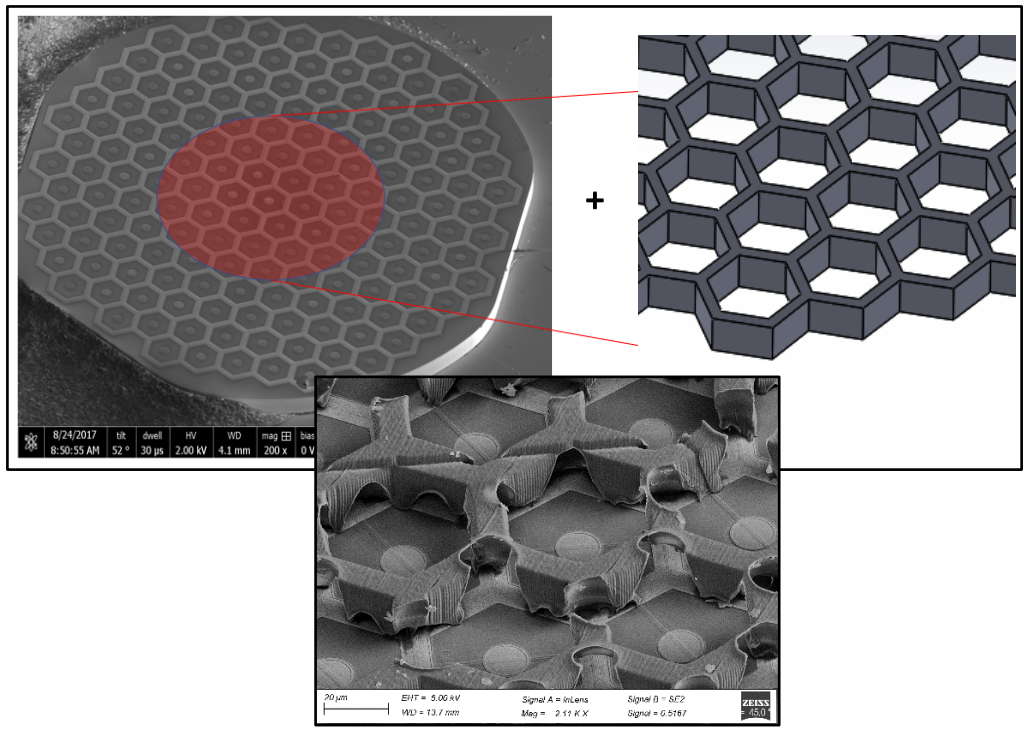
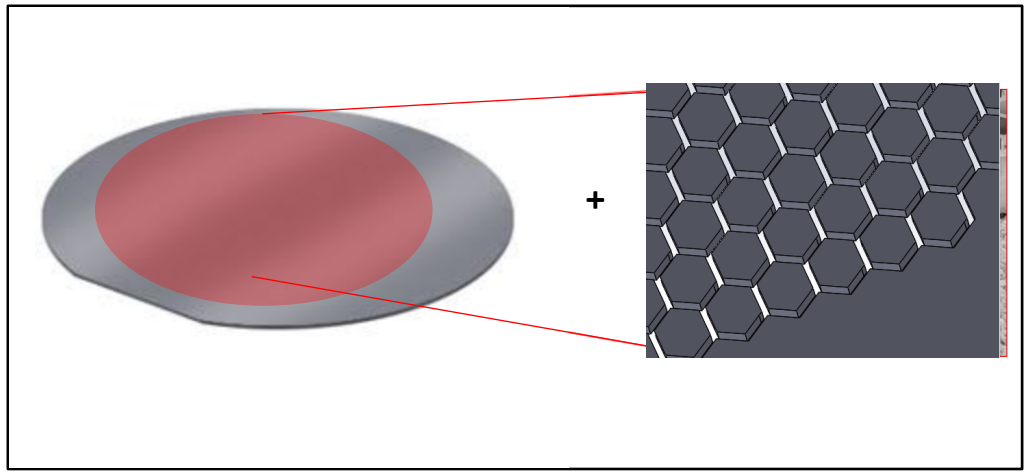
Two-photon lithography for dielectric structures and electroplating molds for retinal prostheses

