GenISys

Advancing the Standard

Multipass Techniques

How to improve stitching, LER, LWR and resolution

Outline

- Multipass with and without field shift
- Advanced Multipass Methods
  - How to retrieve throughput in traditional Multipass?
  - Interstitial field blend
  - Dose overlap
- Summary

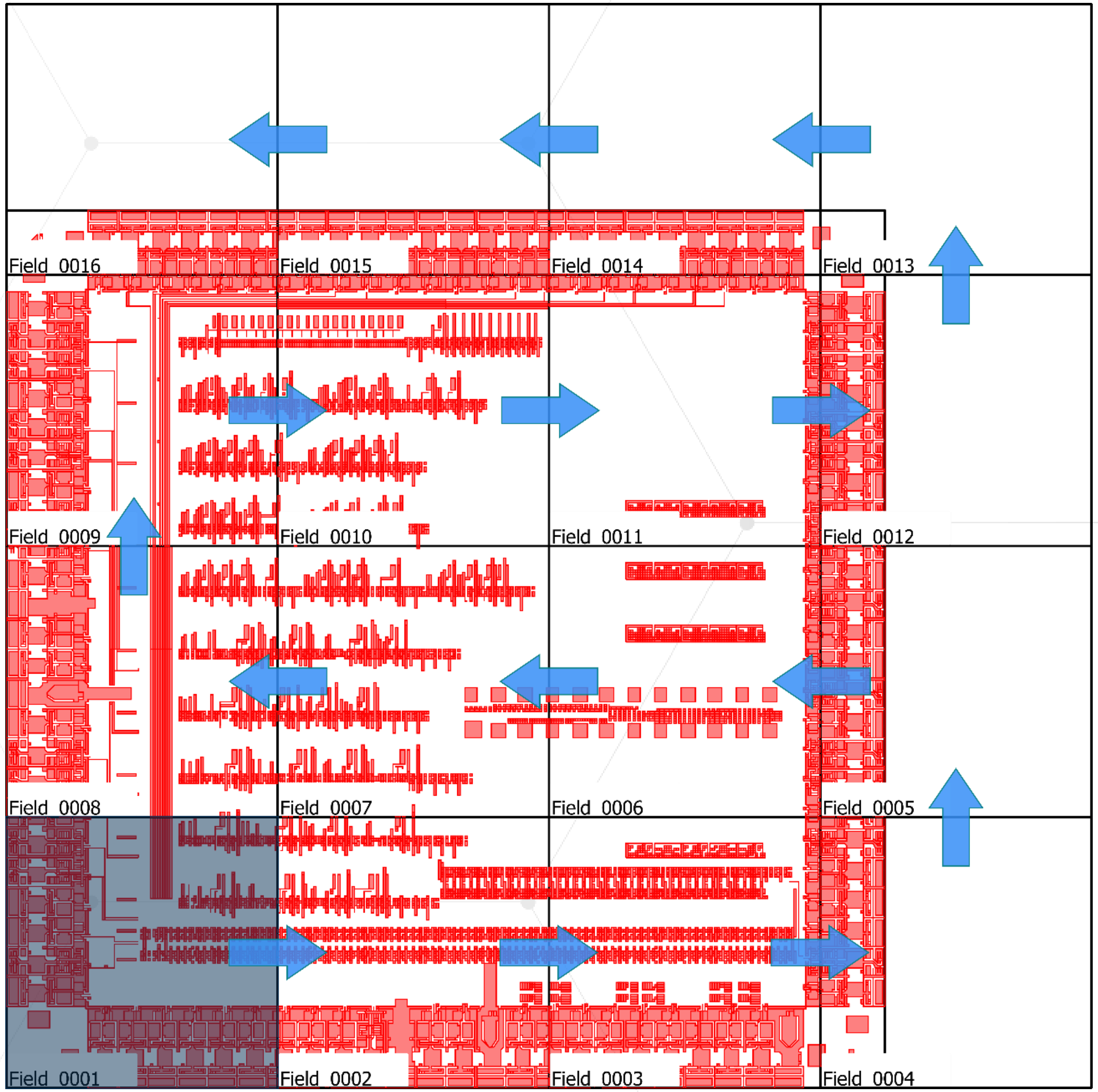
Setting a large layout exposure

Maximum field size is limited:

- E/O Field of View
- DAC-Bits binds field size to resolution

Large layouts need to be „tiled”:

- Uniform tile size
- Start bottom or top left
- Serpentine filling (Meander X)



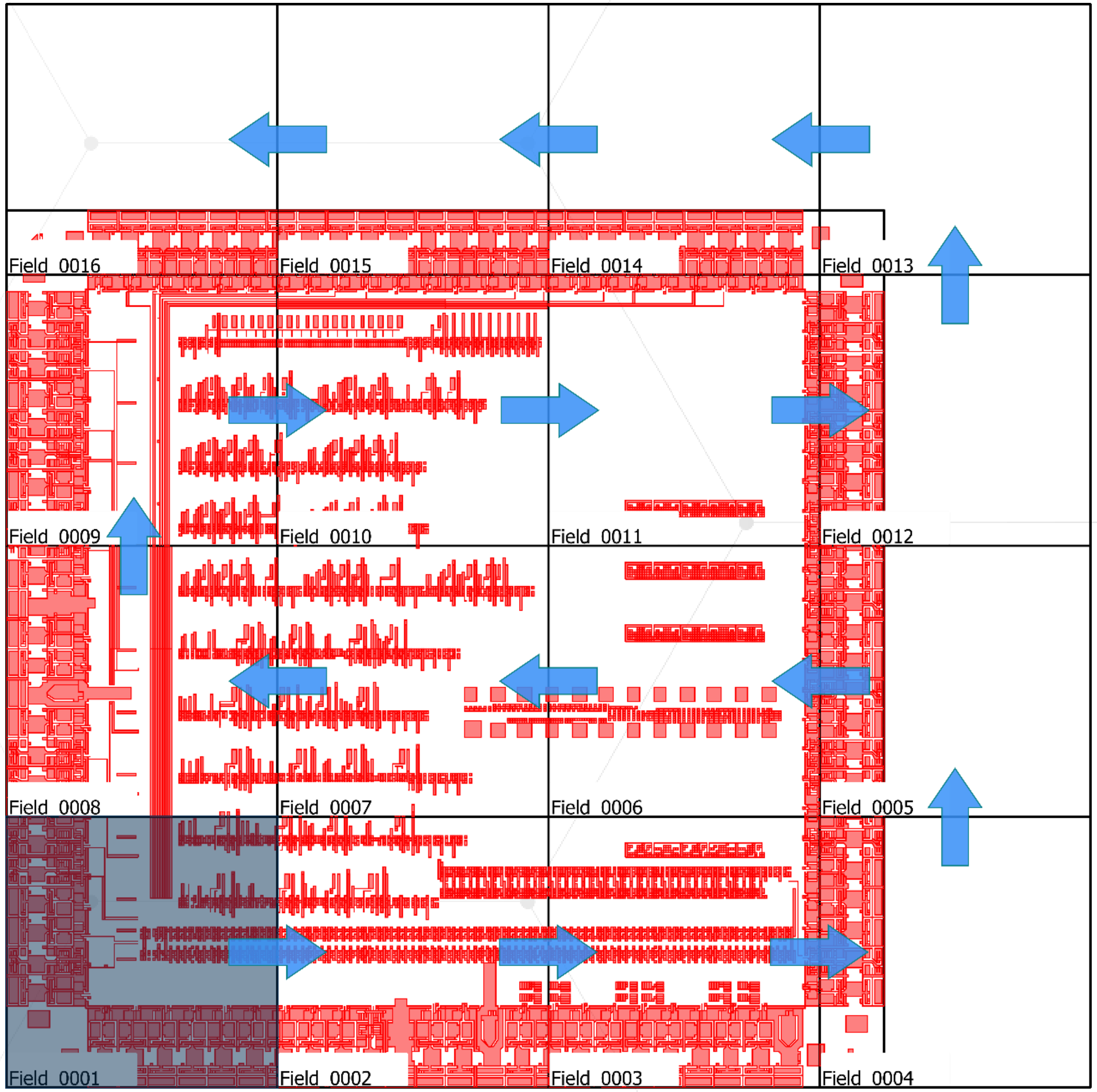
Challenges with tiling

Issues within main field:

- Aberration depends on beam position within the field
- Thermal drift
- Mechanical vibration
- Sub-filed stitching

Issues field to field:

- Stitching at field borders



Fading exposure errors

➡ Multipass method

- Features are exposed multiple times at different locations in the field (centre of field, border of field)
- Fields are exposed in a successive and overlapping fashion

Why does Multipass work?

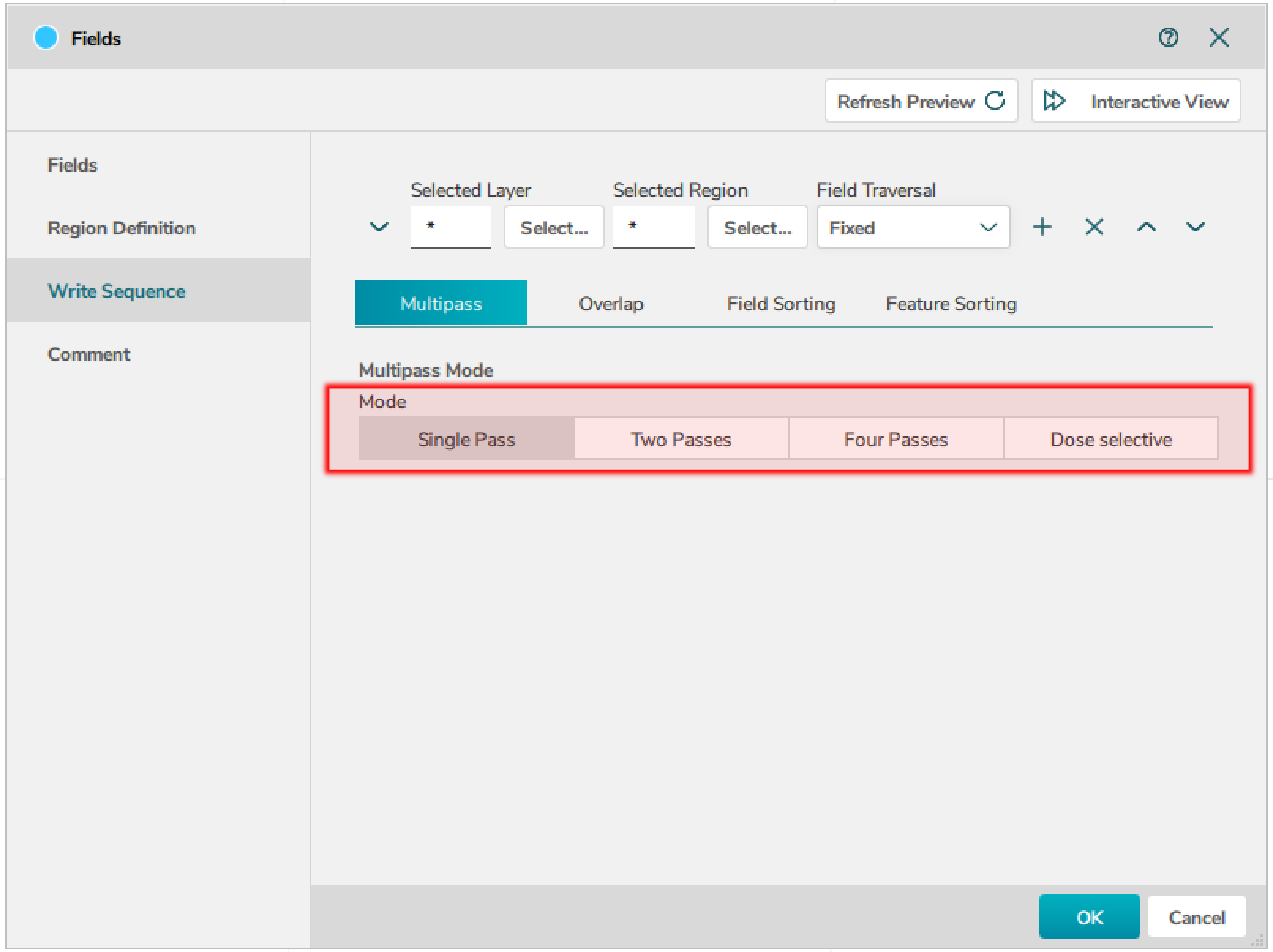
- Multipass reduces statistical errors by averaging
  - Beam Current Fluctuations
  - Beam Jitter, Beam Drift
  - Stage Position Errors, mechanical vibrations

- Multipass reduces systematic errors by offseting
  - Field Distortion and Field Aberration
  - Scan Non-Linearities
  - Shutter Effect
  - X/Y asymmetries due to discrete spots in Y / dragging in X

Fields Multipass

- BEAMER supports:
  - Single pass
  - Two passes*
  - Four passes*
  - Dose selective*

