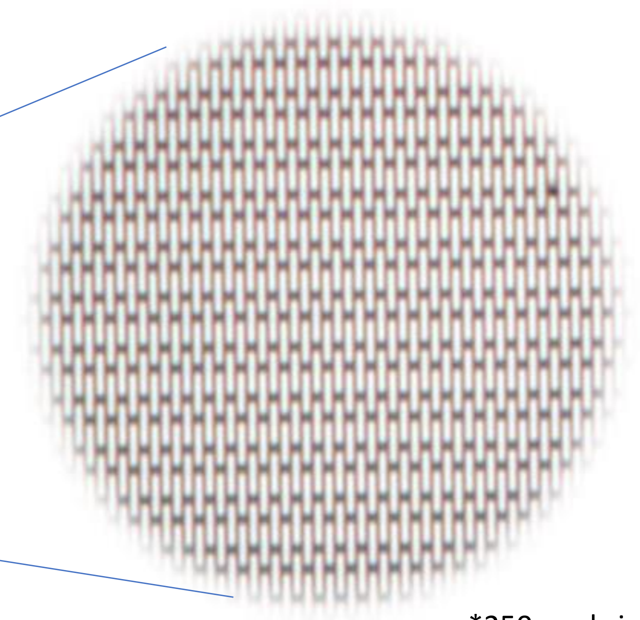

*250 nm brick pattern

eBeam Lithography at NUFAB

NUANCE Tech Talk Series

Serkan Butun

NUANCE
Northwestern University Atomic and Nanoscale Characterization Experimental Center

NU and Regional Facilities/ Coordination

The NUANCE Center

www.nuance.northwestern.edu

ANL - APS
ANL - CNM/NST
CHiMaD

(Tech, Silverman, Hogan, Cook | Northwestern University)

EPIC
Electron Probe Instrumentation Center

SEM, TEM, FIB, EDS, EELS, EBSD, eBL, sample prep

Drs. X. Hu, R. dos Reis, P. Smeets, K. Koo, T. Abbott, N. Gogola, K. Villalon, +PDs

BioCryo
Cryo- and Conventional soft-matter EM

Cryo-TEM, cryo-SEM, cryo-ultramicrotomy

Dr. R. Bleher, E.W. Roth, +PD

Keck-II
Keck Interdisciplinary Surface Science

XPS, ToF-SIMS, FTIR, Ellipsometry

Dr. X. Chen, +PD

SPID
Scanned Probe Imaging & Development

AFM, BPL, NSOM, Confocal Raman, Nano-Indenter

Dr. G. Shekhawat, +PD

NUFAB
Micro/Nano Fabrication

Deposition, Photo-Lith, eBL, Thermo & Wet processing, Etching-Ashing

Drs. N. Basit, A. Dhote, Y. Jia, S. Lu, S. Butun, S. Kreager

SHyNE Director
Open

Business Office
Chad Goeser, Stephanie Torres

Outreach Coordination
Katy Dean, Ruari McDonnell

Program Administration
Lourdes Vazquez, Andrea Blanco

NUFAB Tech FG70 and Cook 4026

NUANCE's NUFAB Facility - Technological Institute, Northwestern University

- *Characterization*
- *Cook Cleanroom*
- *Deposition*
- *Dry Etching - Ashing*
- *E-Beam Lithography*
- *Furnaces*
- *Packaging*
- *Photolithography*
- *Software*
- *Wet Processing*

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Class 100 Clean Room Facility

Quantum Devices, Biomechanical Devices, Electronics, Semiconductor Fabrication, MEMS, NEMS, Plasmonics, Metamaterials, and more ….

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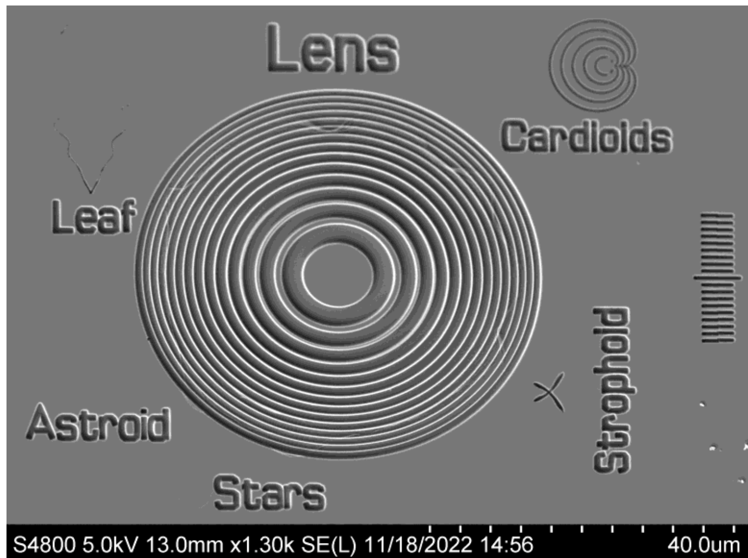
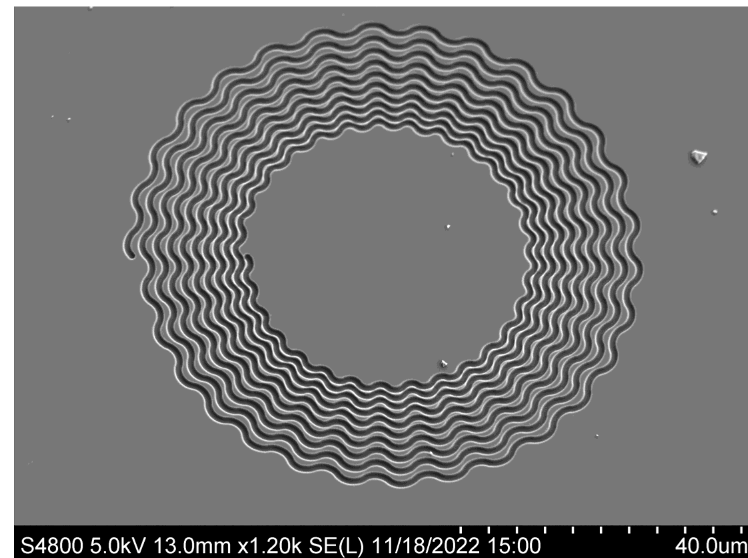
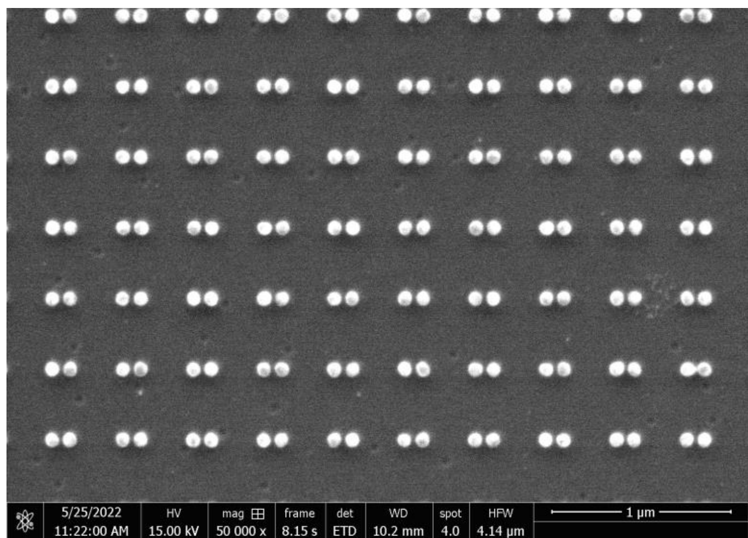


