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Proximity Correction for High Resolution Direct Write

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3rd IMS Workshop, 28.10.2005

Outline

- **Issues in High Resolution Electron Beam Direct Write**
- **Practical approach to Proximity Effect Correction**
- **Results of Back-Simulations**
- **Experimental Examples**

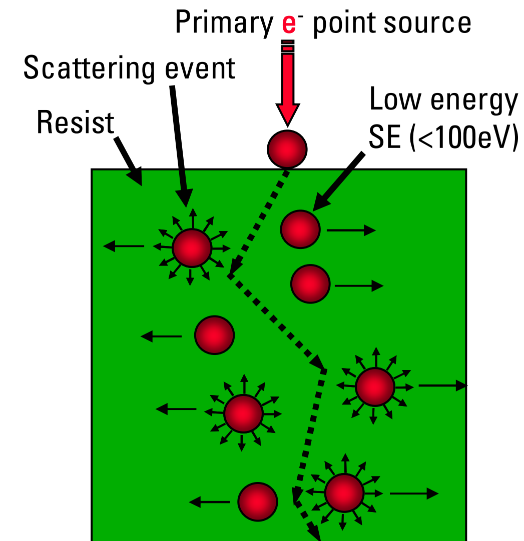
Issues in High Resolution Direct Write

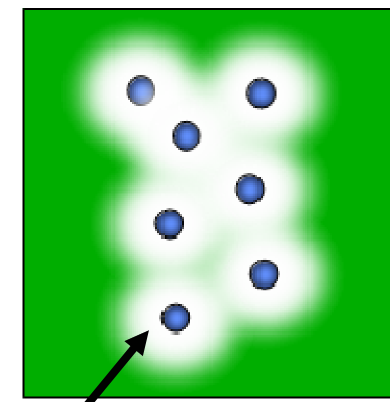
- **SB350/351DW Shaped Electron Beam Writer**
  - **Sub 50 nm resolution**
  - **300 mm wafer direct write capability**
- **Total exposure time determined by required resist dose**
- **Only Chemically Amplified Resists enable reasonable exposure times for full wafers**

Image Generation in Chemically Amplified Resist

- **E-Beam Exposure**
  - **Generation of secondary electrons by forward scattered incident electrons and backscattered electrons (proximity effect)**
  - **Acid generation in resist by secondary electrons**

- **Post Exposure Bake**
  - **Resist deprotection reaction by diffusing acids during high temperature step**