*Optional: Main or sub-field offseting

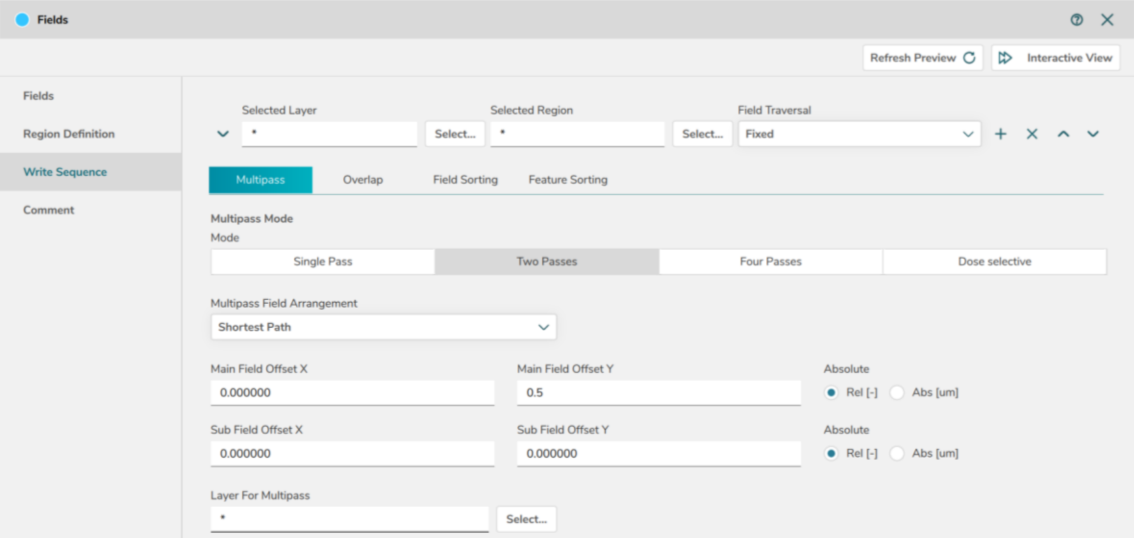


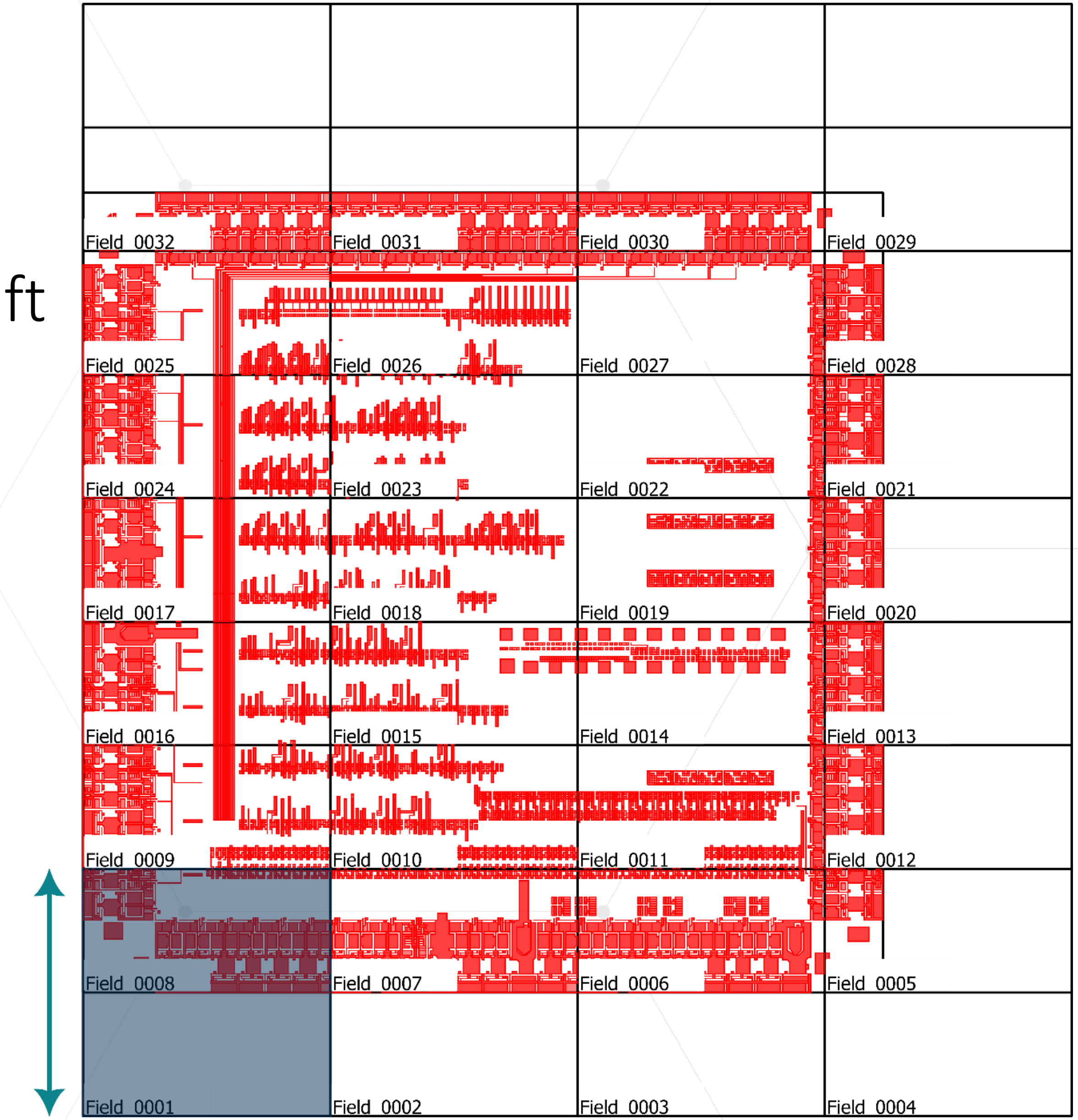
Example Offset Y

Large layout with Field Size: 500 µm

Multipass: Two Passes

Main Field Offset Y: 0.5 Re[-] → Half field size shift





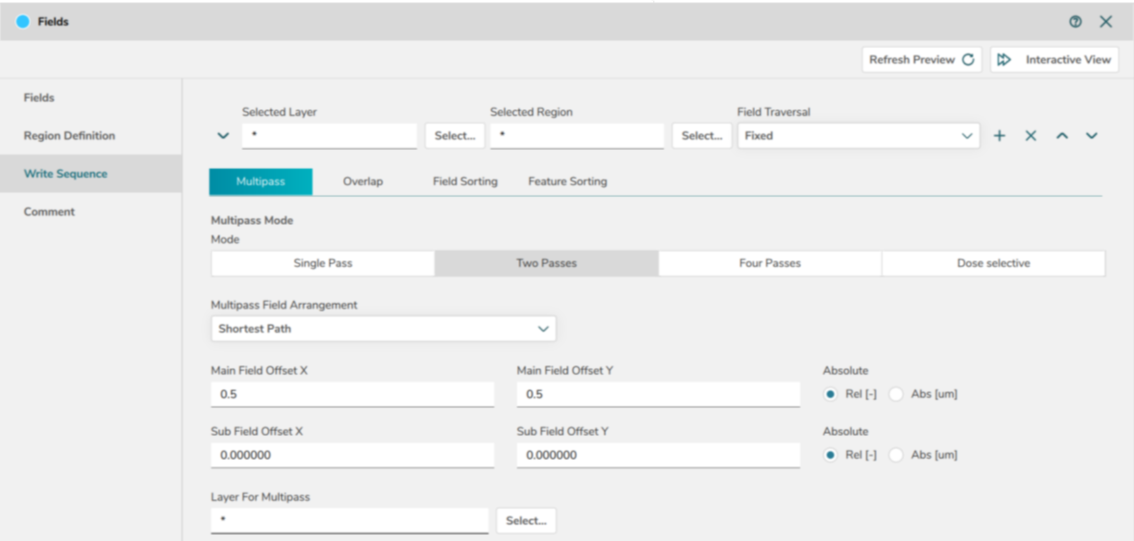
*Colour by Layer

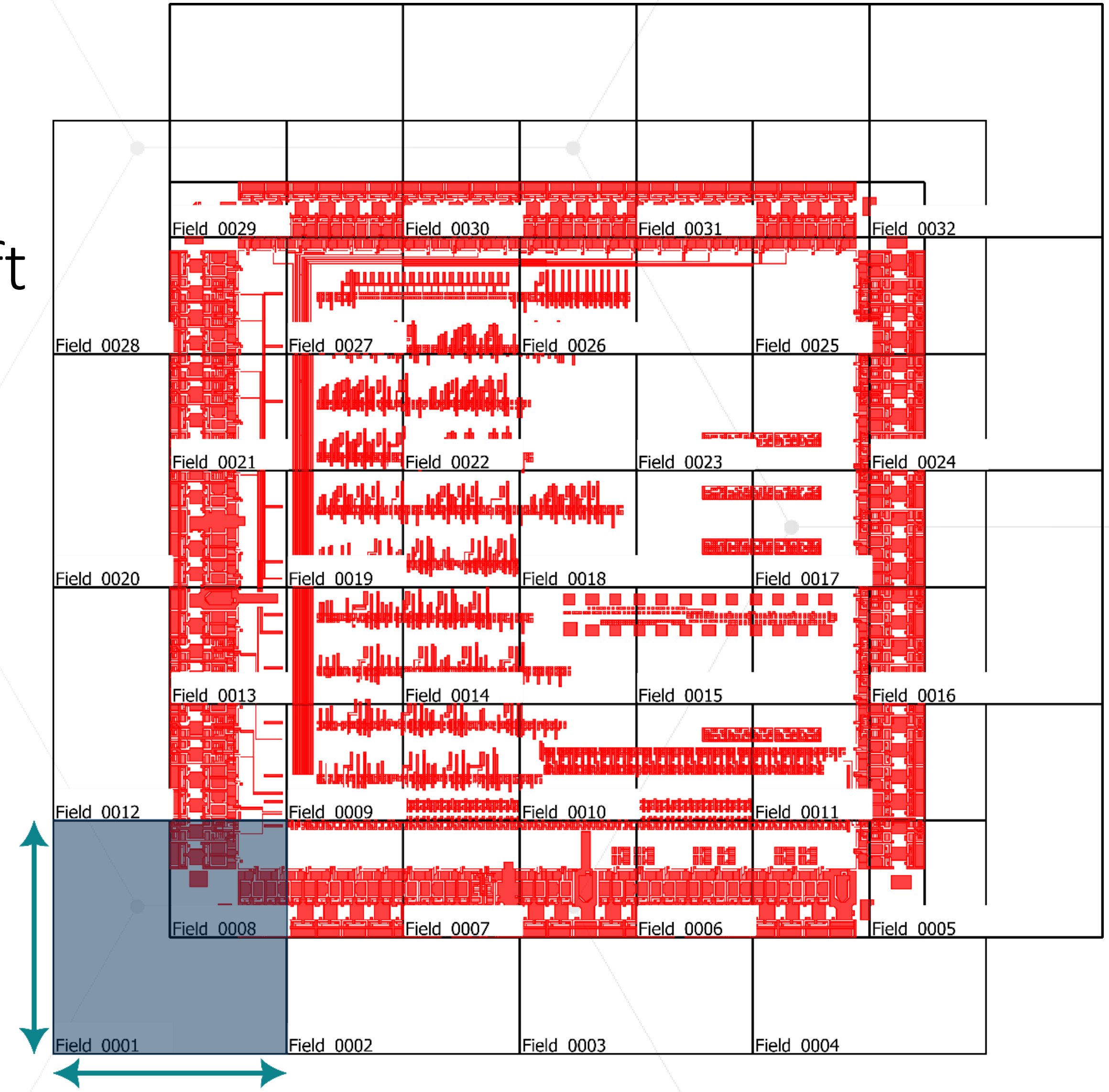
Example Offset XY

Large layout with Field Size: 500 µm

Multipass: Two Passes

Main Field Offset XY: 0.5 Re[-] ➡ Half field size shift





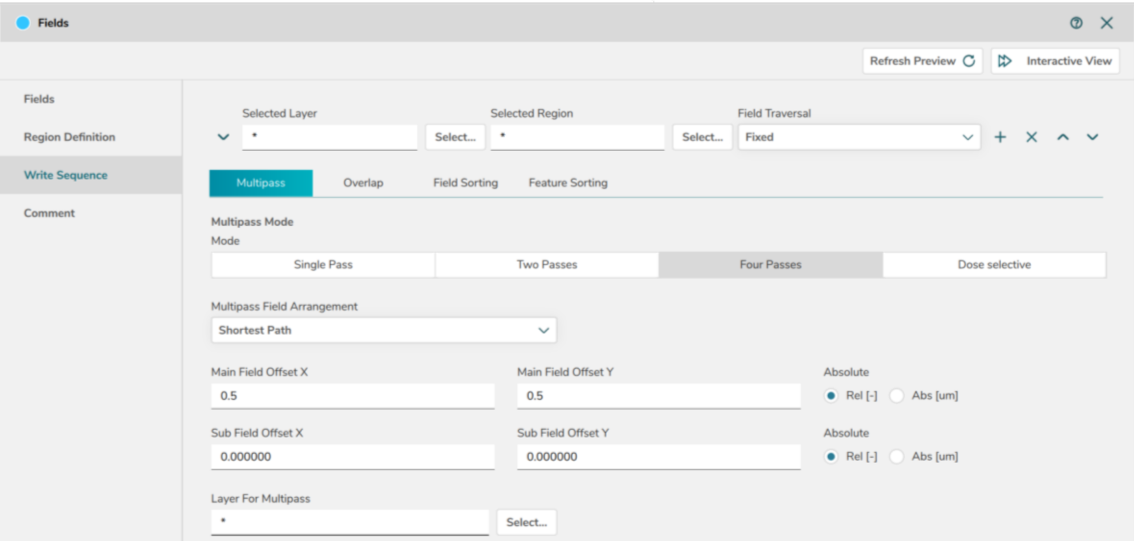
*Colour by Layer

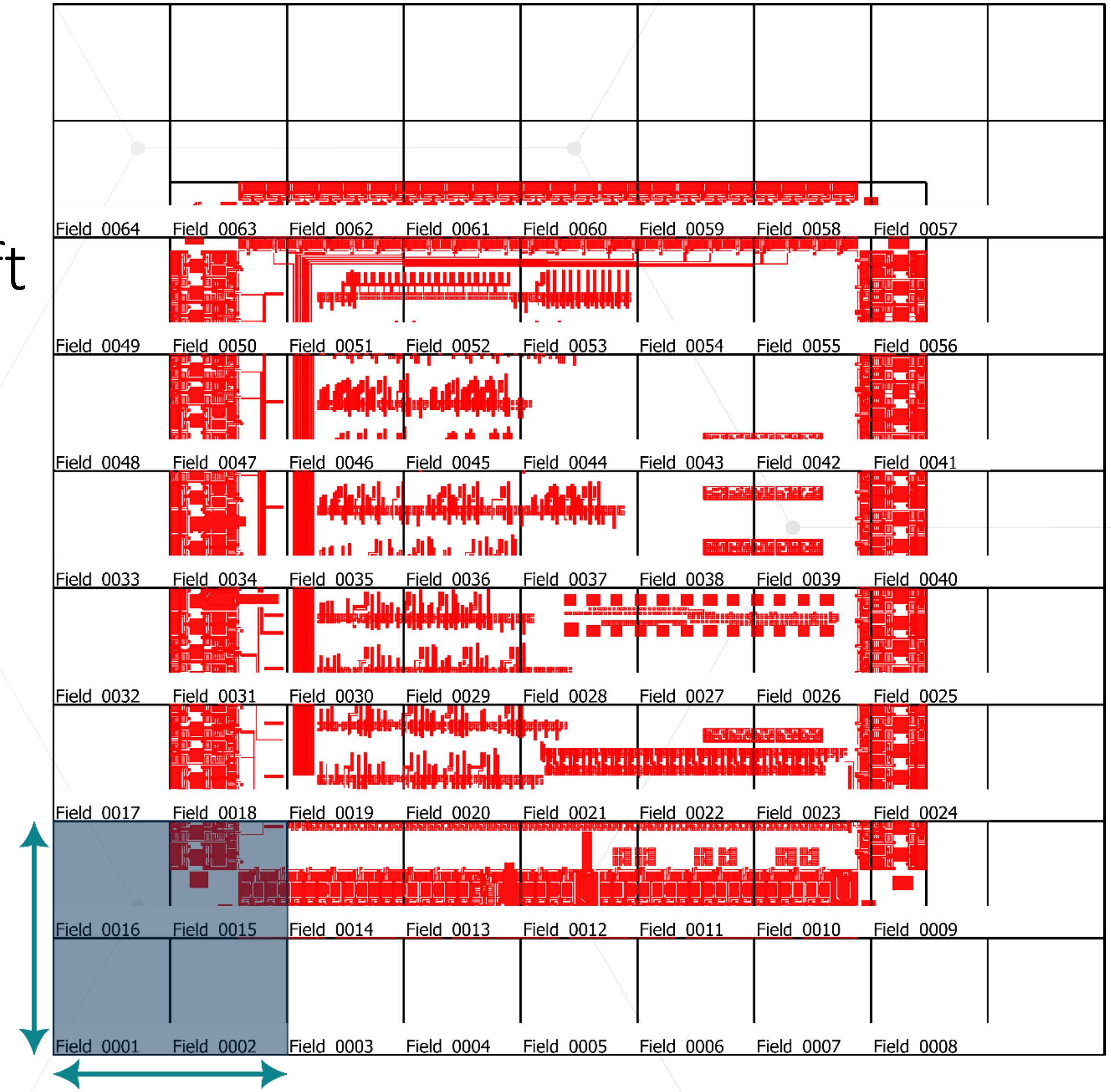
Four Passes and XY Offset

Large layout with Field Size: 500 µm

Multipass: Four Passes

Main Field Offset XY: 0.5 Re[-] → Half field size shift

