Beam Step Size Fracturing for Bragg Grating Waveguides

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UNIVERSITY of WASHINGTON

Washington Nanofabrication Facility

General university nanofabrication facility

Any discipline, any material

JEOL JBX-6300FS e-beam

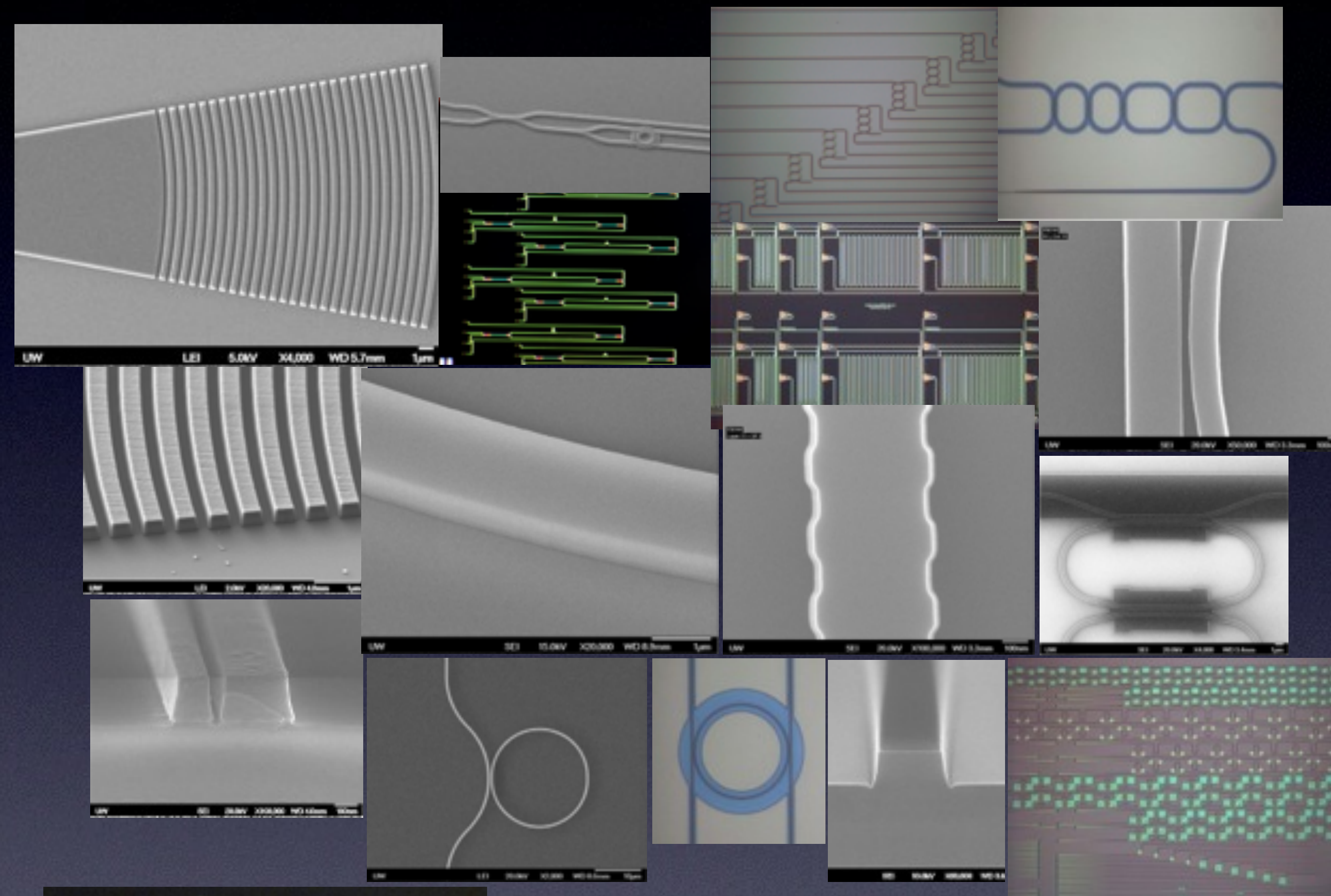
Silicon Photonics

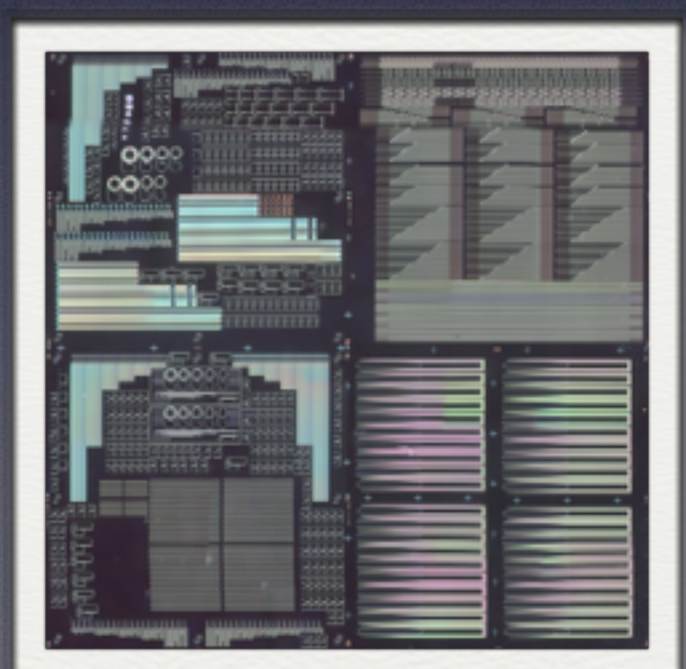
Specializing in silicon photonics

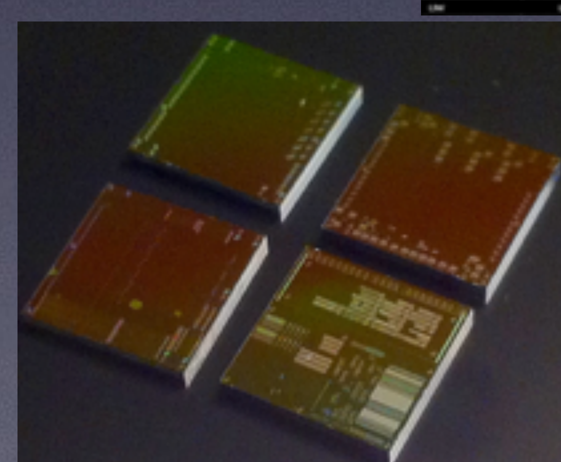
16+ remote customers

3 expose & etch layers

Metallization, Cladding, Dicing, etc.