Length scales

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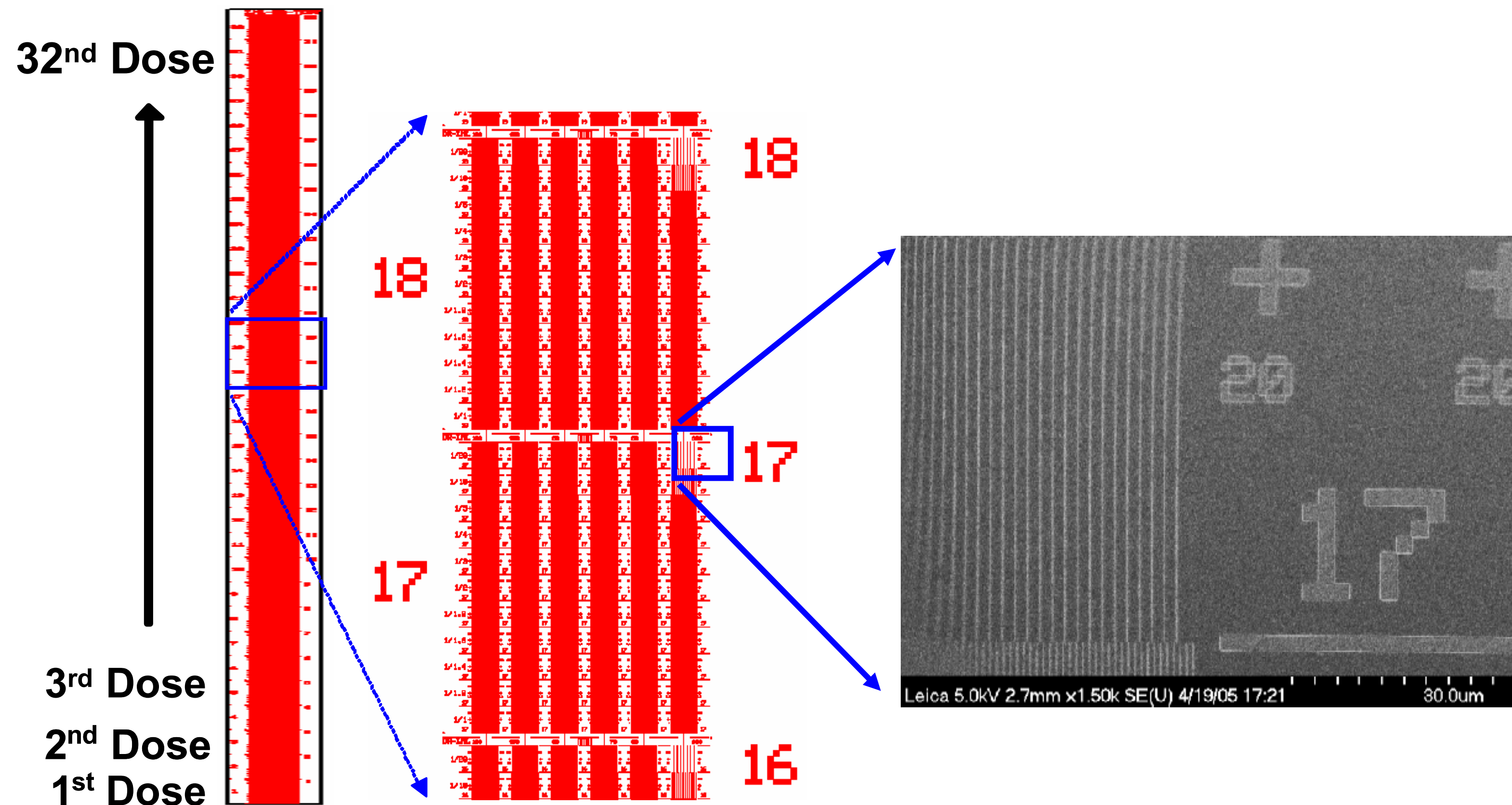
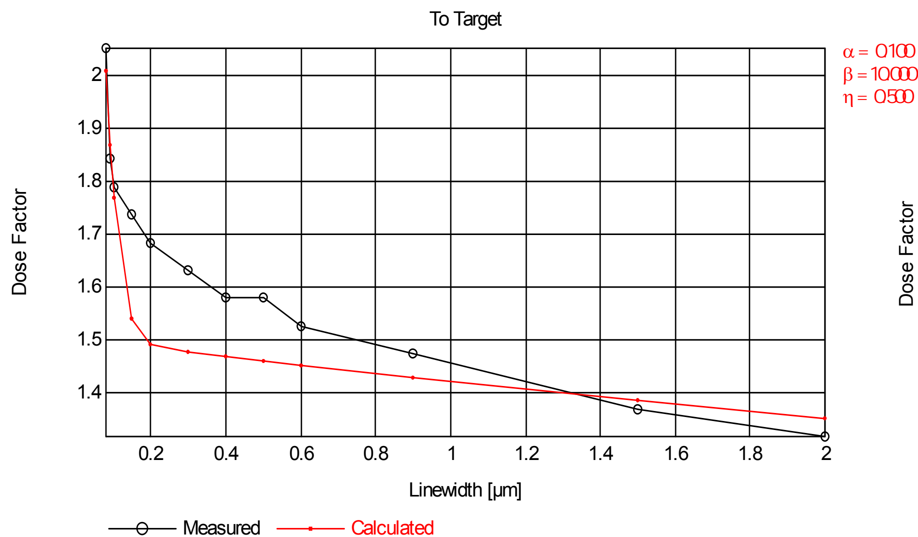
- **E-Beam Exposure**
  - **Radius of forward scattered electrons**
    < 10 nm (200 nm resist thickness, 50keV)
  - **Radius of backscattered electrons**
    ~ 10 µm (50keV, Si)
- **Post Exposure Bake**
  - **Acid diffusion length during deprotection reaction**
    10 – 100 nm
- **Conclusions for high resolution lithography**
  - **Considering deprotection step is essential for CD control with linewidths < 100 nm**
  - **Broaden scope of proximity effect correction**
  - **Difficult to simulate realistically (No parameter free Model)**

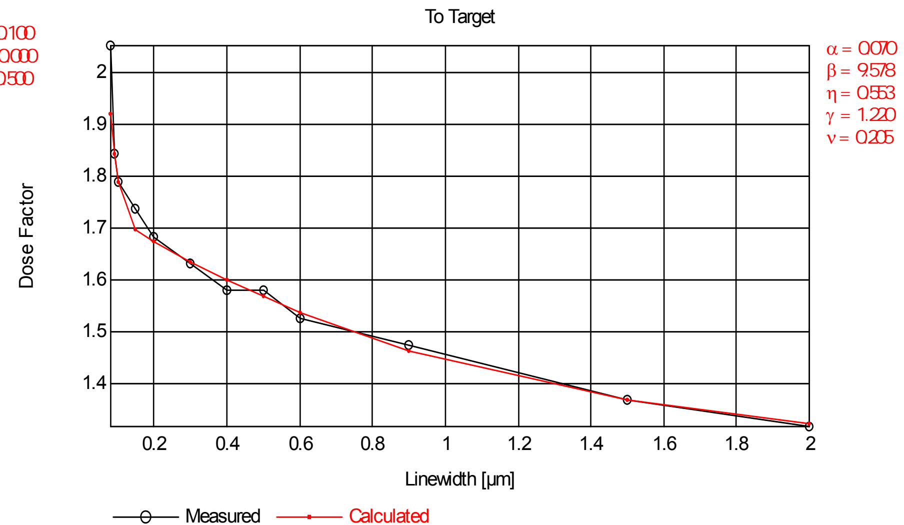
Practical Proximity Correction: Workflow (I)