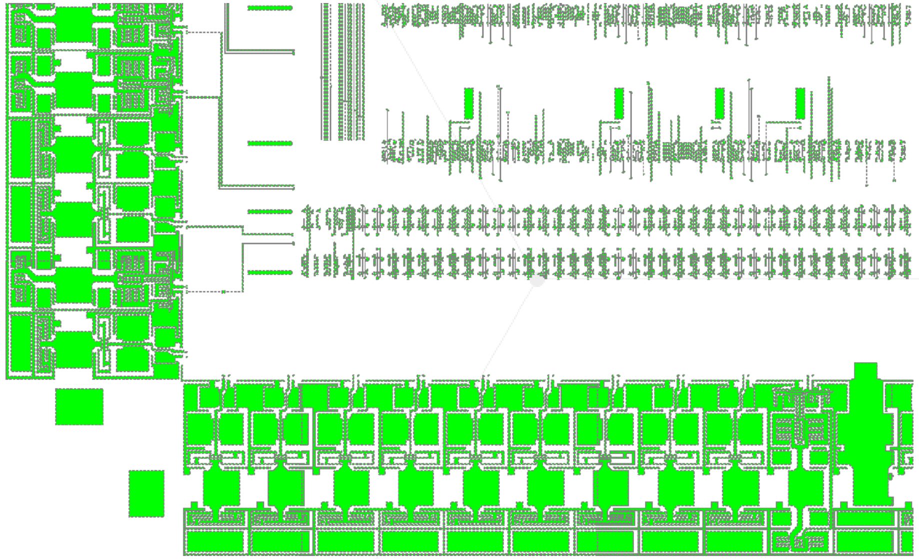




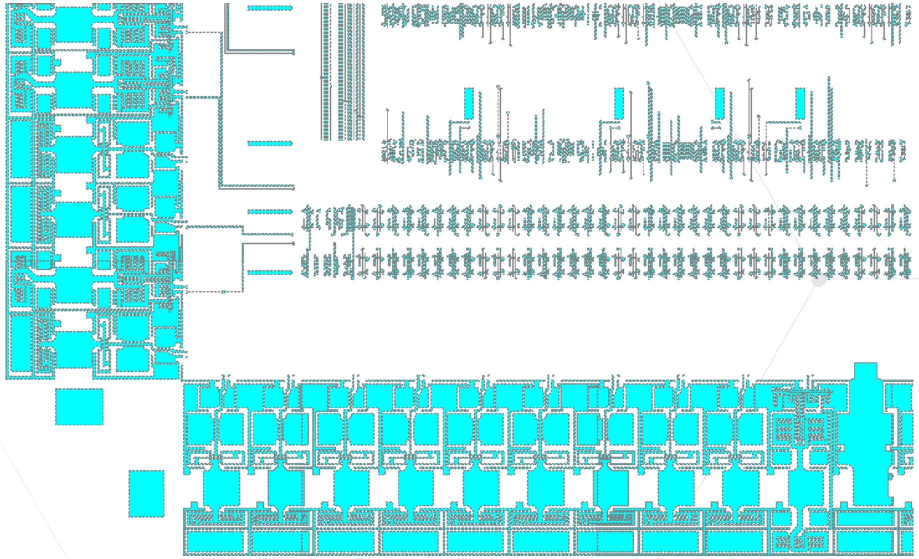
*Colour by Layer

Two and Four passes

The number of passes determines the number of exposures. BEAMER color mode *Overlay* shows this exposure difference.



Two passes



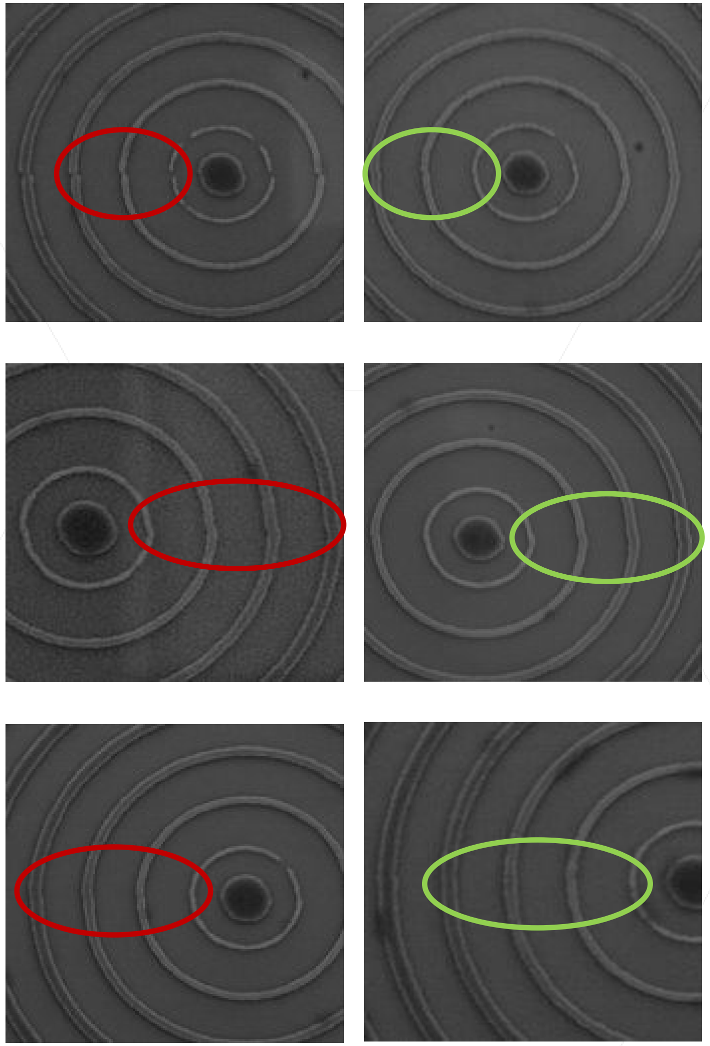
Four passes

BEAMER colour code

*Colour by Overlay

Field example

Systematic errors are averaged through offset strategies ➡ Reduced field stitching

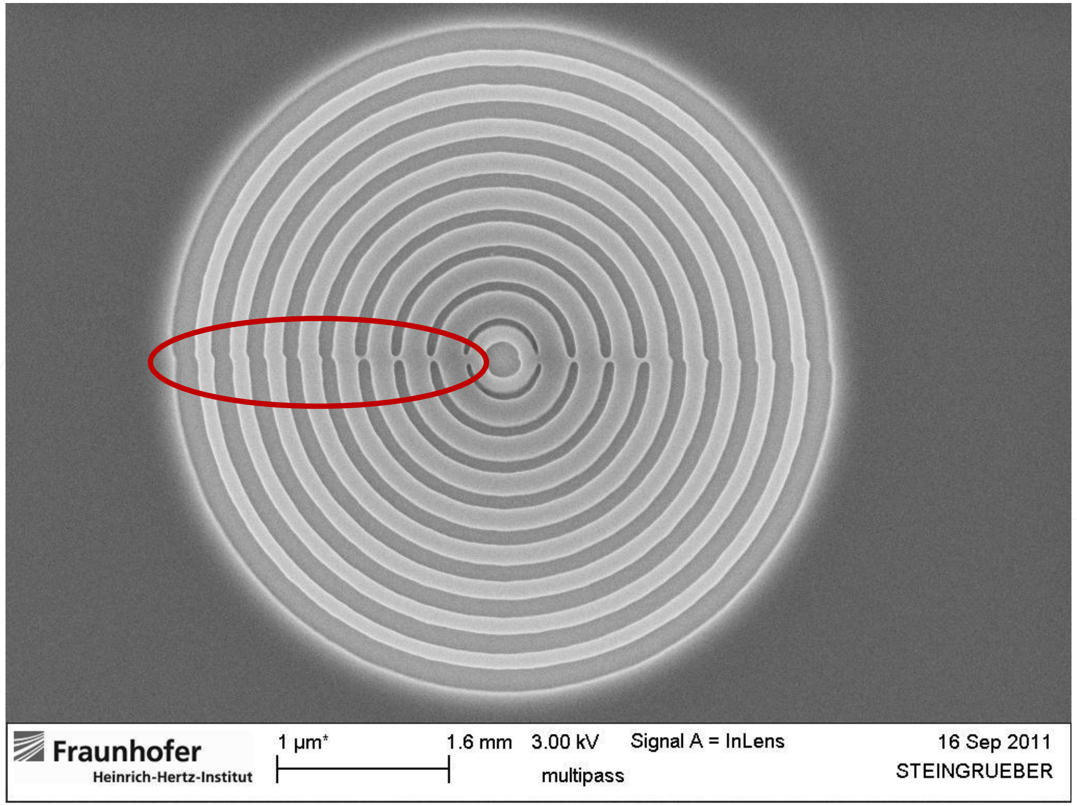


Single pass — Stitching issues

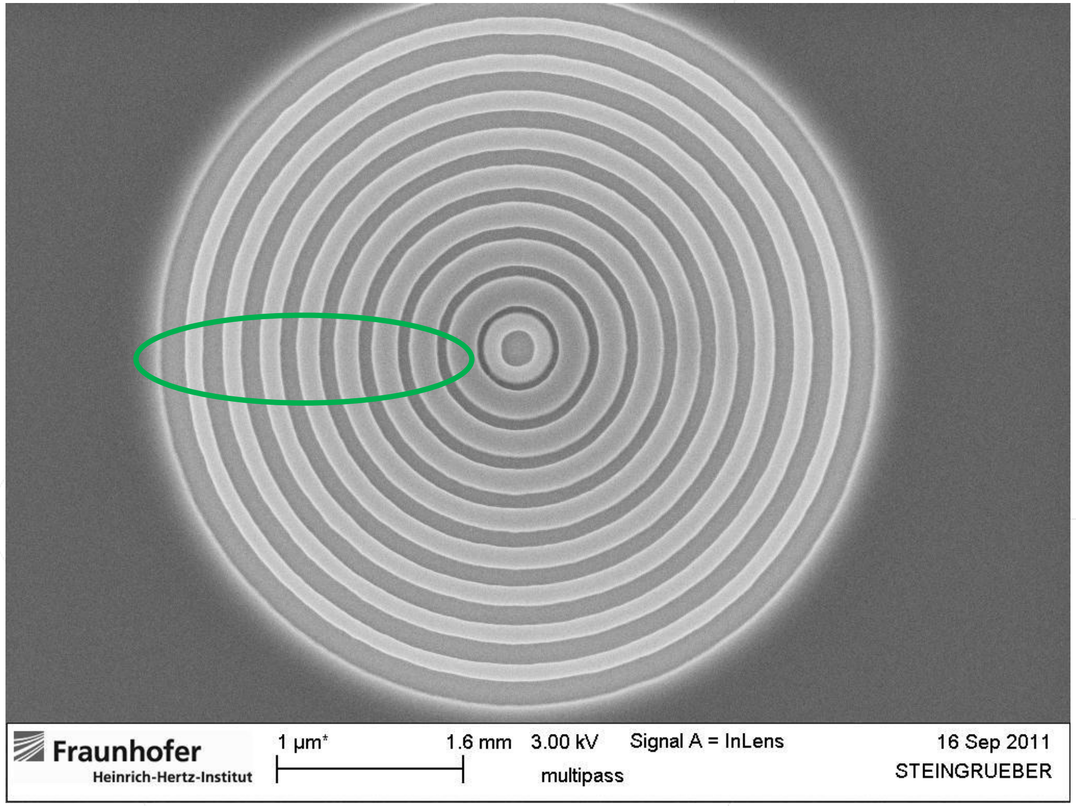
4-pass w/o field shift — Stitching fixed but notching observed

4-pass with field shift — Notching reduced

Multipass in Fresnel lenses



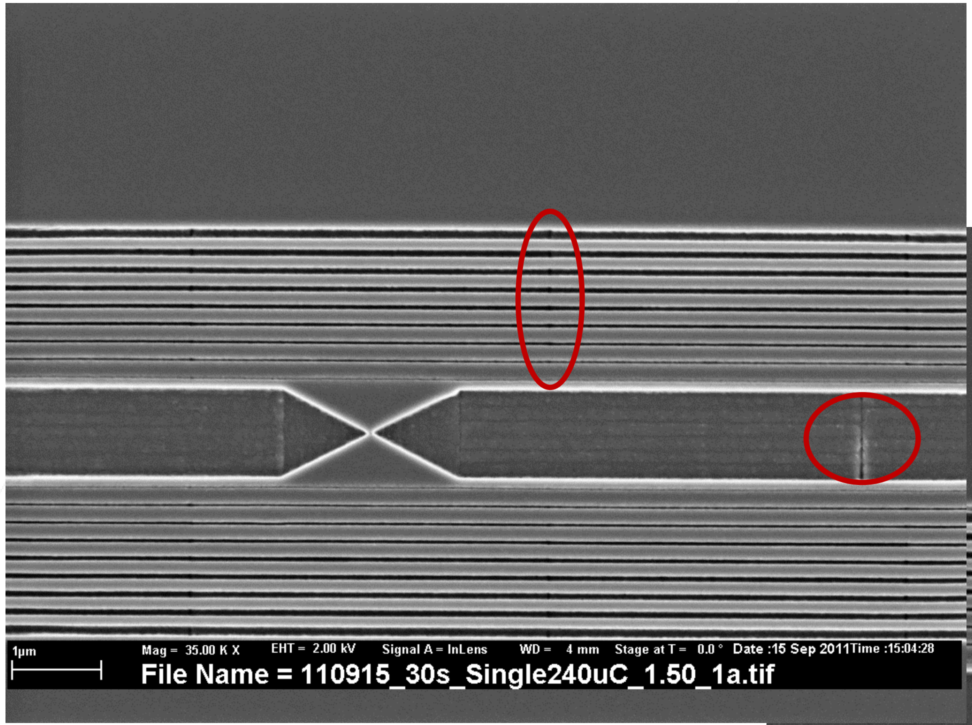
Single pass exposure with stitching errors