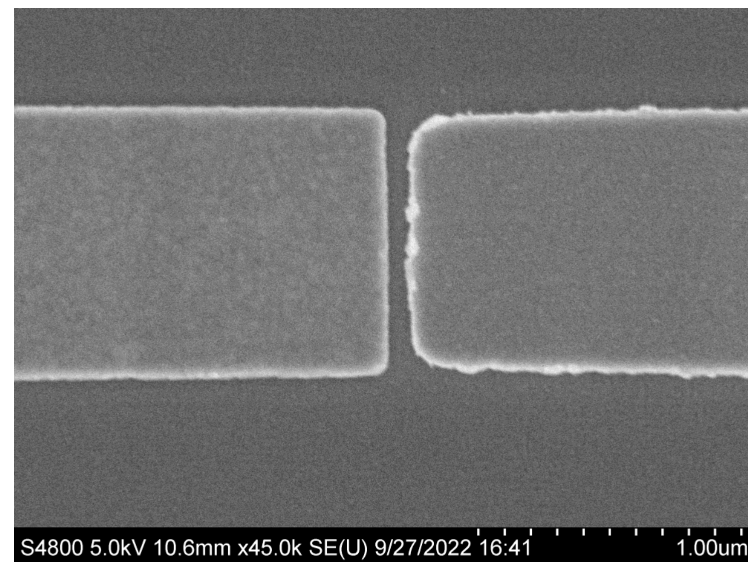
Zone plates, S Butun, NUFAB



Sine Spirals, S Butun, NUFAB



Plasmonic dimers, Sang Min Park, Odom group



Quantum devices, S Butun, NUFAB

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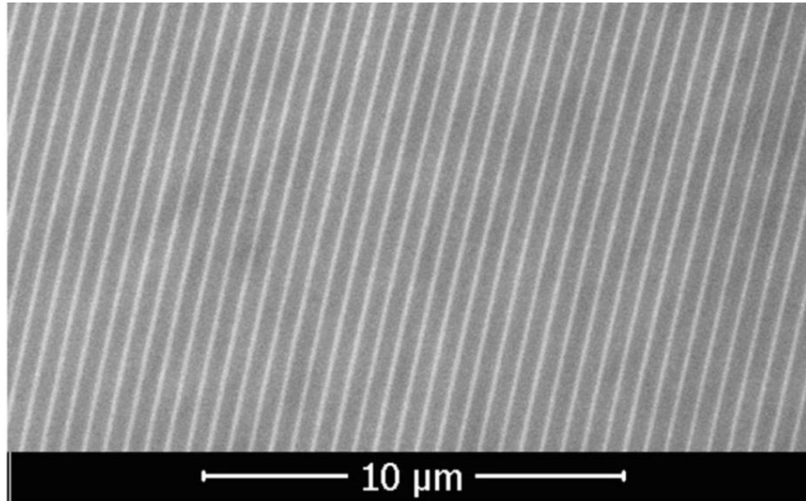
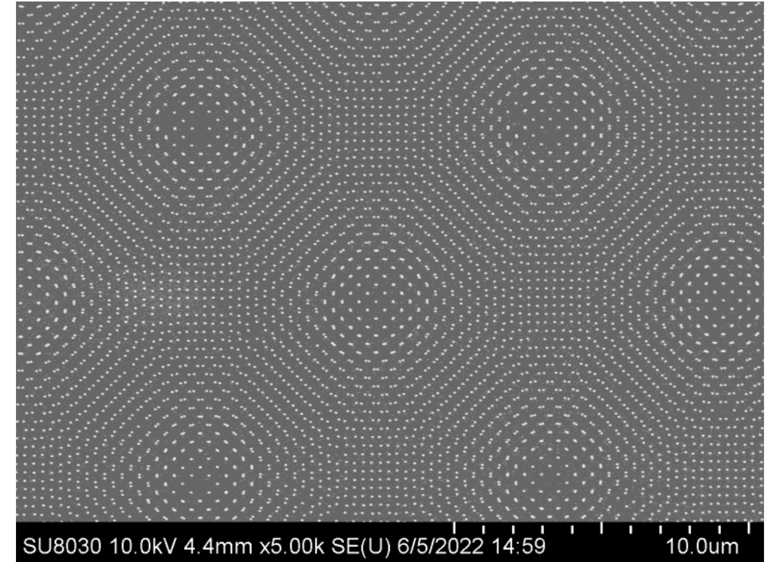
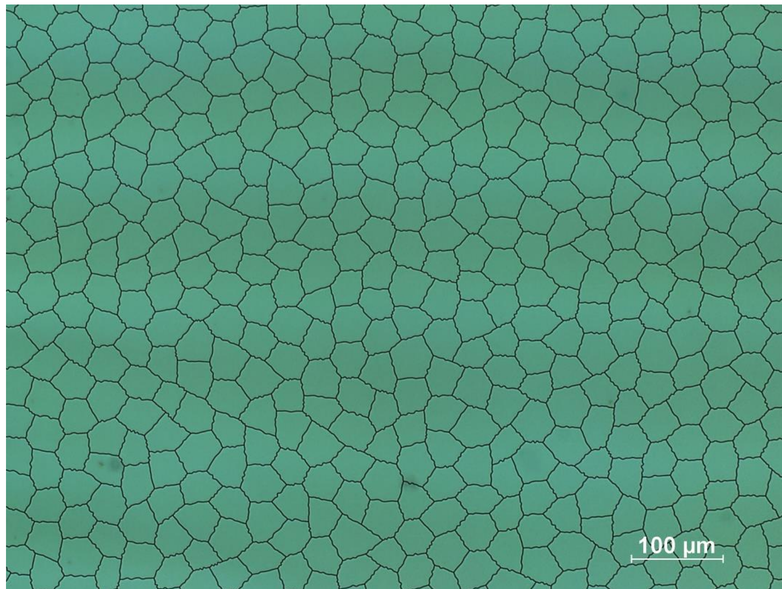


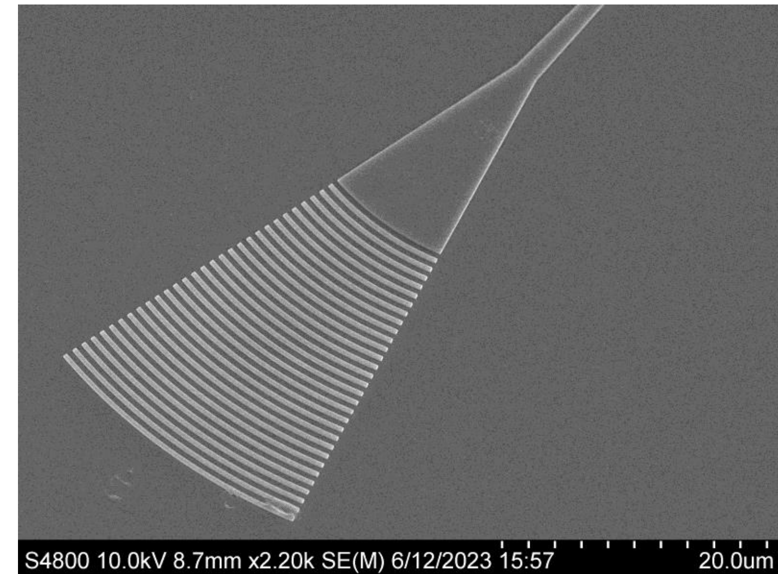
Metalens, 2 mm diameter, Al liftoff on Glass
I Tanriover, Aydin Group



