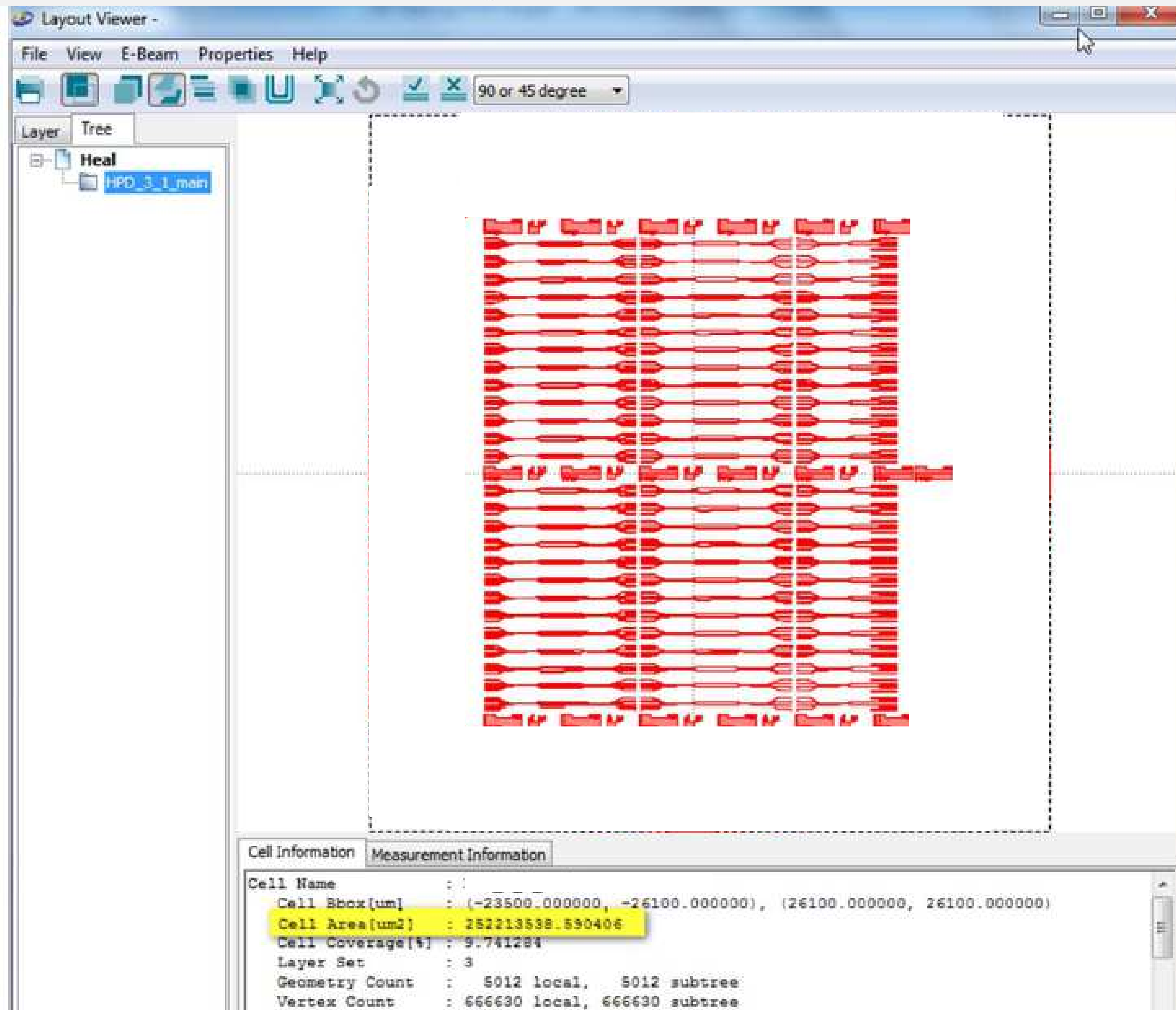


Practical

- 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 the definition of different beam step sizes for each of these patterns. By this approach the machine can write the pattern in minimal time