- **Expose non-corrected test patterns in a dose exposure series and measure CDs**

Practical Proximity Correction: Workflow (II)





- **Simulate proximity effect in exposed test pattern for a given set of parameters**

- **Parameter variation until fit to measured results is achieved**
- **„Back-Simulation“**

Practical Proximity Correction

- **Verification**
  - **Use various test patterns with different emphasis in parameter sensitivity**
  - **Consistent parameter set for several simulations ensures that correction works for arbitrary lithography patterns**

- **Results**
  - **Effective parameters with contributions from electron scattering, acid diffusion and reaction, …**
  - **Not necessarily based on any physical interpretation (but experience shows: Good parameter set IS physically interpretable, otherwise inconsistencies between different simulations will show up)**

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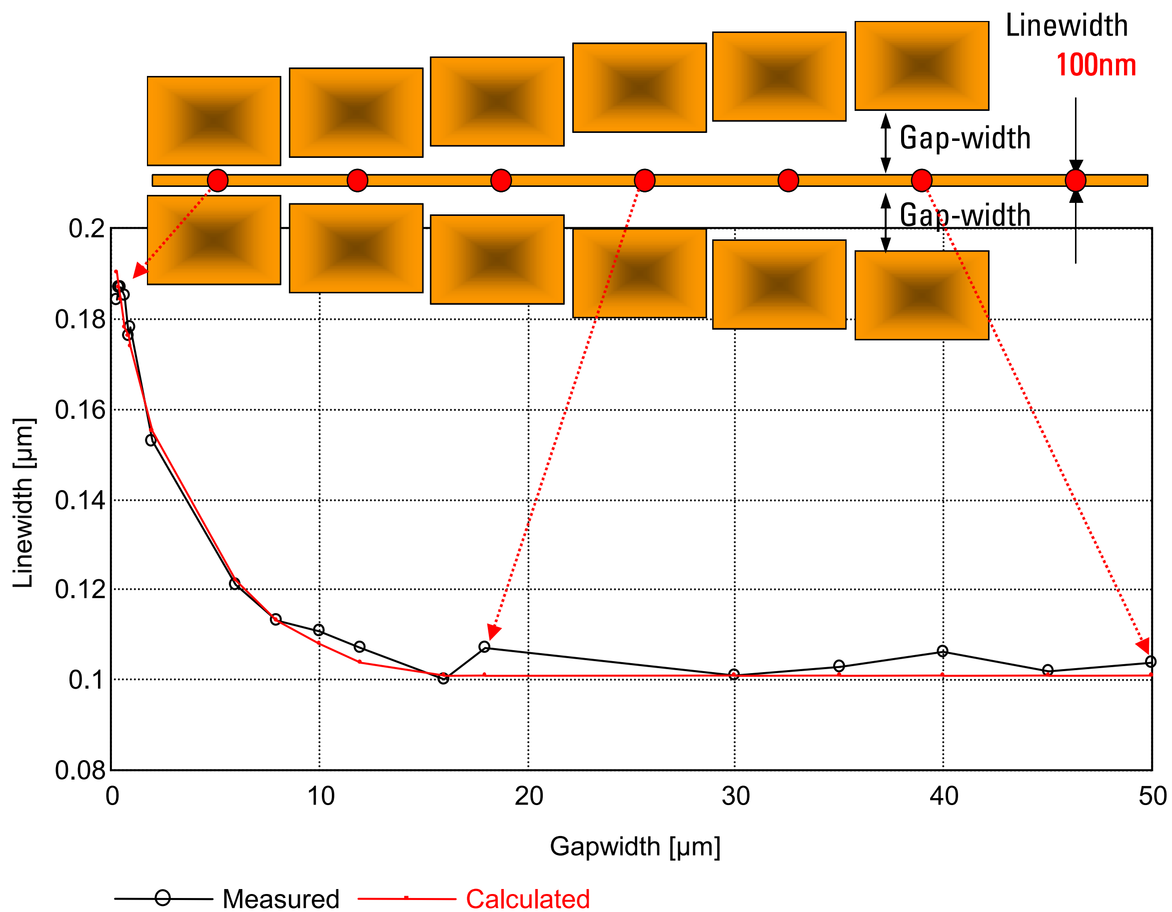
Examples of useful Back-Simulations

Pyramid Simulation



- **Pattern**
  - **Single line in the middle of 2 large pads with different gap widths**
  - **Linewidth increase as gap-width decreases due to backscattering**
- **Sensitive to**
  - **Backscatter parameters (β and η)**

Linewidth vs. Dose Simulation

Overexposed

AEID (arb.u.)