Large area >4mm plasmonic structures, Y Wang, Odom Group



Quasi Random Mesh Network, 2x3 cm2, S Butun, NUFAB



Waveguide Launcher, N Coirier, Mohseni Group

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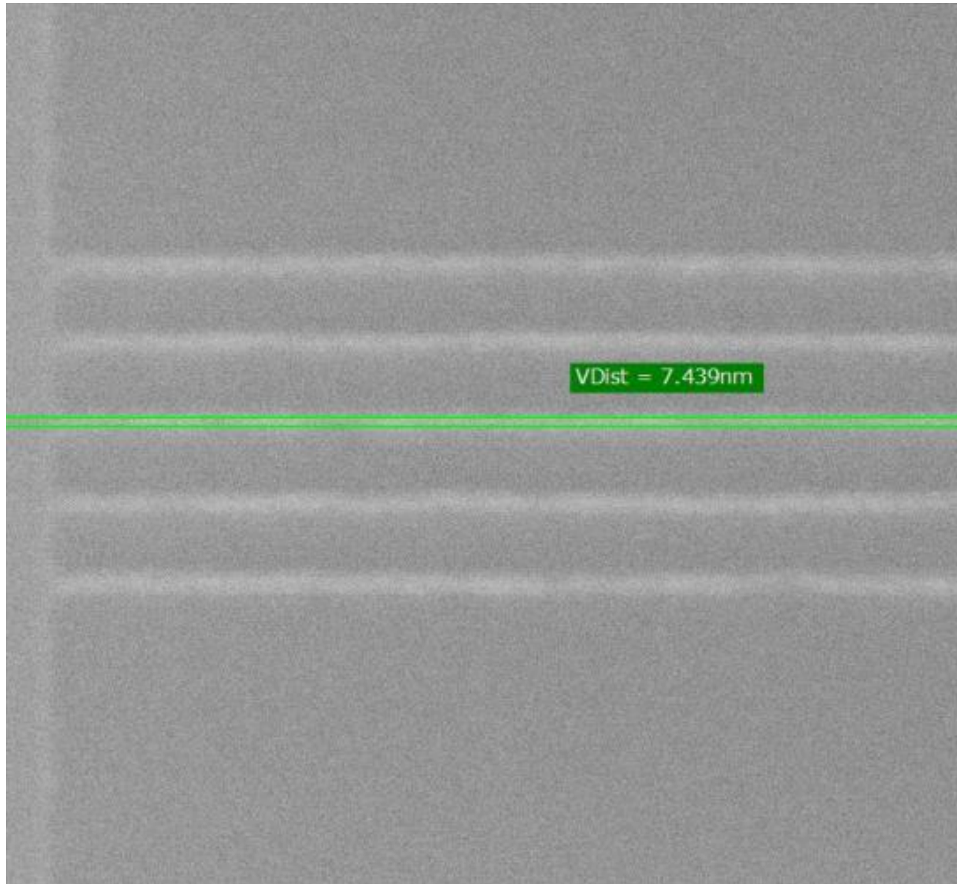
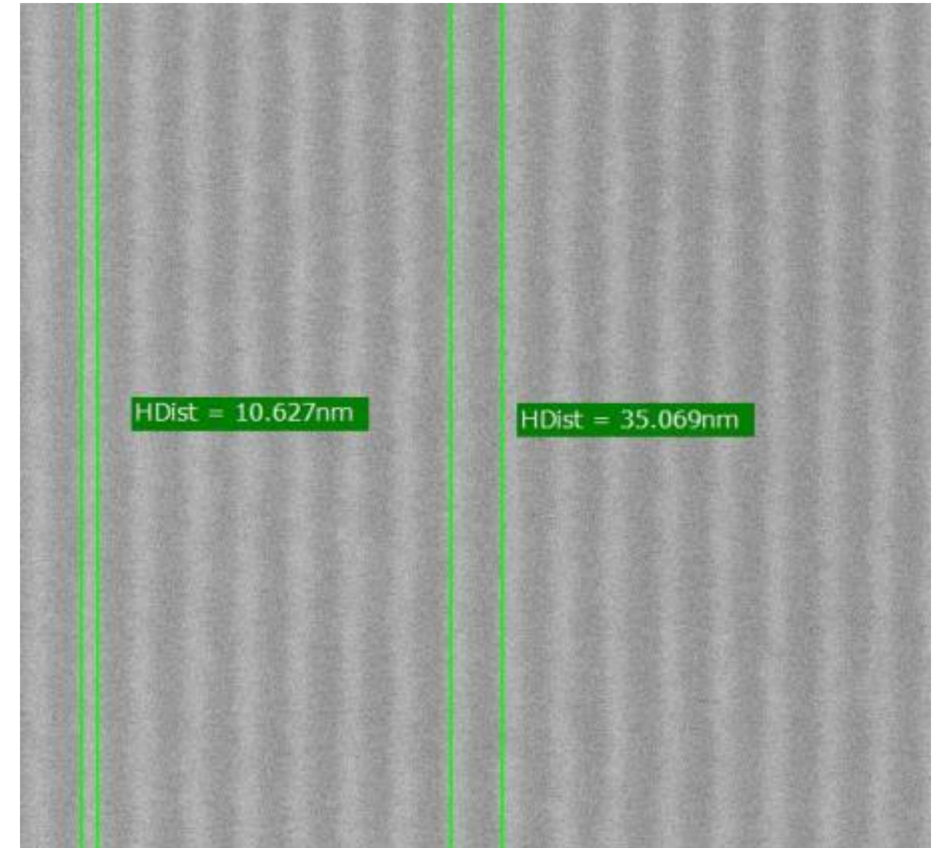
Minimum line width, periodicity





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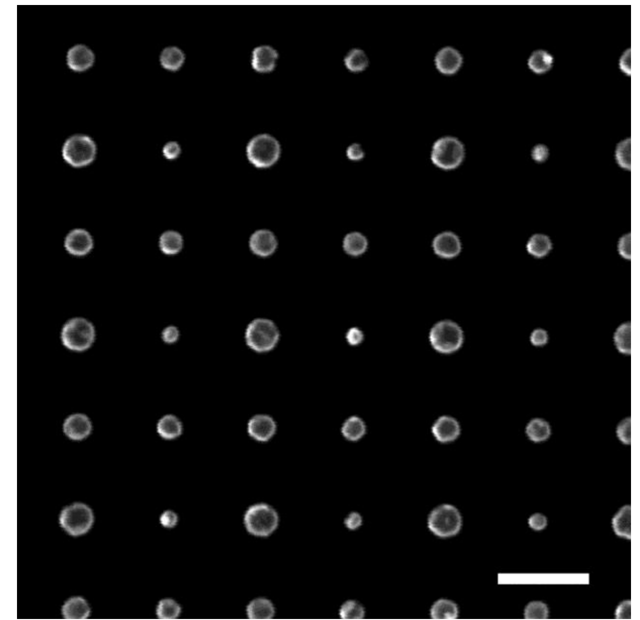
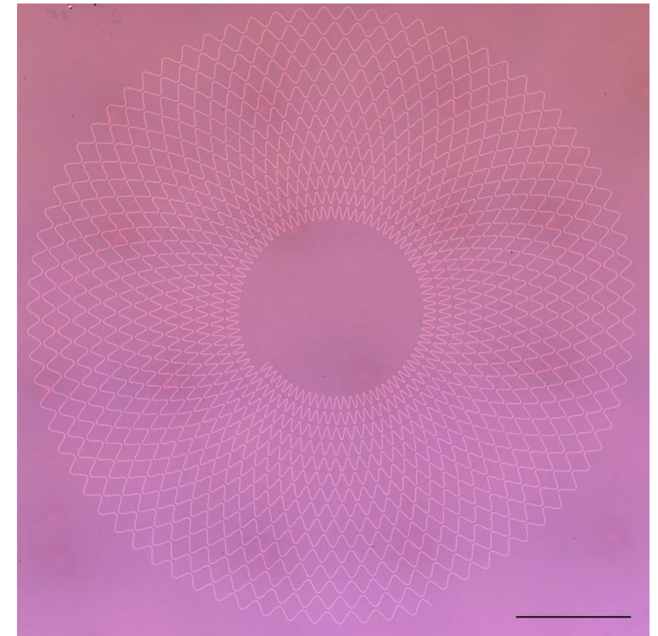
In this talk…

- EBL background
- What NUFAB offers
  - Voyager 100
  - Materials
  - Process tips