Example Waveguide Chip

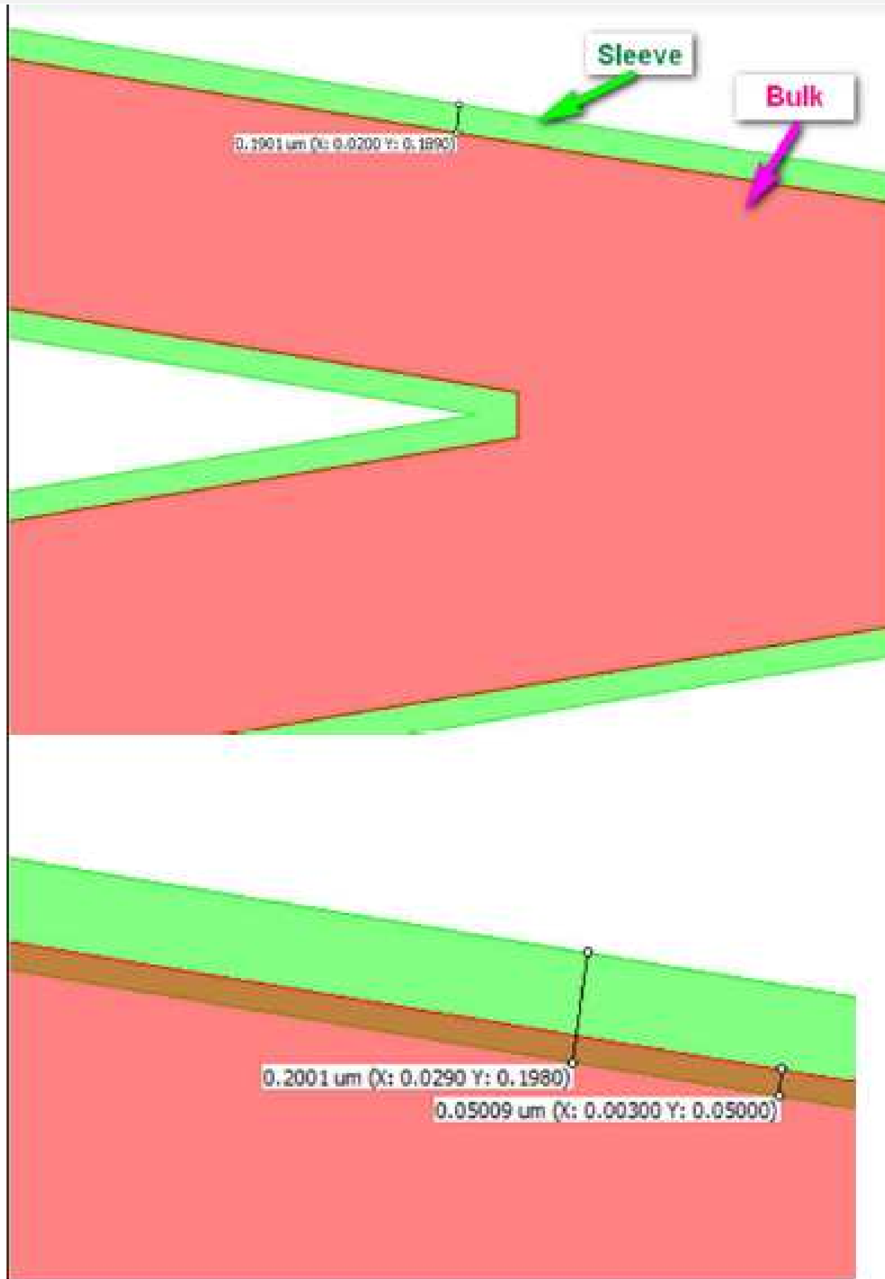


Exposure Aeria:
252213538.590406 µm²
~ 2.5 cm²

Asume Dose required:
200µC / cm²

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

Split Layout in Bulk & Sleeve



Exposure Aeria:
252213538.590406 µm²