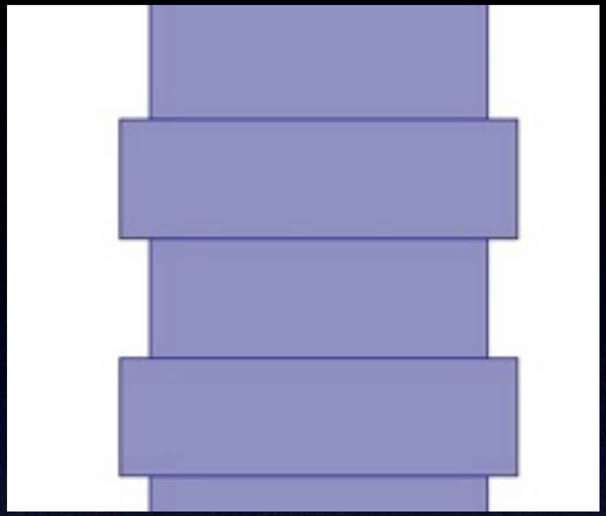


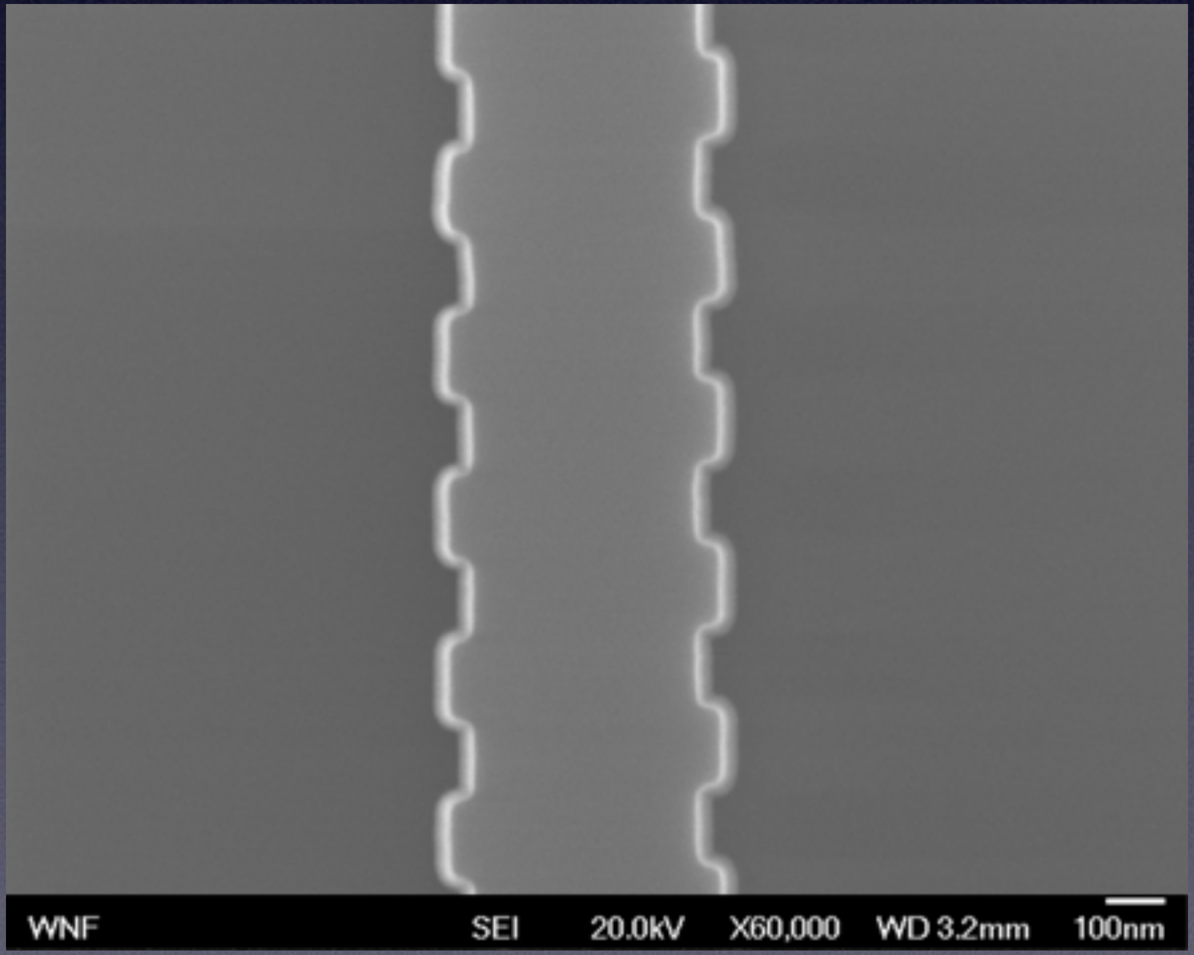




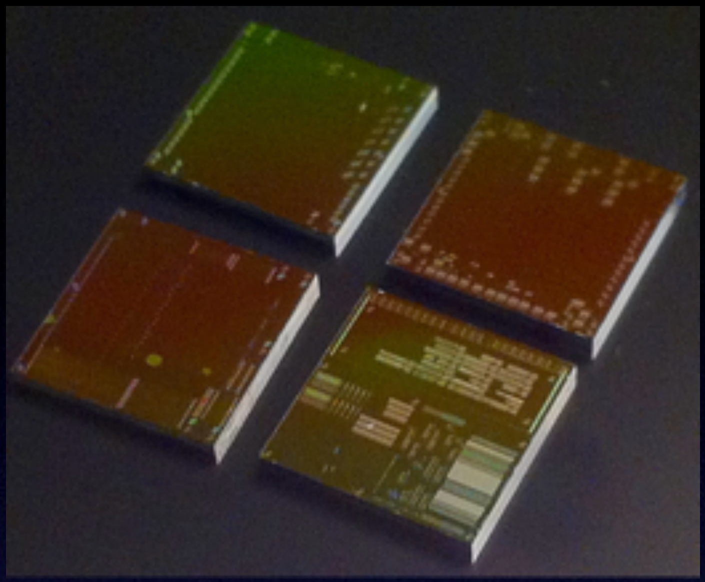
Bragg Gratings

- Bragg Gratings are used in photonic systems for wavelength-division multiplexing, dispersion compensation, and gain equalization, among other signal processing applications.
- In silicon photonics, these can be implemented as corrugated waveguides





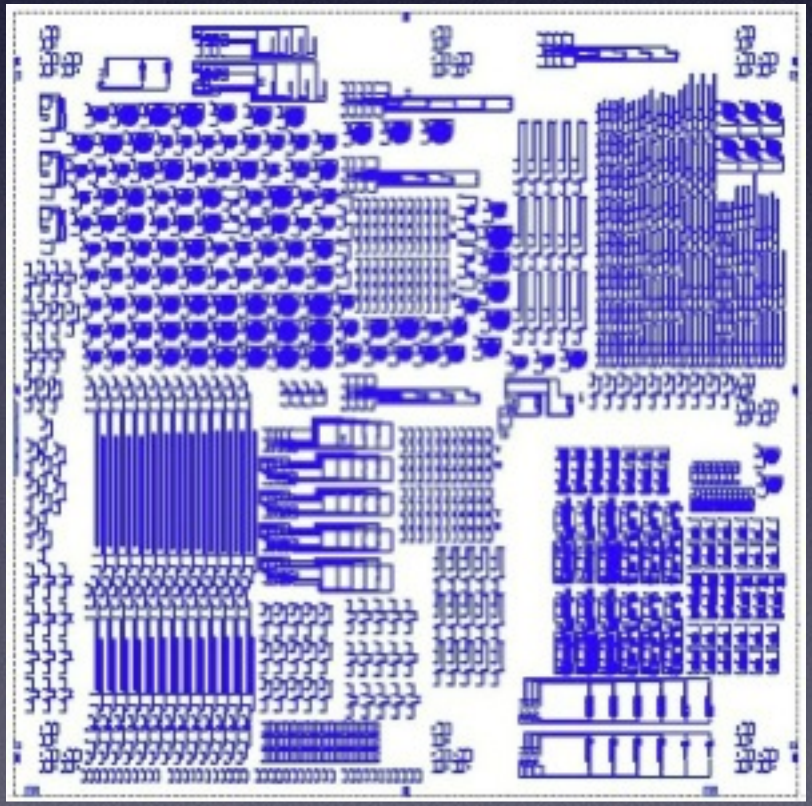
Example Chips



Silicon photonics designs, each 9x9 mm

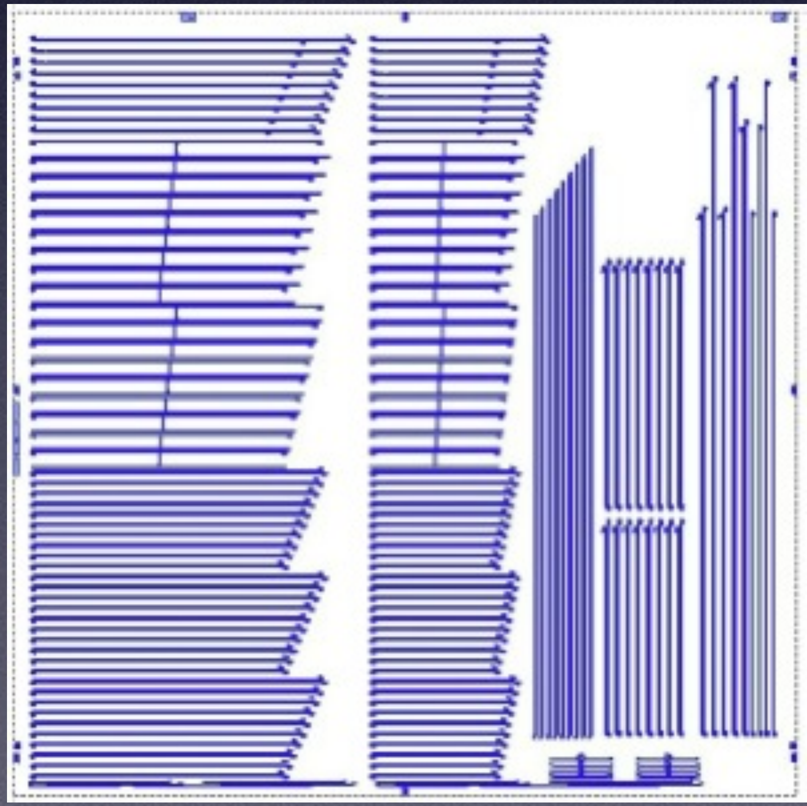
Chip 1

Area = 2.2e6 μm^2



Chip 2

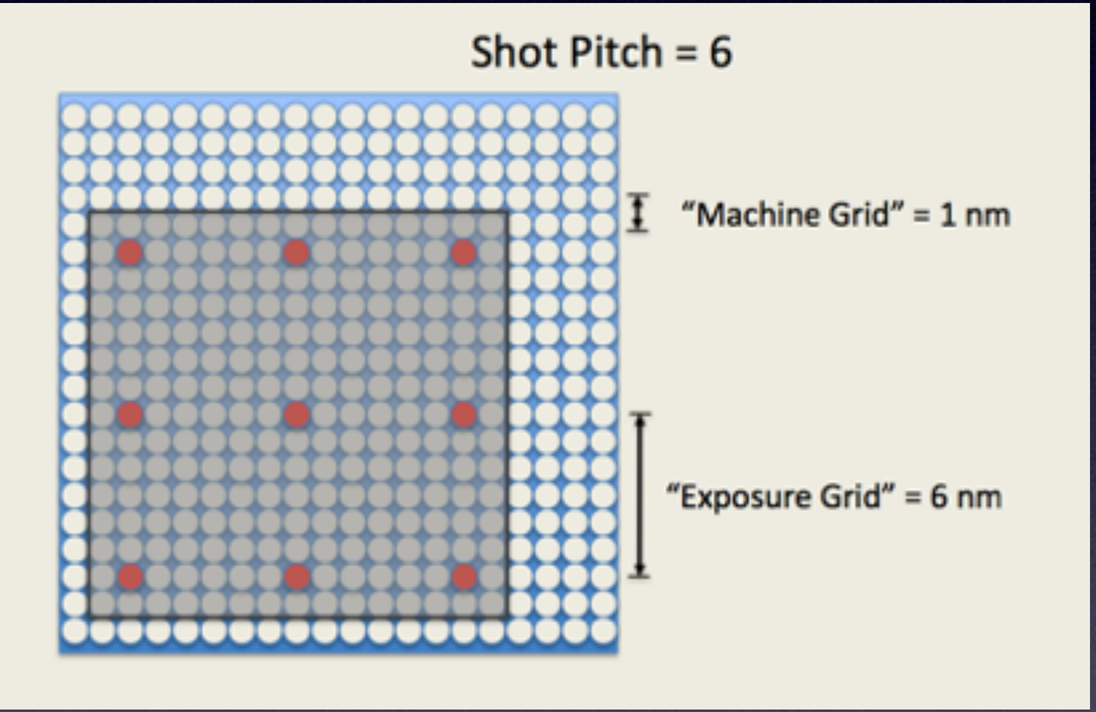
Area = 7.9e5 μm^2



Limitations

- Feature size accuracy and size increment can directly influence device performance
- Smaller fracturing/writing grid is desirable, but results in longer write times, since we have to use a lower beam current for smaller writing grid size. This is a familiar trade-off to everyone using direct-write EBL

$$D\left(\frac{\mu C}{cm^2}\right) = \frac{I_{beam}(pA)\times 100}{F_{shot}(MHz)\times Grid^2_{Exp}(nm)}$$