300 nm



0.5 mm

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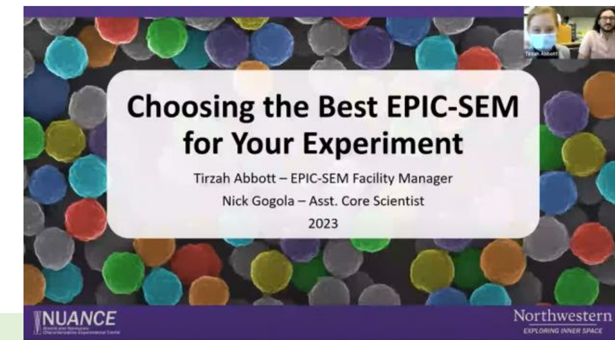
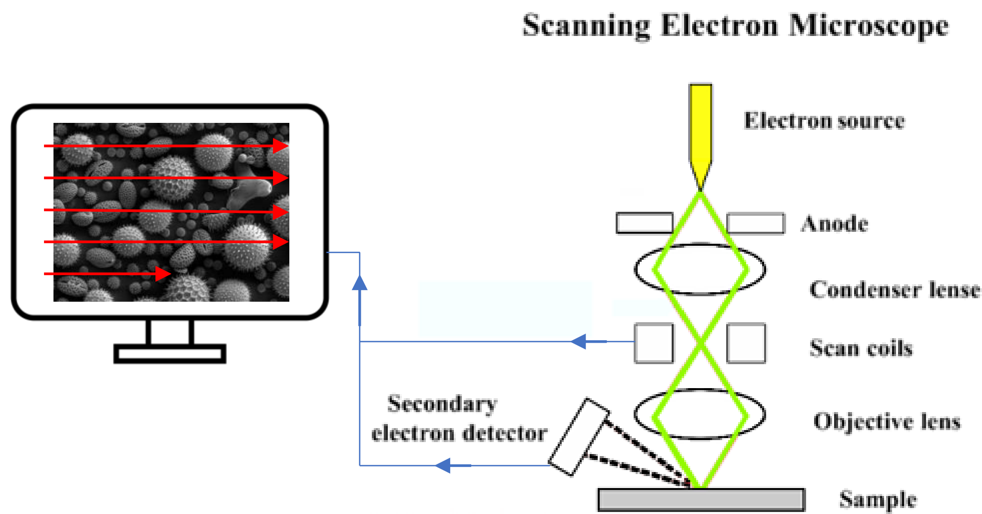
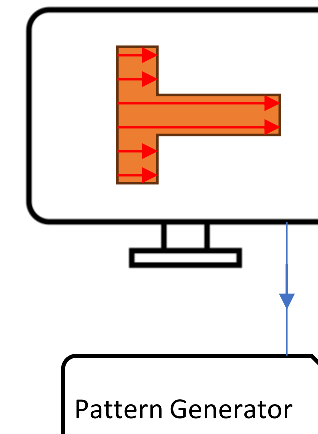
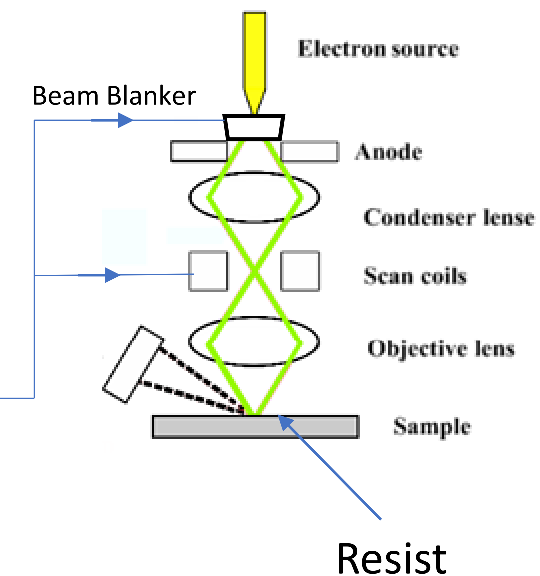
What is eBeam Lithography



- Patterning with electrons.
- Allows patterning sub 10 nm scale
- Serial process – patterns are exposed pixel by pixel







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Raith Voyager100

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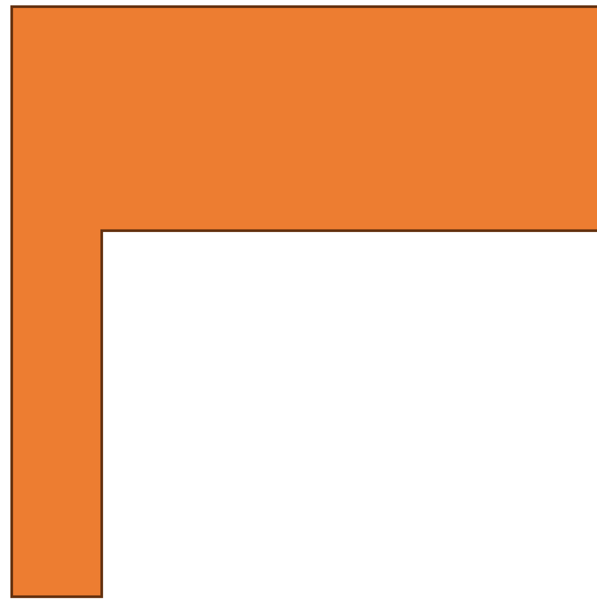
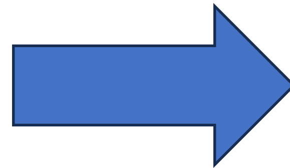
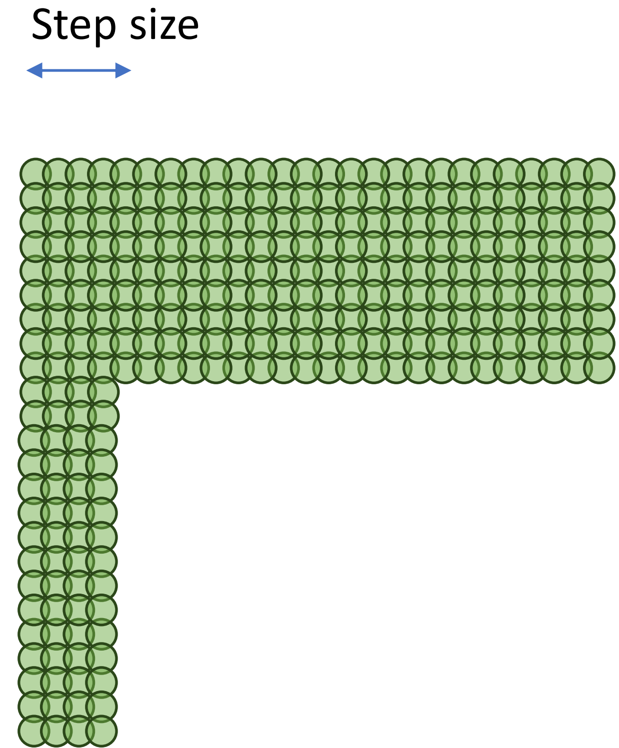
- 3 nm beam size
- 50 kV column
- 20bit pattern processor
- Overlay accuracy ~10 nm
- Stich field accuracy ~10 nm
- Interferometric stage
- 100 x 100 mm2 writing area
- FBMS – fixed beam moving stage exposure

How it works - fracturing







CAD design

What EBL exposes

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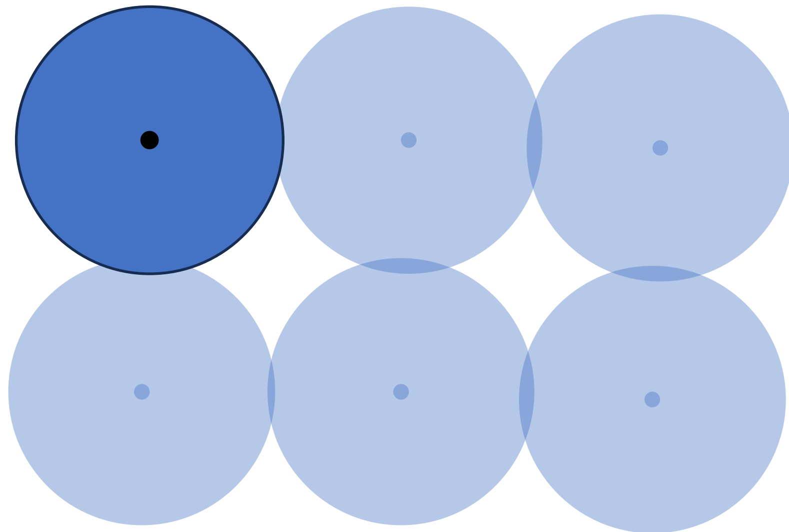
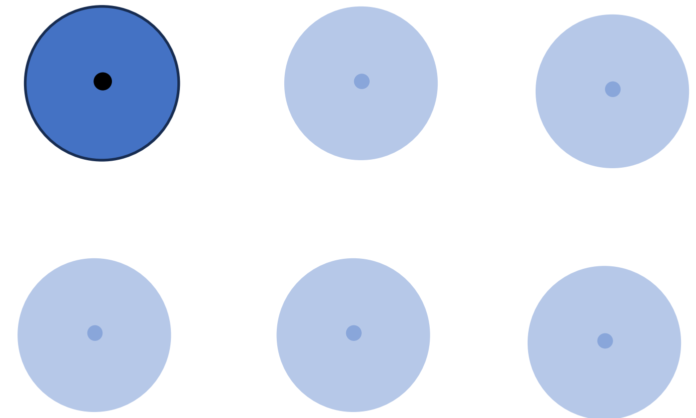
Beam Current vs dose vs pixel size

$$Dose = \frac{Beam\ Current\ \times Dwell\ time}{step\ size\ \times line\ spacing}$$