Tiffany W Huang, Charles Z. Chen, Jack Andraka, and David Heydari

Staff mentor: Swaroop Kommera, External mentors: Palanker lab



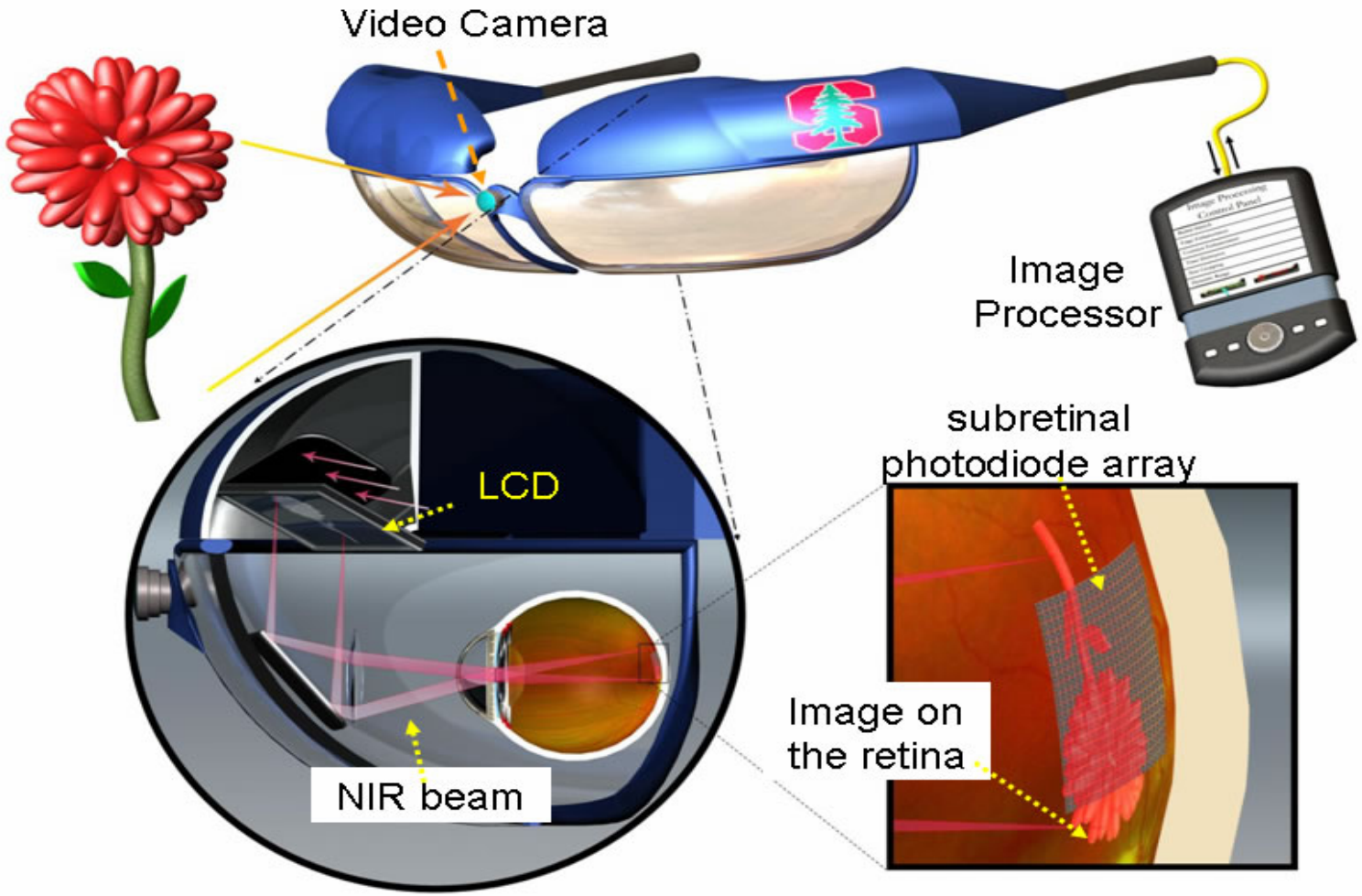
I. Resist structures

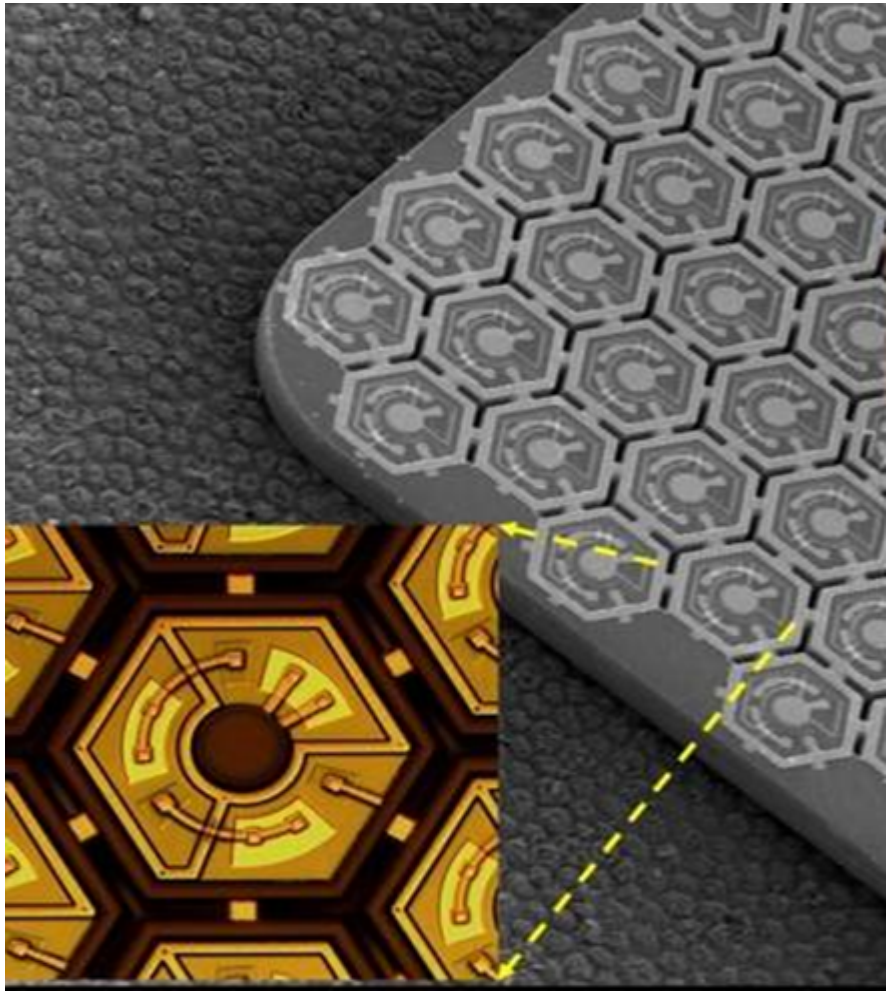


II. Resist molds

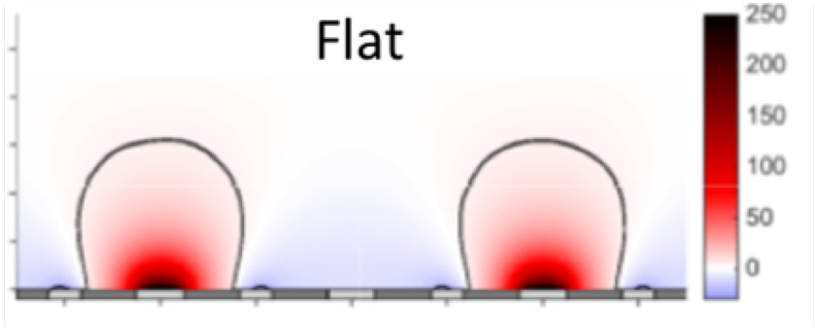
Stanford University

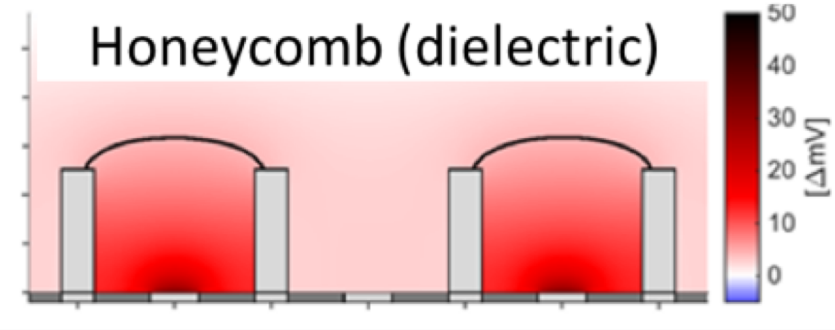
Previous work in Palanker Lab

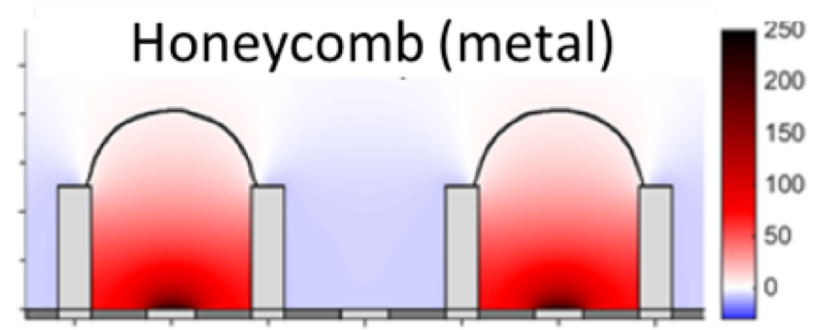


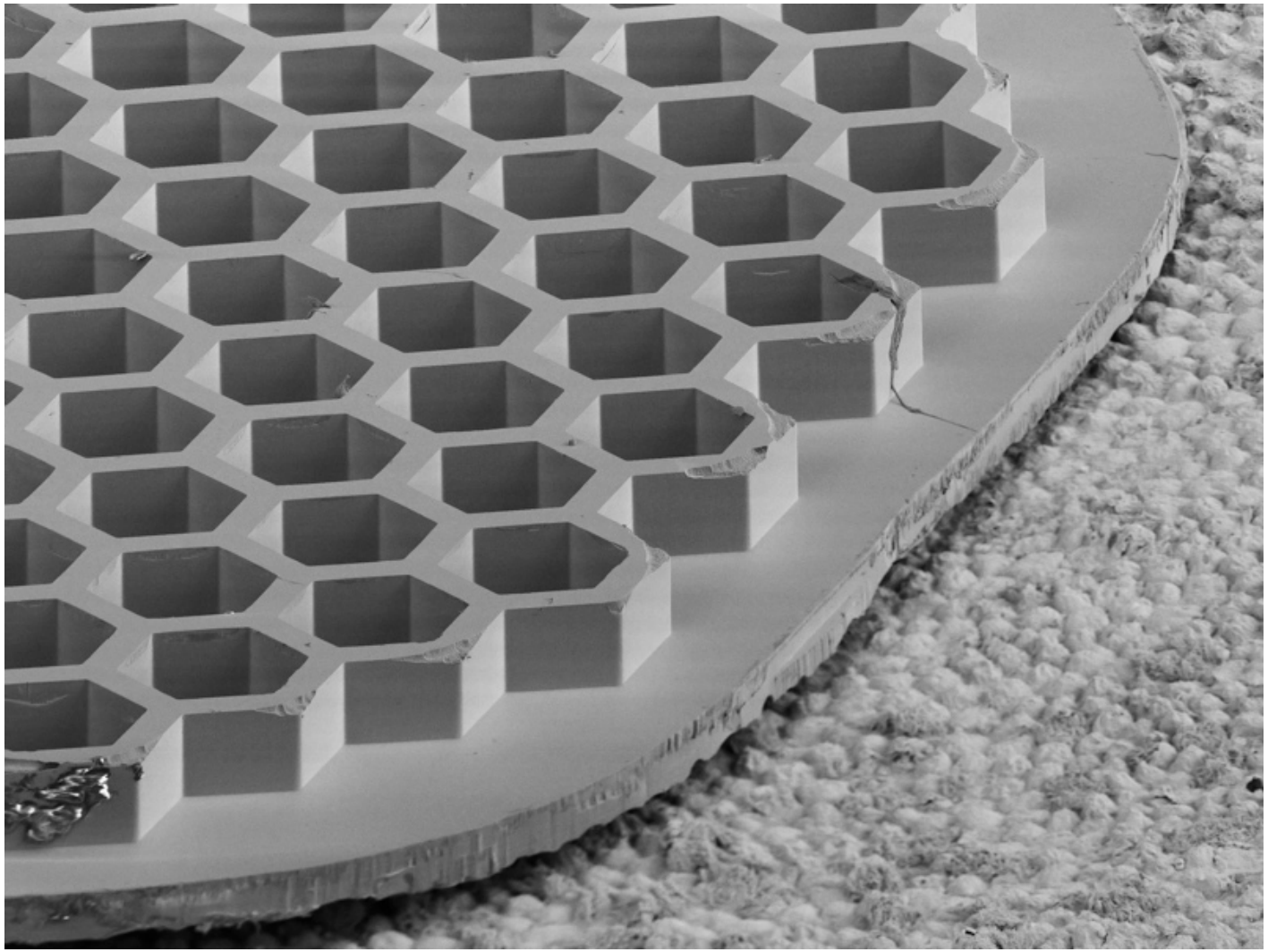


Smaller Pixels -> Better Acuity + Problems



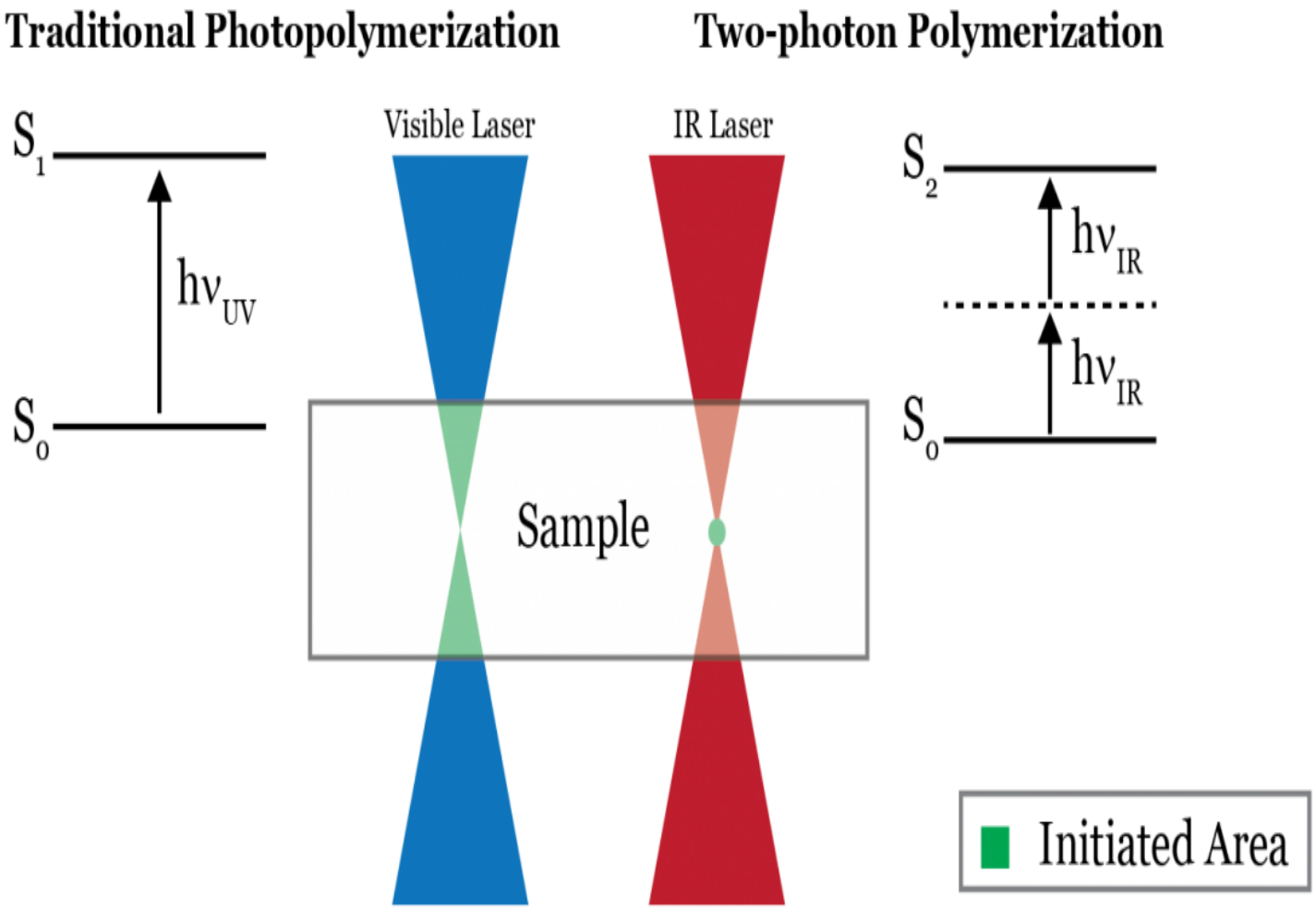


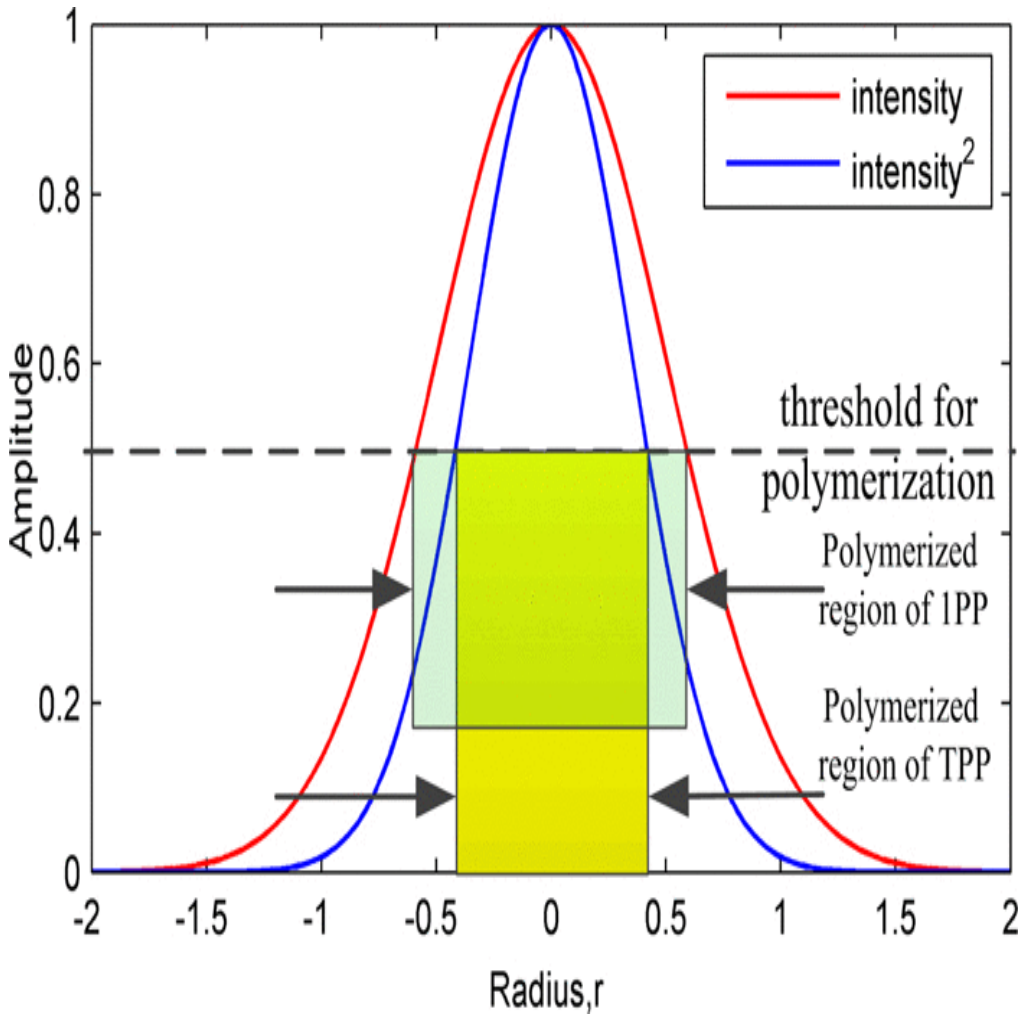




Picture courtesy: Thomas Flores

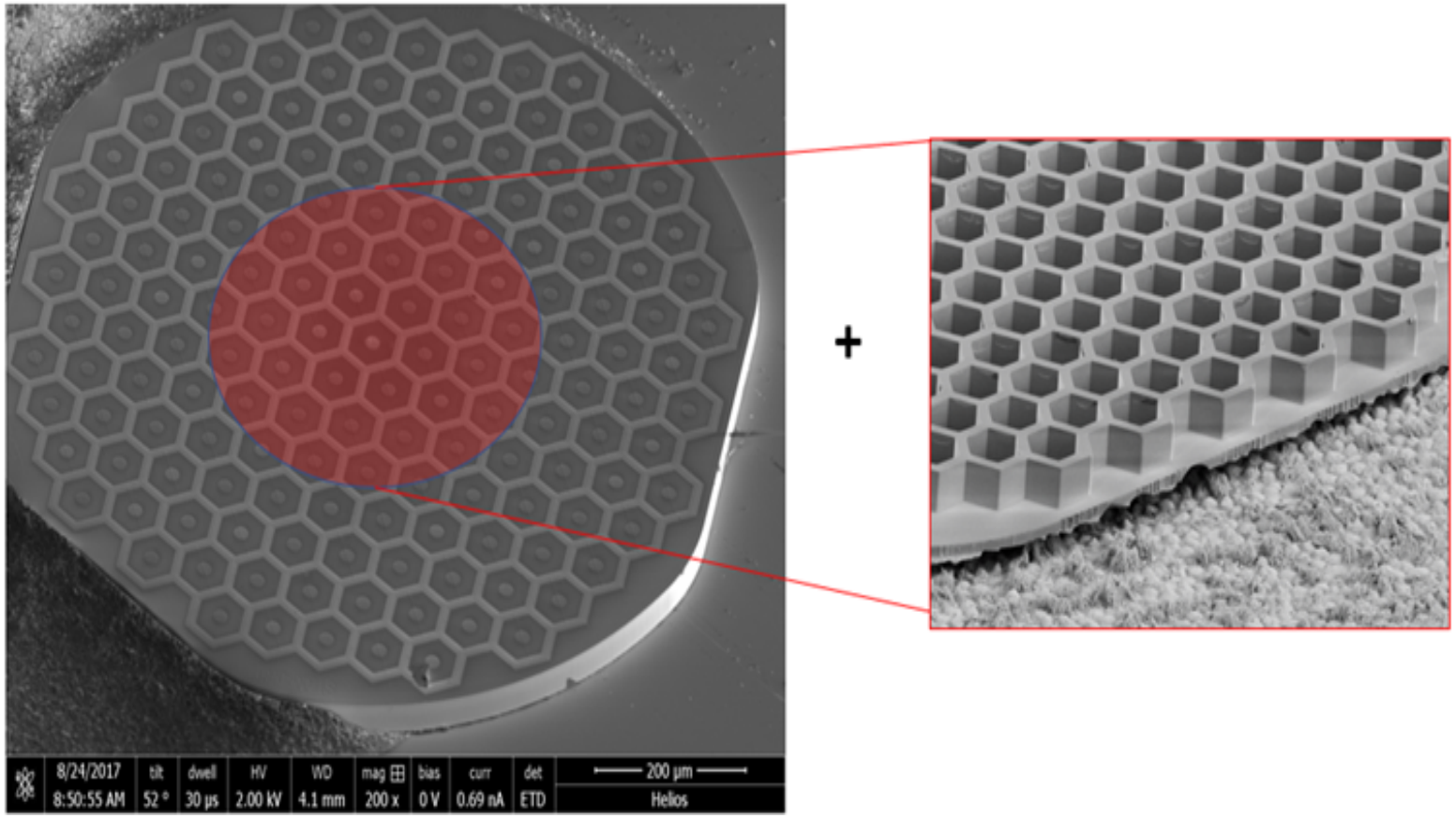
Two-Photon Lithography



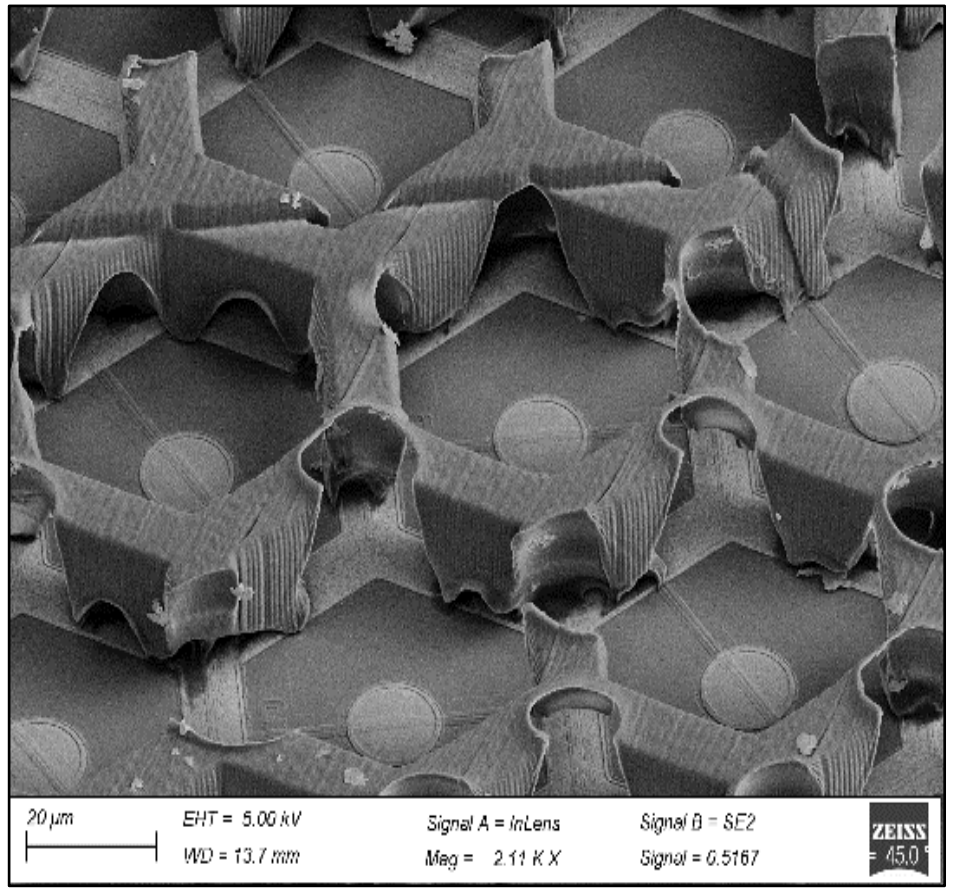


Zhou et al., AIP 5 (2015)

Thermal Bubbling: A Local or Global Issue?