~ 2.5 cm²

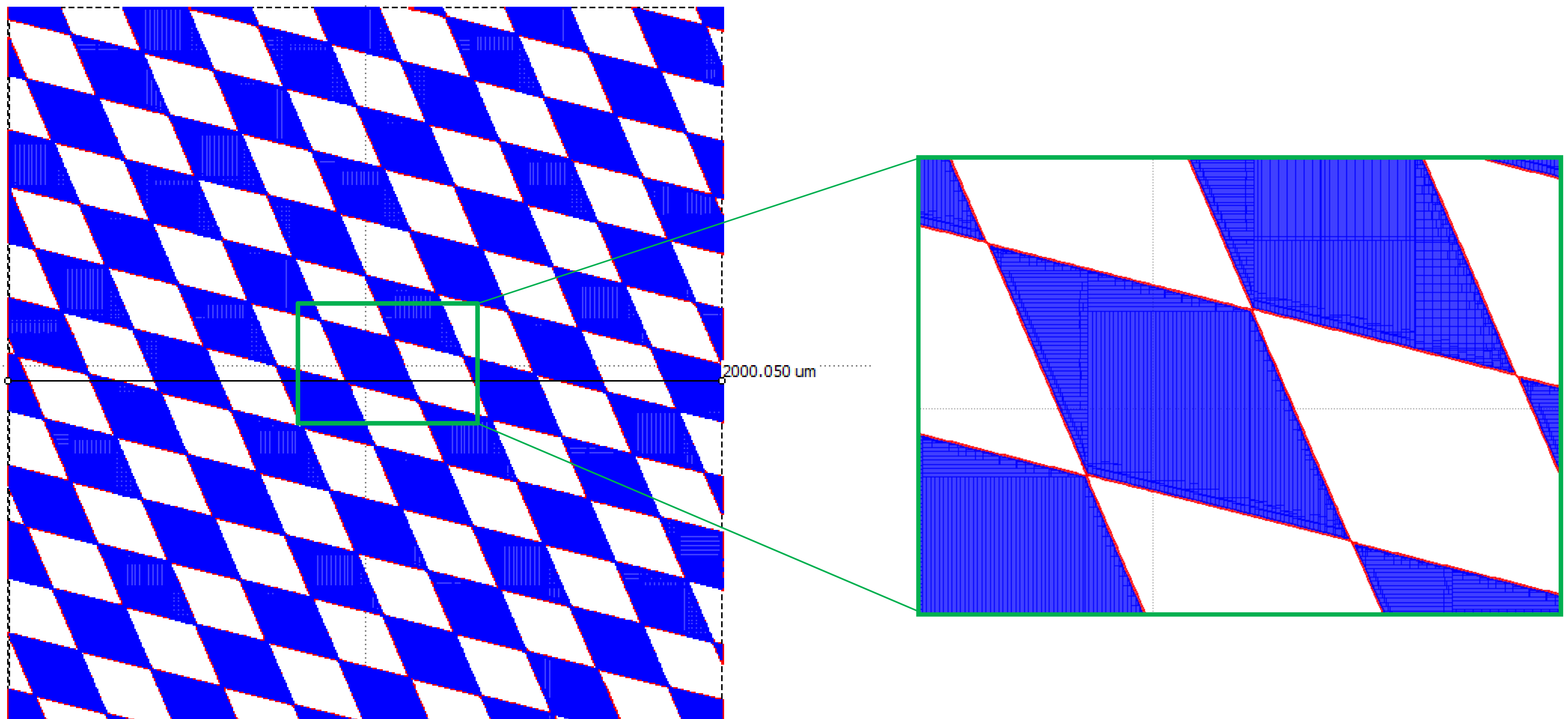
Slit Layout to **Sleeve** with area:
1115968.374040 µm²
~ 0,01 cm²
Expose with 1nA takes: ~ 30 min

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

Total exposure including switching current takes ~ 4 hour!