Threshold

Linewidth [µm]

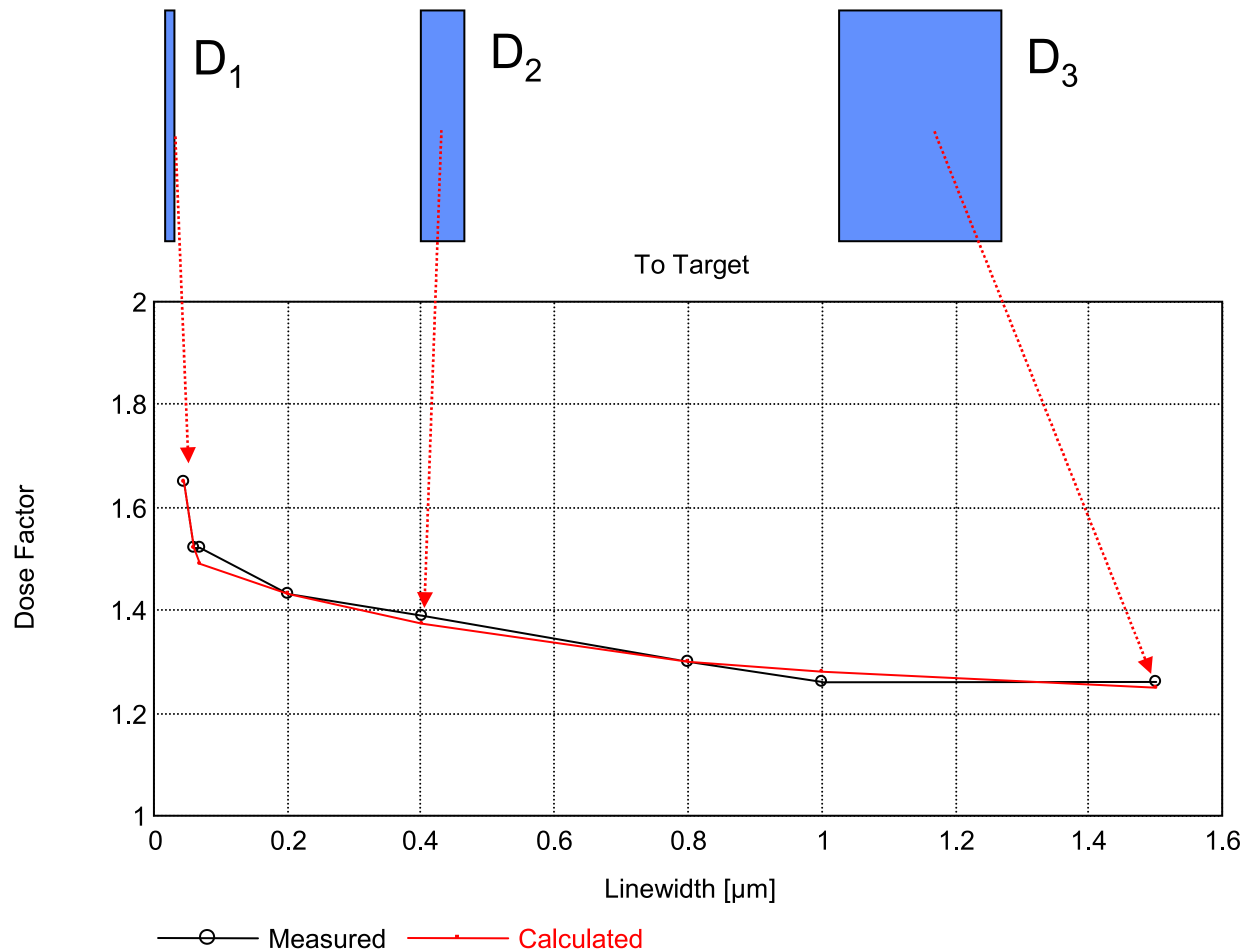
20
19
18
17
16
15

40 60 80 100 120 140 160 180 200

Dose [µC/cm²]