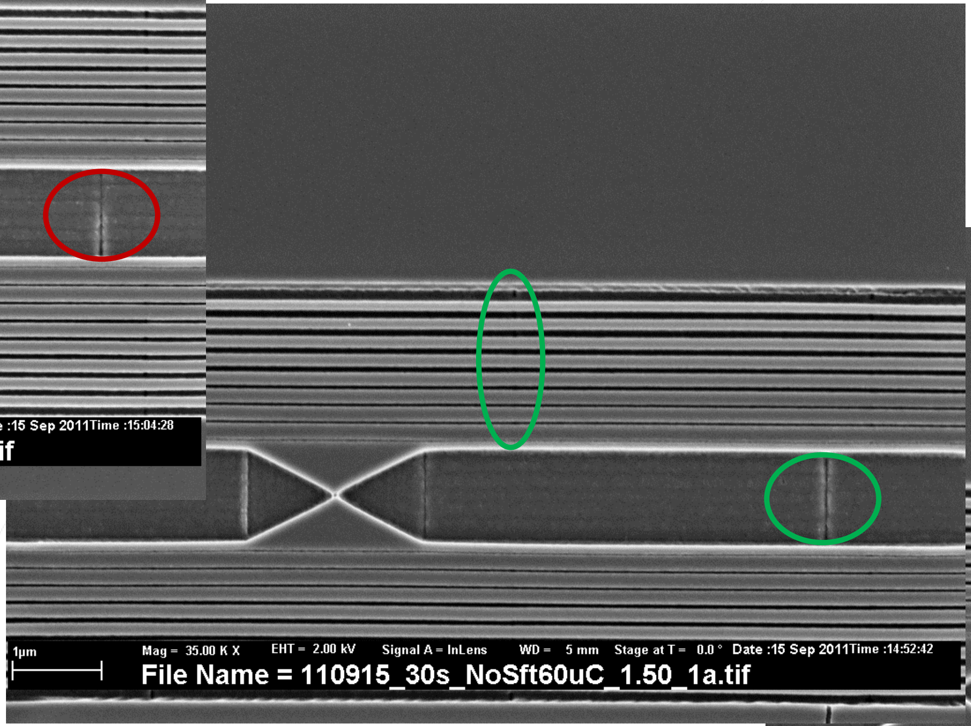
Pattern fractured with multi-pass

- Reduced Line Edge Roughness (LER) ➡ Improved resolution

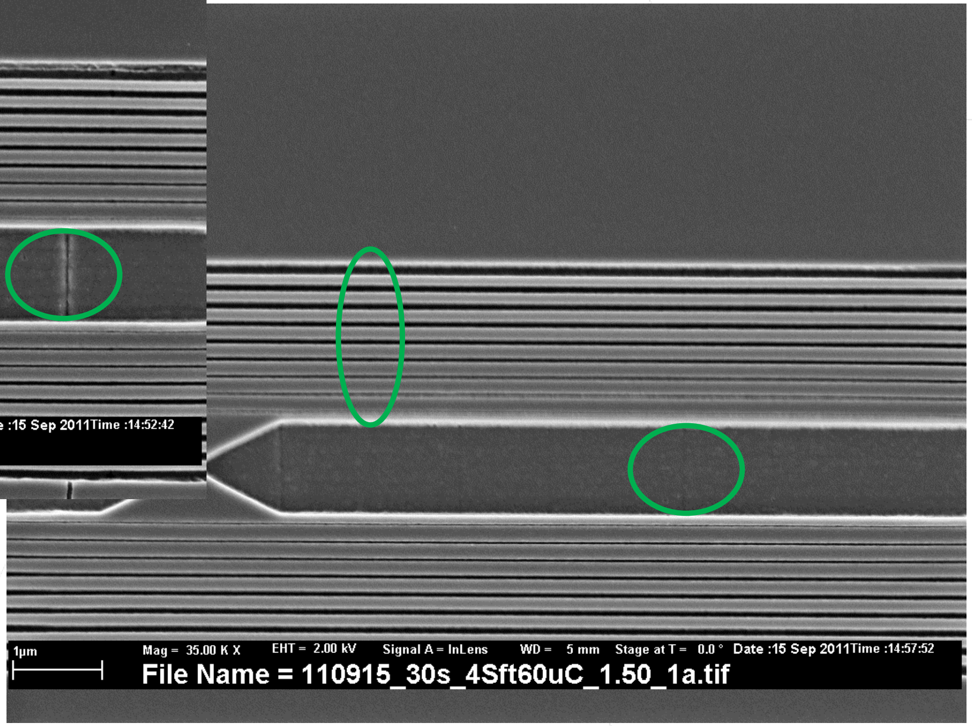
Subfield shift example



Single pass



4-passes w/o subfield offset



4-passes with subfield offset

Advantages and Drawbacks

- Traditional Multipass results increases lithography quality
  - Reduces Line Edge Roughness (LER) and Line Width Roughness (LWR)
  - Reduces systematical errors
    - field/subfield offset reduces stitching errors
  - Improves positional accuracy
    - field shifts compensate for field placement issues due to aberrations
  - Creates a homogenous energy distribution

- Slower throughput
  - Beam-on time tends to be longer
    - Exposure dose increases ➡ Dose and currend need to be manually reduced
    - Increased exposure time
  - Large file size
  - Large Overhead
    - More stage moves ➡ more settling times

Advantage of BEAMER Multipass

- Conventional multipass is manual
  - User needs to prepare multiple exposure files with different field size settings or shifted extend and set the multiple exposure at job-deck
    - The pattern is exposed sequentially: 1st exposure of full layout needs to be completed before 2nd starts
    - Alignment between exposures is needed to keep accuracy, meaning longer exposure time
    - Subfield shifting is not possible
    - Selective multipass is not possible

- BEAMER Multipass
  - The multipass is exposed within one exposure file
    - No need for multiple exposure files and special job-deck preparation
    - Writing field order is optimised to keep highest position accuracy
    - Multi-exposure without stage move is possible for high resolution
    - Subfield shifting is possible
    - Selective multipass is possible by
      - Layer
      - Dose
      - Region

Outline

- Multipass with and without field shift
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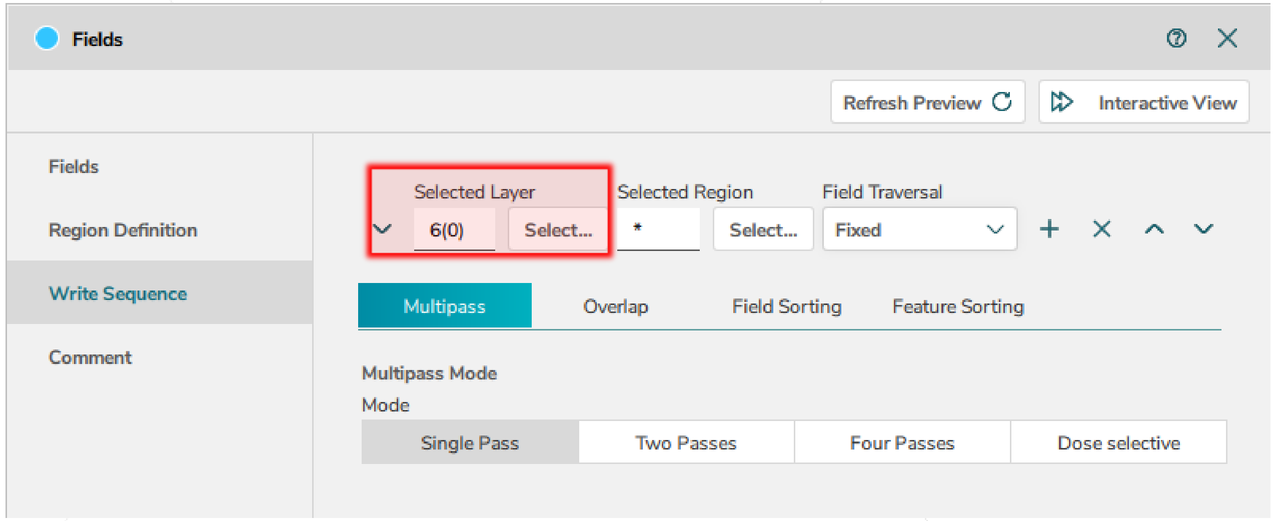
Advanced methods

- Different applications require distinct strategies:
  - 3D structures require multipass for high doses, holograms are field size sensitive, and waveguides require field stitching mitigation

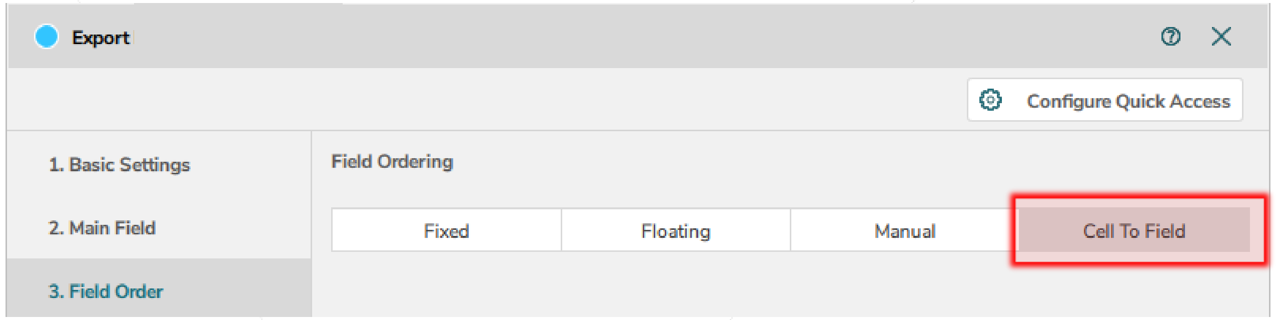
- Options are implemented for:
  - Dose dependent multipass
  - “Blending” features at field borders
  - Generic approaches
    - Merging of machine files into one file
    - Layer selective multipass

Generic Approaches

- Layer selective multipass
  - Multipass for features within a specified layer only



- Merge machine files
  - *Export Field Ordering* gets a new option to use cells as field definitions
    - Allows to merge machine files where each field is imported as a cell
  - Patterns can be split and merged in any thinkable way



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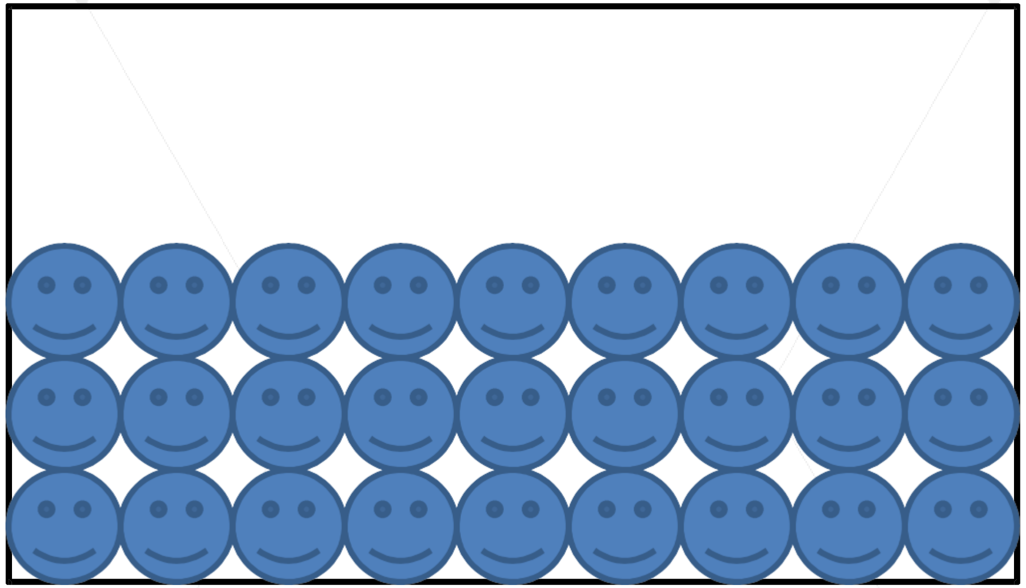
4-passes with double Shot Pitch

- 4-passes does NOT have to increase the beam-on time iff

➡ The spot pitch is doubled

- Doubling the spot pitch does NOT decrease resolution
  - Results in the same filling as single pass

Multipass subfield strategy



Single Pass Fill

Single pass has a continue filling approach of a feature

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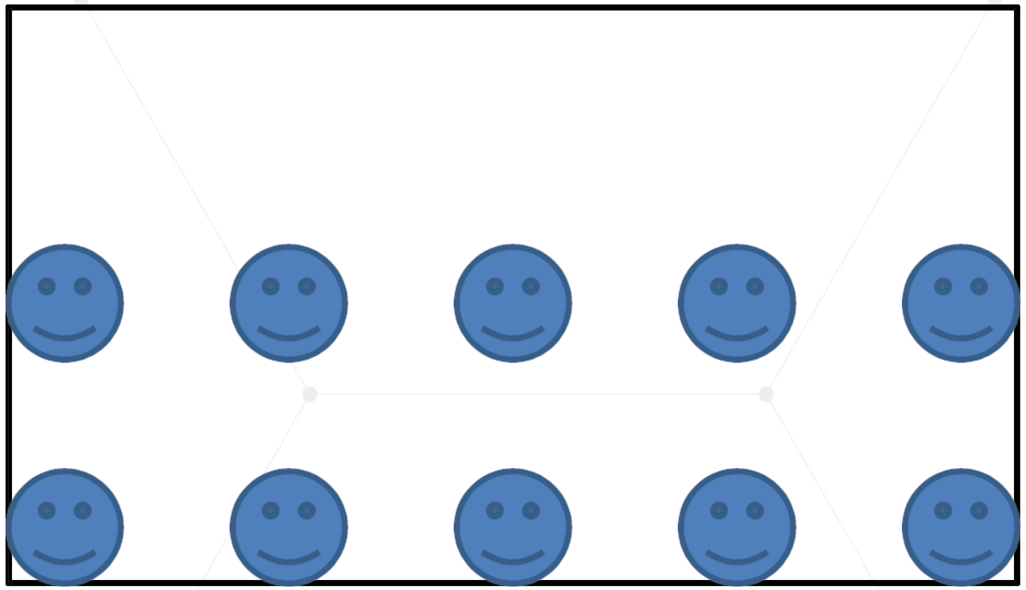
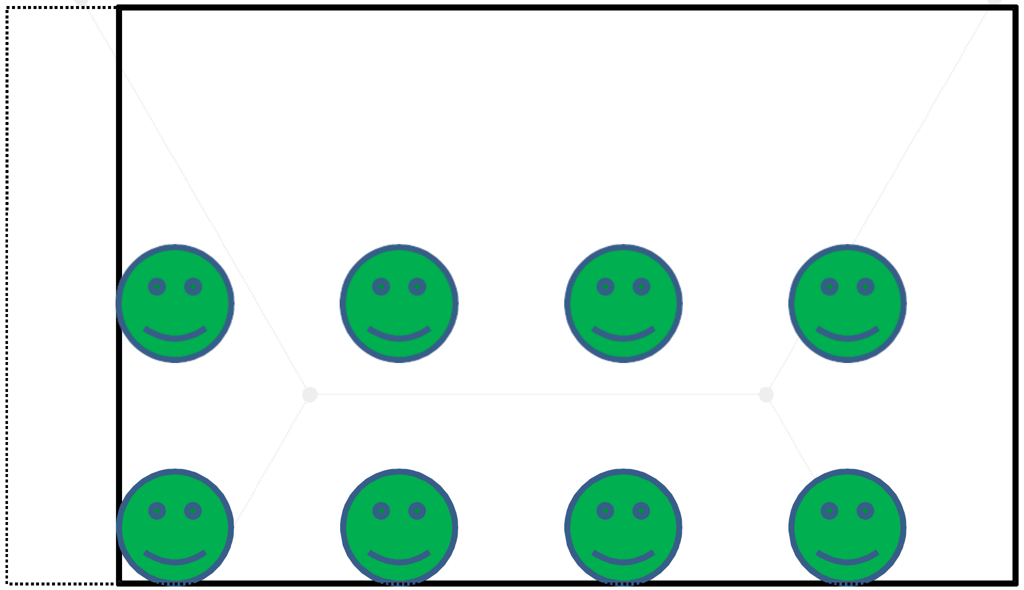
Multipass subfield strategy