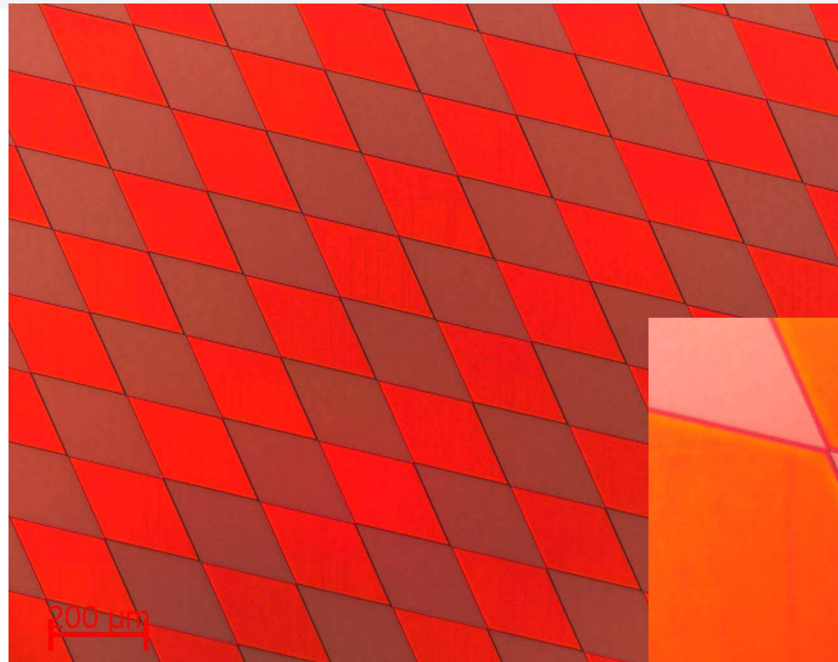
Exposure test

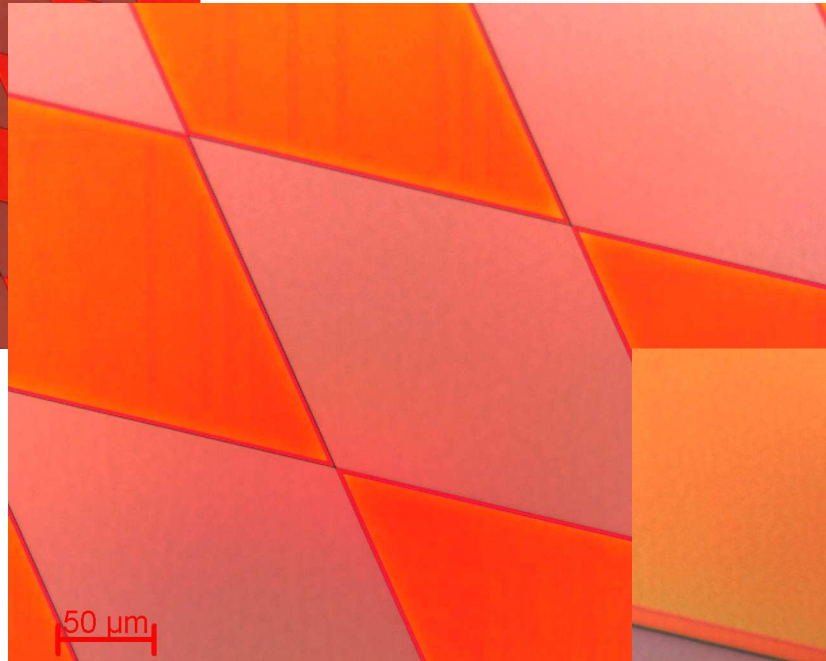
A 2000µm x 2000µm pattern was exposed using the Bulk & Sleeve method.