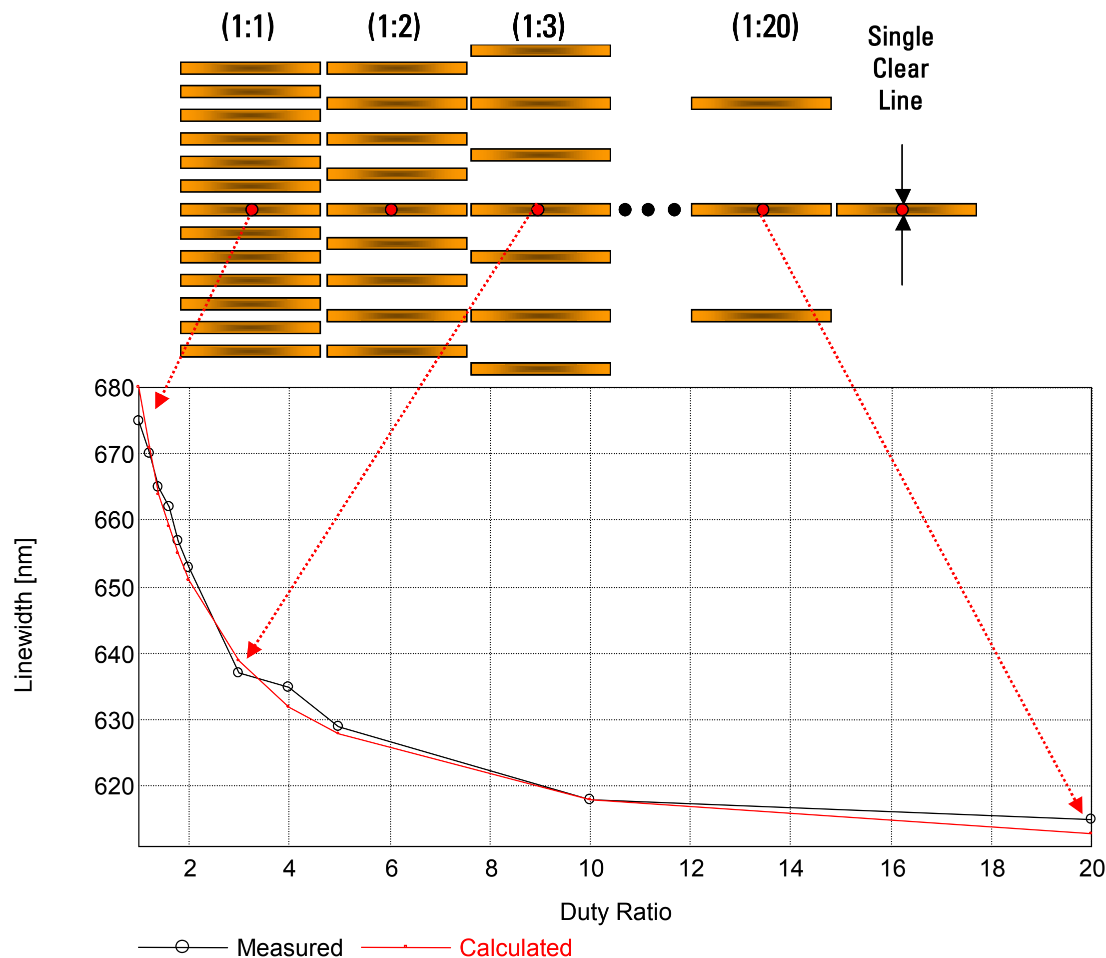
- **Pattern**
  - **Broad single line in exposure series**
- **Sensitive to**
  - **All parameters,**
  - **Directly „reproduces“ proximity function**
- **Issues**
  - **Extreme over-exposure dose**
  - **Saturation effects ?**