4-Passes – 1st Pass

4-passes with subfield shift results in the same pixel filling as single pass approach

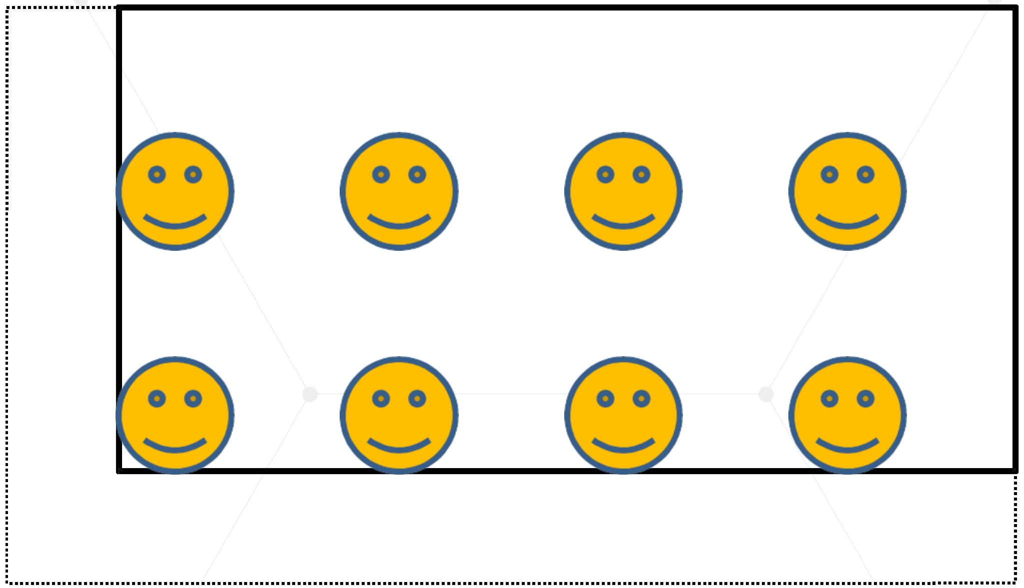
Multipass subfield strategy



4-Passes – 2nd Pass

4-passes with subfield shift results in the same pixel filling as single pass approach

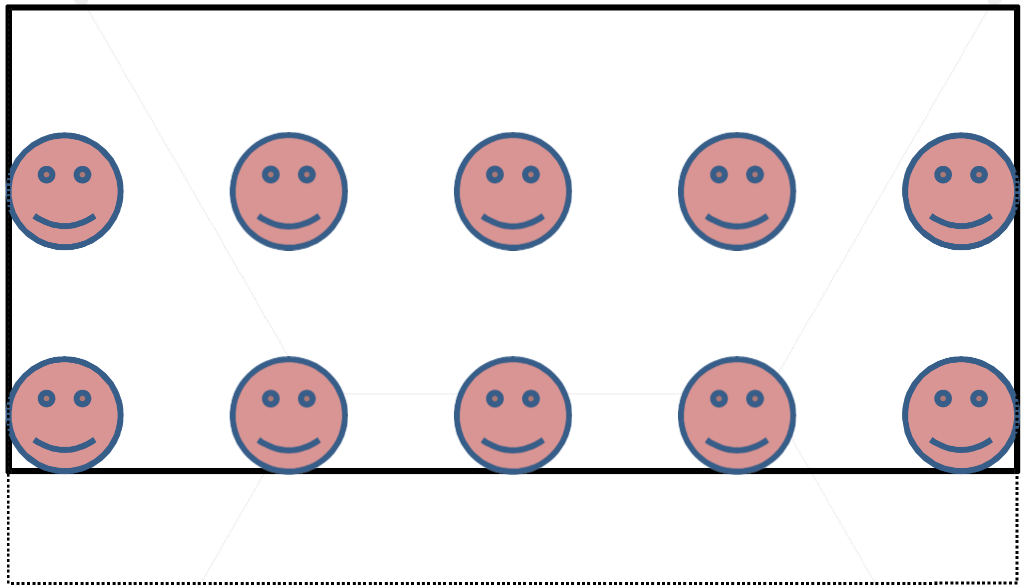
Multipass subfield strategy



4-Passes – 3rd Pass

4-passes with subfield shift results in the same pixel filling as single pass approach

Multipass subfield strategy



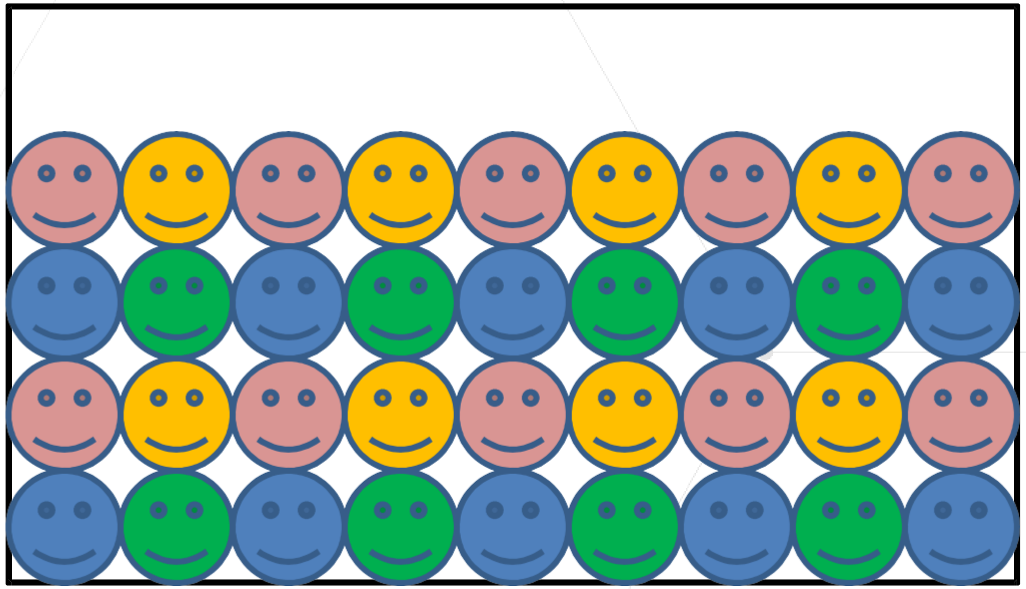
4-Passes – 4th Pass

4-passes with subfield shift results in the same pixel filling as single pass approach

Multipass subfield strategy

4-passes with subfield shift results in the same pixel filling as single pass approach

- Excepting additional field movements, this results in the same throughput as single pass
- Carries all the benefits of averaging statistical / systematic errors



4-Passes – Final

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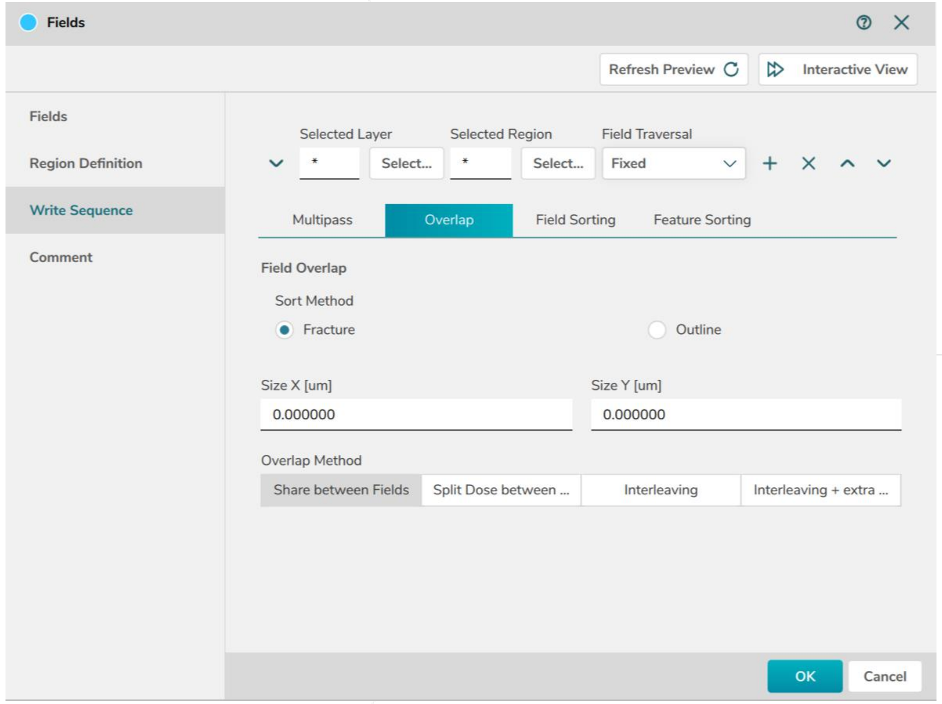
Overlapping methods

- Using single pass for features inside a field
  - Enables *Sort Method*
    - *Fracture*
    - *Outline*

- For Single, Two, Four-passes and Dose selective
  - Overlap methods avalaible
    - *Share between Fields*
    - *Split Dose between Fields*
    - *Interleaving*
    - *Interleaving + extra field*



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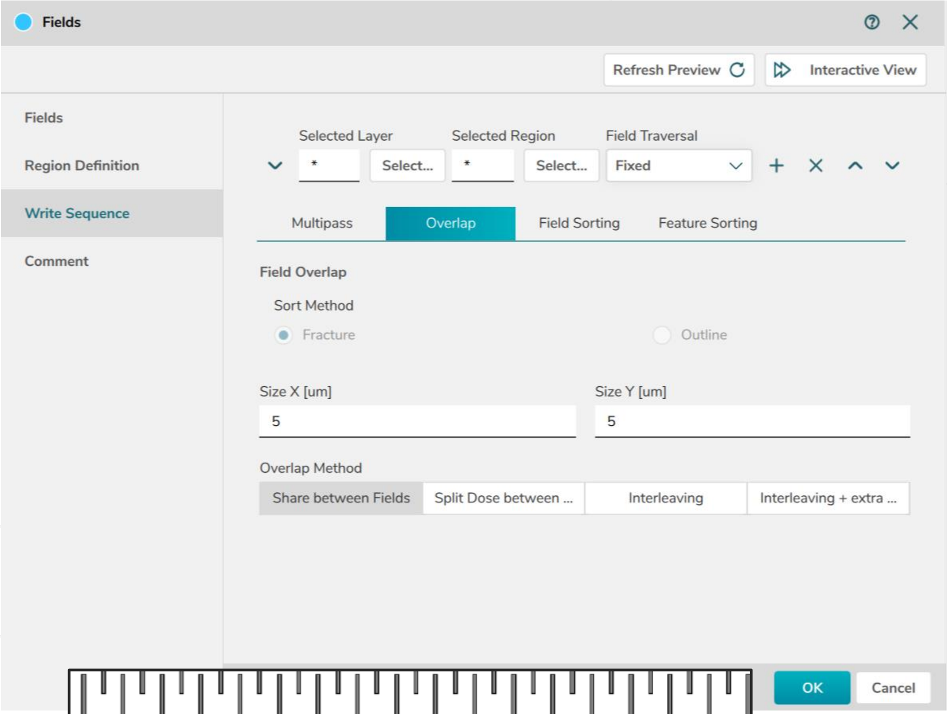
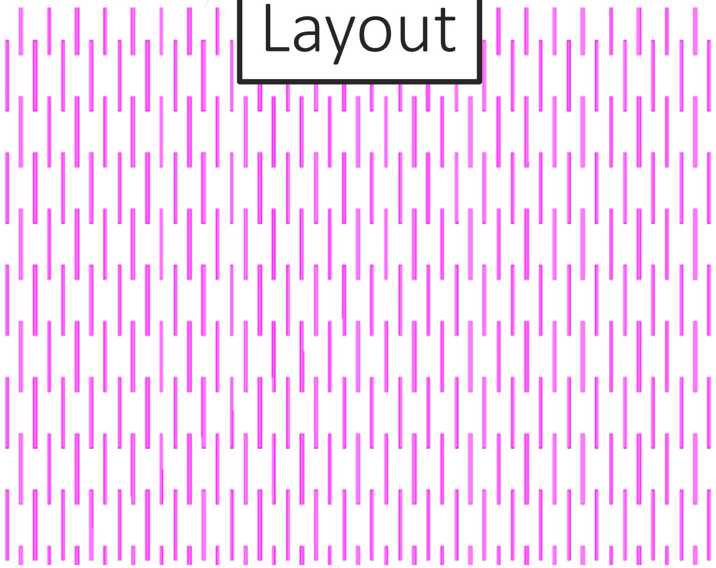
Overlapping examples