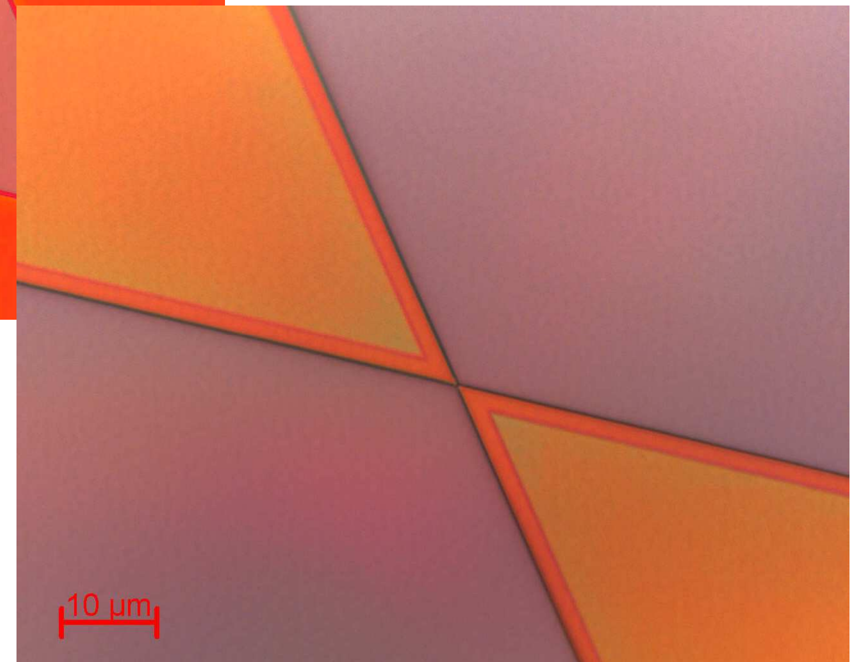


Exposure results

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







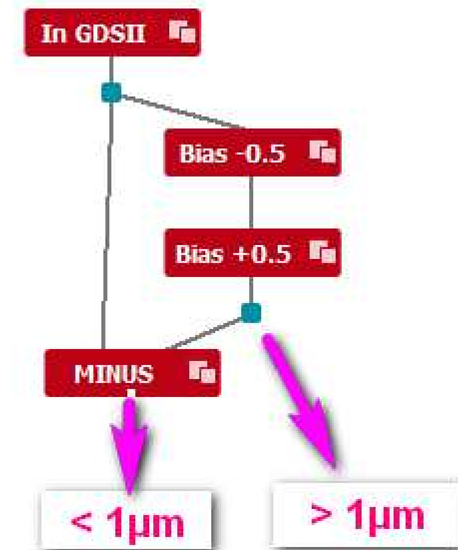
Conditions:
bulk:
100nm resol, 20na cur, 10uC, 2xmultipass, 16.7MHz
sleeve:
25nm resol, 2na cur, 10uC, 2xmultipass, 30.6MHz

Result

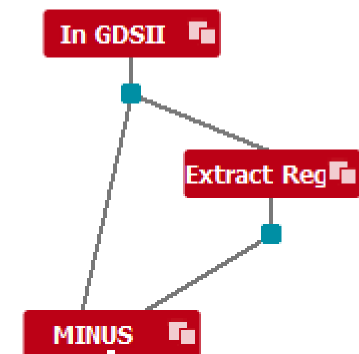
- Pattern exposure time without Bulk and Sleeve was about 2hours 30 Minutes