Long dwell time



Short dwell time

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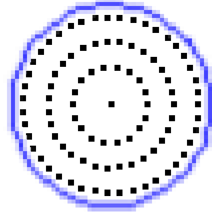
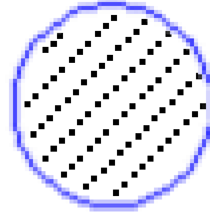
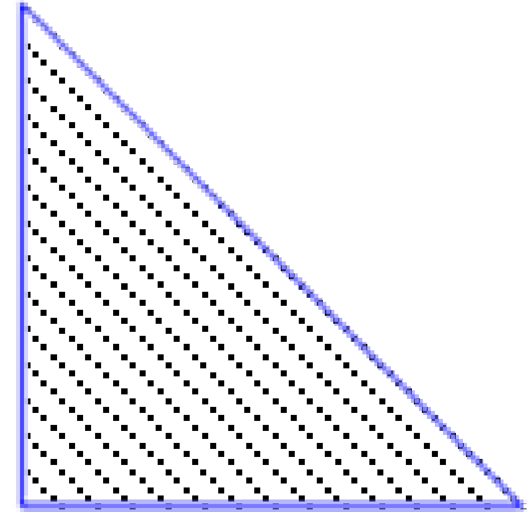
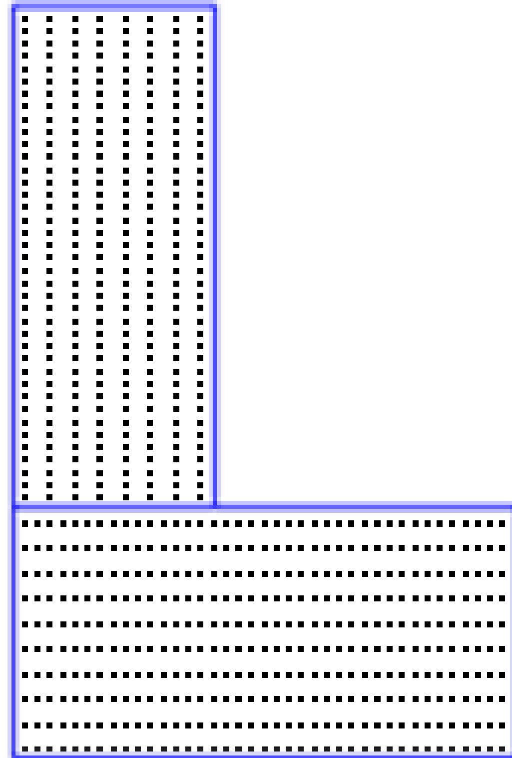
Raith Circle

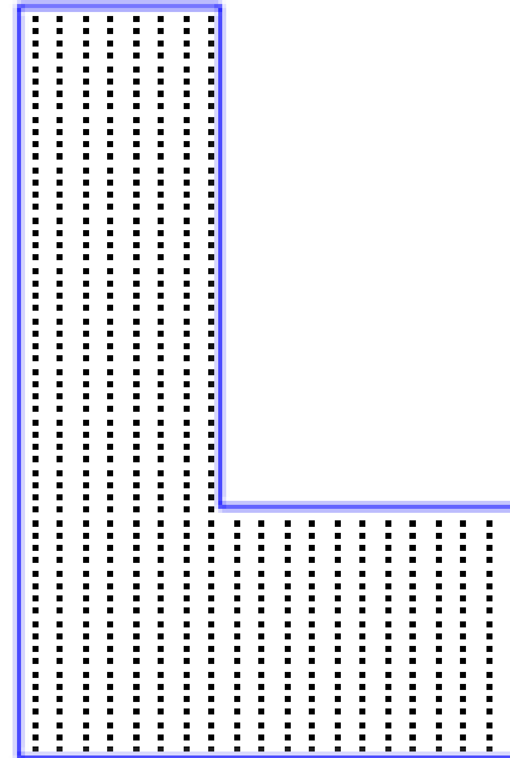


Polygon









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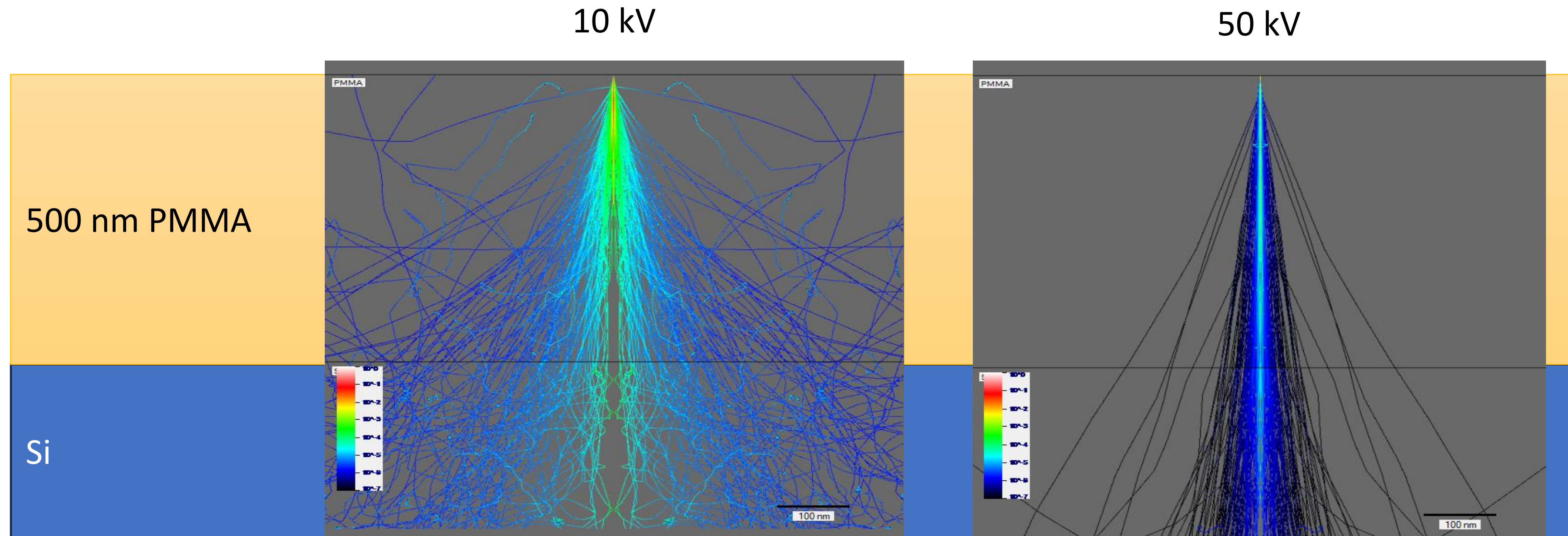
Effect of accelerator voltage