Optimal Dose To Target Simulation



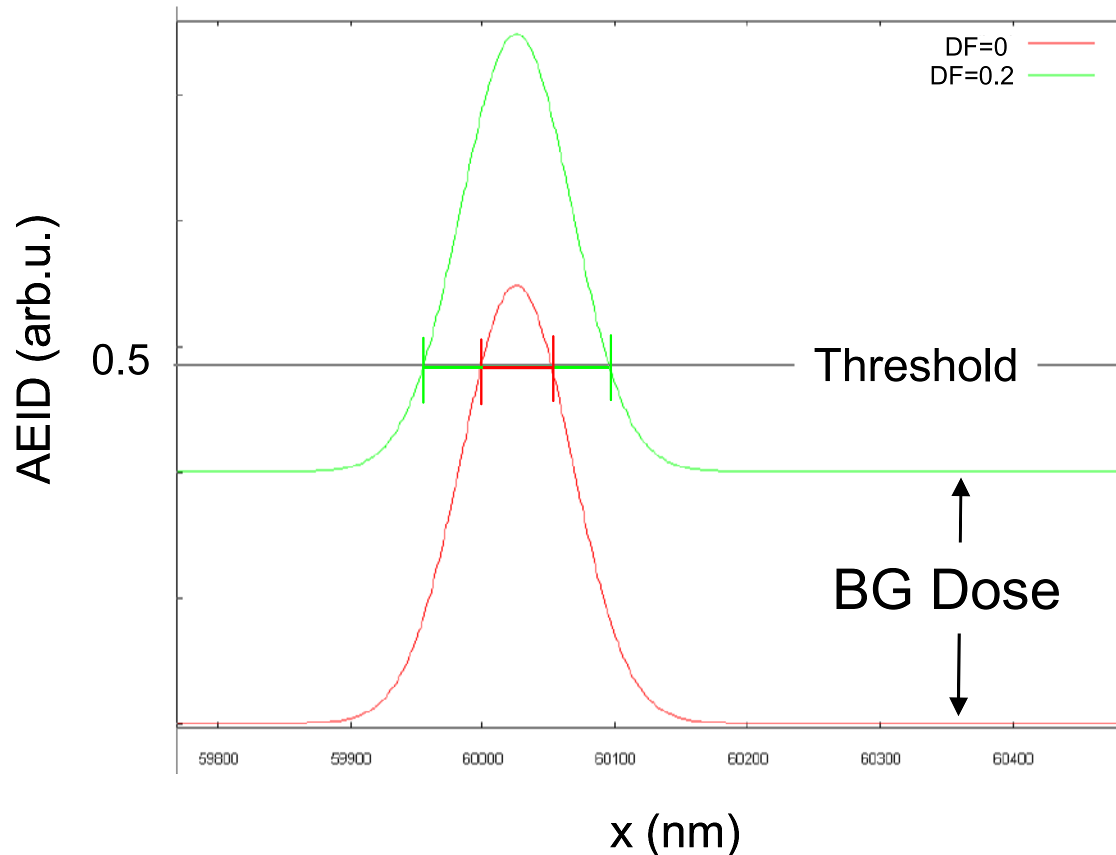
- **Pattern**
  - **Isolated Lines in exposure series**
  - **Determine Optimal Dose to reach Target linewidth**
- **Sensitive to**
  - **Short range parameters**
  - **η-Ratio: Short to long range**
- **Application**
  - **Excellent for sparse layouts**

Duty Ratio Simulation



- **Pattern**
  - **Dense line fields in different ratios of lines to spaces**
- **Sensitive to**
  - **Short range parameter**

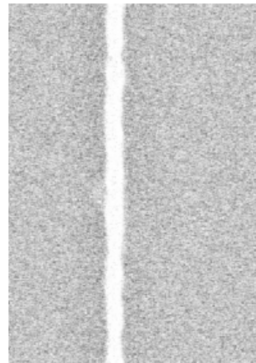
Offset Simulation



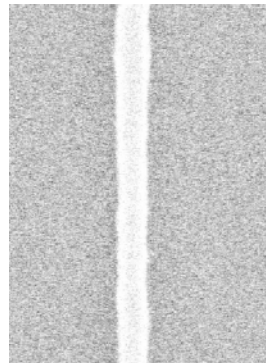
- **Pattern**
  - **Double Exposure of a single line and a large background square**
  - **Exposure series of background dose**
  - **All background doses<Threshold**
  - **Simulates dense layouts**
- **Sensitive to**
  - **Short range parameters**