Exposure Grid
= Writing Grid
= Beam Step Size
= Shot Pitch

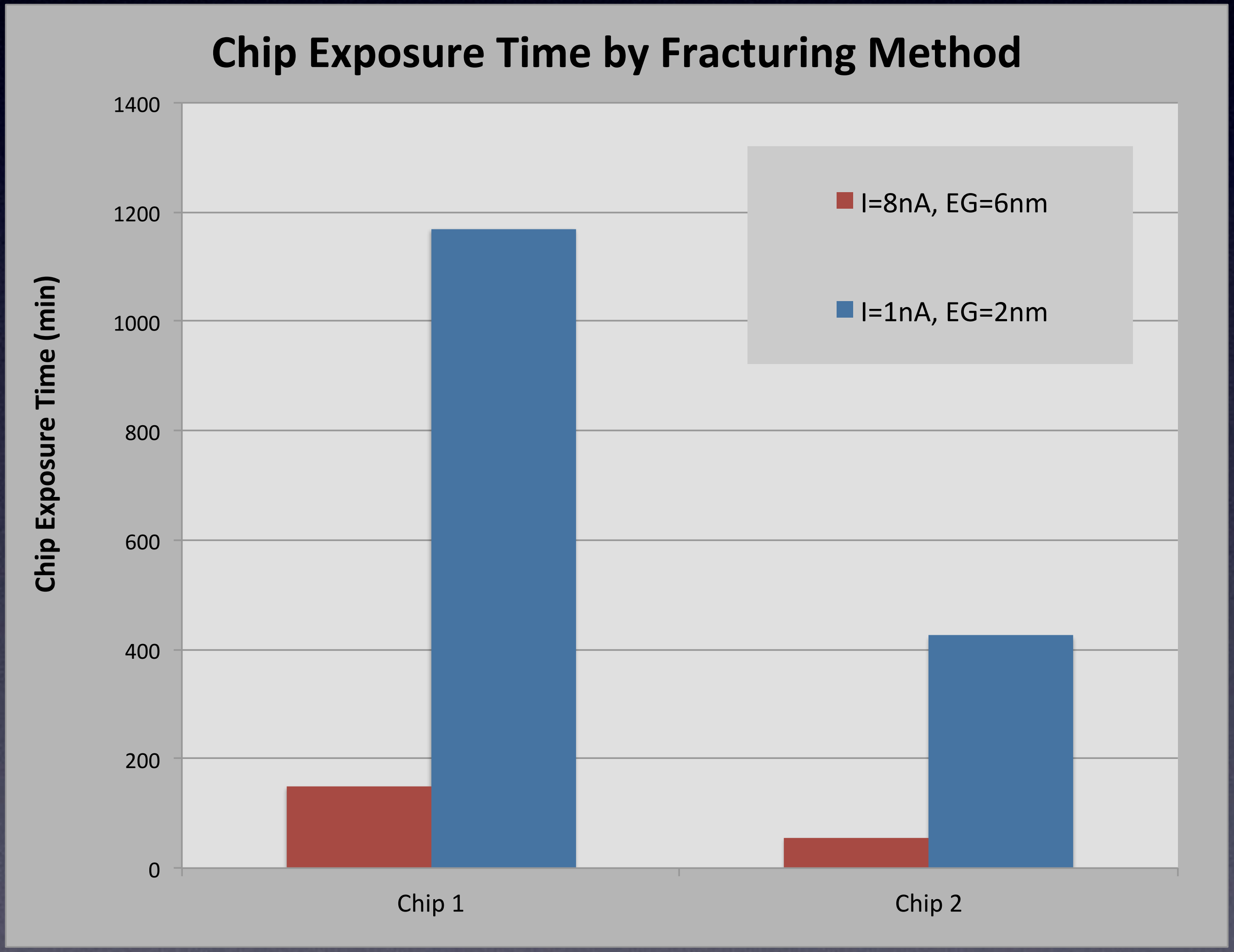
Example Timing 1

Standard Conditions:

I_{beam} = 8 nA, BSS = 6 nm

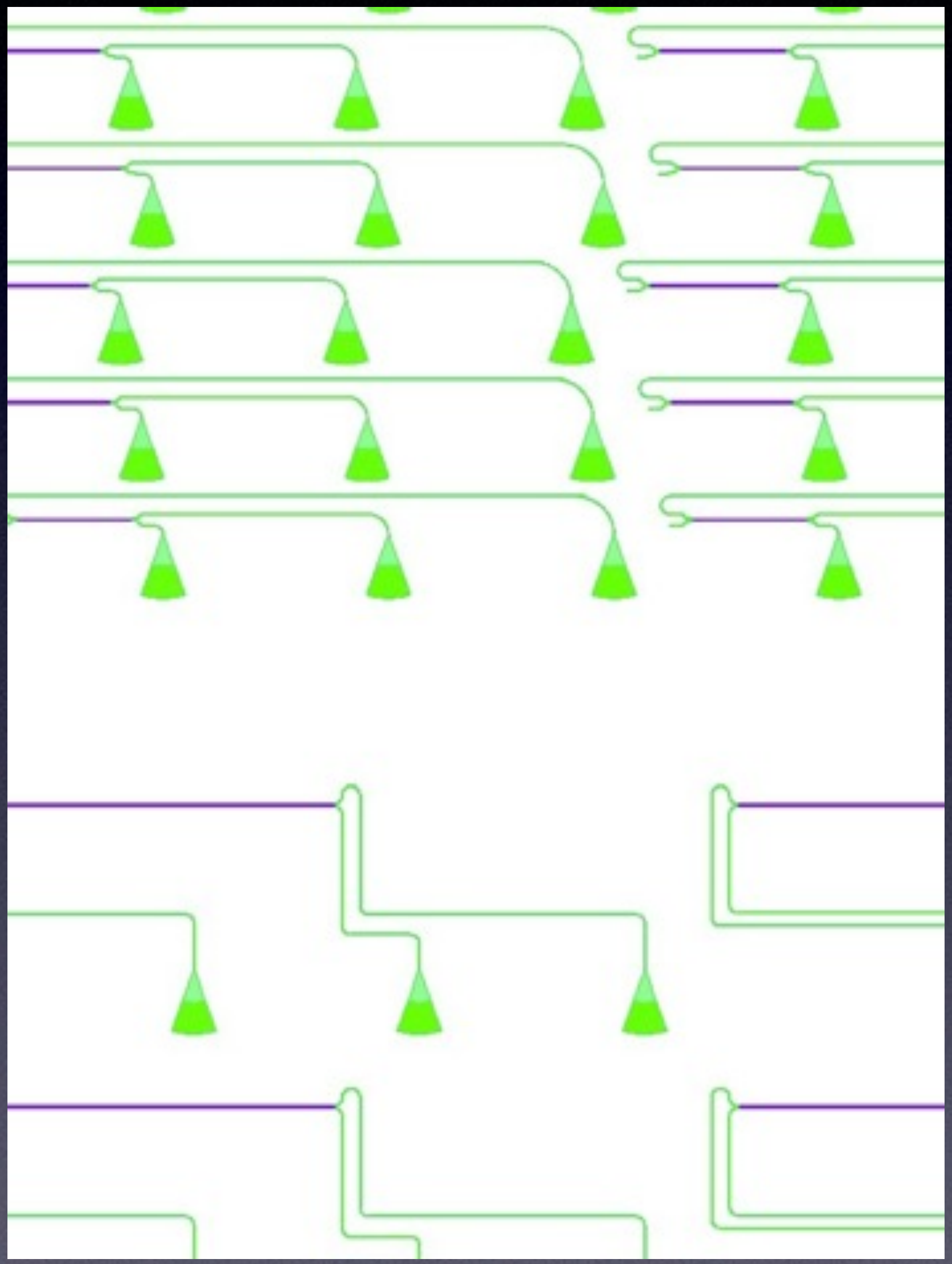
Fine Grid Conditions:

I_{beam} = 1nA, BSS = 2 nm



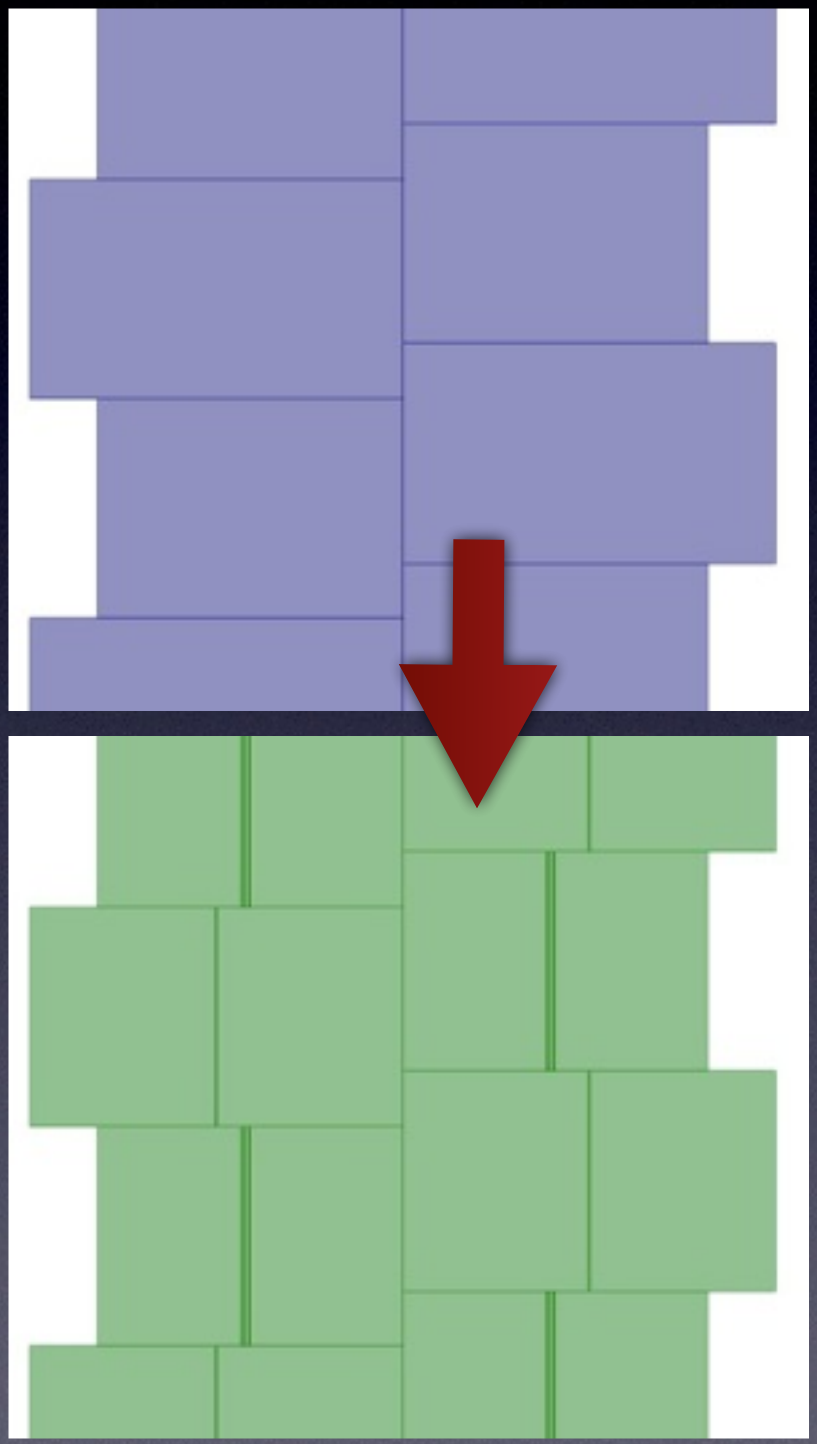
Alternative: Coarse/Fine Split

- One option is to split the exposure into two parts, written with two beam currents
  - Requires change of beam current, lens stabilization wait, and recalibration at second beam current for each chip
  - Possibility of placement mismatch from system or environmental drift (careful design to include intentional overlaps may compensate)

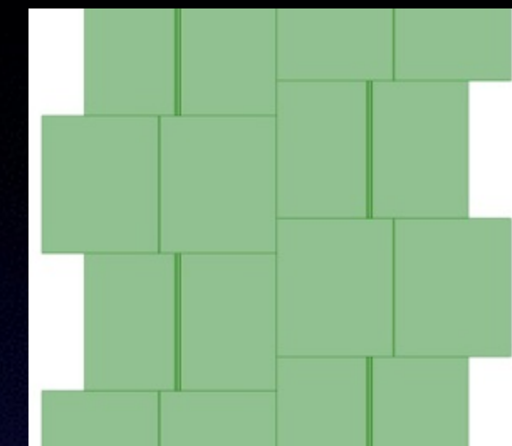


Alternative: Shot Pitch Fracturing

- Beamer option of Beam Step Size Fracturing gives you a clever method to still get the edge placement of fine-grid shape fracturing while writing with larger beam currents
- Sub-fractures designs with overlapping regions buried in the middle



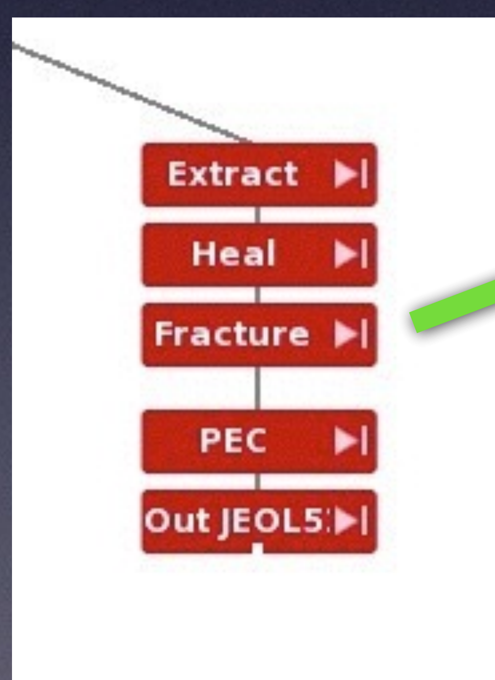
Beam Step Size Fracturing

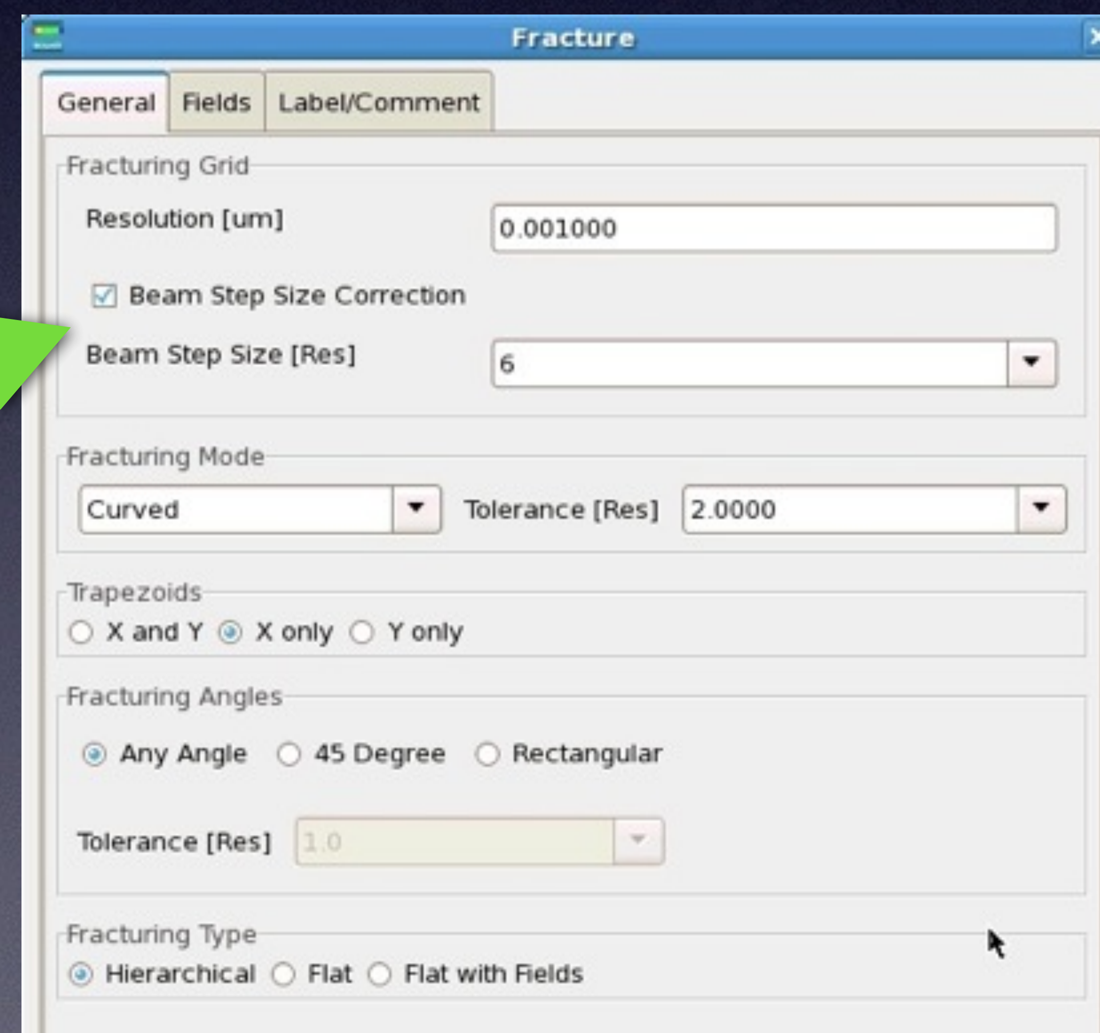


- The size of each shape is still a multiple of the Beam Step Size, in this case 6 nm
- The outer edges are now placed to the 1 nm machine grid
- Small overlapping shapes buried in the middle of the shape
- What was 2 shapes in conventional fracturing is now 5 shapes