Better undercut
Collapsing

Better resolution

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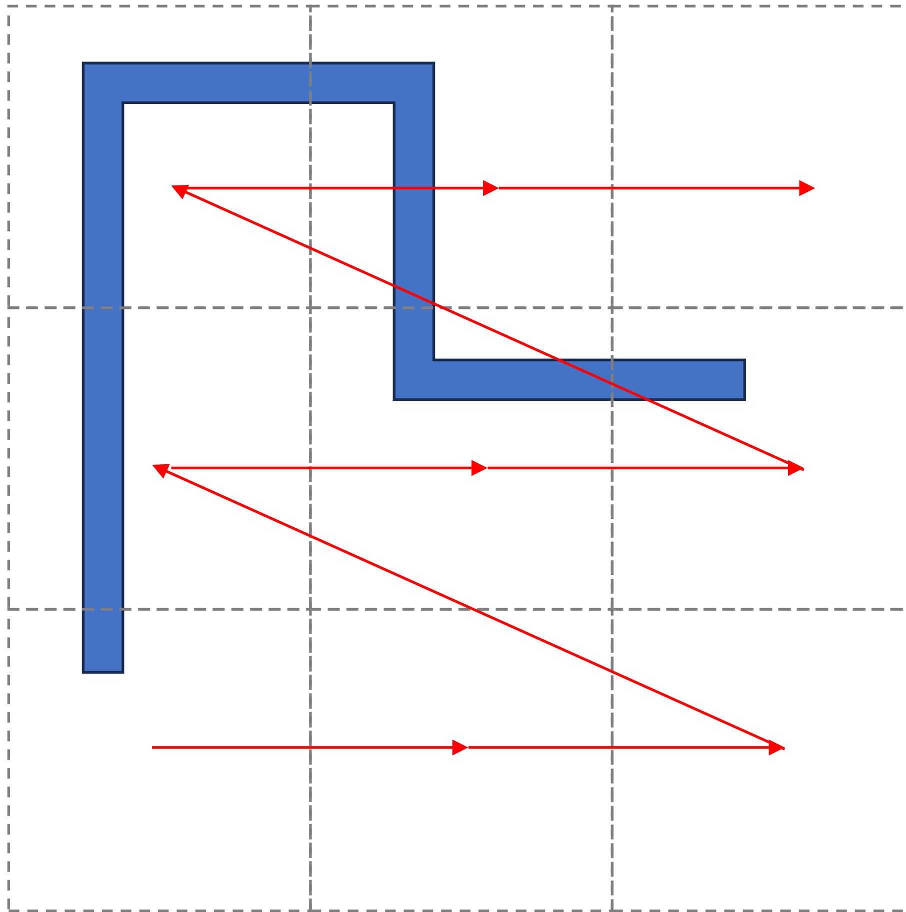
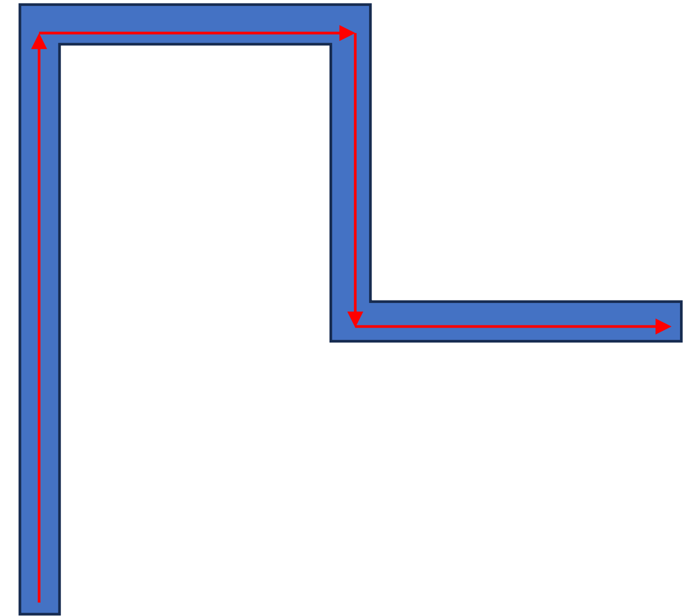
Two writing techniques



Stitch and go
Most common



FBMS

Long interconnects
Waveguides

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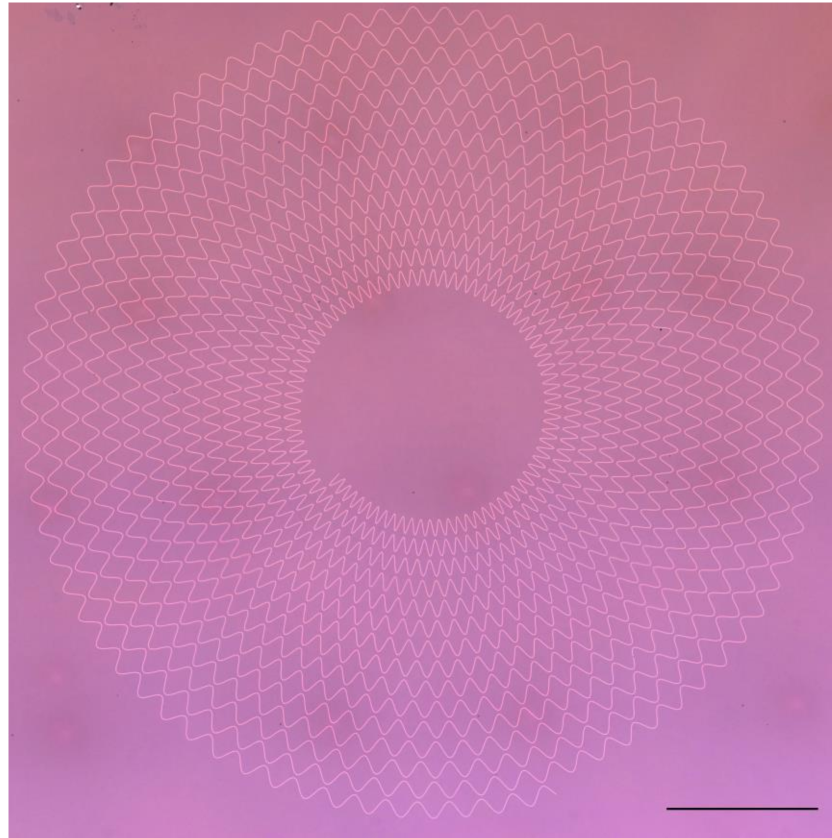
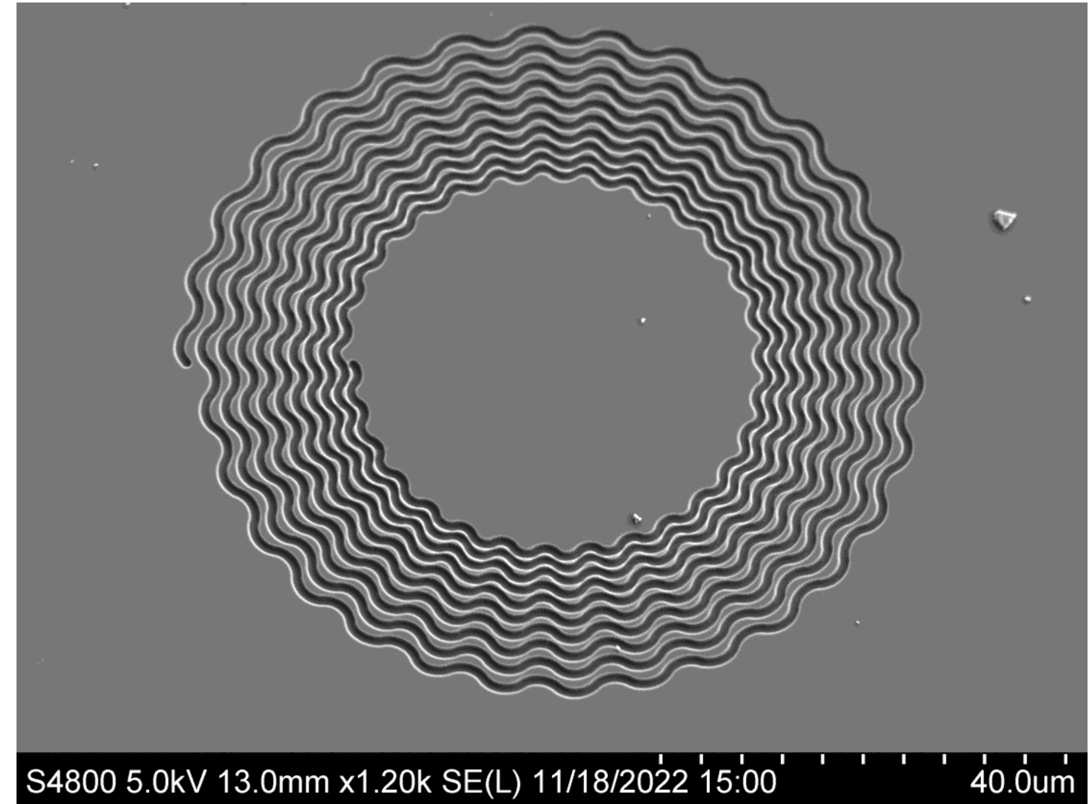
FBMS examples