Offset Measurement

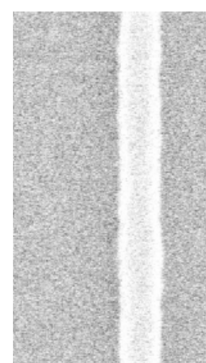
Background exposure starts to appear



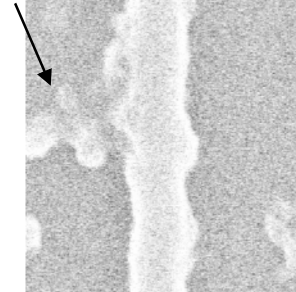
Offset: 0



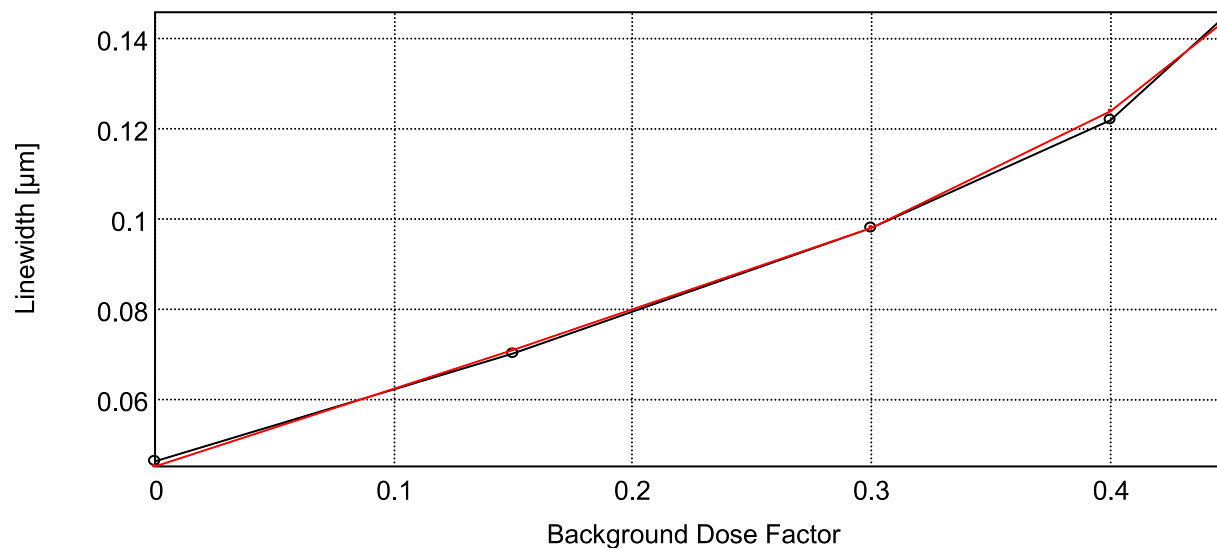
Offset: 0.15



Offset: 0.3



Offset: 0.45

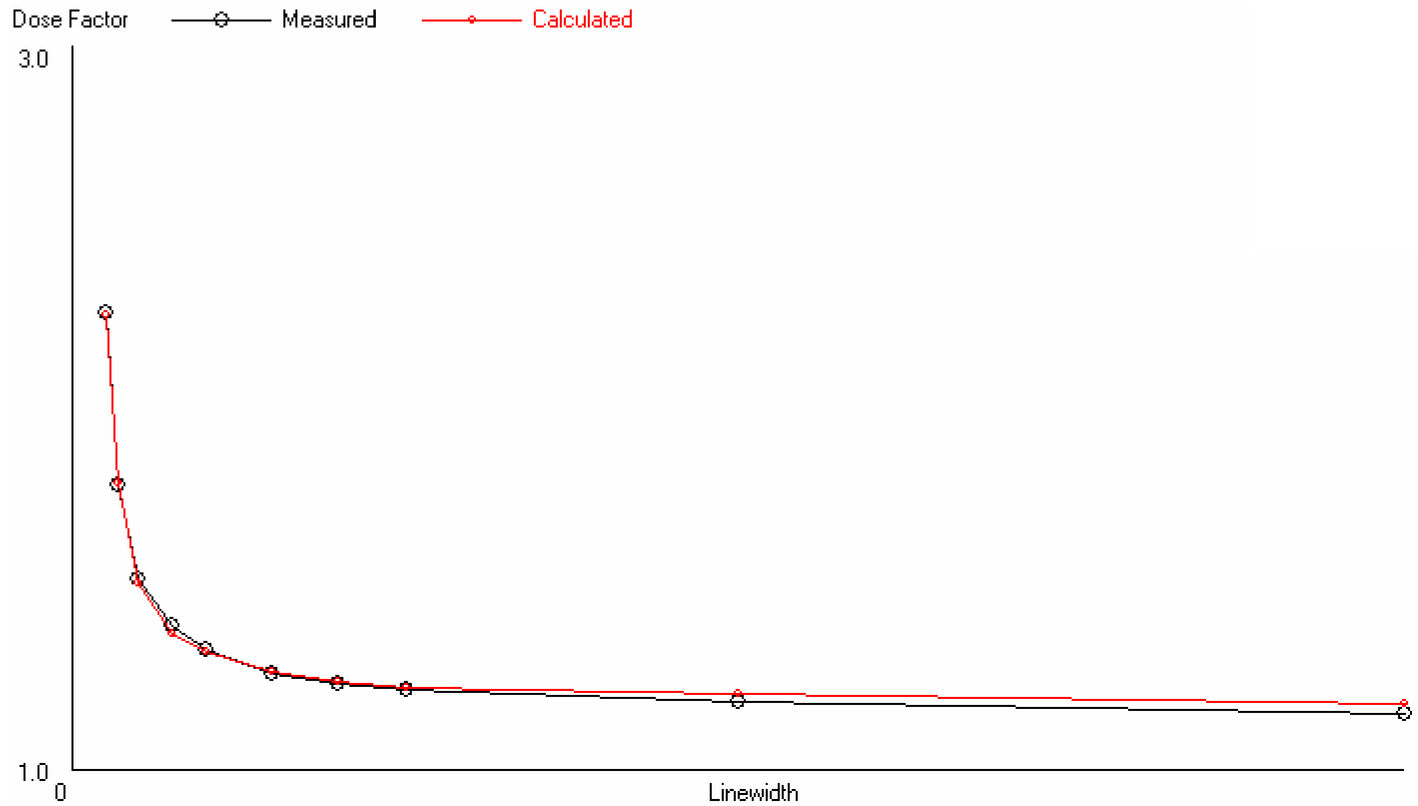


- **Negative CA Resist**
- **45 nm line with various offsets**
- **Good fit for all offsets**
- **Consistency check: All linewidths should fit with the same parameter set**

Optimization

- **Use proximity corrected exposures**
  - **If initial PEC is known, subsequent exposures may use correction and dose exposure series with smaller latitude**
  - **Increases data preparation effort**
  - **Decreases necessary number of measurements**
- **Pattern sizing (Edge bias)**
  - **Often decreases CD vs. Dose variation**