Beamer Implementation

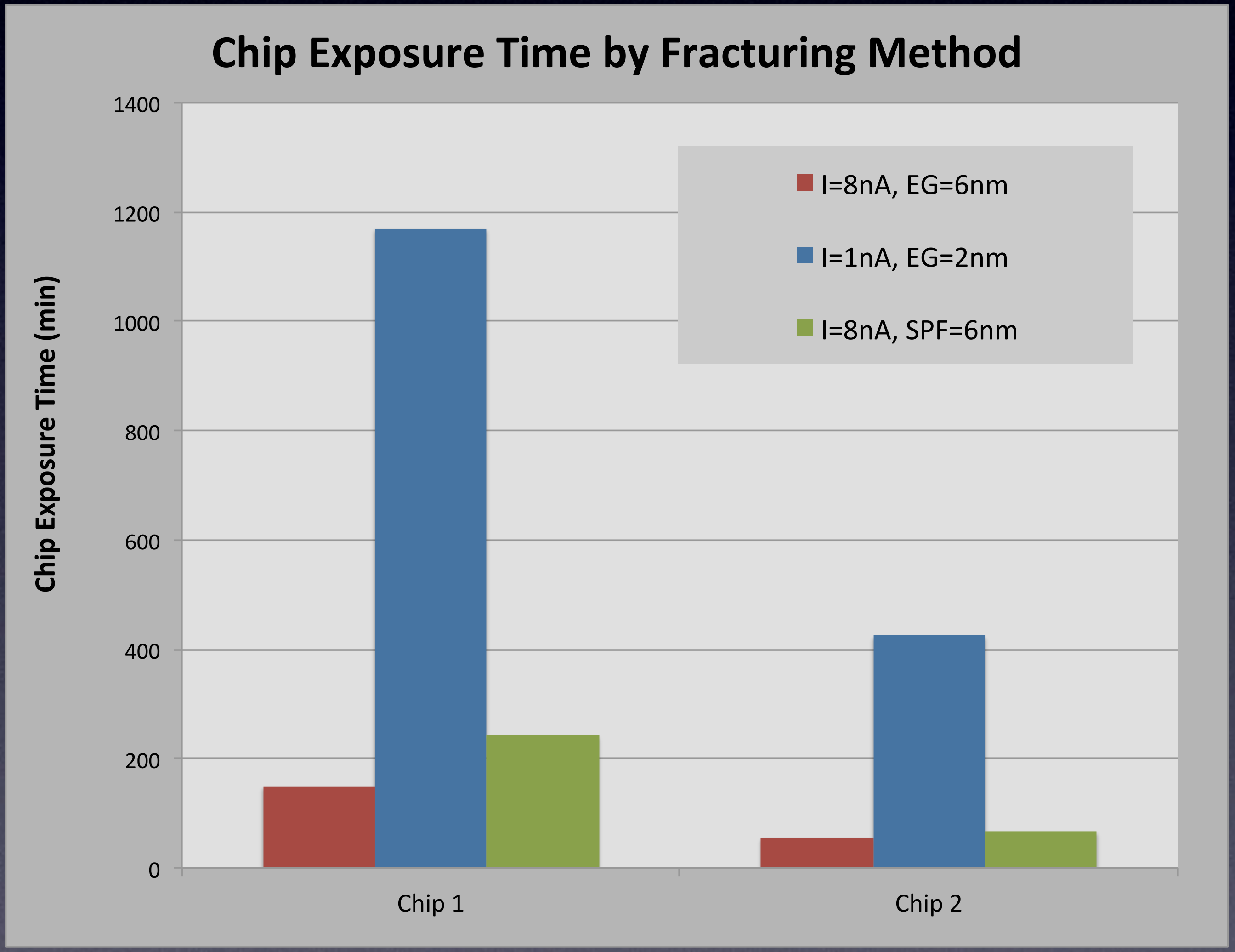
- In the Fracture module
  - Beam Step Size Correction
  - In multiples of the machine resolution (machine placement grid)





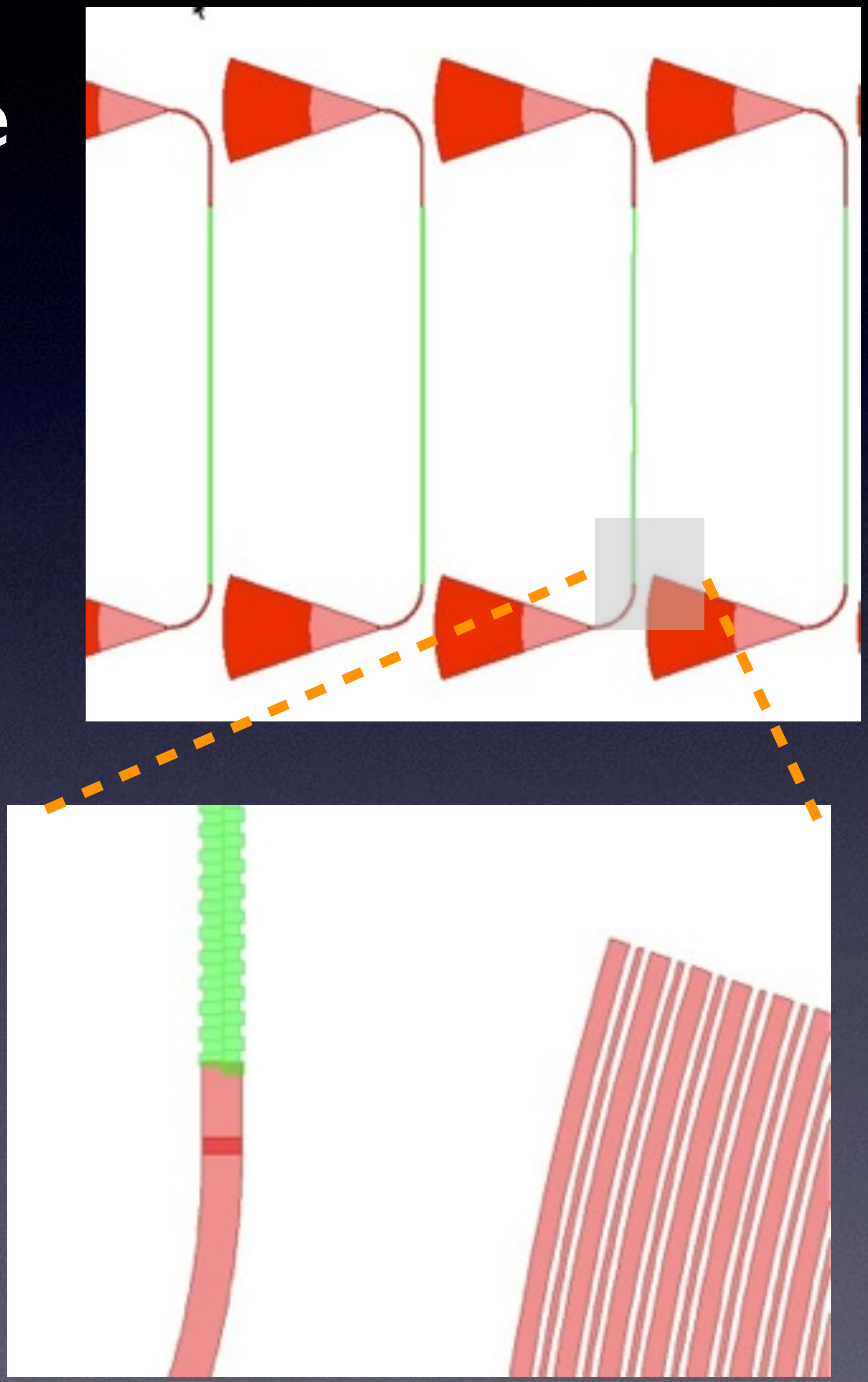
BSS Fracturing Results

- Exposure times much faster than using a smaller current
- But exposure times also longer than standard fracturing, due to shape overhead (machine dependent)
- (File sizes significantly larger, but who cares?)



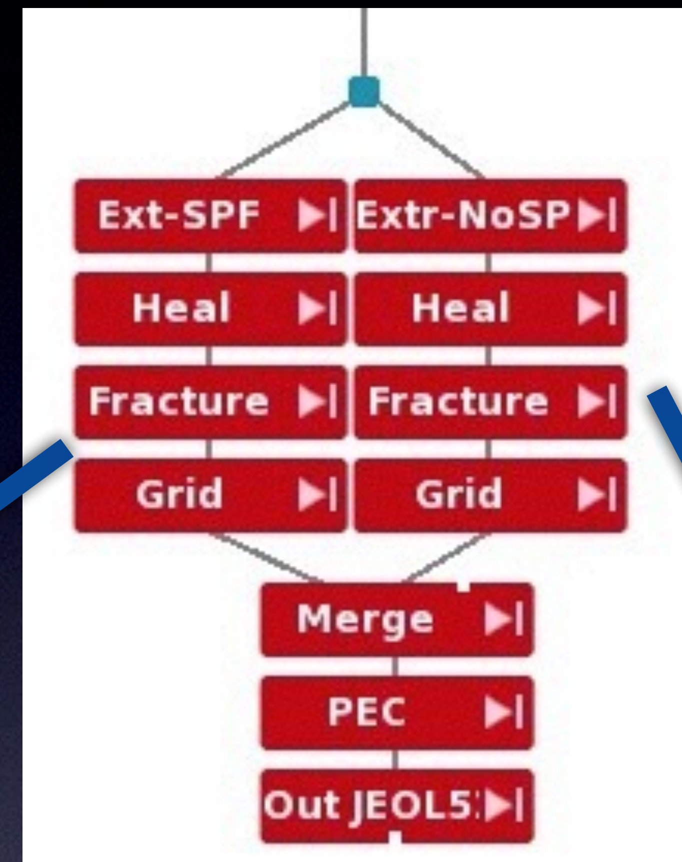
Hybrid BSS/Non-BSS Fracturing

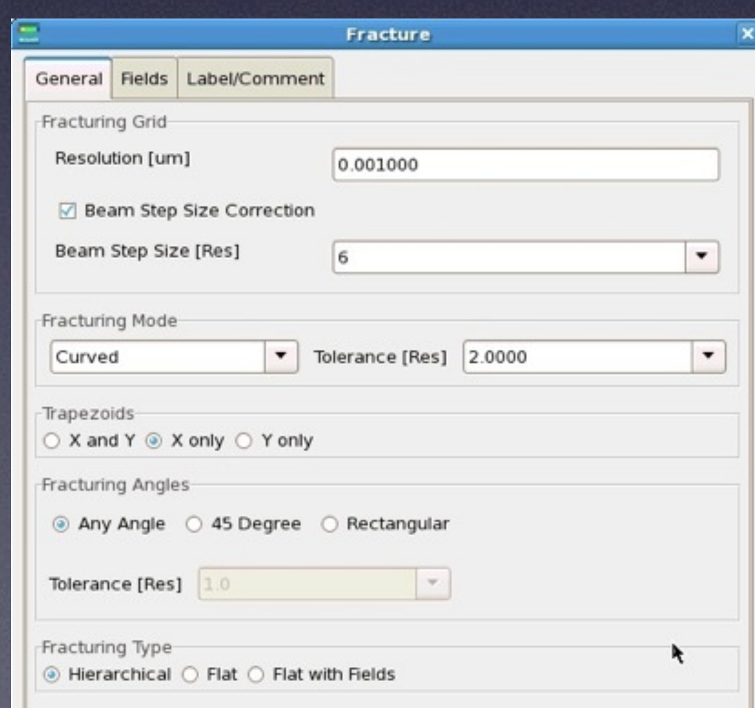
- Akin to the split beam exposure above
  - Just fracture the pattern segments differently, but expose together, at the same beam current
  - Only those parts which benefit from Beam Step Size Correction will get it.
  - No readjustment, no stabilization, no recalibration, no drift shift, no added stage moves
  - Does require designers to separate critical and non-critical segments