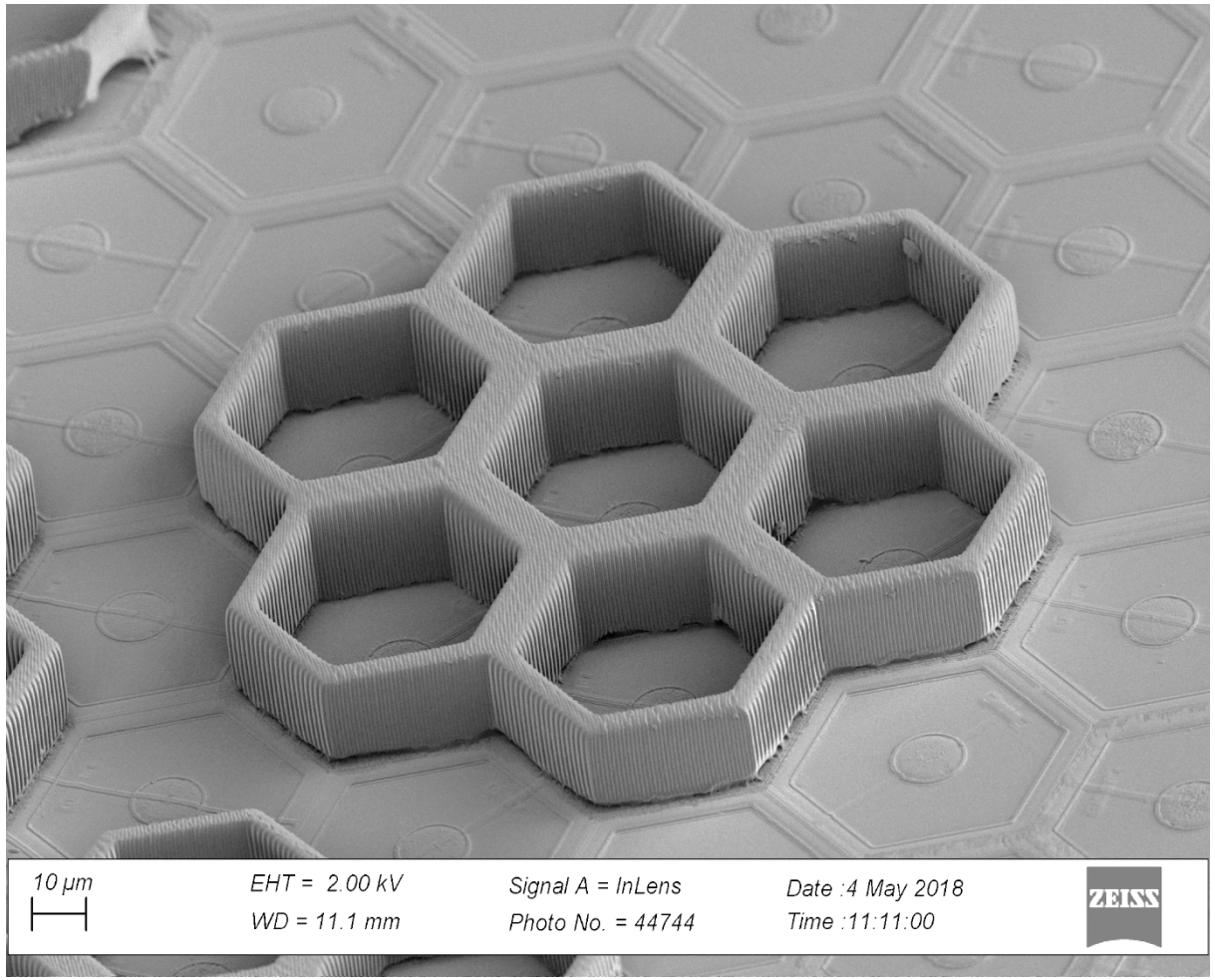
+



Picture courtesy: Thomas Flores

Two Directions for Exploration

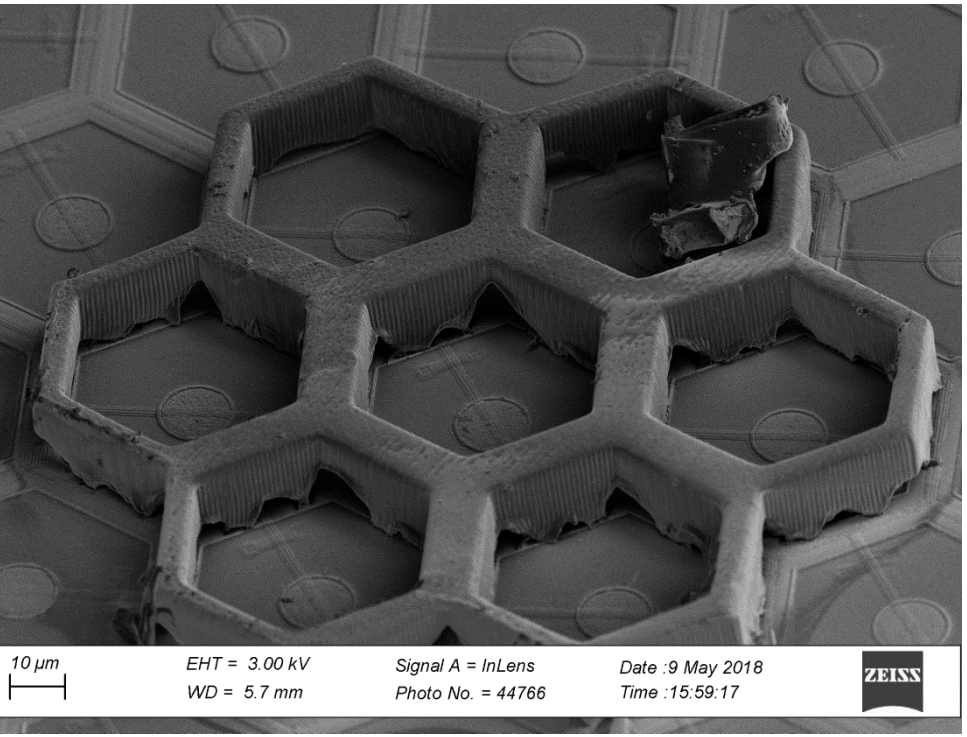
- Adhesive (needs to be removable, flat, thermally conductive)
  - Nail Polish (highly variable performance)
  - Silver Paint (<0.5% typically)
  - PDMS (always flat)
- Parameter Space
  - Laser Power
  - Scanning Speed
  - Hatching Distance
  - Slicing Distance



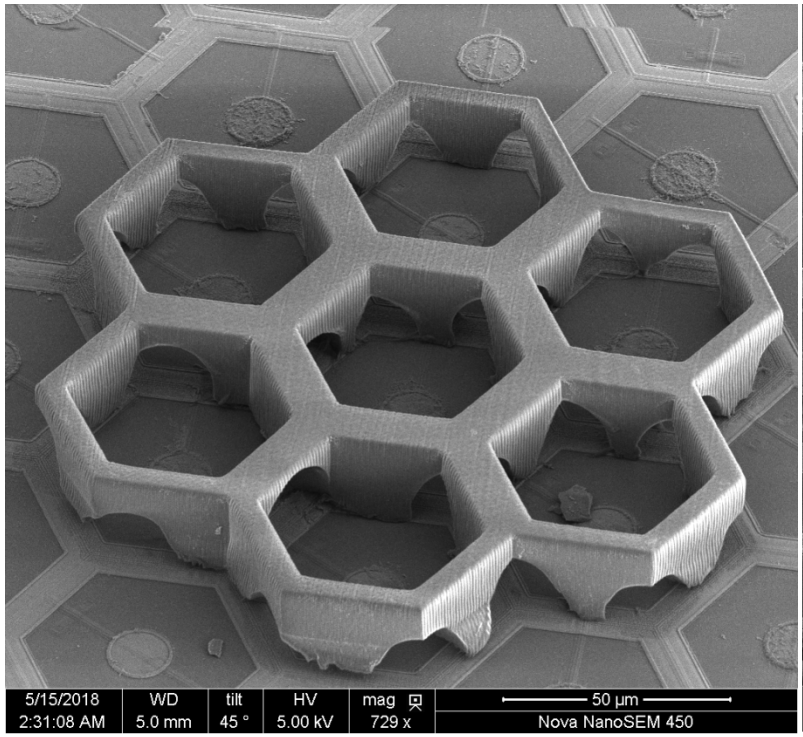
P = 20%, V = 500, H = S = 0.8um

Adhesive Choice

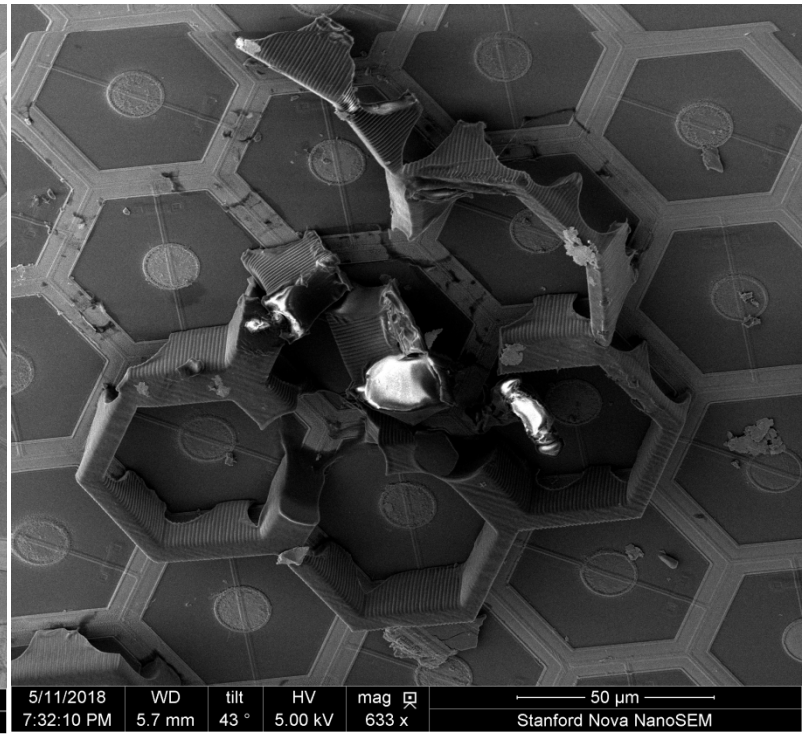
P = 30%, V = 2500, H = 0.5um, S = 1um



PDMS



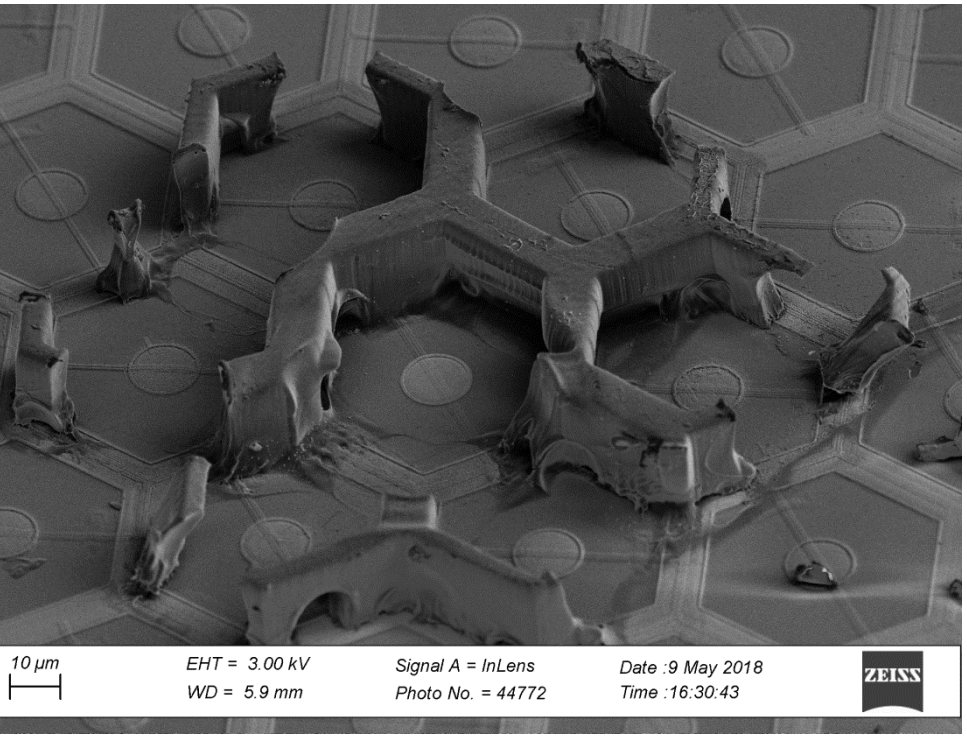
Nail Polish



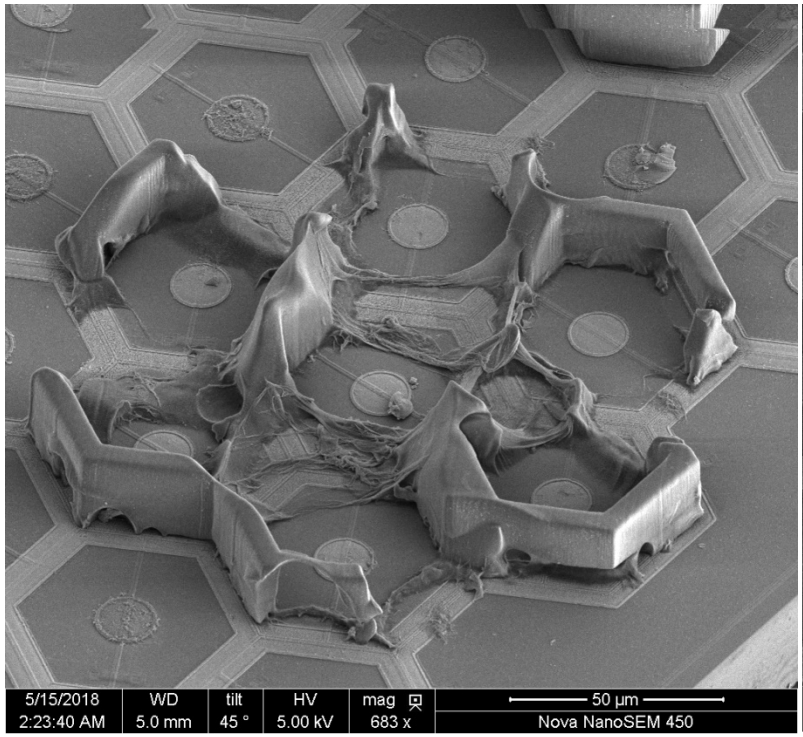
Silver Paint

Adhesive Choice

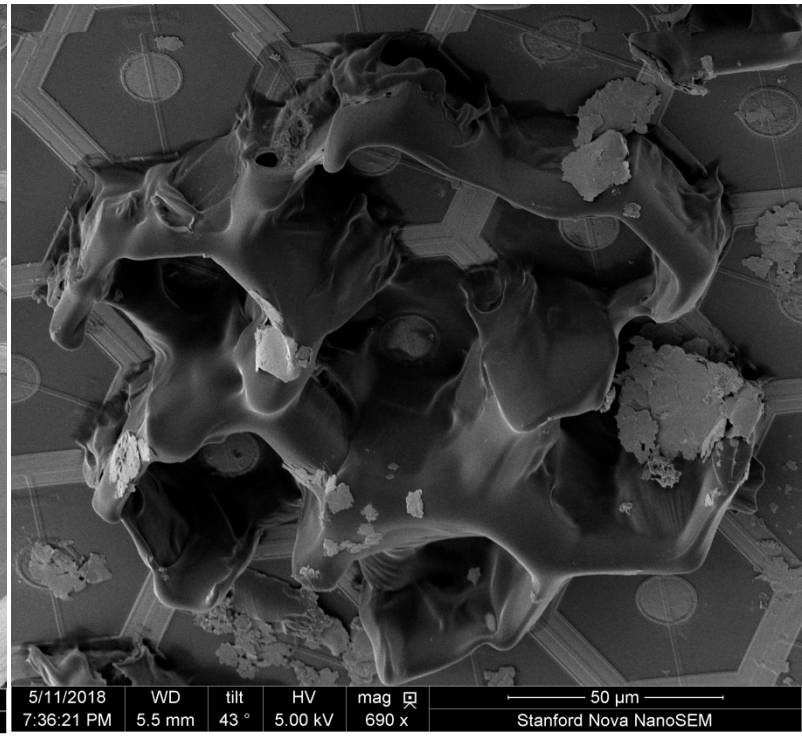
P = 100%, V = 100K, H = 0.3um, S = 0.3um