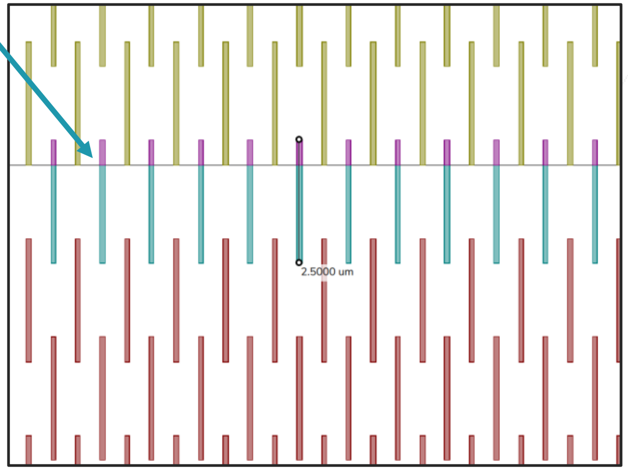
- Field Overlap
  - Size XY
  - Overlap Method
    - Share Between Fields



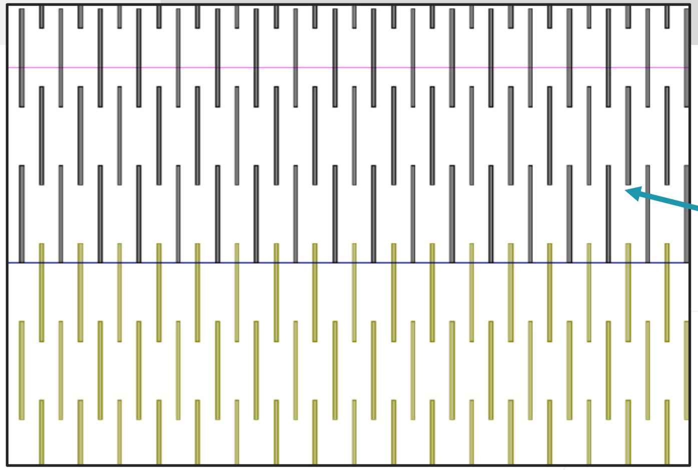
Layout



Potential stitching



Overlap = 0



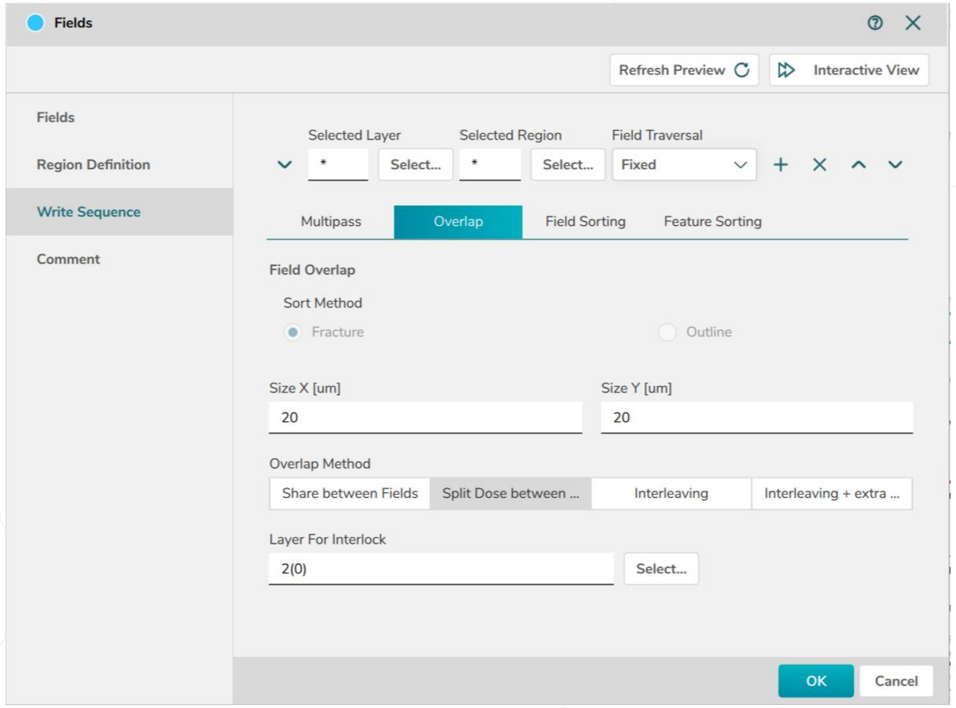
Stitching avoided

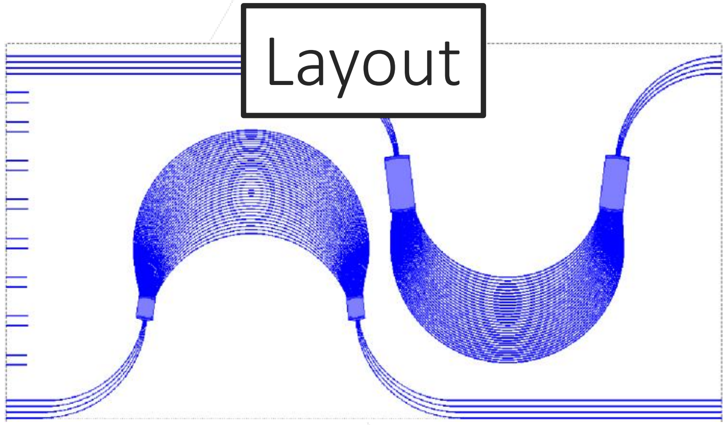
Overlap = 5 µm

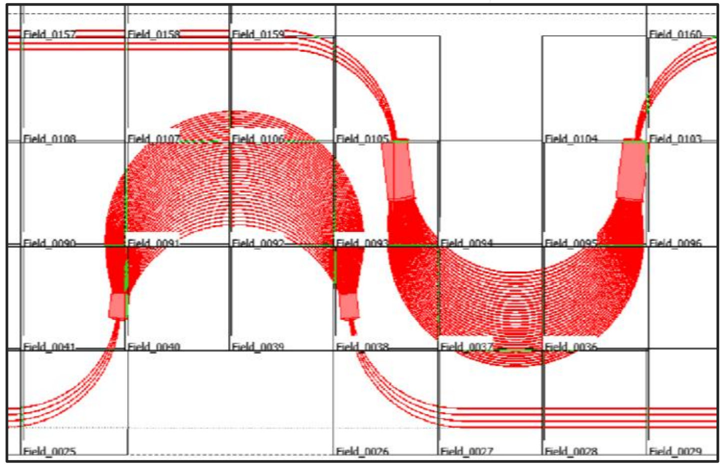
*Color by Cell

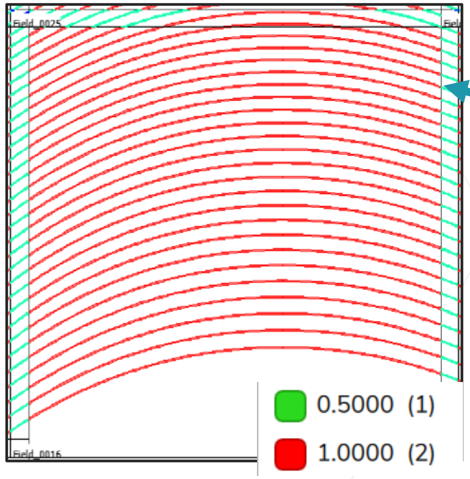
Overlapping examples

- Field Overlap
  - Size XY
  - Overlap Method
    - Split Dose between Fieds







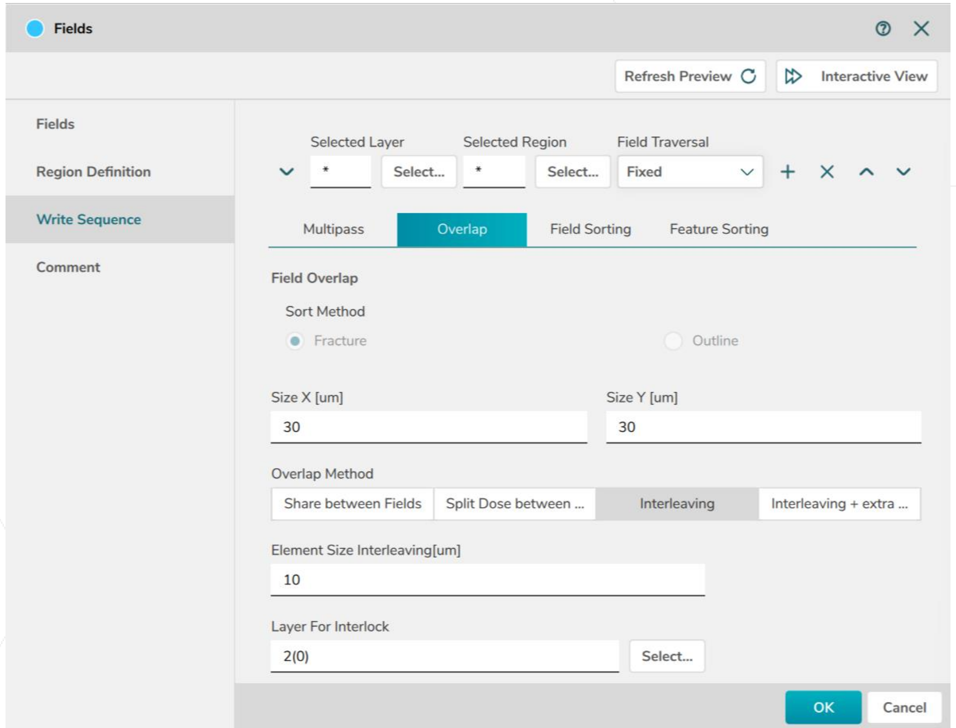


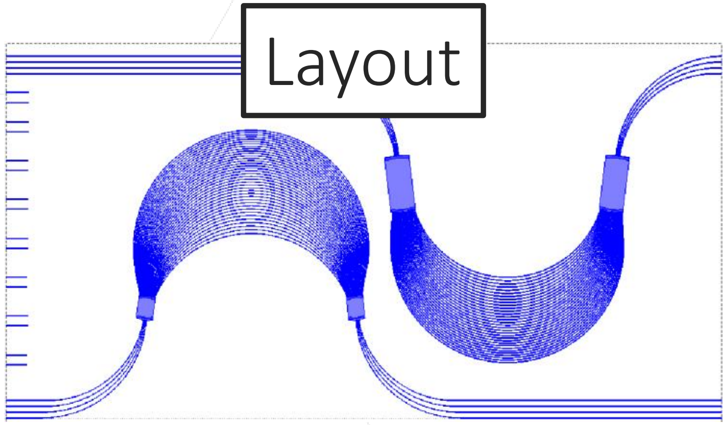
Shared dose area

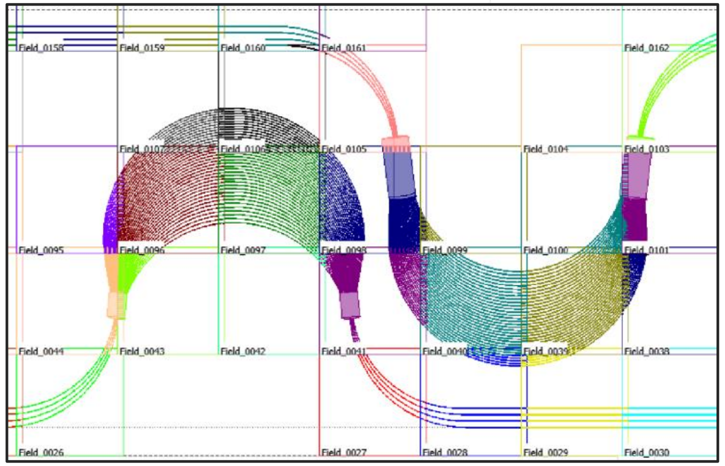
*Color by Dose

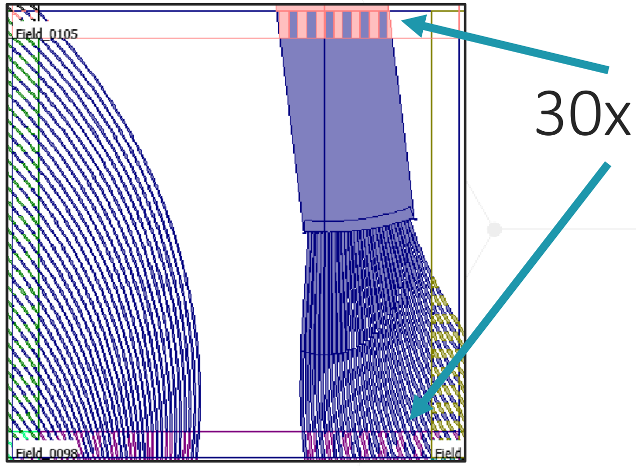
Overlapping examples

- Field Overlap
  - Size XY
  - Overlap Method
    - Interleaving









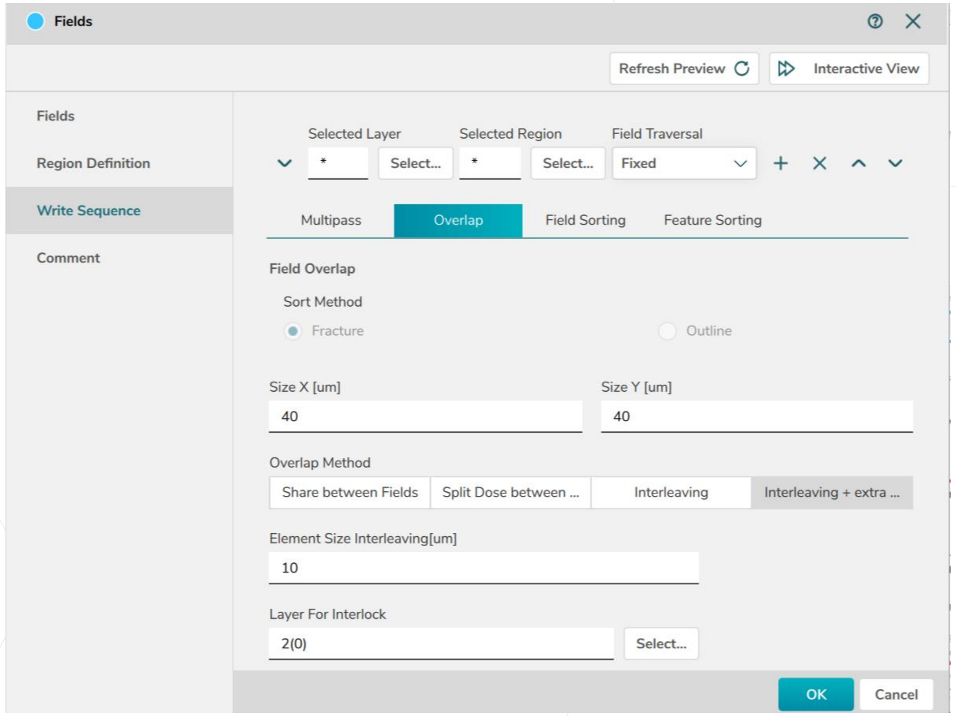
$30 \times 10\ \mu m^2$

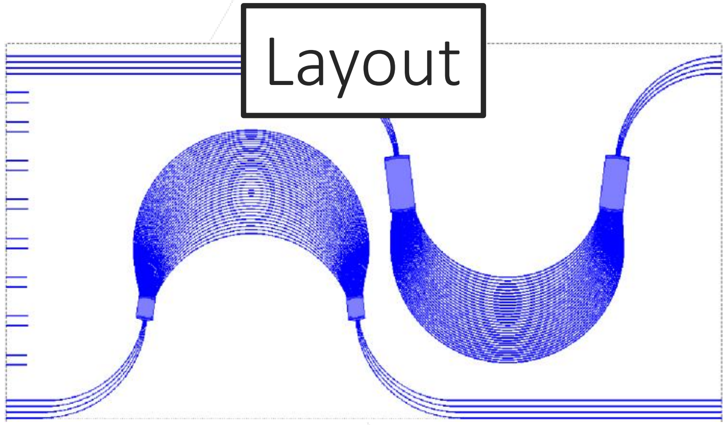
Field overlap is **minimum** 2x size interleaving