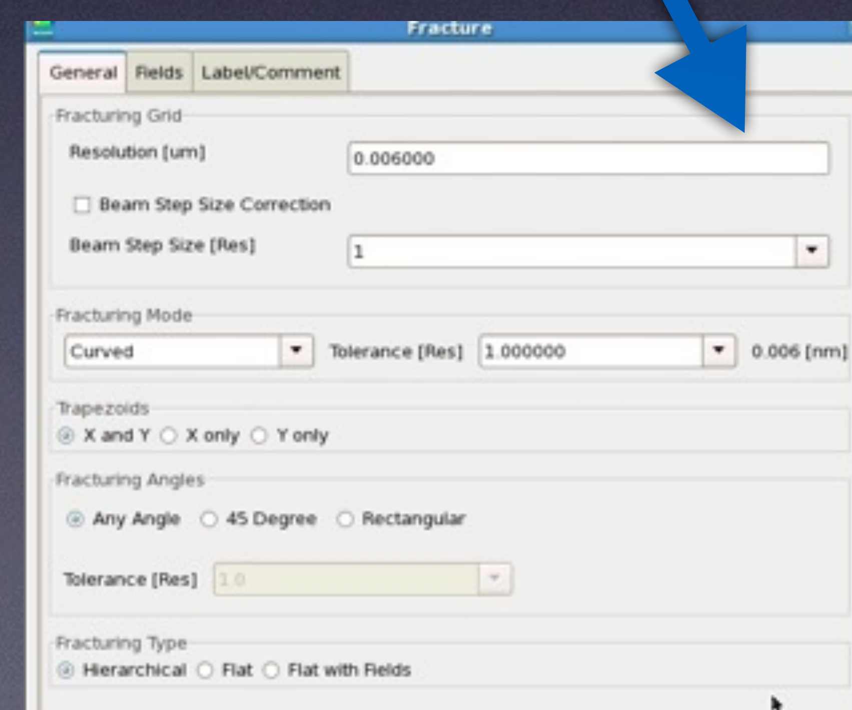


Beamer Implementation

- Fracture the two parts independently, then merge back together before output.
- All written in a single pass