PDMS

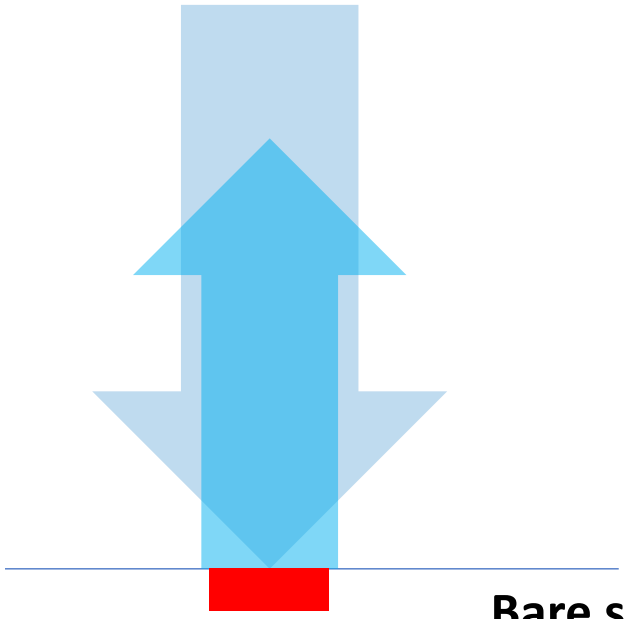


Nail Polish

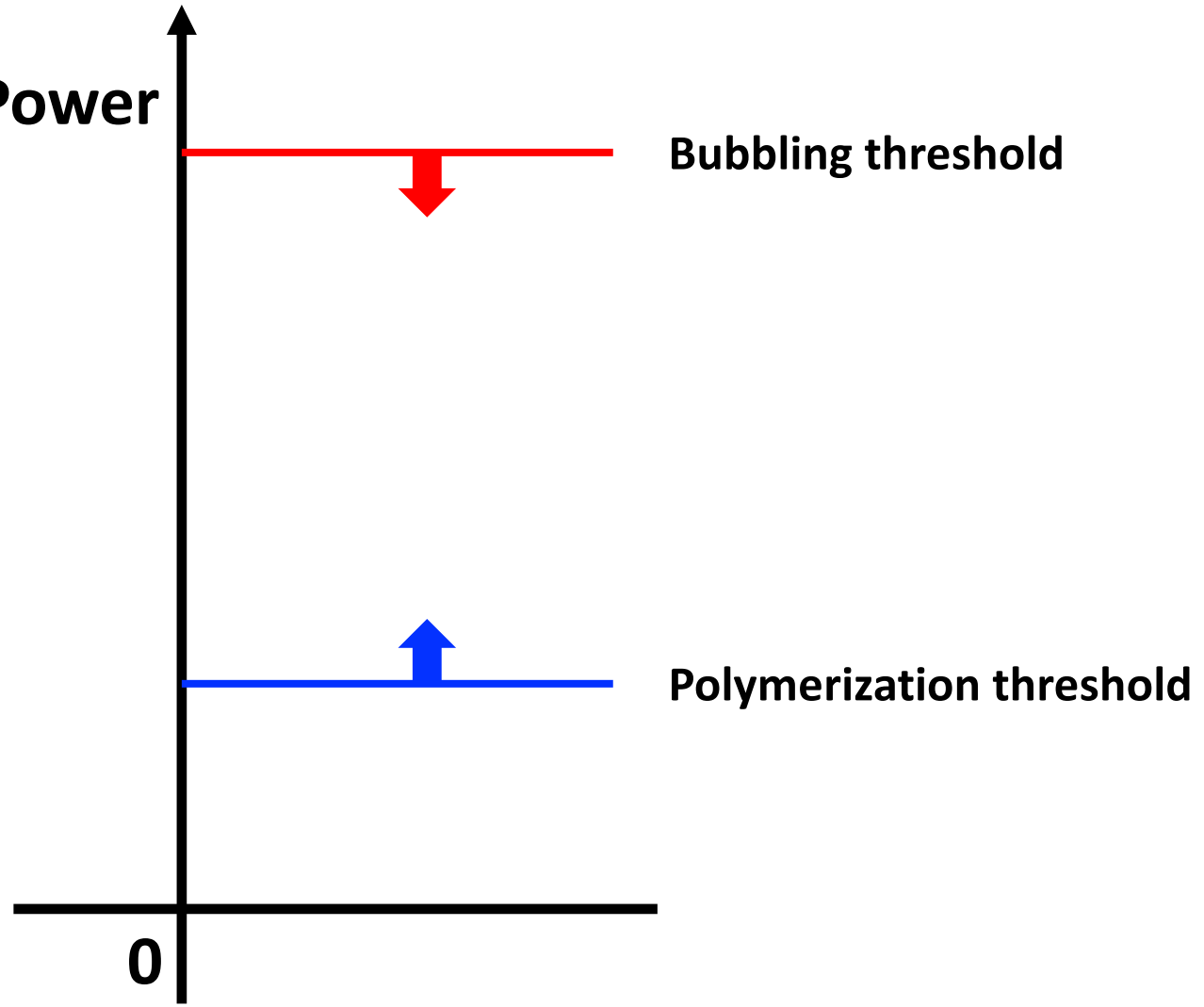


Silver Paint

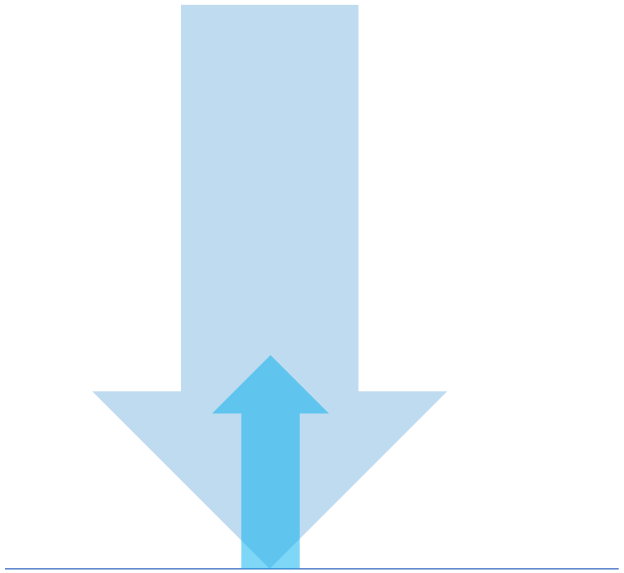
Overheating: A second thought



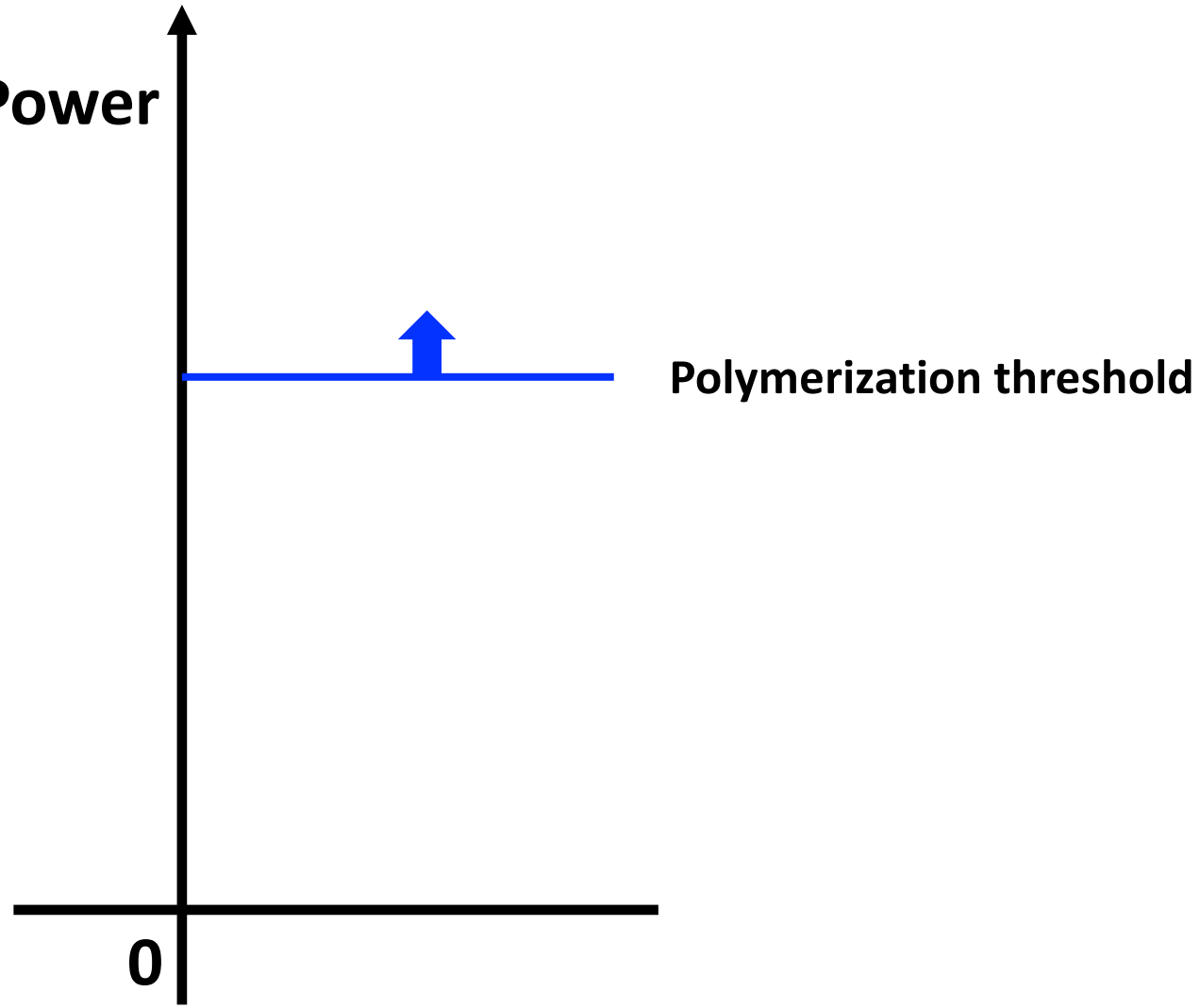
Bare silicon interface
(reflective)



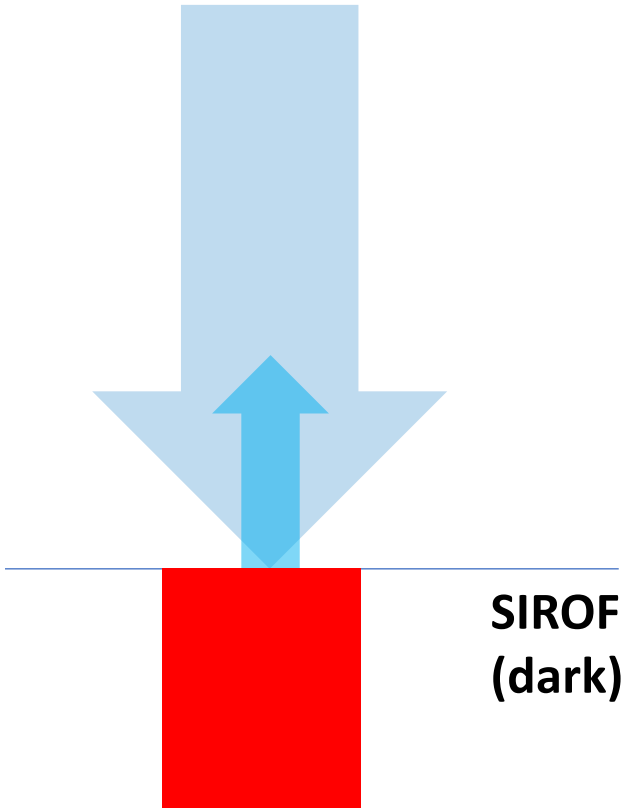
Overheating: A second thought

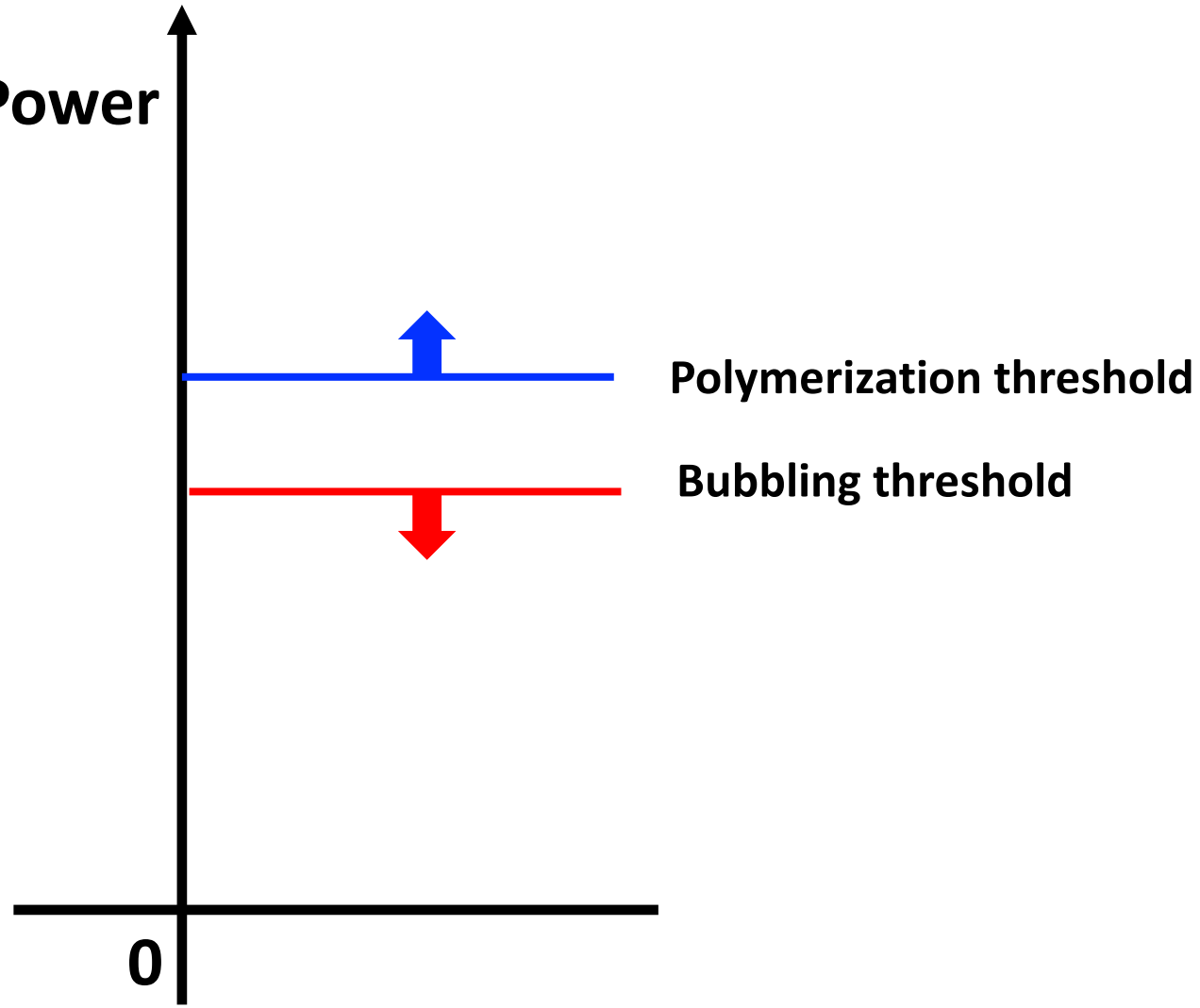


SIROF interface
(dark)