- Using Bulk & Sleeve with the PEC process reduced the time to about 25 minutes
- The total time saving is at 570%
- Keep in mind: we used two different exposure files so beam switching, calibration and such occur twice. This adds up and reduce the theoretical maximum gain.

Alternatives

- Coarse - Fine Split



- Extract critical region or layer



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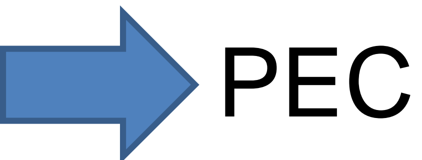
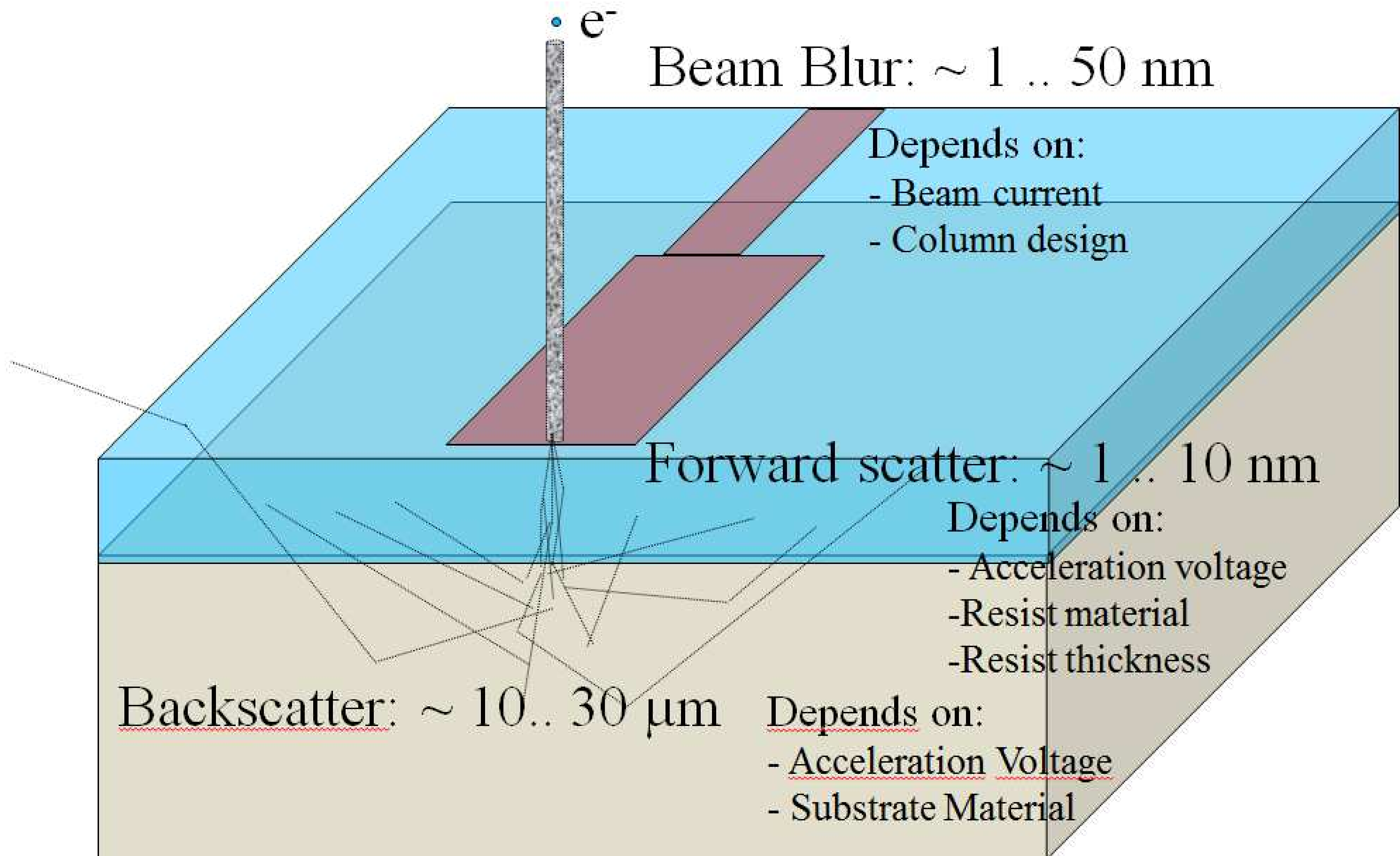