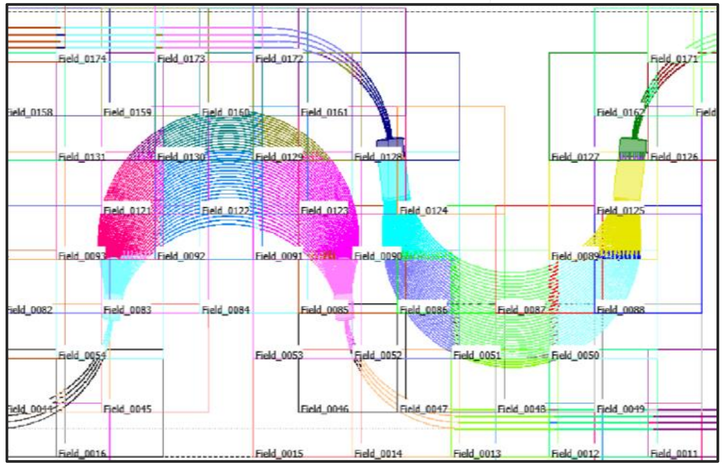
*Color by Cell

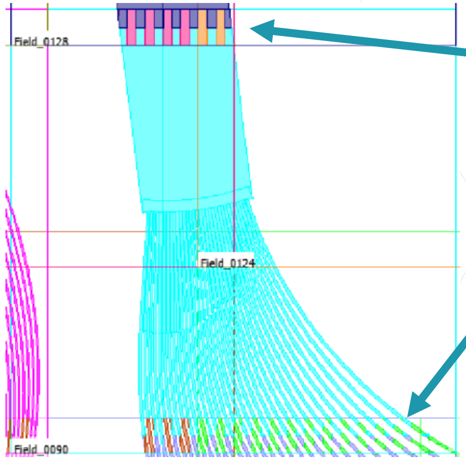
Overlapping examples

- Field Overlap
  - Size XY
  - Overlap Method
    - Interleaving + extra Field









40x10 µm²

Field overlap is a **multiple** of 4x size interleaving

*Color by Cell

Benefits

- All pattern data is *Single Pass* exposed

➡ Base dose stays the same

➡ Frequency range stays the same

➡ Beam current stays the same

➡ Exposed area is equal to the single pass
  - Overall exposure time is comparable to single pass

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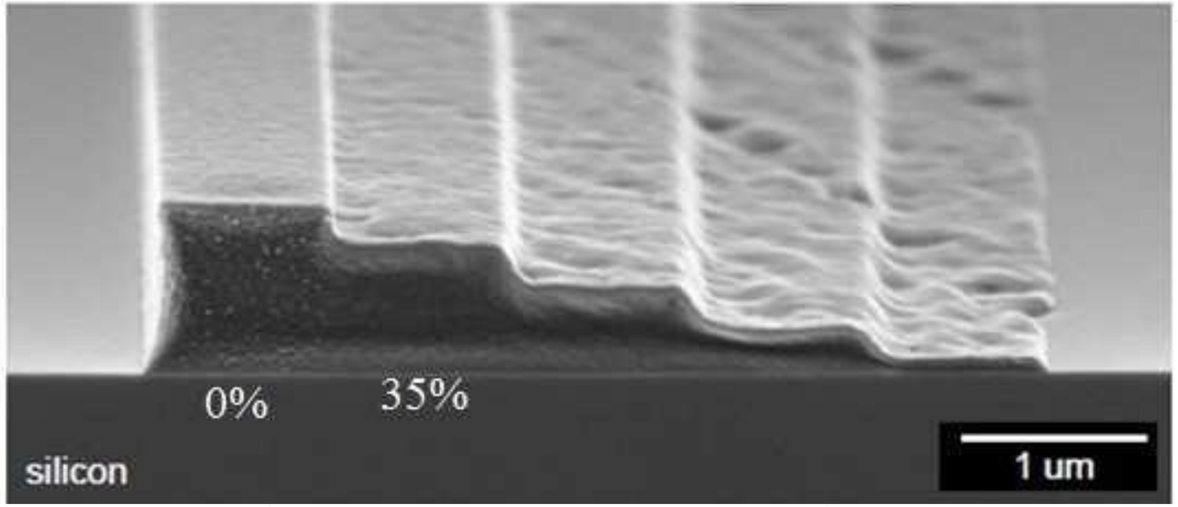
What about 3D structures?



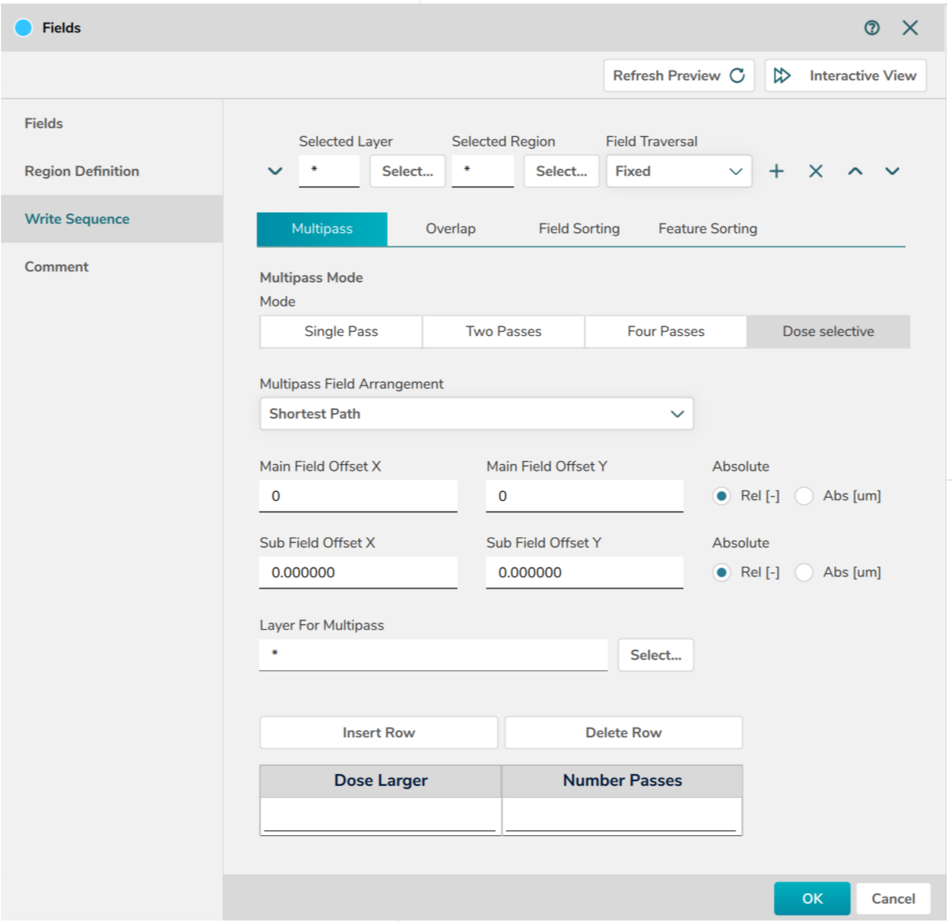
- Larger Dose (bottom steps) exhibit more noise
- **BEAMER** does *Dose selective* multipass

Dose Multipass Example

Dose Class	Original Dose	Adapted Dose	#Passes
0	1,031772	1,031772	1
1	1,219605	1,219605	1
2	1,441632	1,441632	1
3	1,704079	0,8520395	2
4	2,014304	1,007152	2
5	2,381005	1,1905025	2
6	2,814463	0,938154333	3
7	3,326832	1,108944	3

Approximated values

Multi-exposure Sequence



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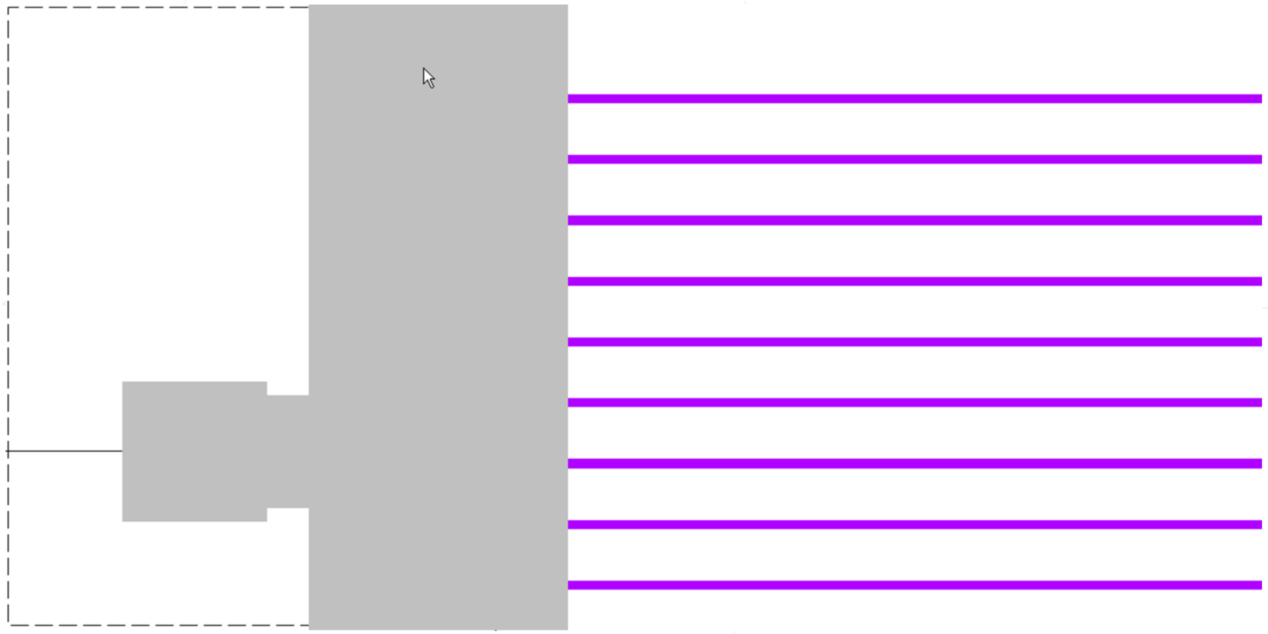
Summary

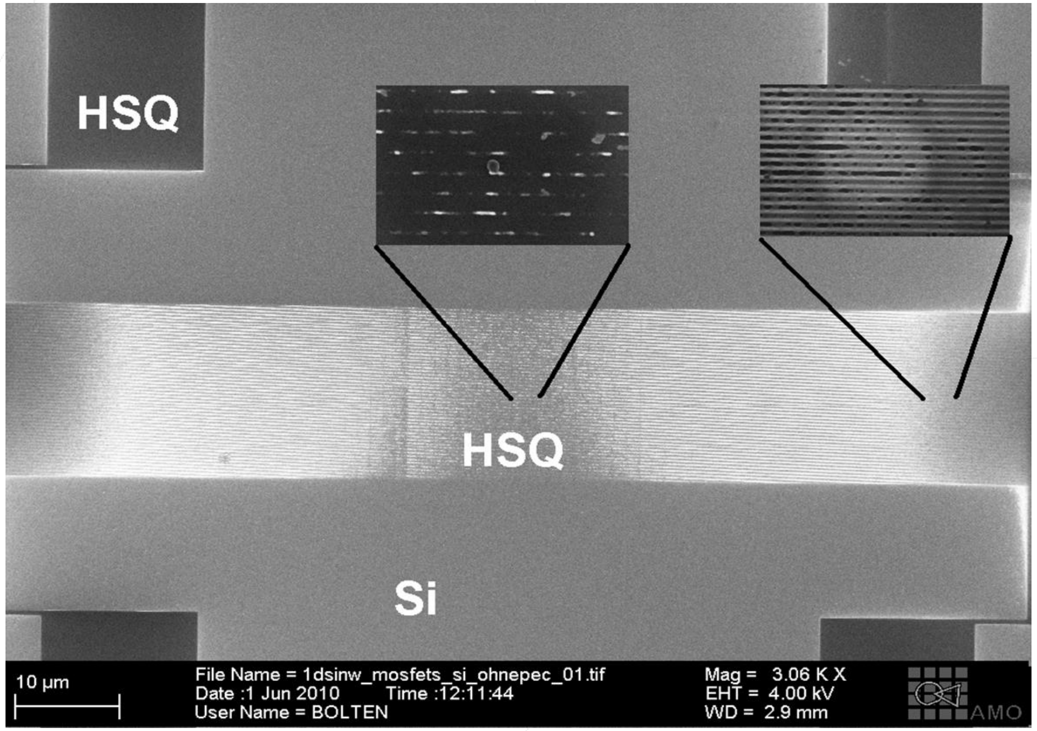
- Traditional multipass improves LER, LWR, field- and subfield-stitching issues at the expense of throughput
- Improving the throughput while maintaining the benefit of multipass is possible using
  - 4-pass at 2x shot pitch for photonic applications
  - Interstitial field blending for large area high resolution devices
  - Dose multipass for 3D- and nano-structures
  - Generic approaches that allow to split the pattern in any thinkable way