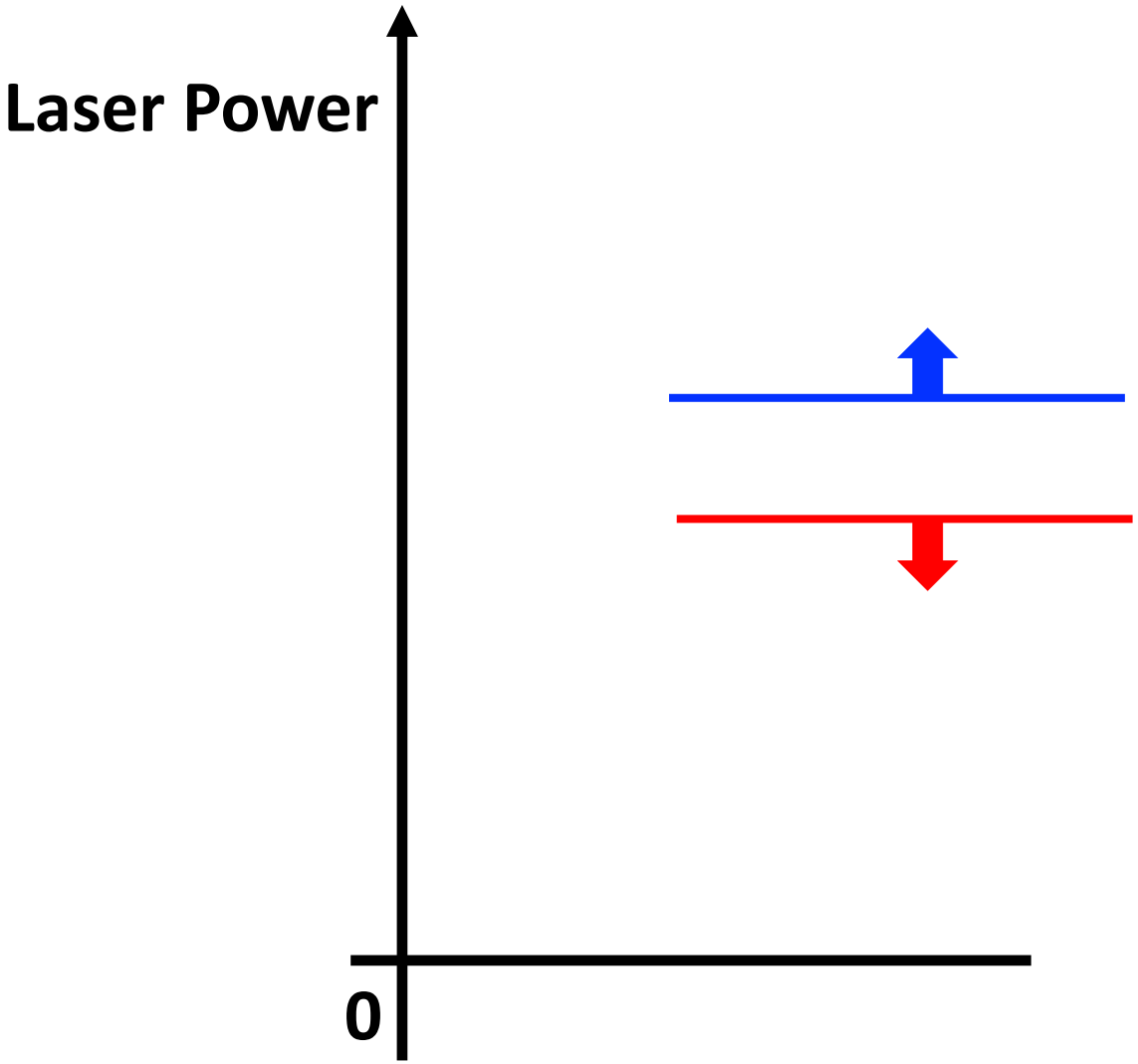


Overheating: A second thought

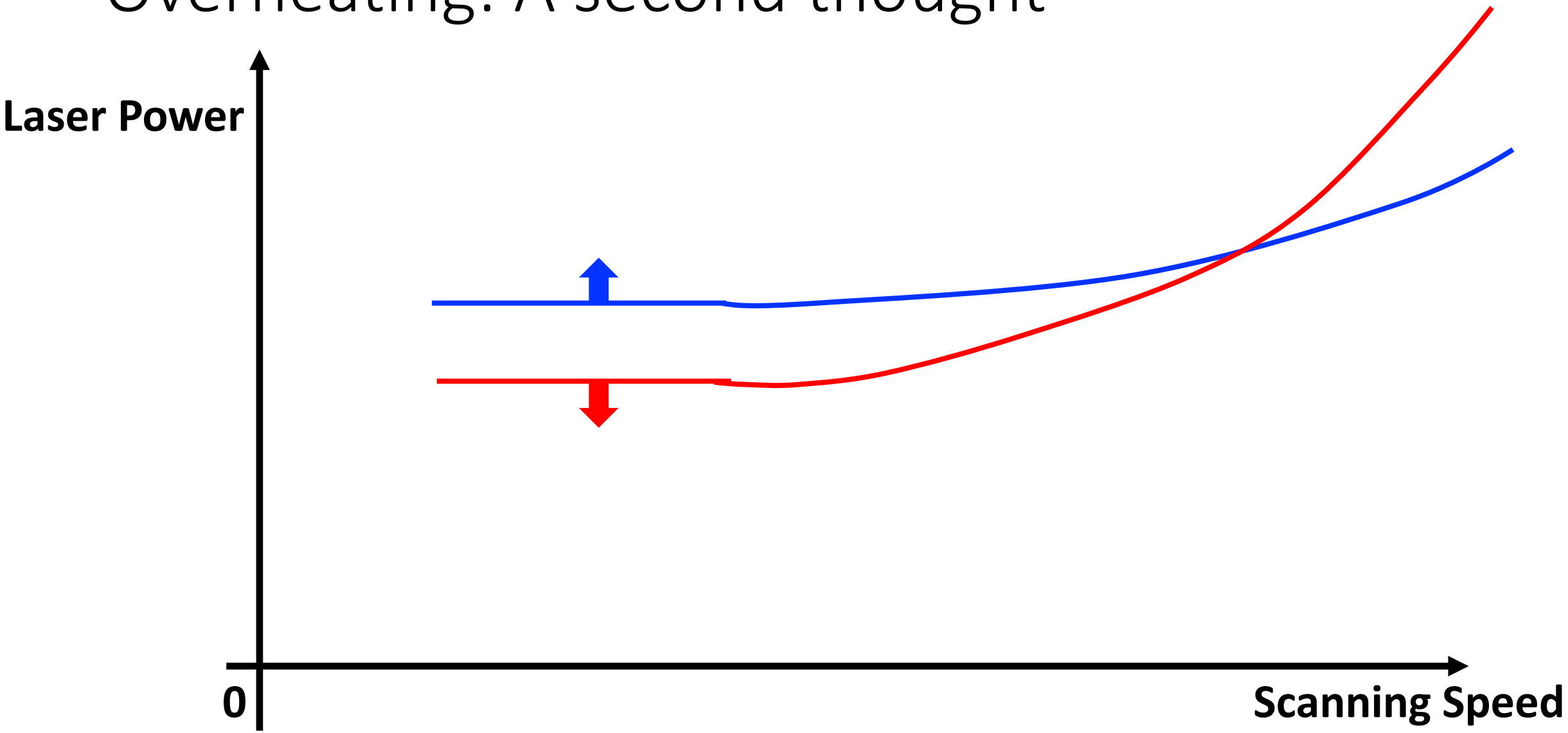




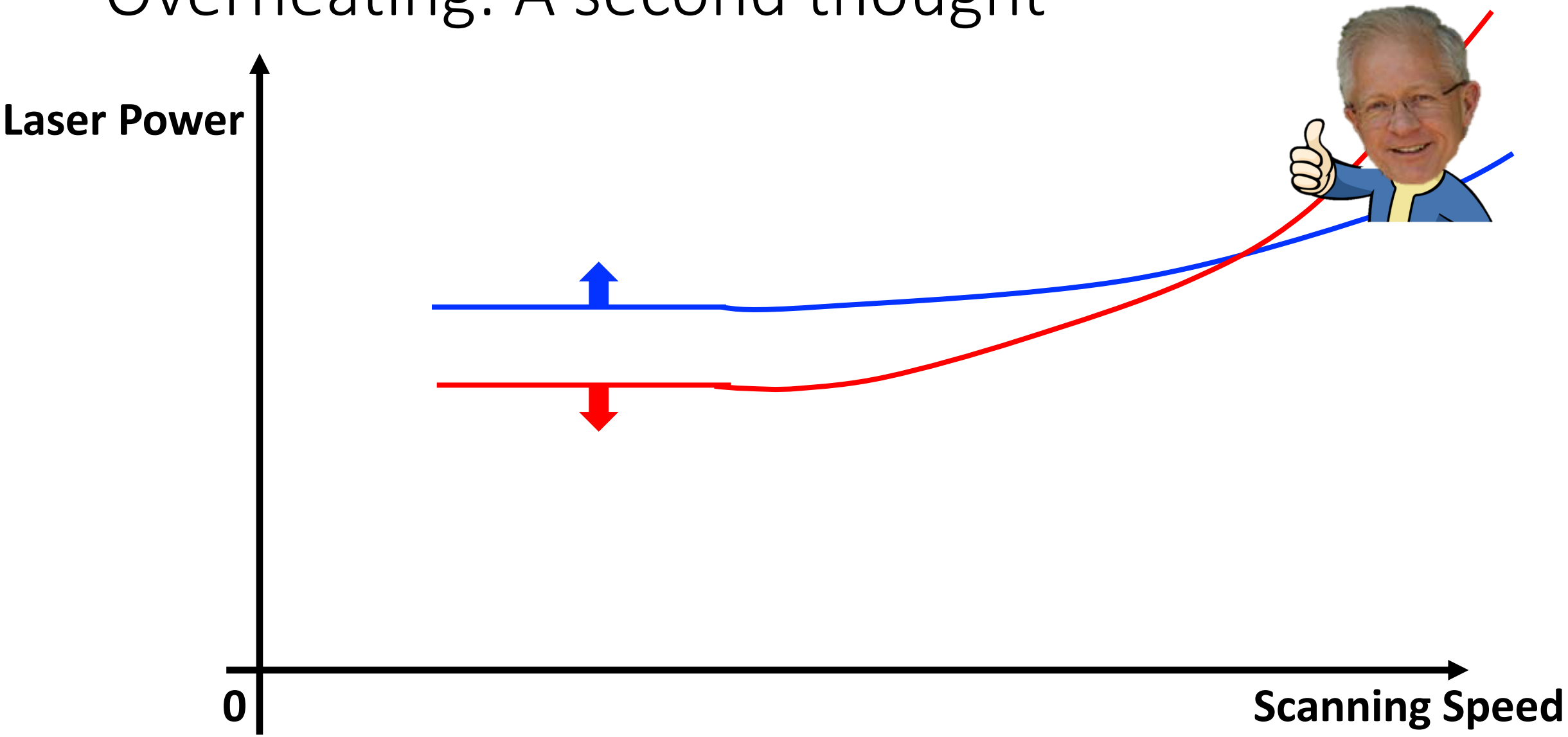
Overheating: A second thought



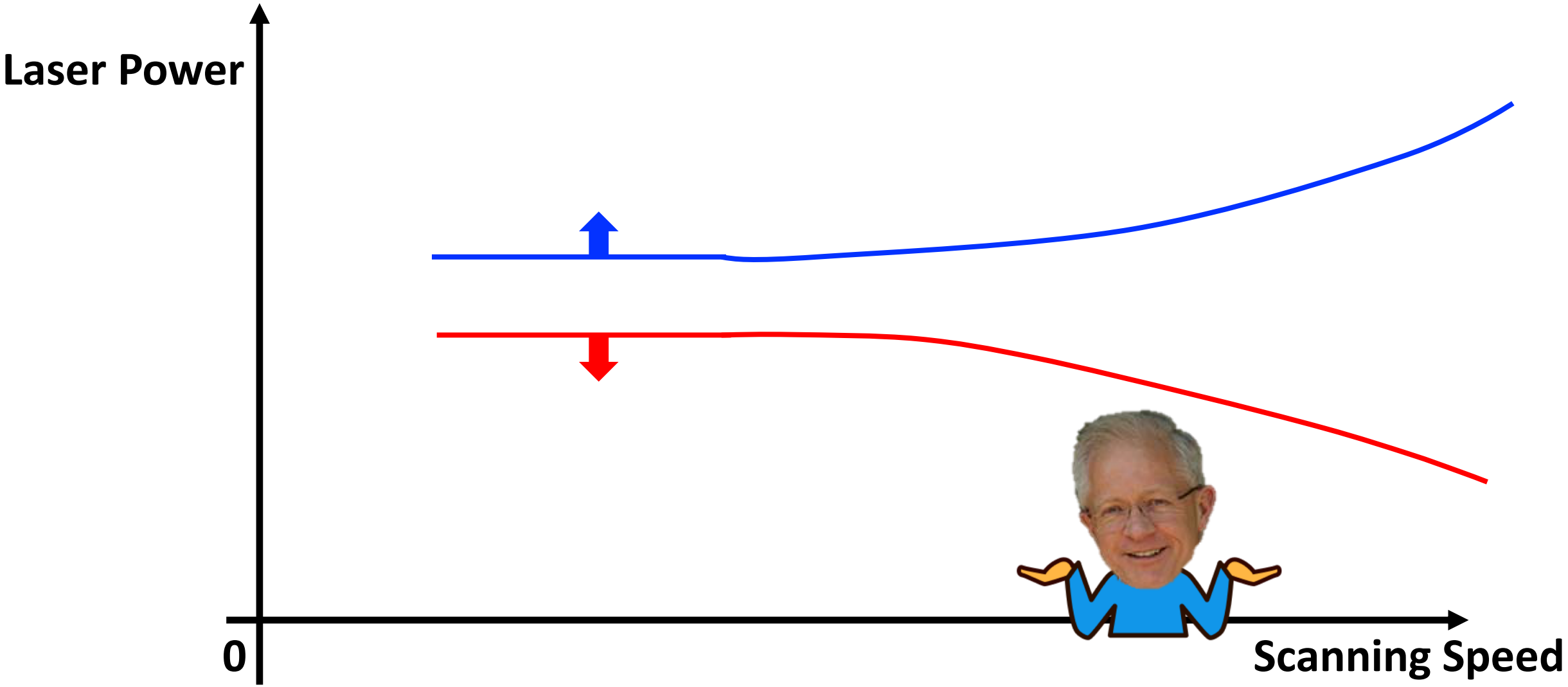
Overheating: A second thought



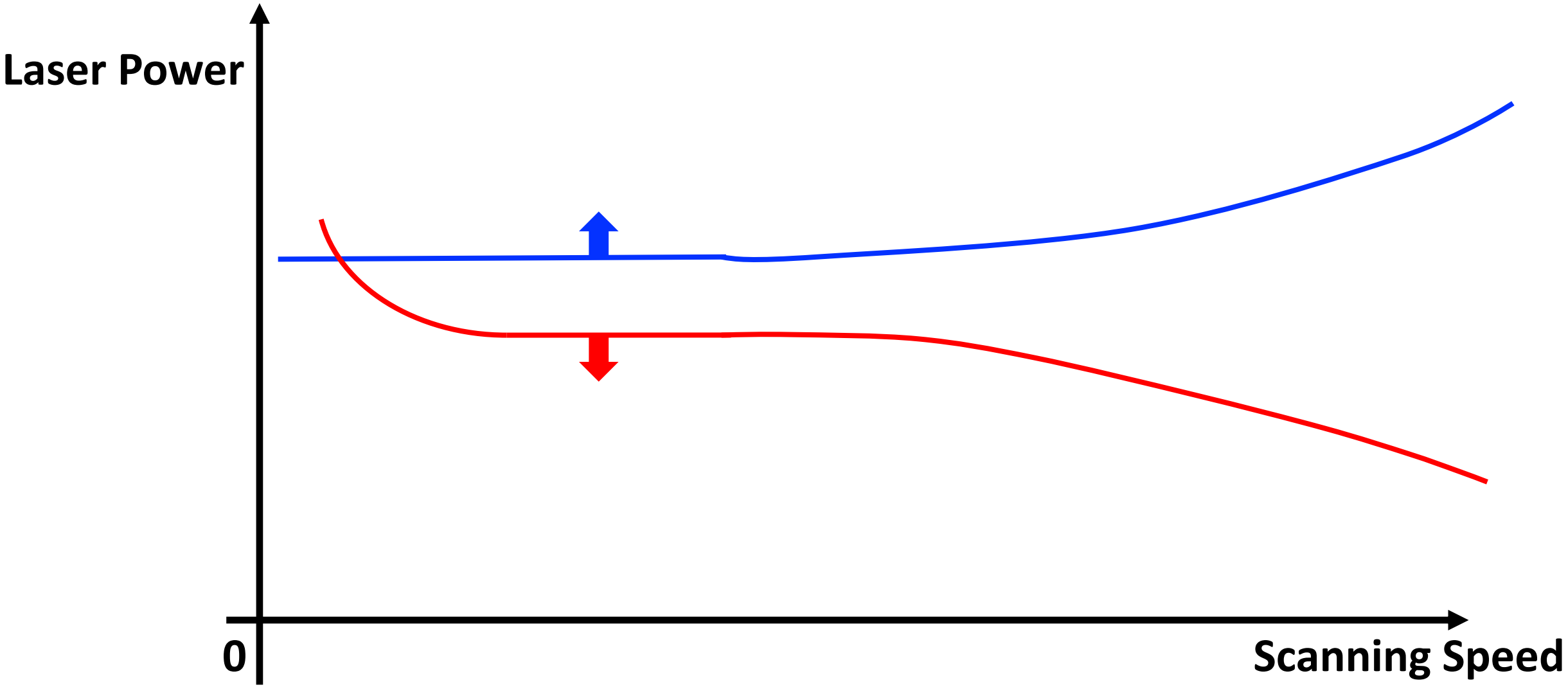
Overheating: A second thought



Overheating: A second thought

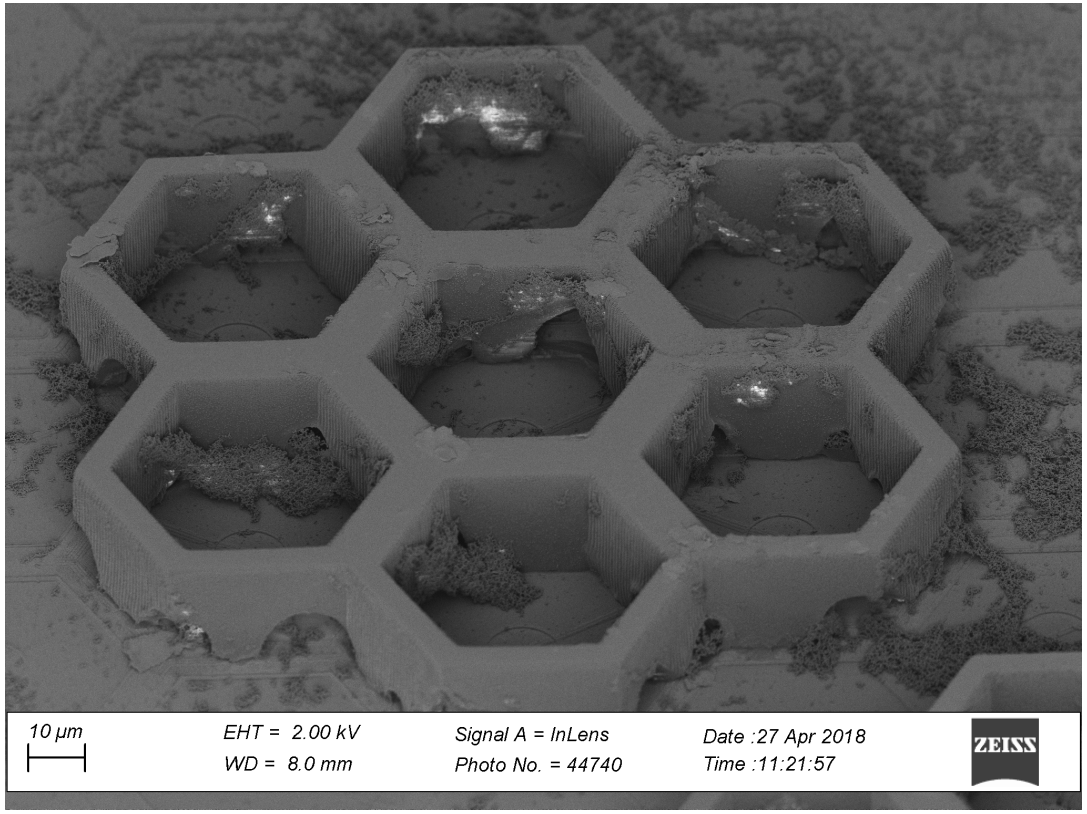


Overheating: A second thought

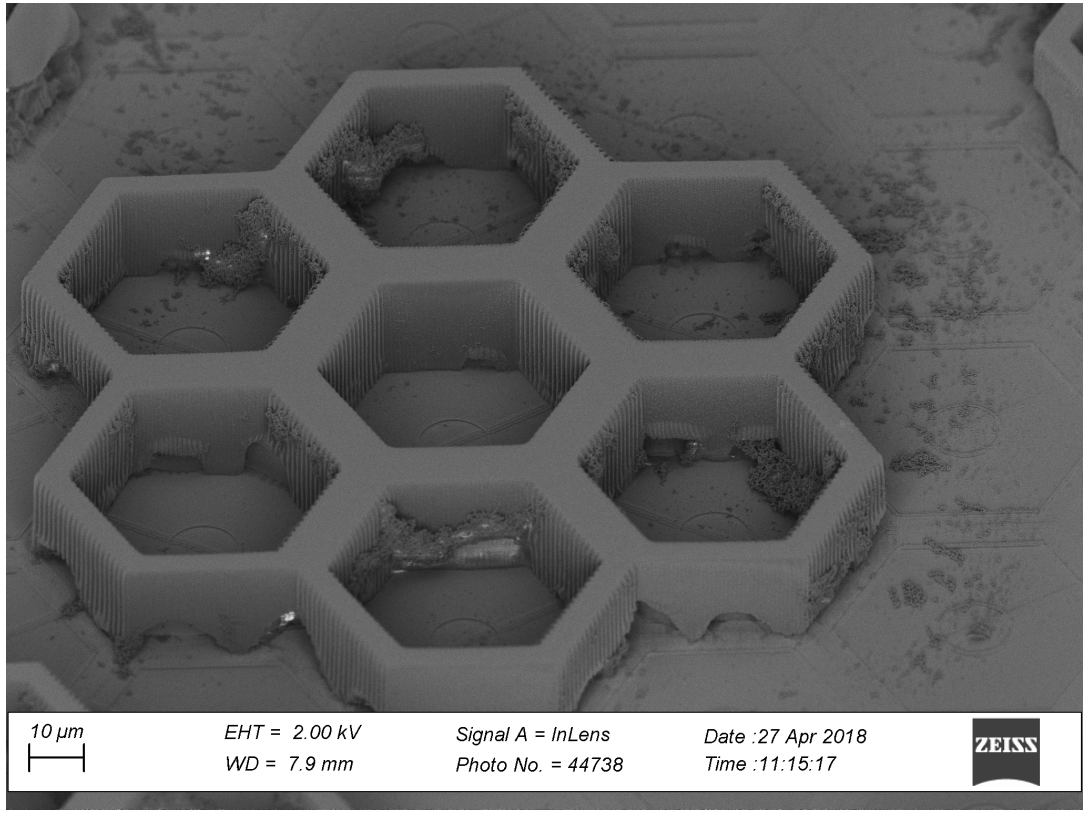


Overheating: A second thought

hatching distance = 0.5um, slicing distance = 1um, power = 30%