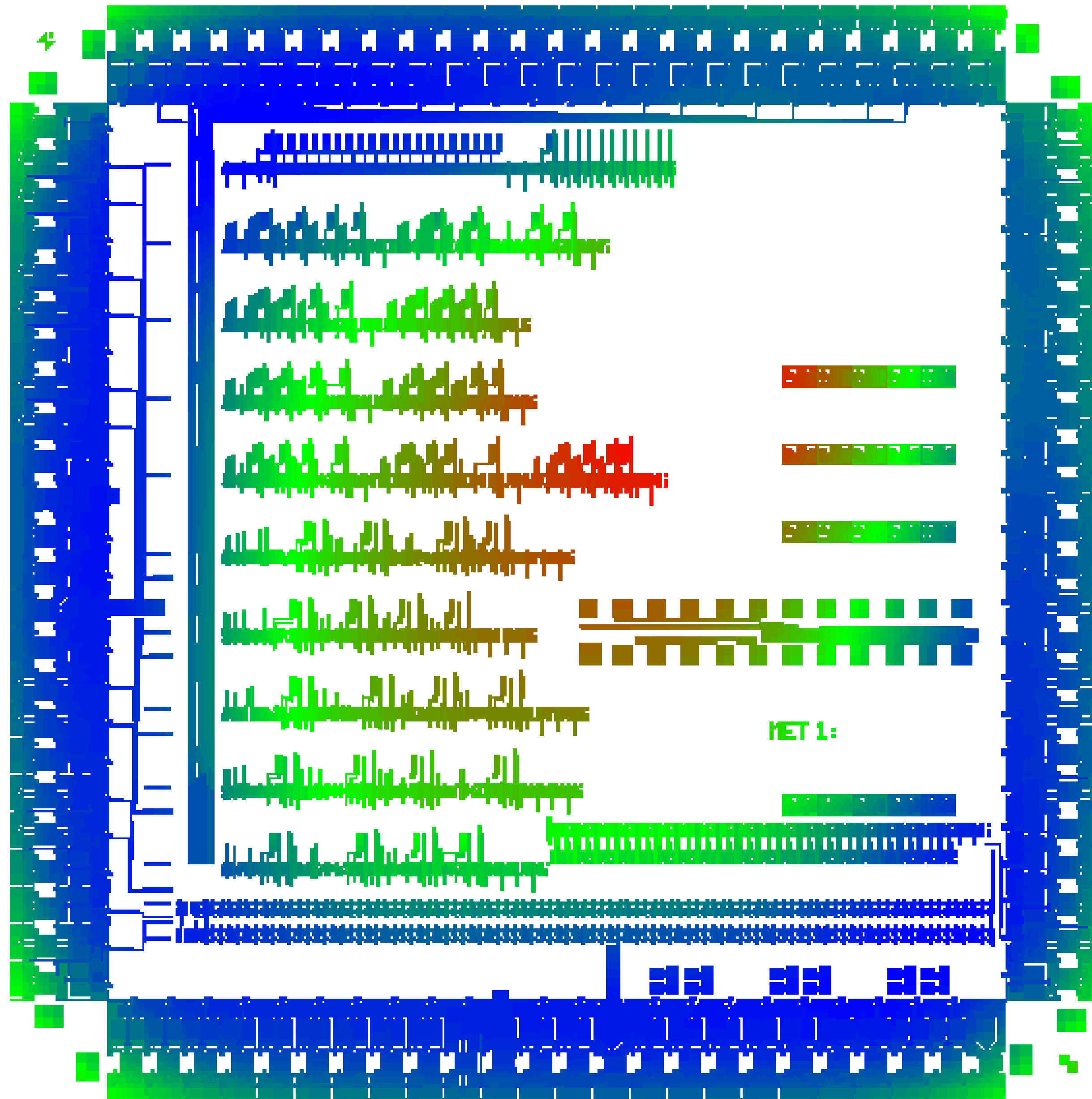
PEC

- Multi-Pass
- Summary

Electron Scattering Effect

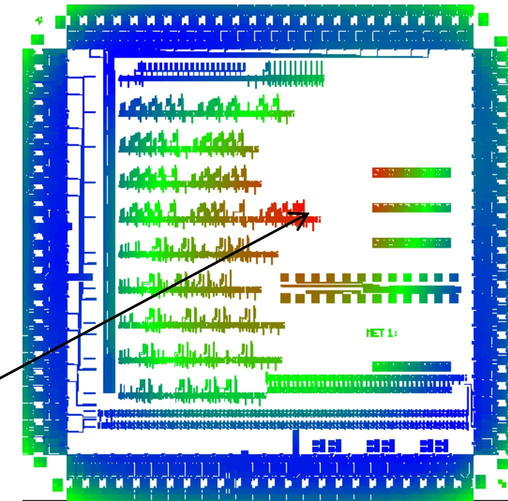


Density Dependent Dose



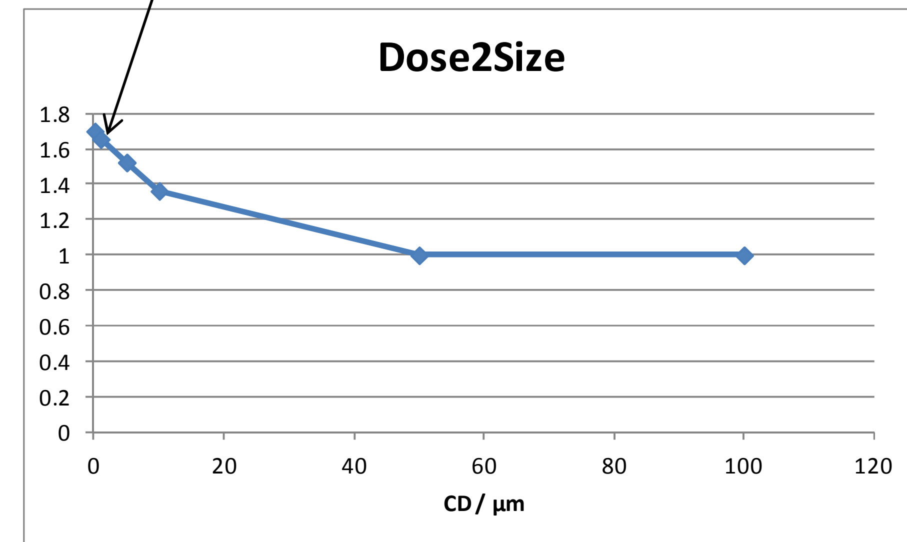
PEC Benefits

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



- Improves write time
  - Without PEC, entire pattern has to be written at Dose2Size 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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- Significant write time reductions through
  - Bulk-Sleeve - up to 90%
  - PEC – up to 50%
- Significant accuracy improvements through
  - Bulk-Sleeve
  - PEC
- If write time is an issue, use Bulk-sleeve, PEC

Thank you

For question and more information please contact
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