Nano-wire Example

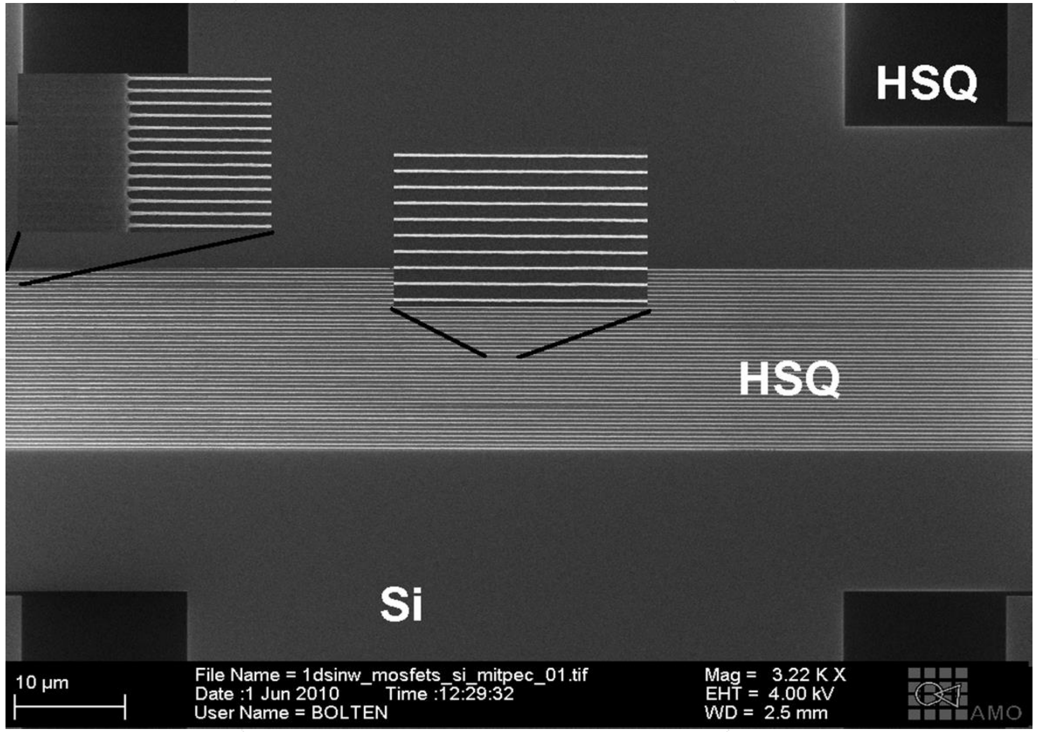
- The following work from AMO shows the benefit of PEC in conjunction with Multipass
  - PEC is needed to correct for different densities
    - Wires have small density, pads a large density
  - Multipass is needed to average statistical noise



No PEC



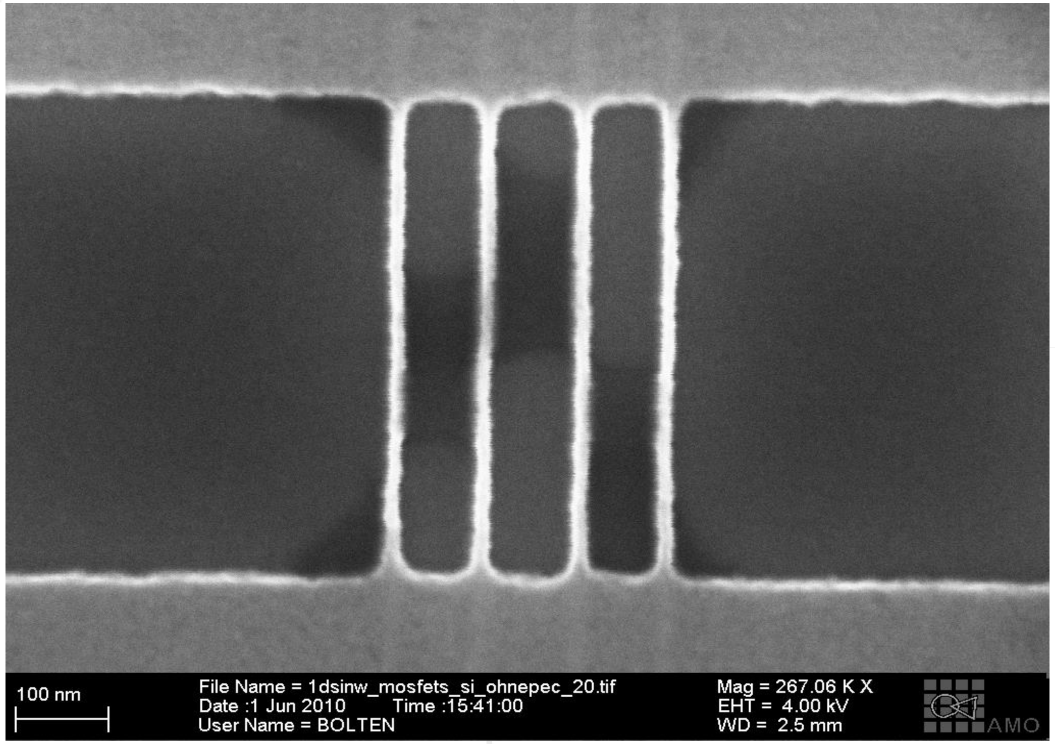
PEC exposure



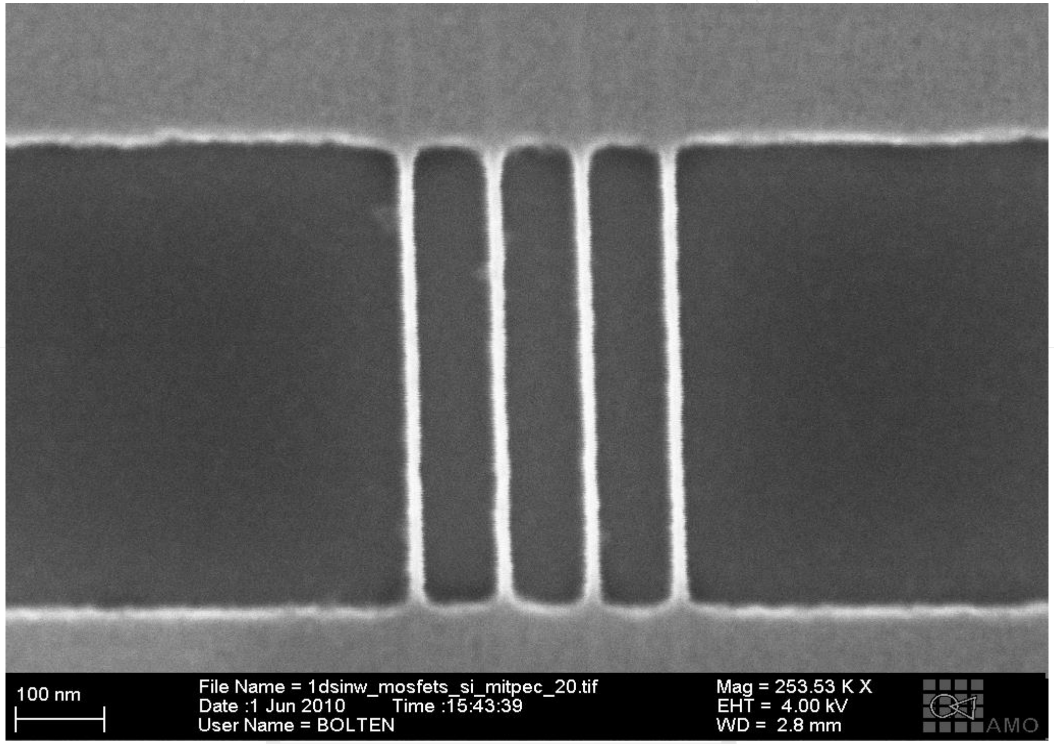
PEC mandatory for fabrication of dense nanowire arrays

Multipass results

Single Pass



Multipass



Multi-pass exposure strategy can significantly reduce both LER and LWR

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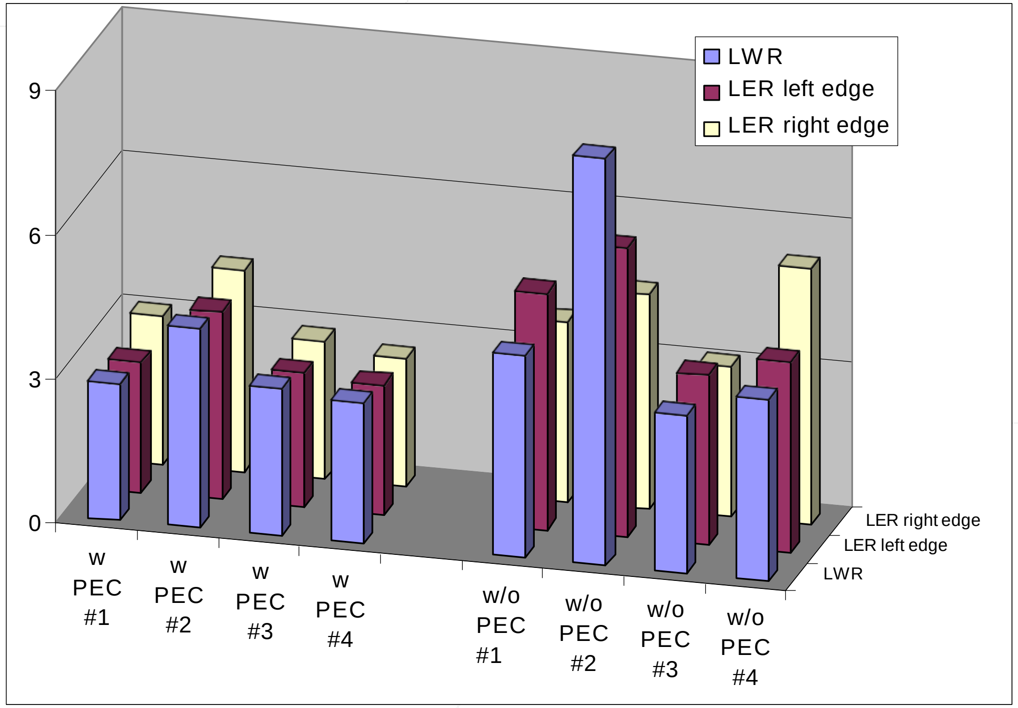
Analysis of SEM image data

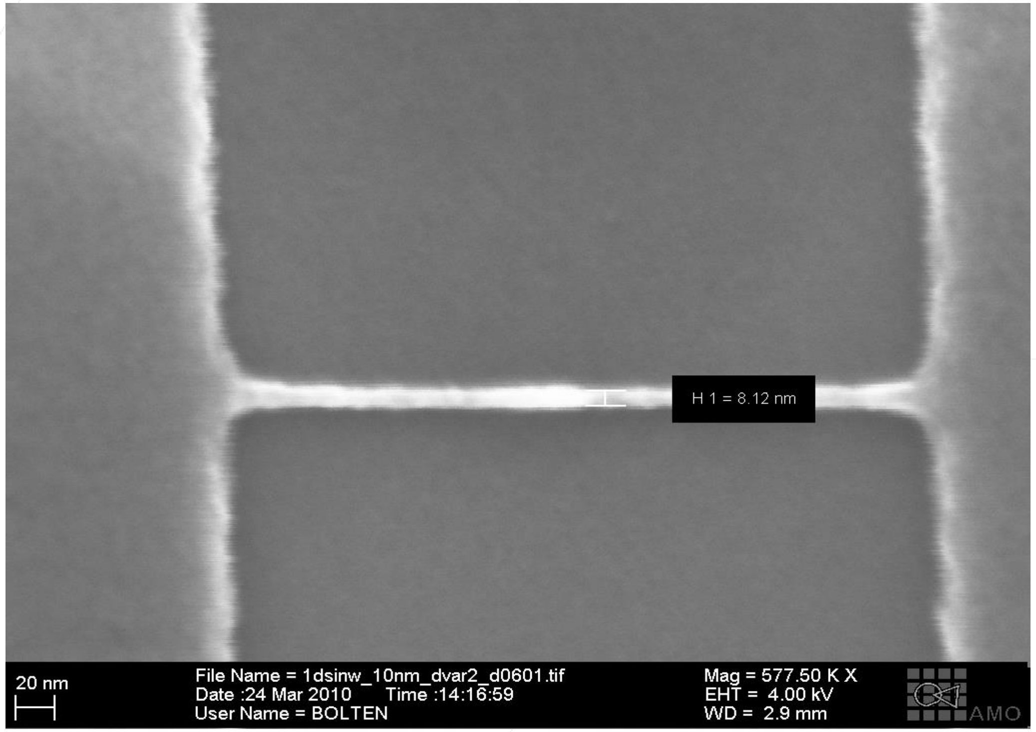


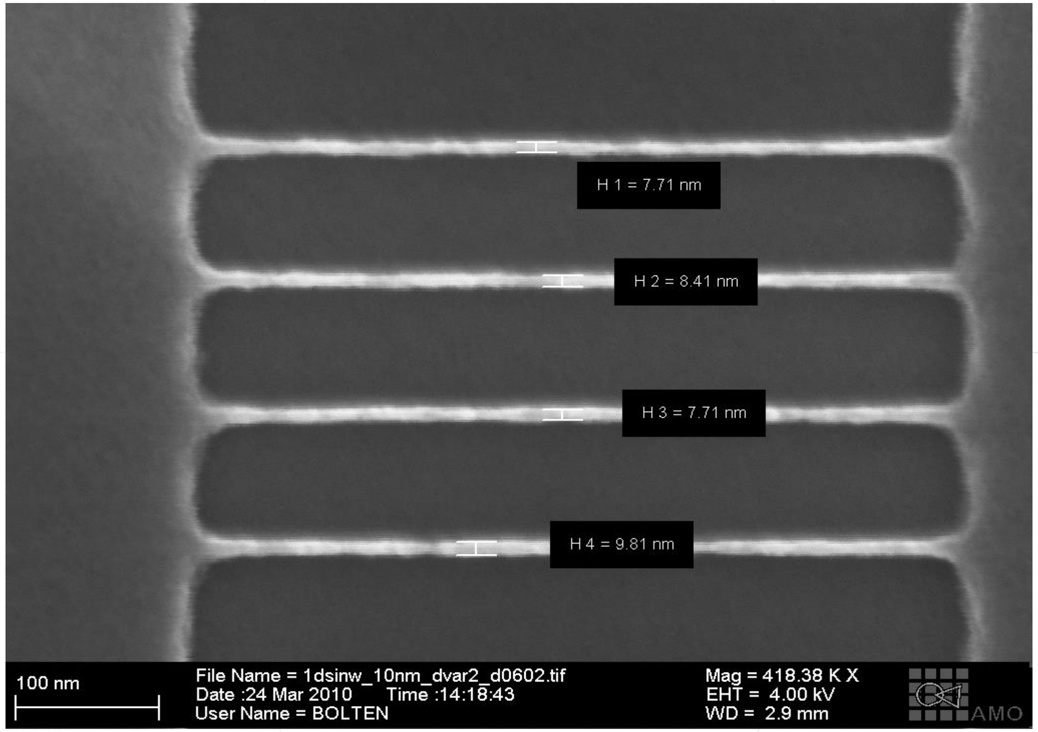
- LER
  - Single pass:~4nm,
  - Multi-pass: ~3nm
- LWR
  - Single pass: ~5nm
  - Multi pass: ~3nm

With multi-pass exposure strategy ~25% less LER and ~40% less LWR

Resolution results

Sub-10nm resolution





Resist features as narrow as ~8nm have been fabricated using PEC and multi-pass

Thank You!

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