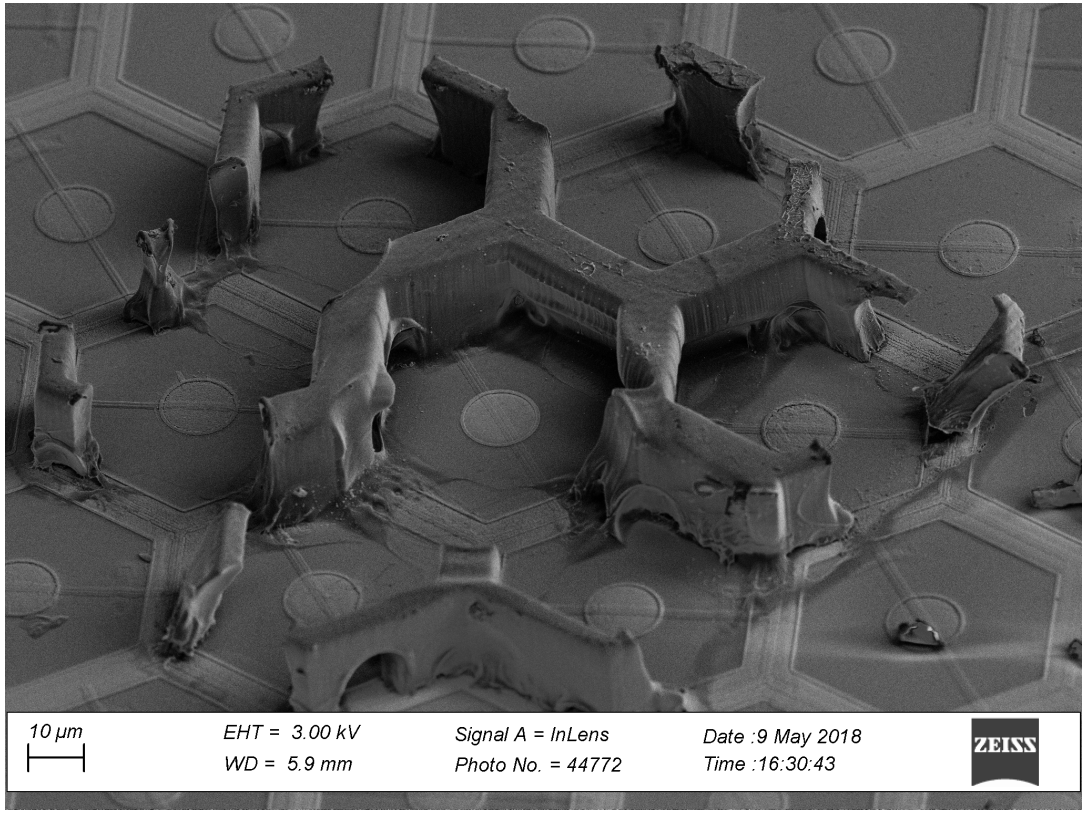
Scanning speed = 2000um/s



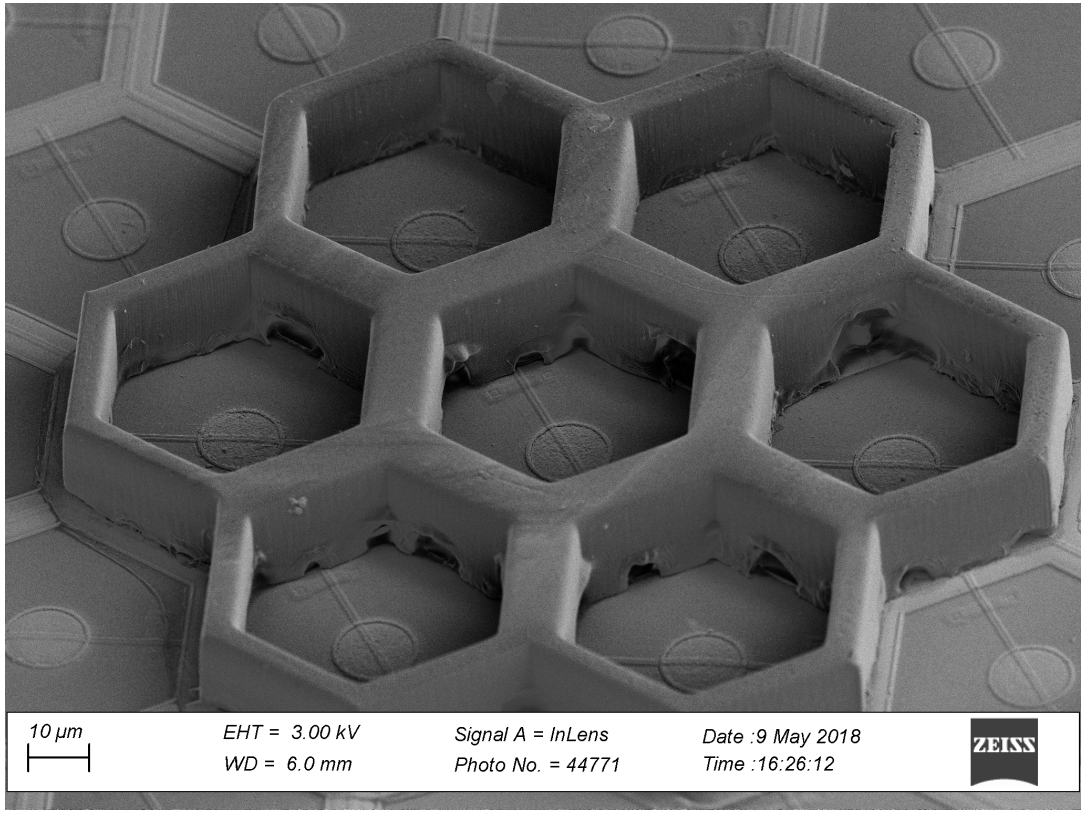
Scanning speed = 1000um/s

Overheating: A second thought

hatching distance = slicing distance = 0.3um



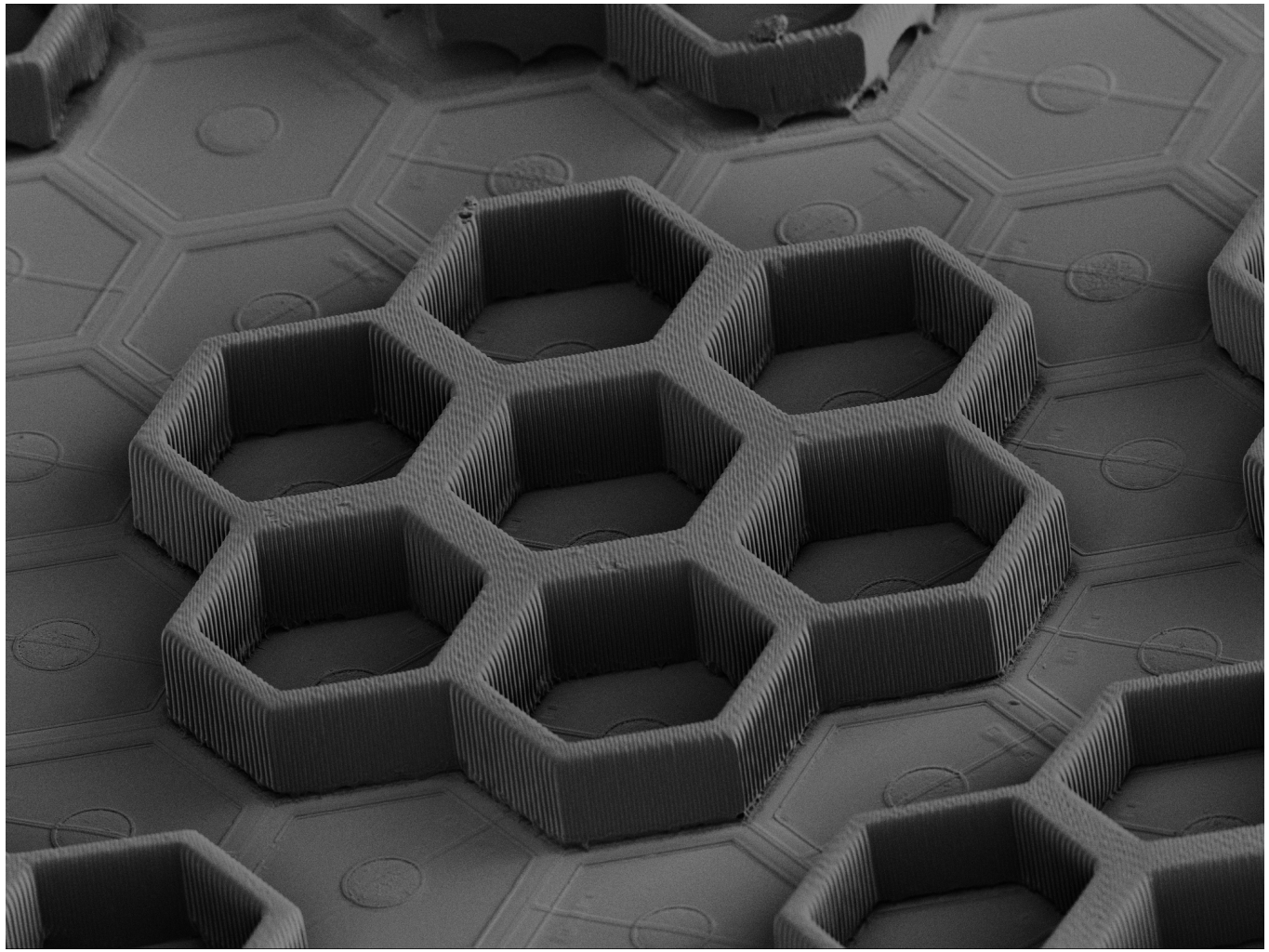
12x power inject



Scanning speed = 100,000um/s, power = 100%

Scanning speed = 2,500um/s, power = 30%

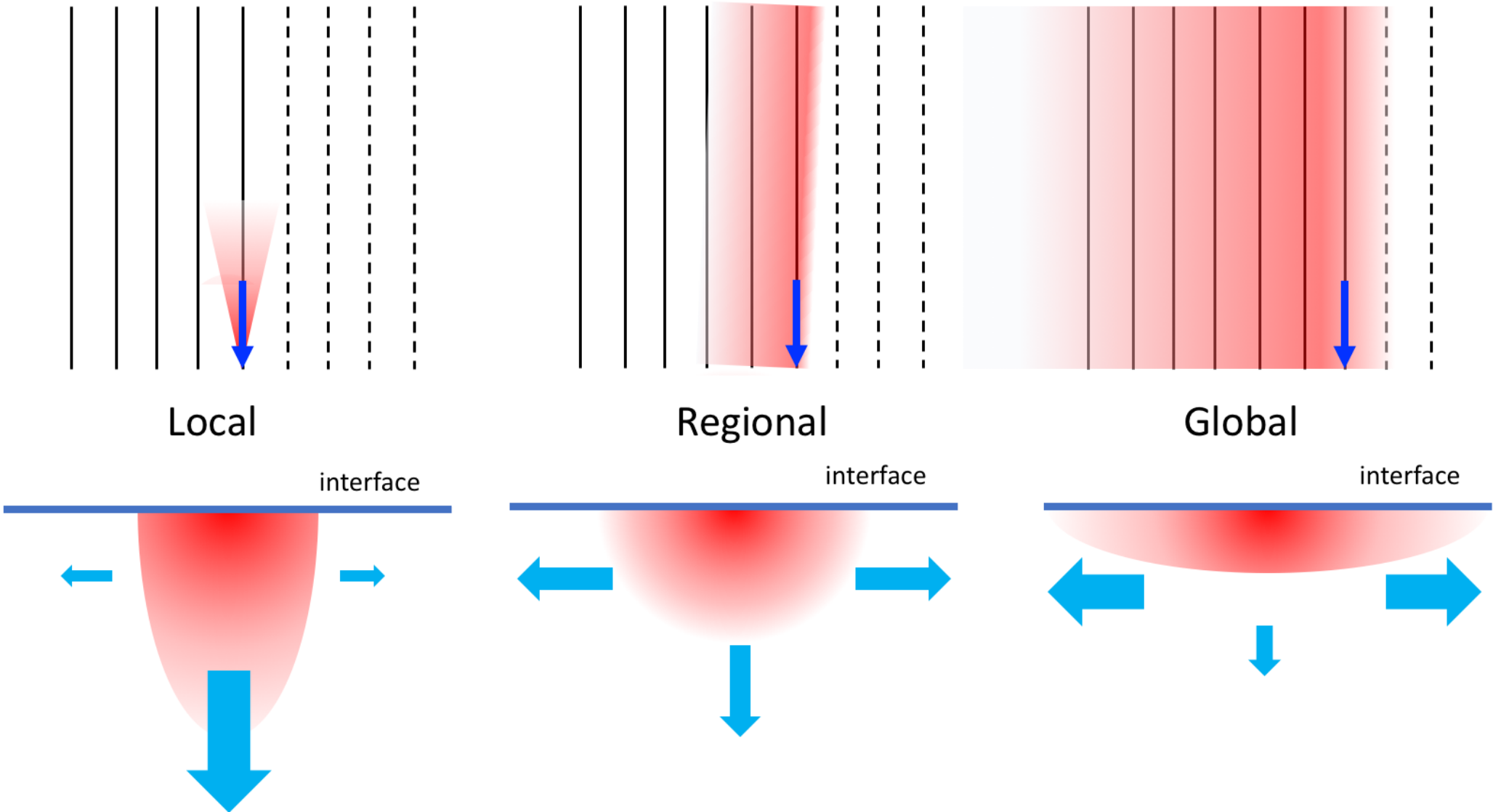
Overheating: A second thought



- **Power = 15%**
- **Scanning speed = 250um/s**
- **Hatching distance = 0.8um**
- **Slicing distance = 0.8um**