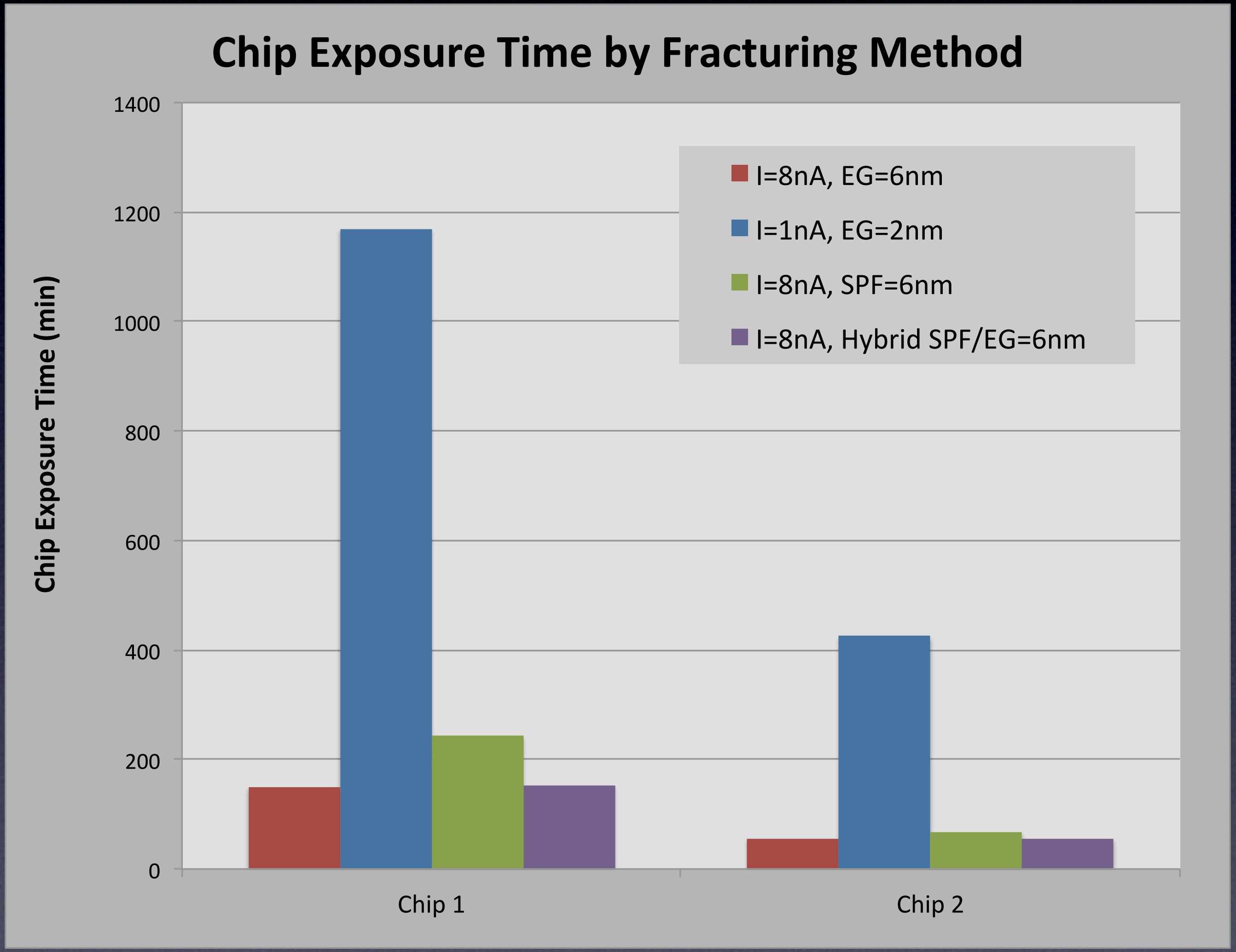


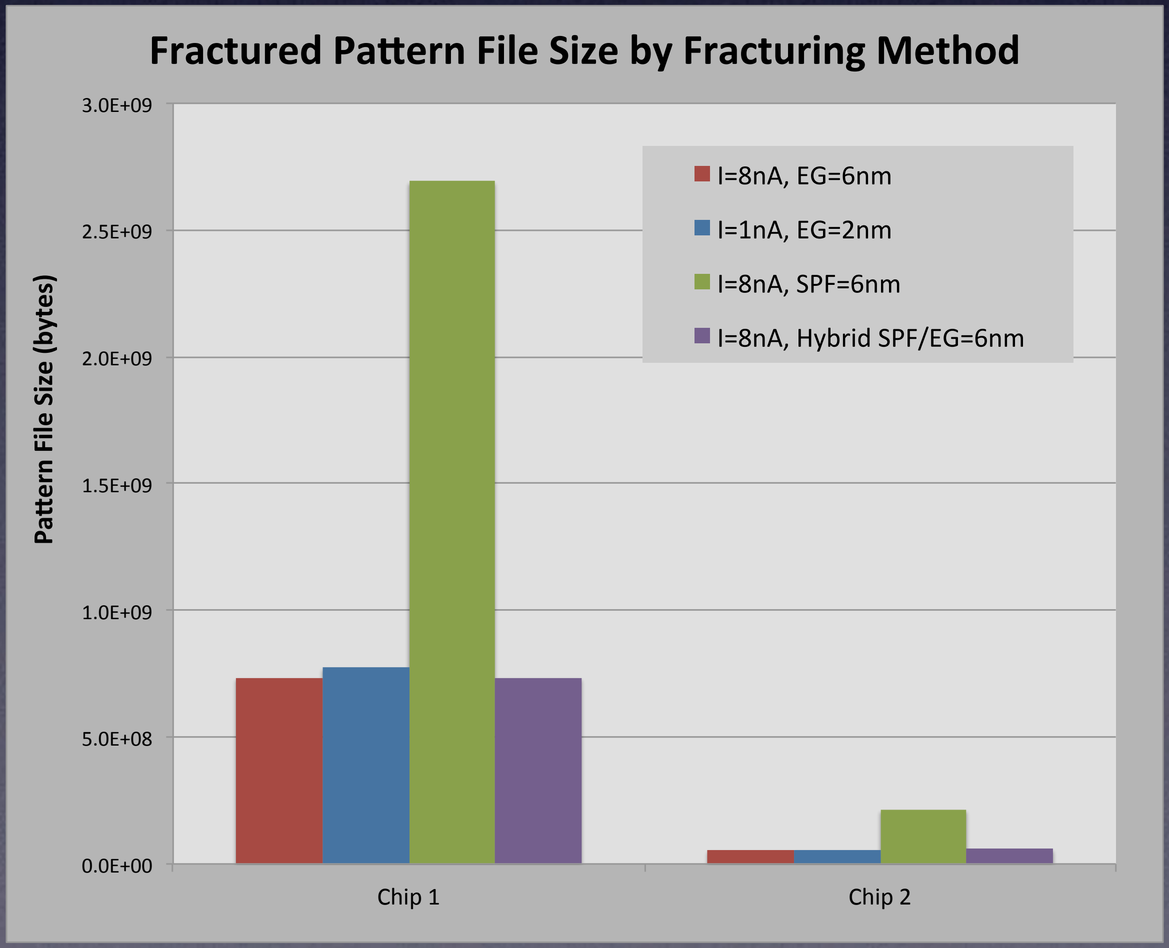




Hybrid BSS Fracturing Results

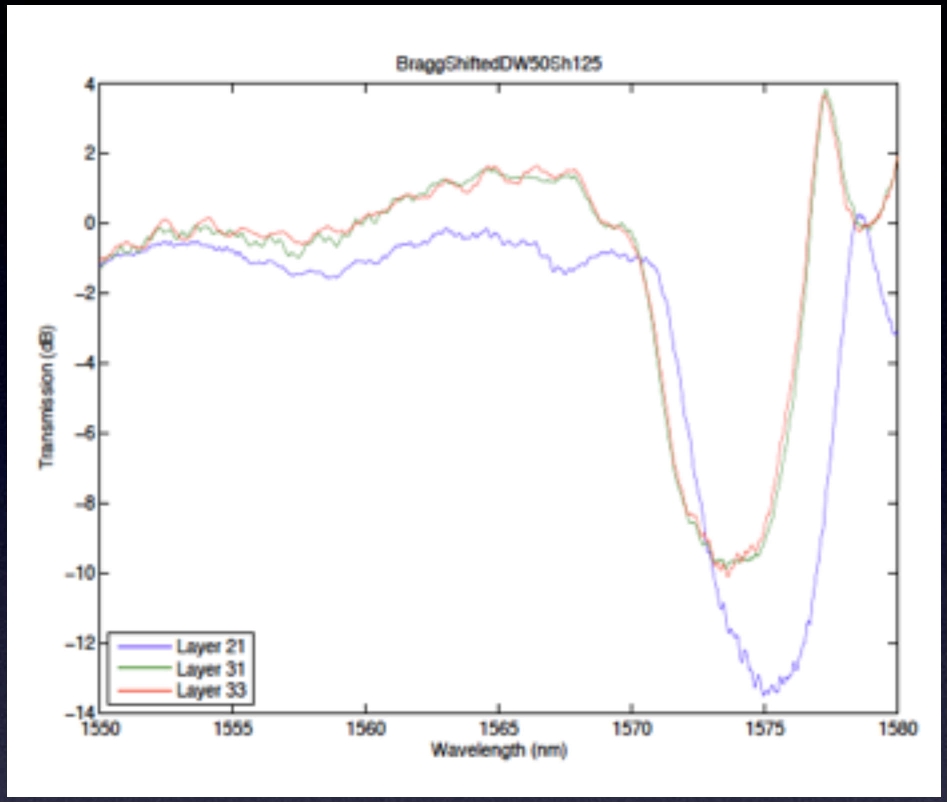
- Hybrid Beam Step Size Fracturing works
  - A good compromise
  - File sizes also smaller, reduced overhead

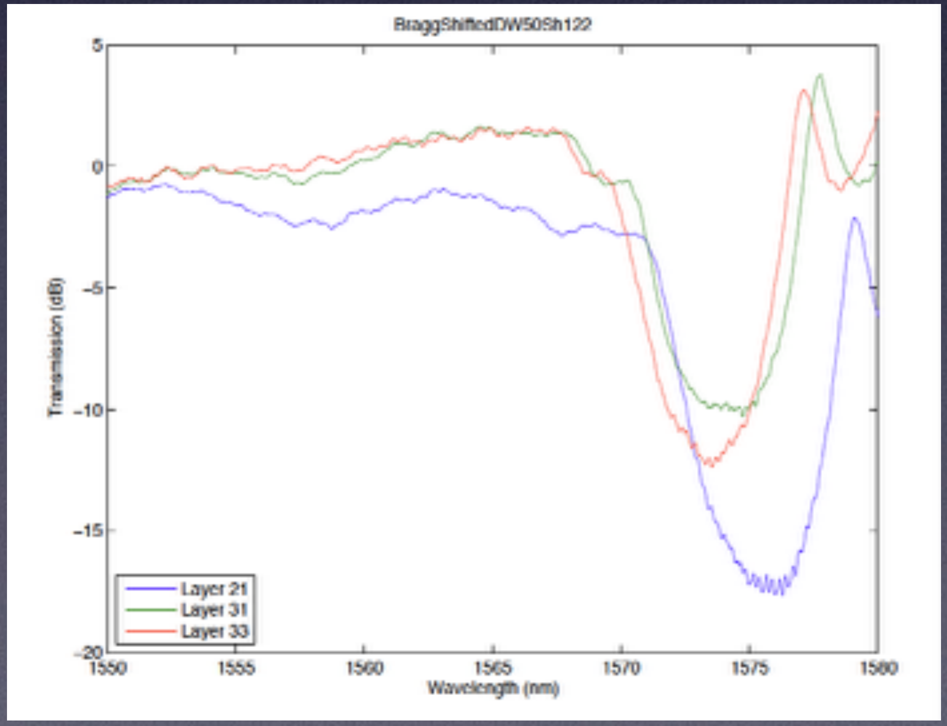




Optical Performance

Optical transmission spectra of a filter show narrower bandwidth for the devices written with shot pitch fracturing, but more measurements are in progress to better understand performance.

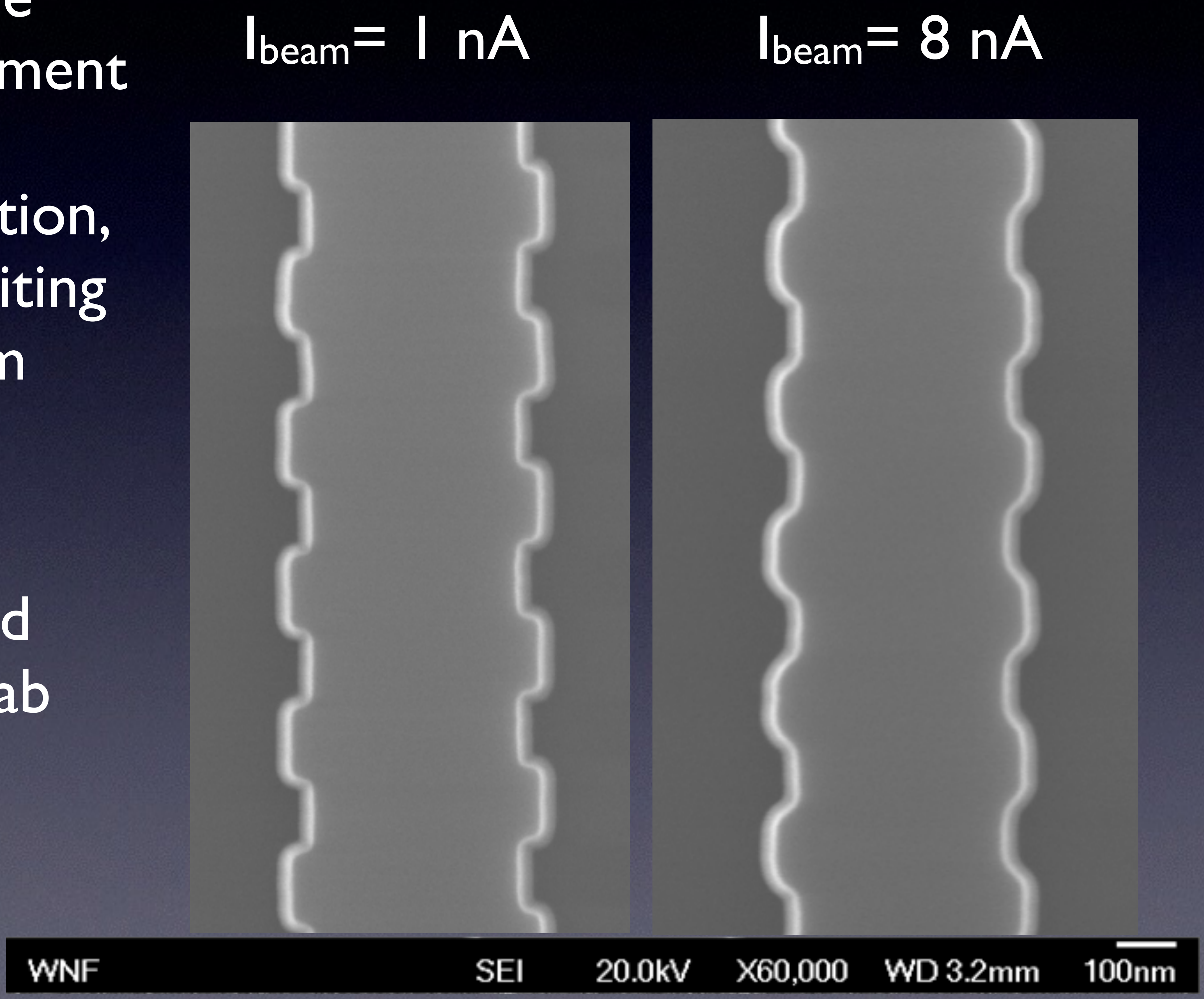




Process Trade-off

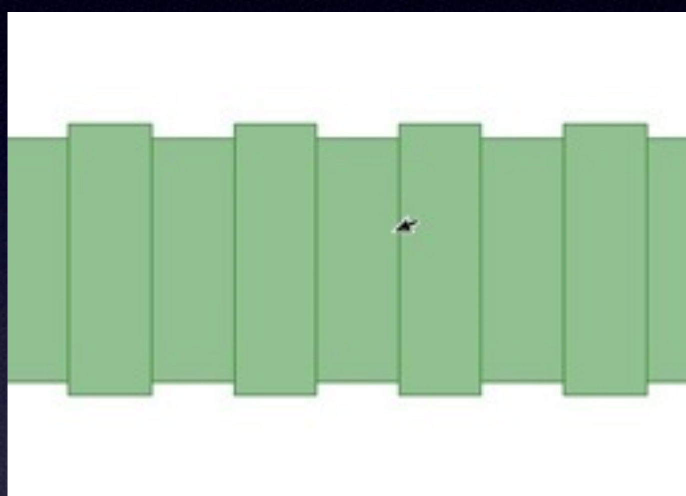
SPF can place feature edges and can increment sizes with the full machine grid resolution, but a tradeoff of writing with the larger beam current is increased corner rounding.