  - **Iso/dense bias unavoidable if sizing is not considered during proximity effect correction**
  - **May be used if supported by proximity corrector (e.g. PROXECCO by PDF Solutions)**

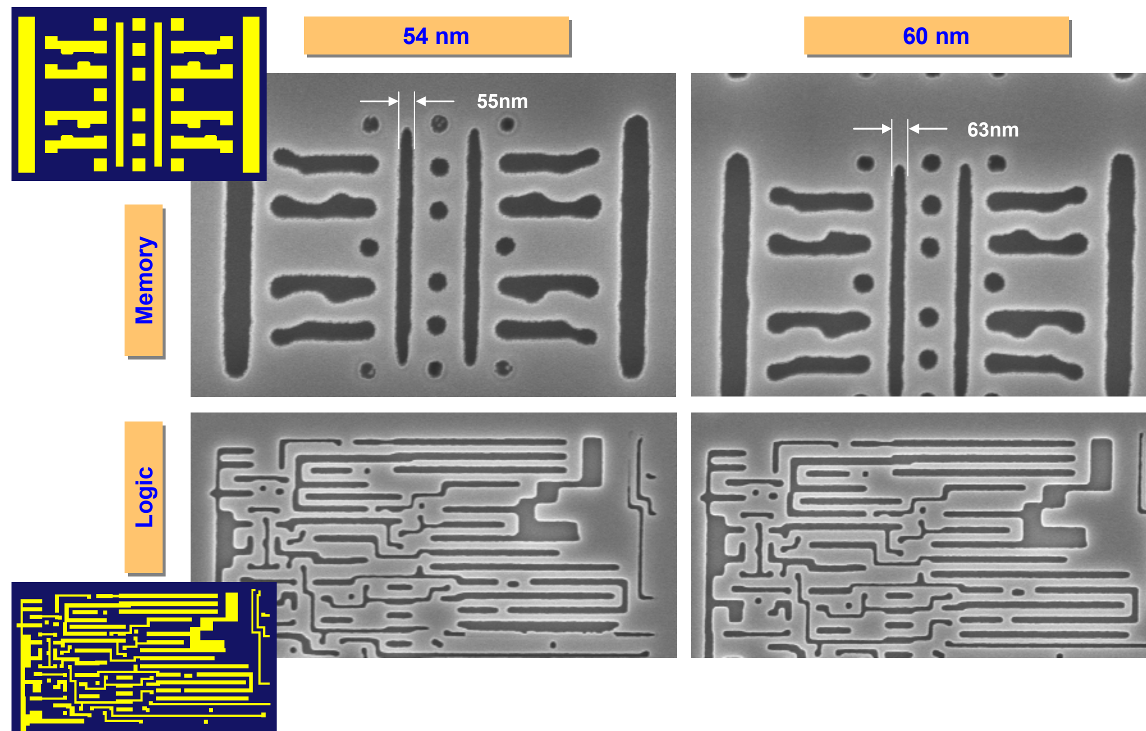
Example: PEC Optimization for Nanoimprint Template Writing



$\alpha = 0.077$ [µm]

- **Sensitivity to α - parameter change**

Template: Device Pattern



- **Nanoimprint template**
- **Positive Tone CA-Resist**
- **Written with optimized proximity correction**

Images courtesy of IMS Chips Stuttgart, BACUS 2005

Conclusion

- **High Resolution Electron Beam Direct Write**
  - **Diffusion during post exposure bake has to be taken into account for accurate CD control**
  - **Broaden scope of proximity effect correction**
- **Practical Proximity Effect Correction**
  - **Expose specially designed, uncorrected test patterns and perform back-simulation**