100,000um/s :
Nanoscribe standard value

Overheating: A second thought



Overheating: A second thought

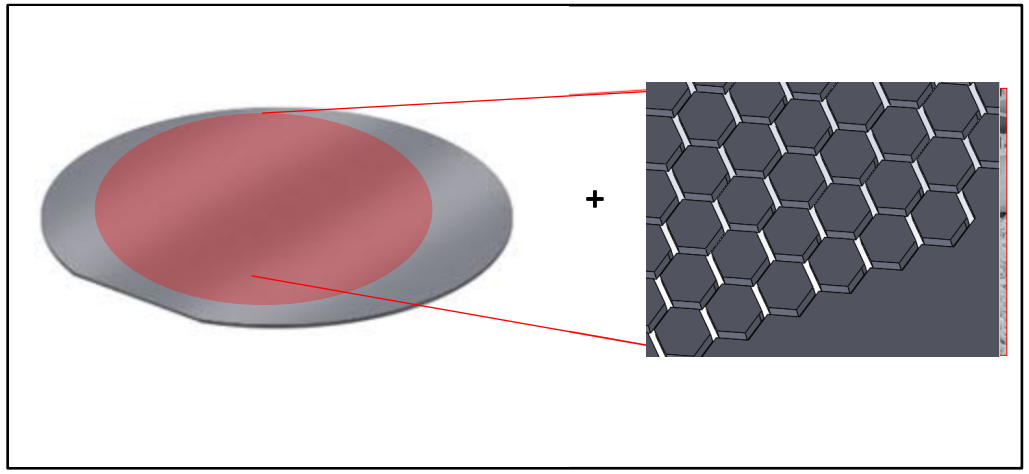
Mode		Local	Regional	Global
Dominant cause		Laser point overheats	A few neighboring lines overheat	Whole substrate overheats
Lateral Diff.		Relatively slow	Similar to vertical	Relatively fast
Vertical Diff.		Relatively fast	Similar to lateral	Relatively slow
Parameter tuning direction	Laser power	↓	↓	↓
	Scanning speed	↑	↓	Not relevant
	Hatching Dist.	Not relevant	↑	↑
	Slicing Dist.	Not relevant	↓	↓

Outline

1. Introduction
   - Retinal prosthesis
   - Two-photon lithography
2. Resist structures
3. **Resist molds**

Resist molds

Fabrication process criteria

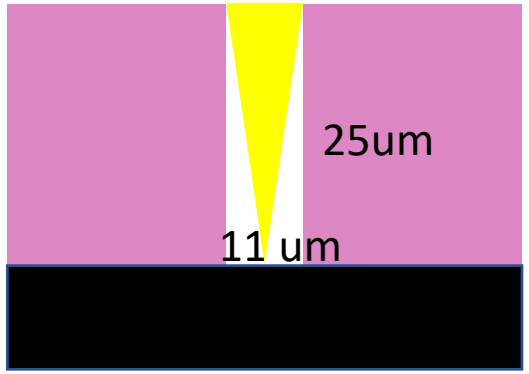


- Electroplating molds
- High-aspect ratio wells
- Smooth sidewalls
- Structural integrity and quality

Fabrication techniques

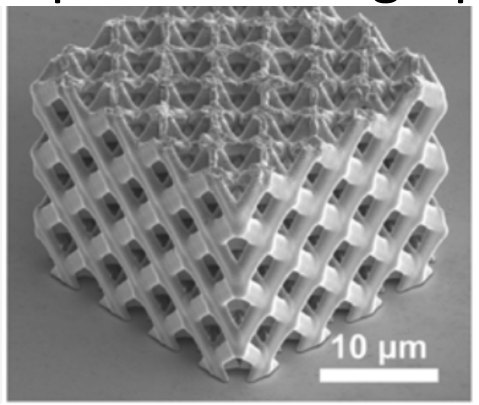
- Projection lithography

$$NA = \eta \sin(\alpha)$$



- Angle = 12 deg
- NA must be < 0.2.
- ASML: NA = 0.54

- Two-photon lithography

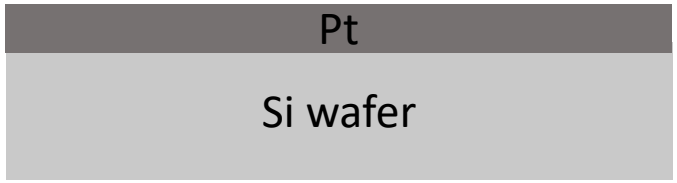


- Electroplated gold lattice using 30um resist
- HAR achievable!
- Very slow

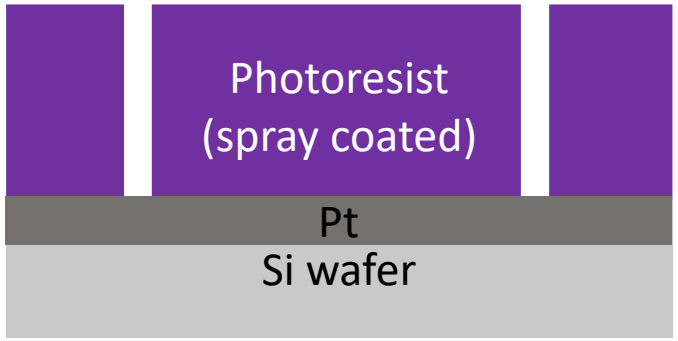
X Gu Extreme Mech Lett. 2 (2015) 7-14

Process

Sample prep

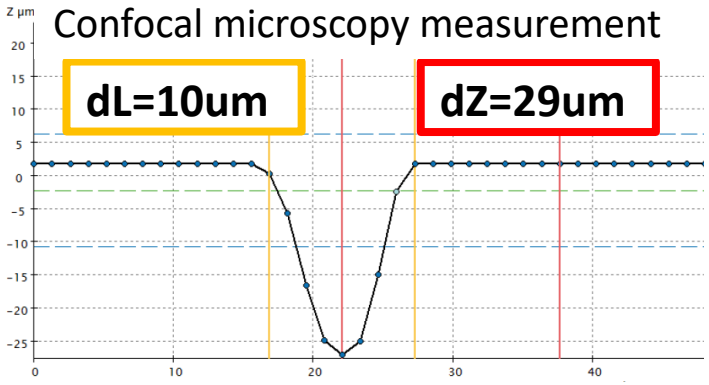


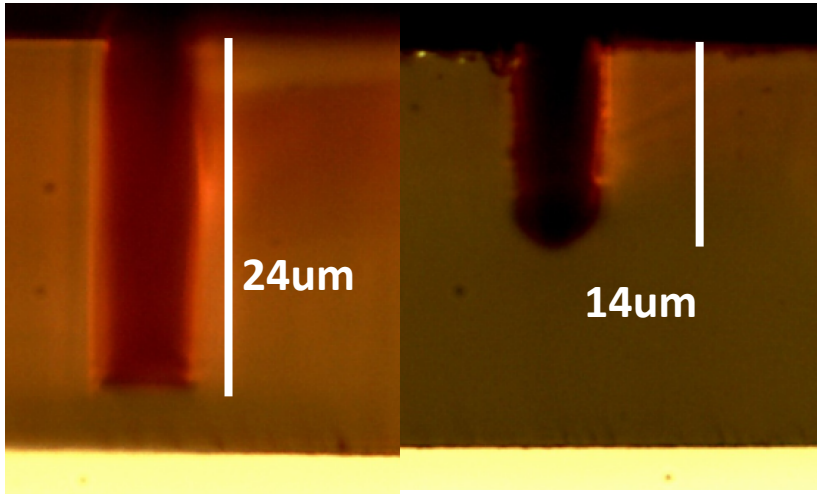
1. Clean wafer
2. HMDS prime on svgcoat2
3. Spraycoat 25 passes resist on wafer



4. Hot plate 5min at 90C
5. Wait 3+ hrs

Exposure: cross-section of resist





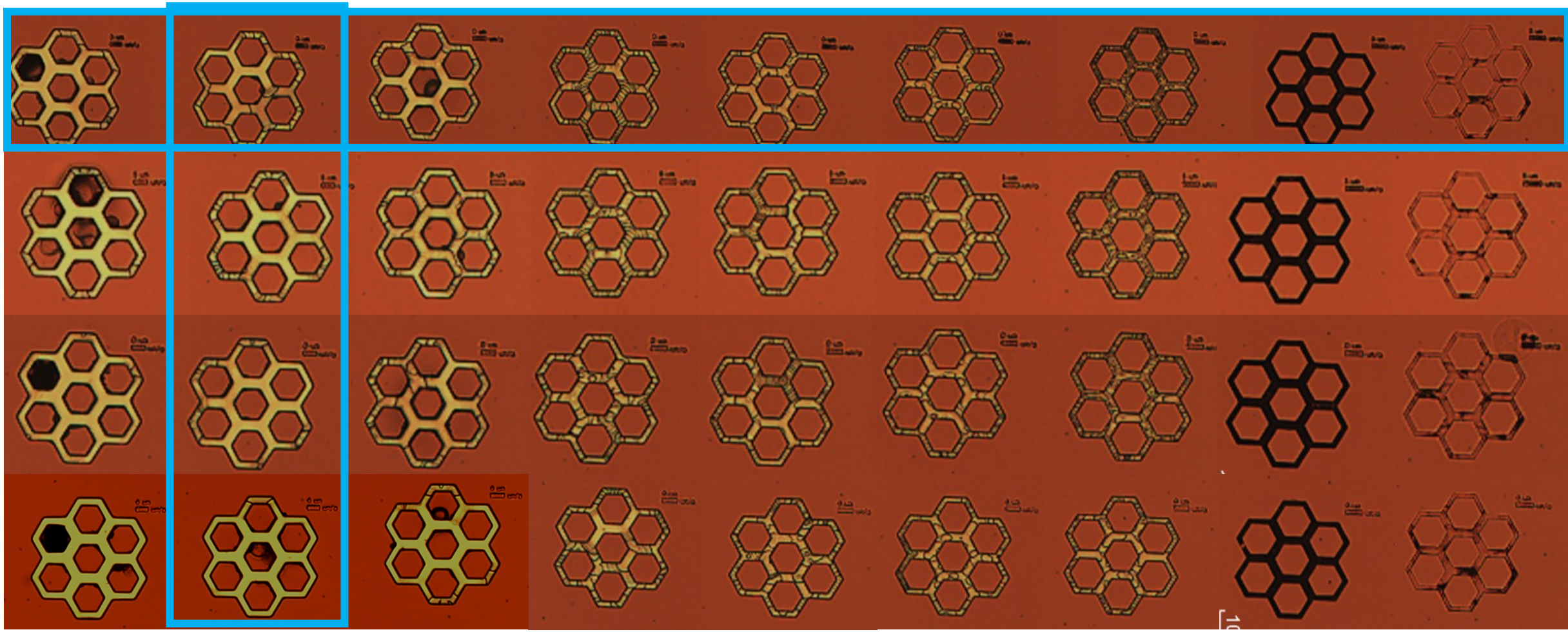
- Did not polymerize to the bottom of the resist
- Edge looks very smooth! ✓

- Exposure matrix
  - Vary interface position and scan speed
    - Scan speed
      - mm/s: 6 8 10 20 30 40 50 100 150
    - Interface position
      - 25um: [um] 0.5 1 2 4 6 8 10
      - 4um: [um] 0.5 1 2 3 4

25um resist

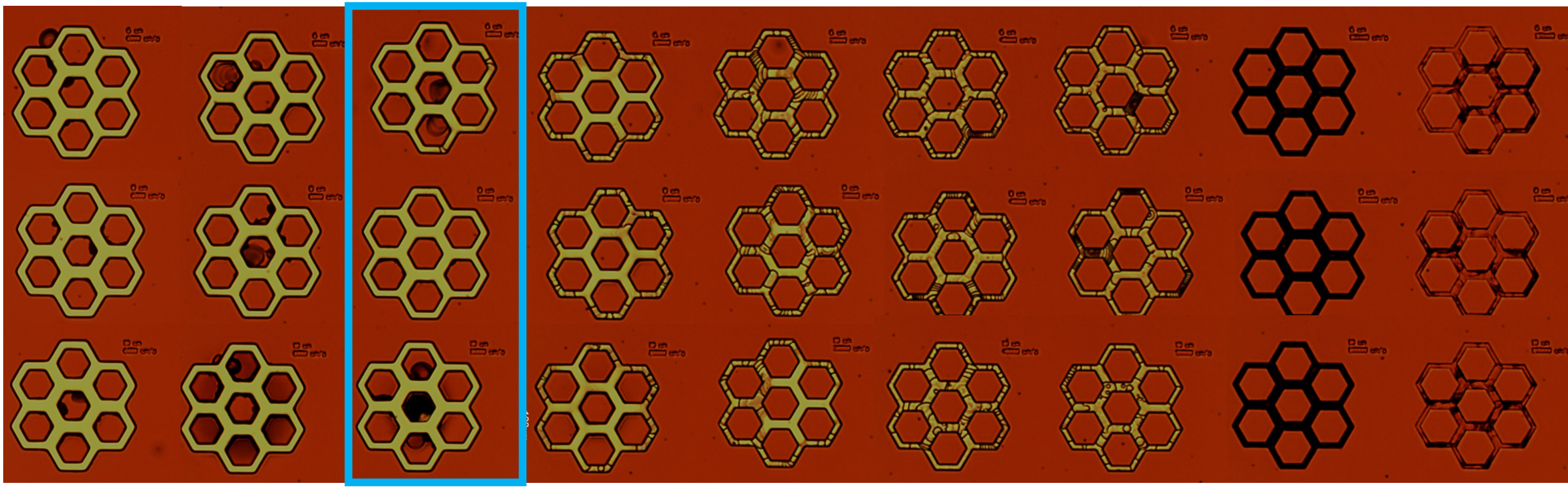
Slower speed = Higher dose = Clearer pattern

Lower interface = clearer pattern?

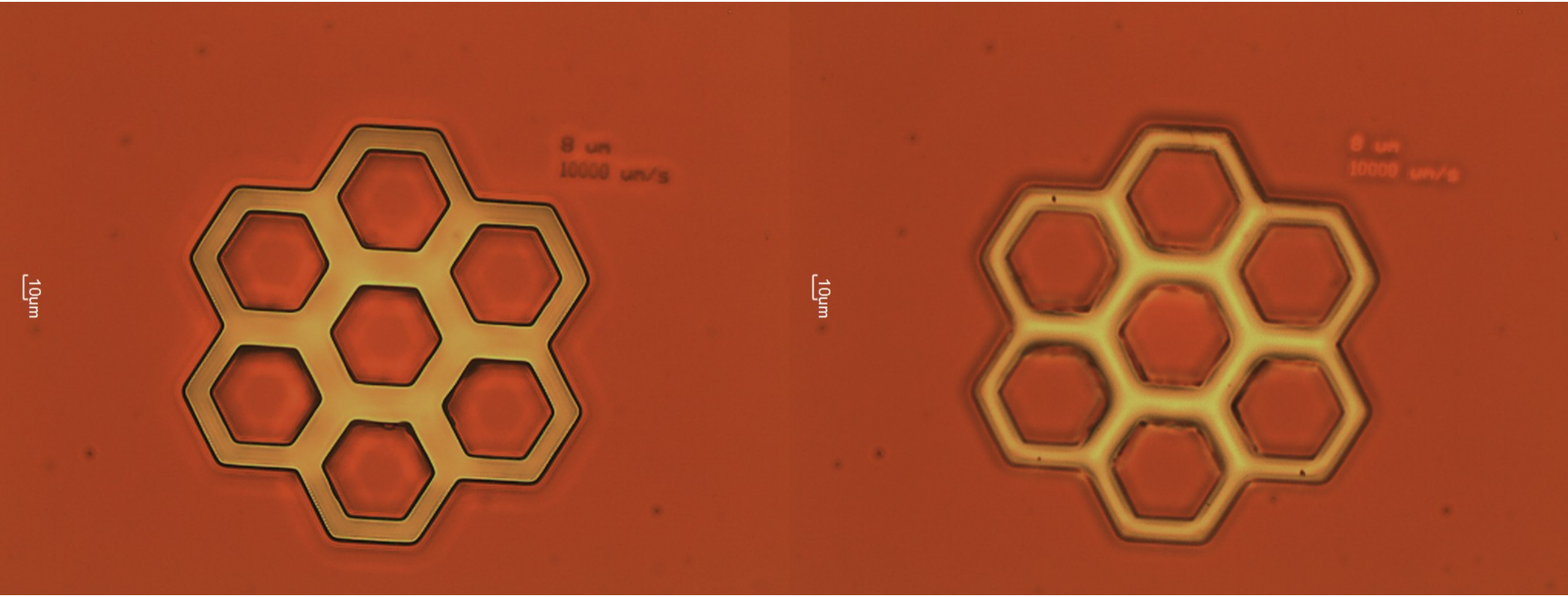


25um resist

Lower interface = clearer pattern? Is Nanoscribe recognizing interface? Is resist sensitivity changing?