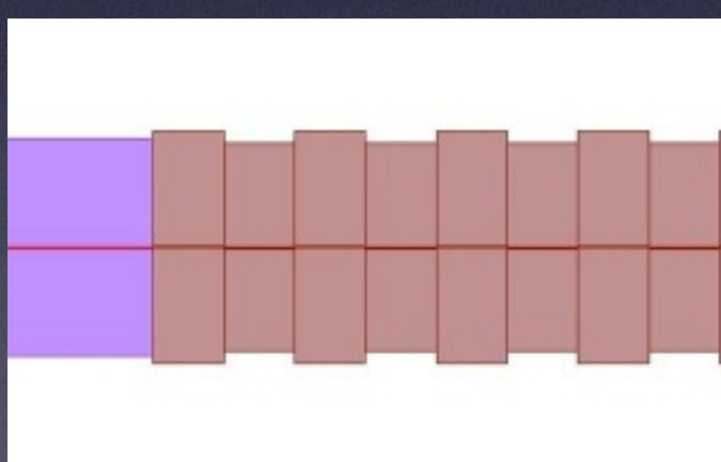
This will be explored more in upcoming fab runs.



Beamer Details

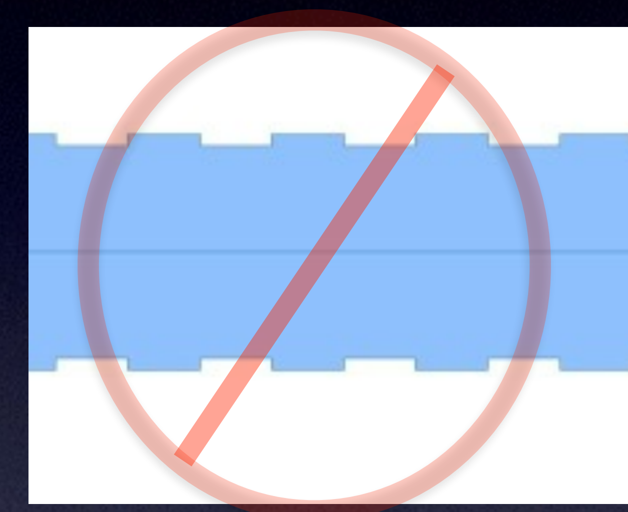
Design as separate rectangles

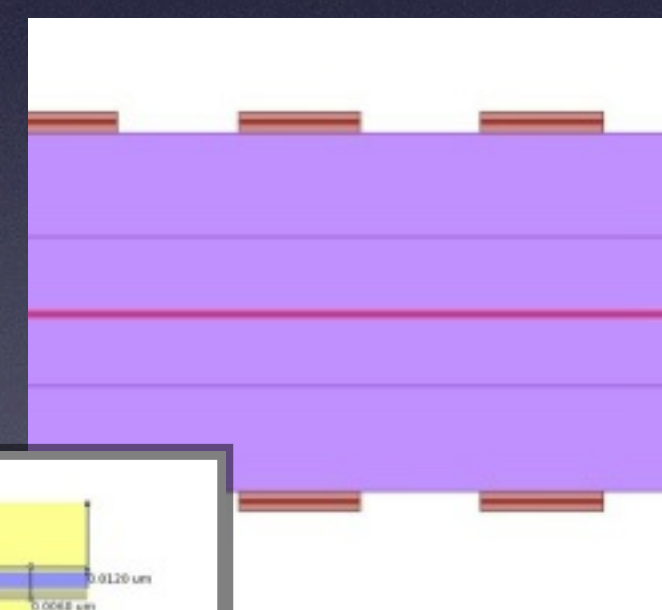


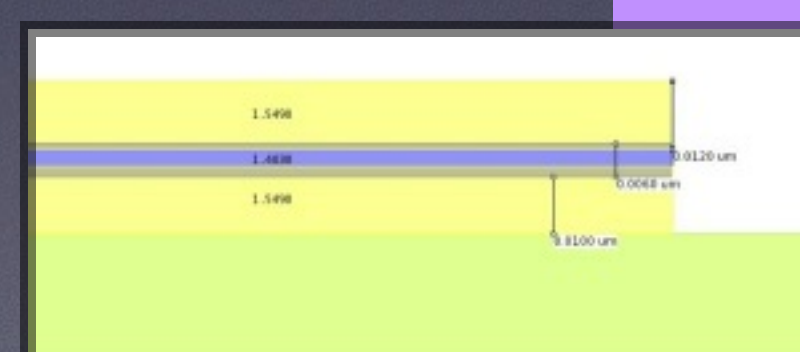


The output from the BSSC fracturing module naturally depends heavily on the input. Some fractures would not be expected to perform as well as others, given practical machine limitations, eg. shape placement noise.

Do not design as a polygon

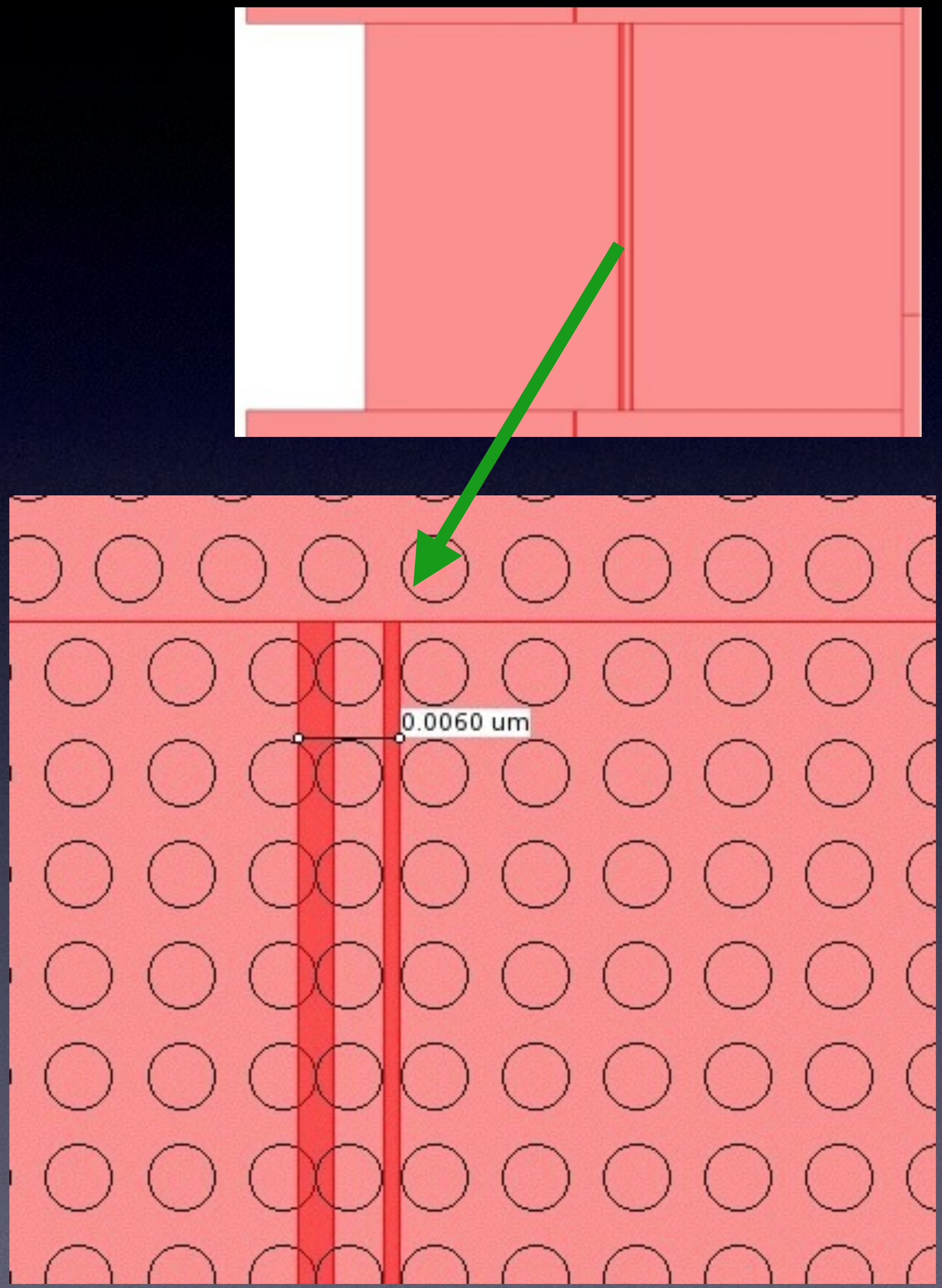






Beamer Details 2

BSSC often generates small 'sliver' shapes that are only a single beam-step wide. If these are buried within a much larger shape, are they really necessary?



Conclusions

- Beam Step Size Correction is useful for devices needing exact edge placement or very fine feature size increment
- Allows exposure to happen at higher beam currents than otherwise required for fine grid placements, so write speed can be significantly faster
- Can be selectively applied to appropriate pattern areas to avoid excessive shape count & overhead