3 mm across



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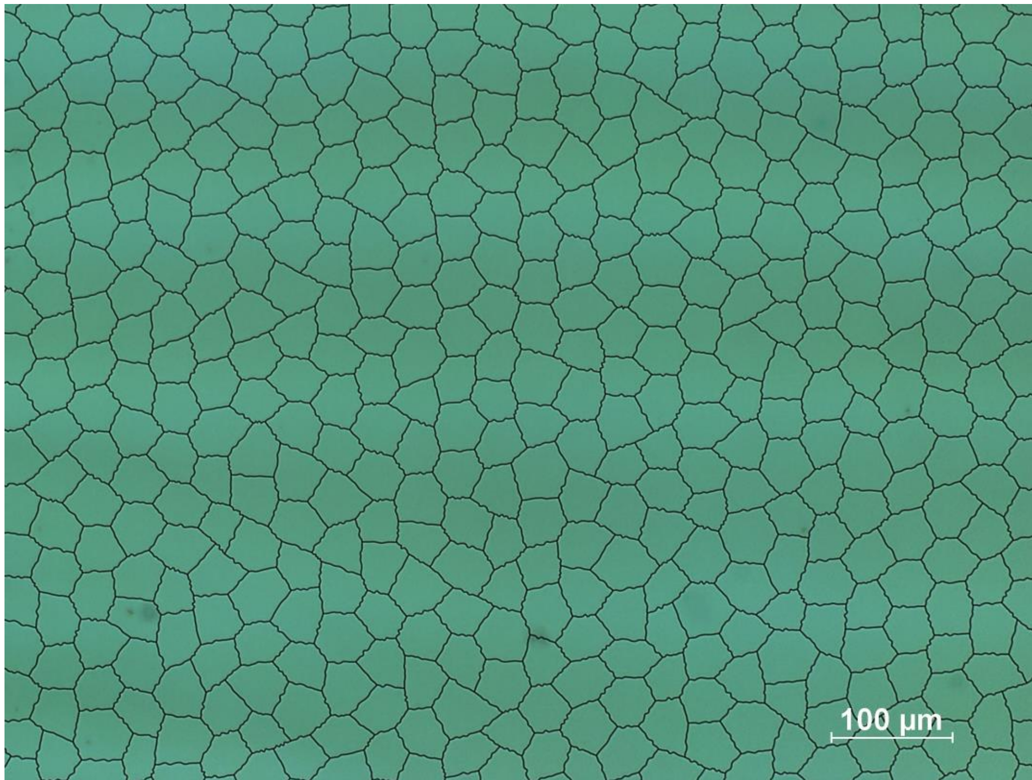
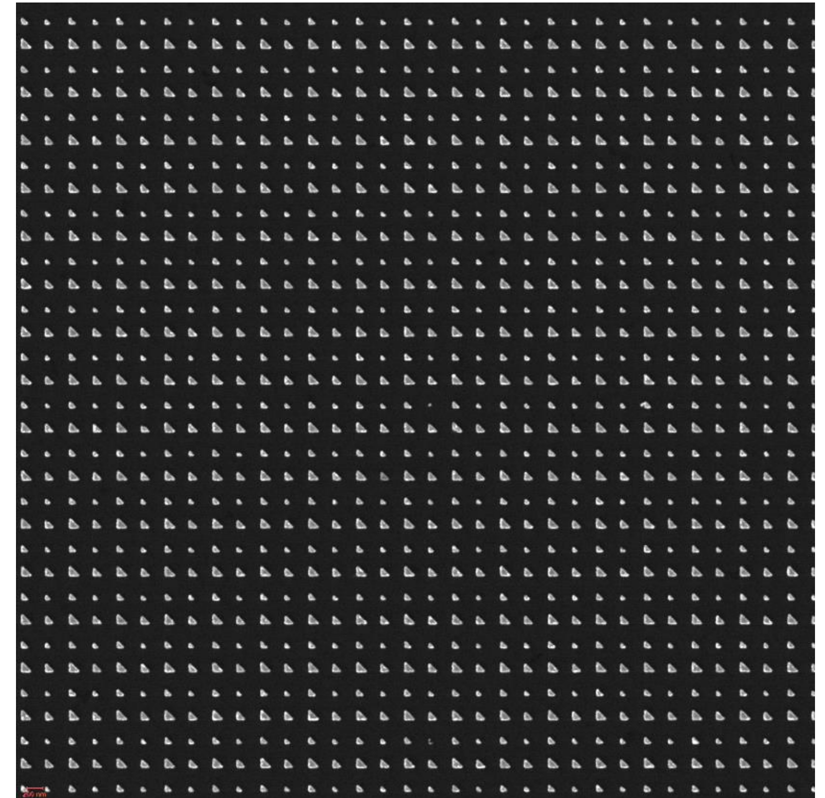
Efficient large area patterning

Large area periodic nanostructure can be made in reasonable time with high beam current

8x8 mm2 area of **100 nm disks** with **300 nm** pitch ~ 2 hours



Random network – 800 nm linewidth 2x3 cm2, 1.5 h



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CAD – Computer Aided Design software

- VOYAGER100 built in GDS editor
- KLAYOUT - https://www.klayout.de/
- Scripting
  - Matlab (https://github.com/ahryciw/Raith_GDSII) Univ. of Alberta
  - Python (gdstk, ezdxf)

I do not recommend using Autocad and dxf files !