25um: Best

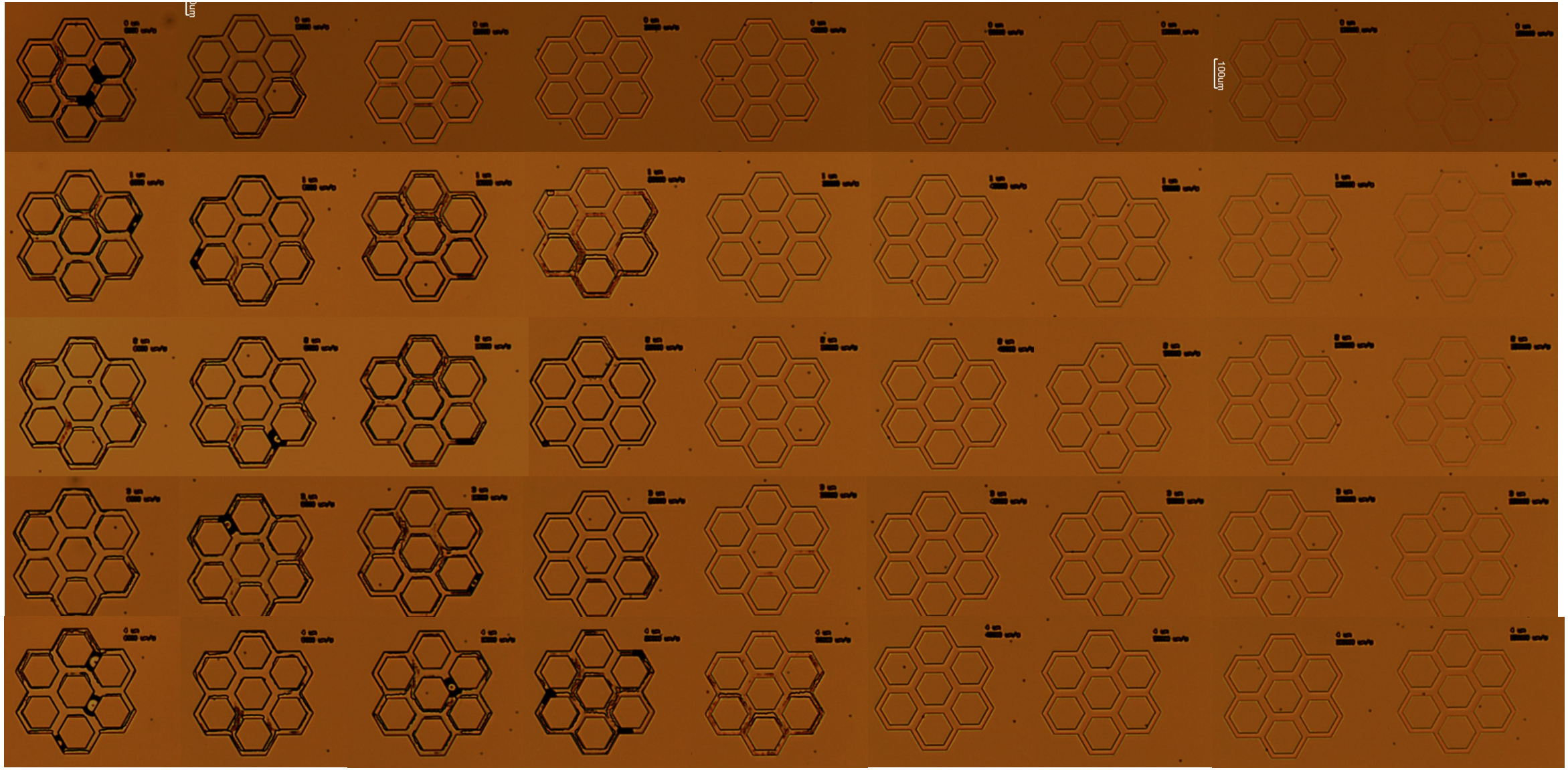


Top

Bottom

Residue still visible

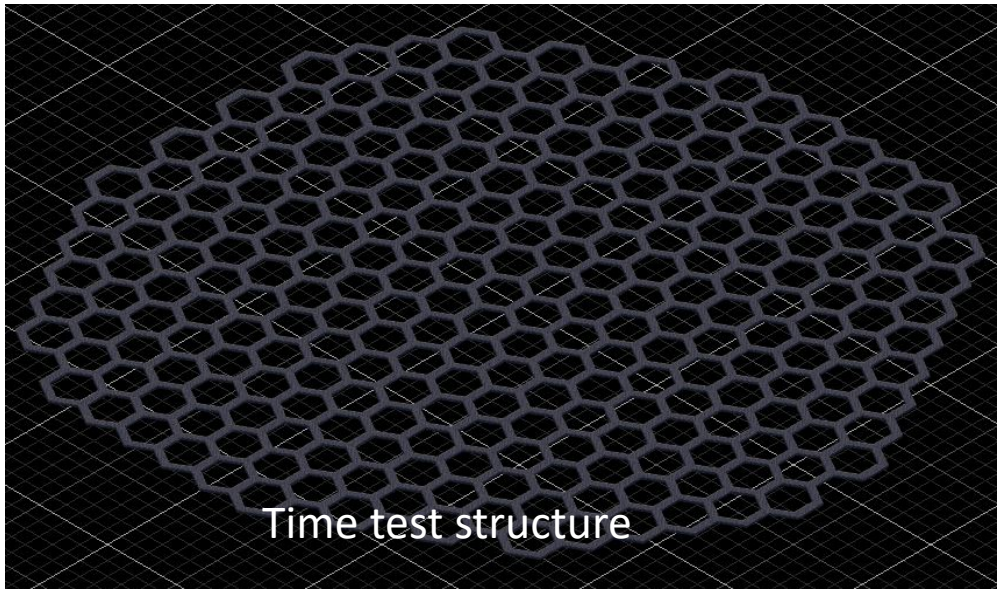
4um resist

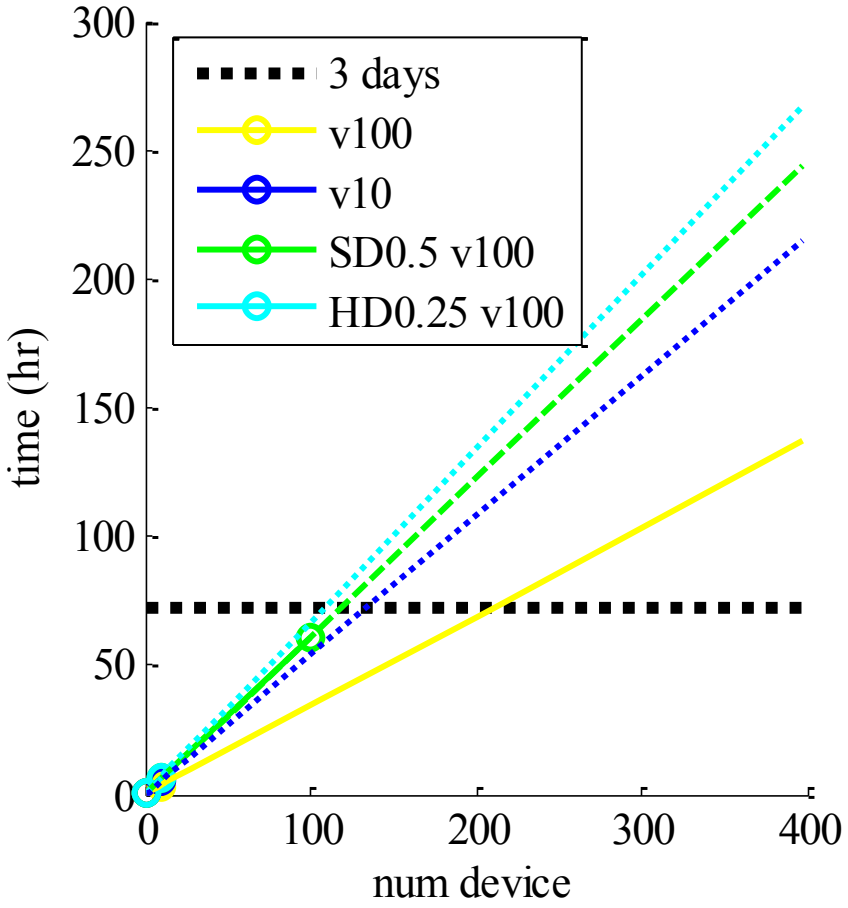

0.5 um
1.0 um
2.0 um
3.0 um
4.0 um
6mm/s
8mm/s
10mm/s
20mm/s
30mm/s
40mm/s
50mm/s
100mm/s
150mm/s

Full wafer two-photon lithography

- Write times
  - Typical write times: ~seconds – few days
  - Write time depends on:
    - Speed
    - Linear distance traversed

- Estimate write time using Describe



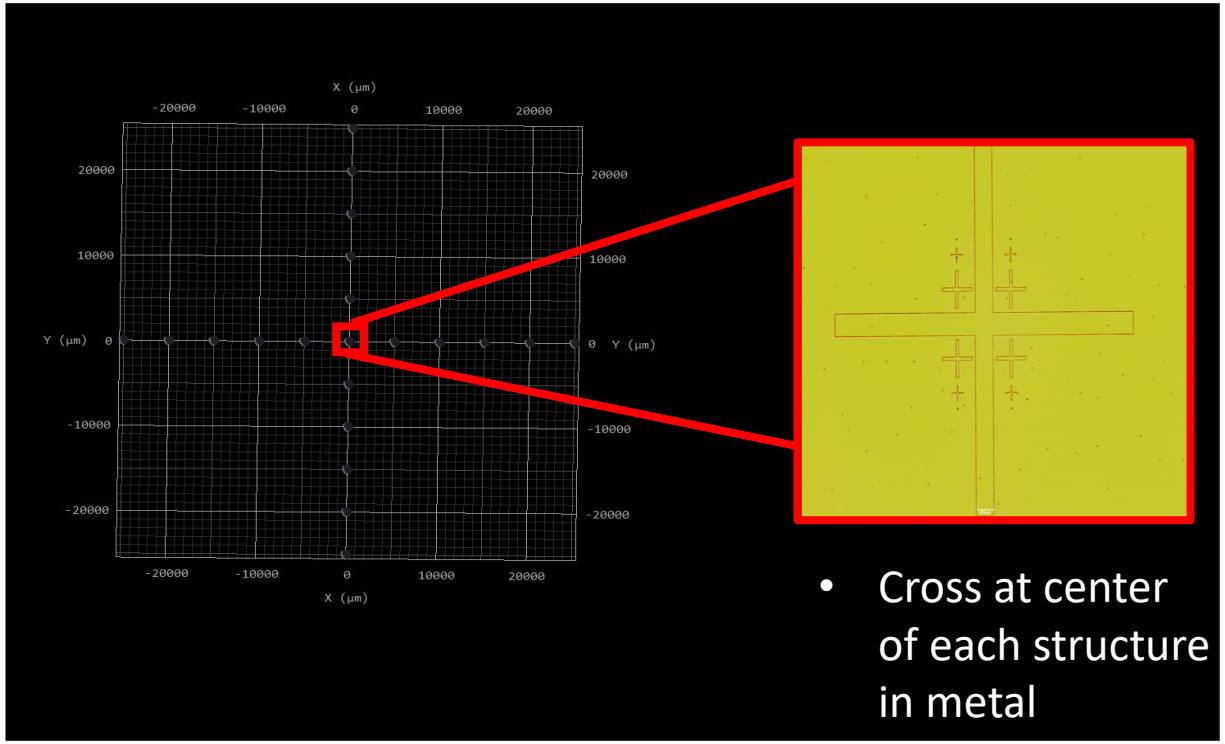


- Decrease v by 10 = 36% decrease in throughput
- Decrease SD by 2 = 44% decrease in throughput
  Decrease HD by 2 = 48% decrease in throughput

Full wafer two-photon lithography

- Alignment:
  - Two-photon lithography is serial
  - Over large areas, stage error dominates

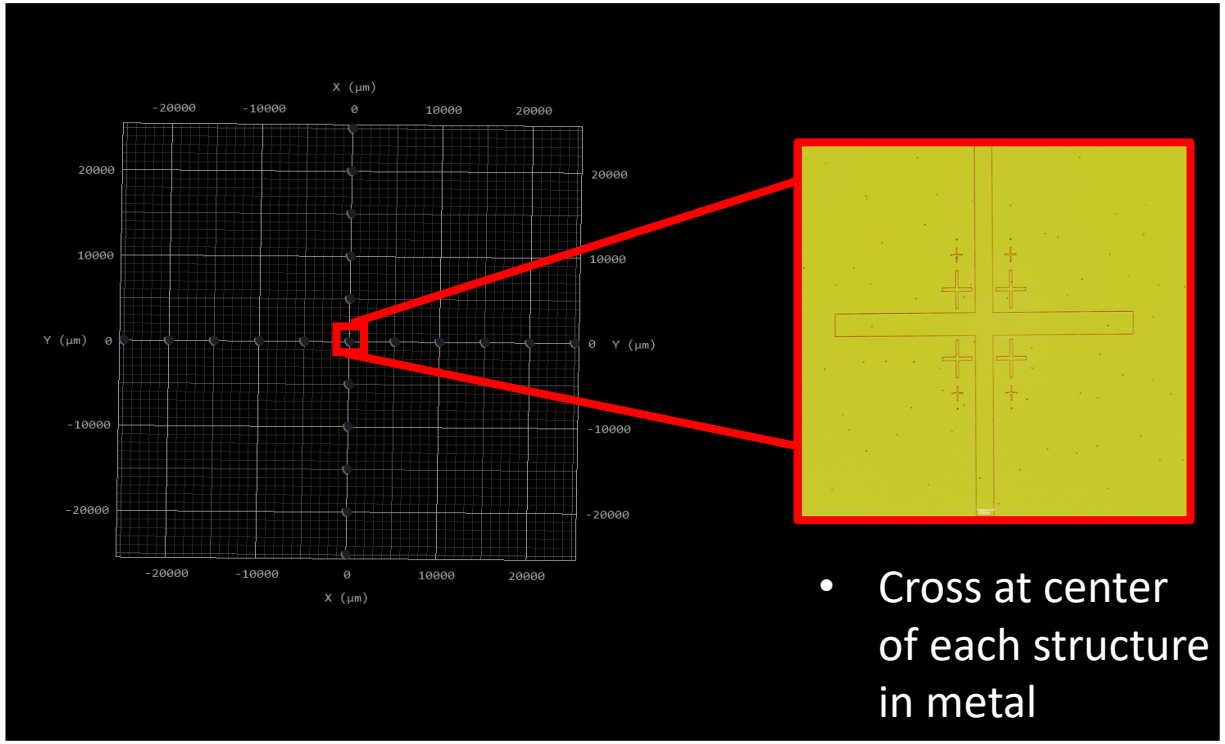
- Estimate stage error:
  - Pattern metal crosses across wafer with Heidelberg
  - Pattern crosses atop existing crosses with nanoscribe
  - Measure misalignment



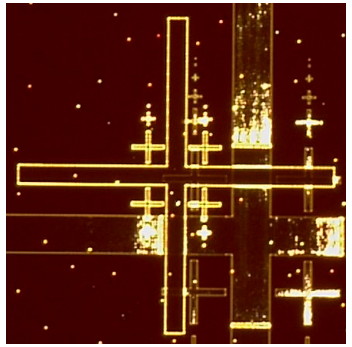
Full wafer two-photon lithography

- Alignment:
  - Two-photon lithography is serial
  - Over large areas, stage error dominates

- Estimate stage error:
  - Pattern metal crosses across wafer with Heidelberg
  - Pattern crosses atop existing crosses with nanoscribe
  - Measure misalignment



- **Minimal misalignment in x-direction**
- **Large misalignment in y-direction**



	Edge					Center
X-Dir [um]	<3	<3	<3	<3	<3	N/A
Y-Dir [um]	85	60	45	25	10	N/A

Conclusions

- Resist structures
  - Achieved test structure on SIROF substrate with limited bubbling
  - Explained effect of ‘bubbling’
  - Gave recommendations for best conditions to eliminate ‘bubbling effect
- Resist molds
  - Found best exposure conditions for thick resist
  - Explored considerations for full-wafer lithography
    - Write time
    - Alignment