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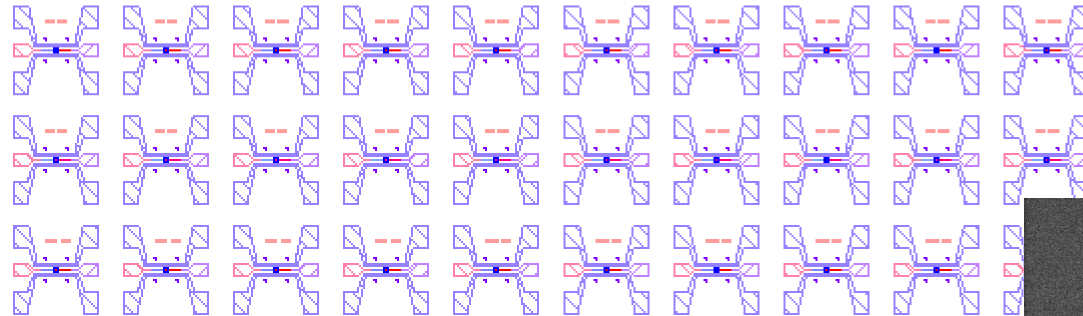
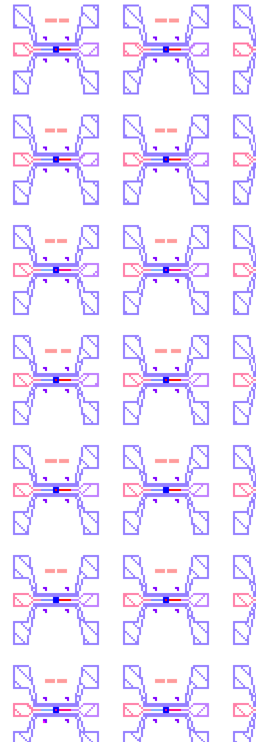
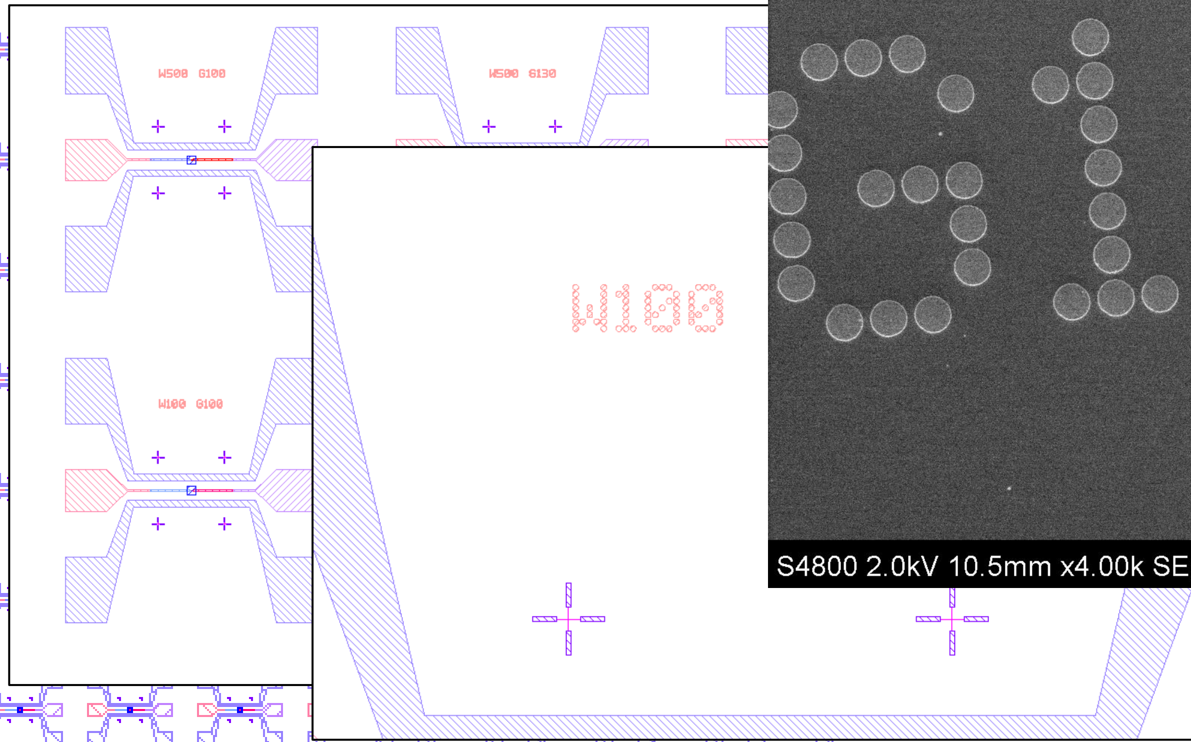
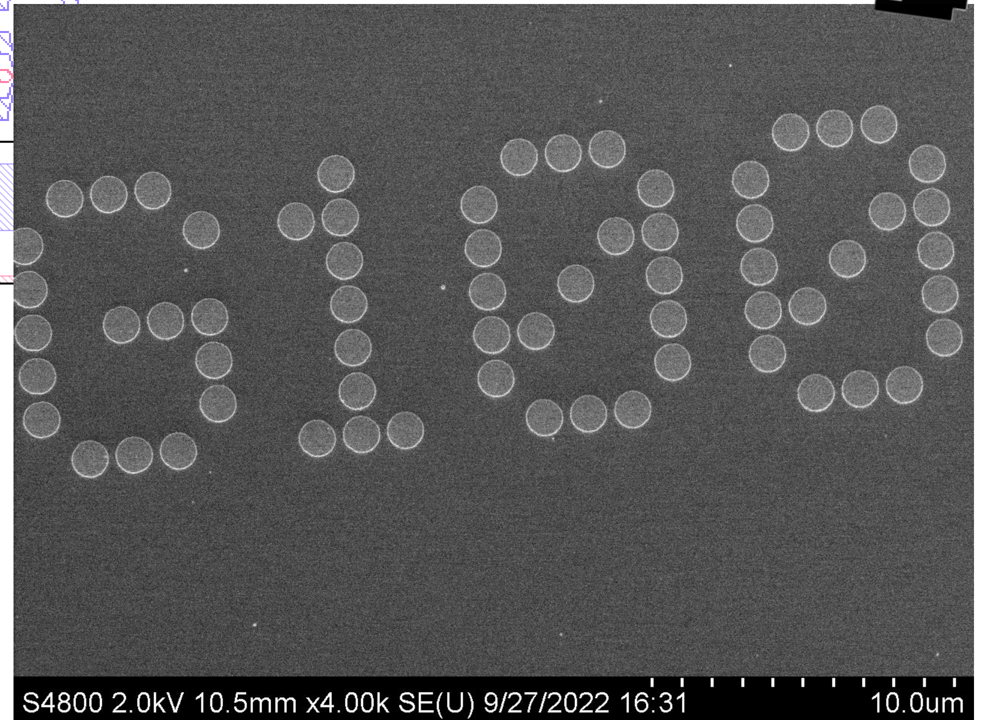
Scripting - gdstk



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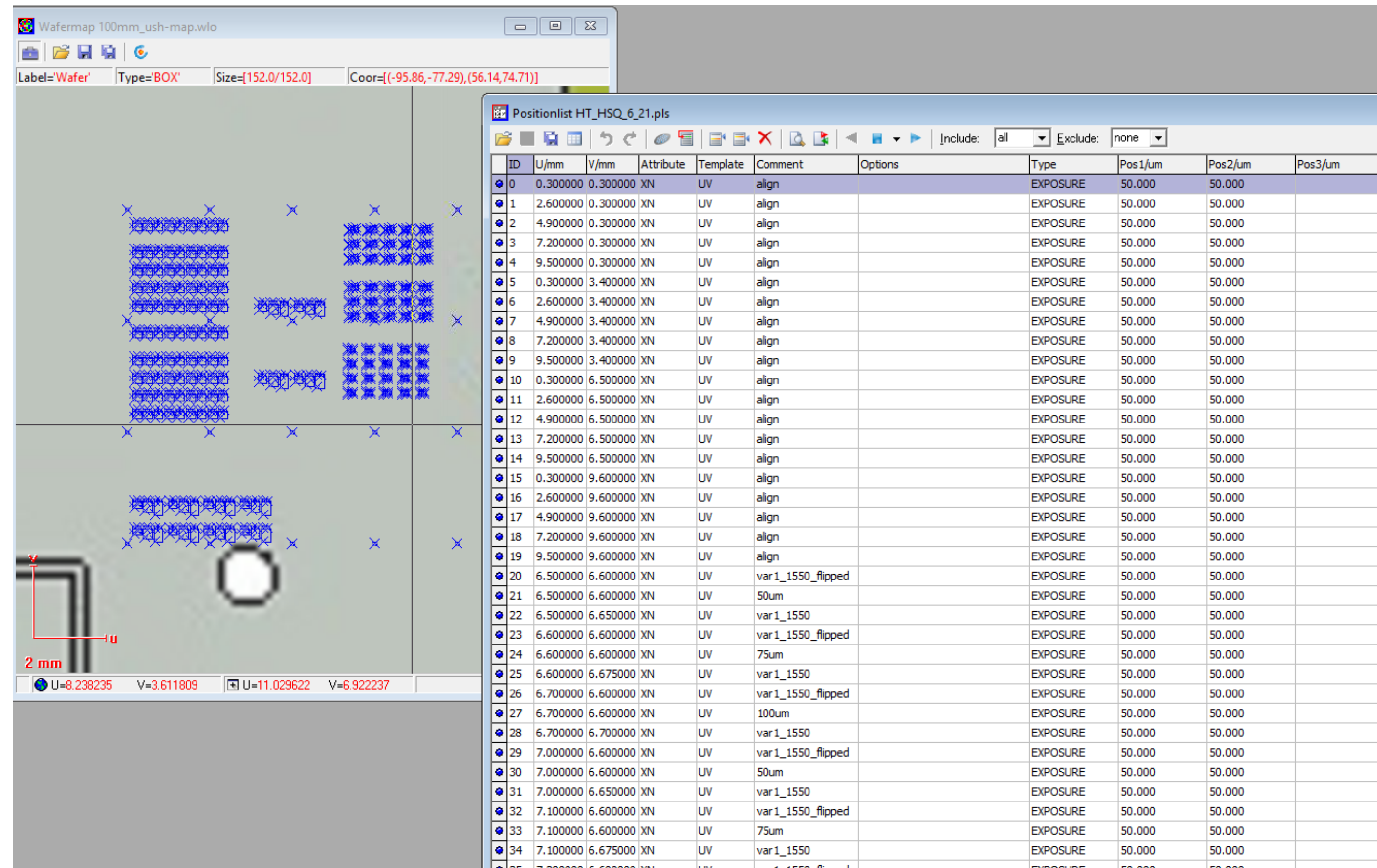
Raith_GDSII package by Univ of Alberta

- Create Raith Specific objects – Raith Circles, FBMS etc
- Create custom Position lists



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7	4.900000	3.400000	XN	UV	align		EXPOSURE	50.000	50.000	
8	7.200000	3.400000	XN	UV	align		EXPOSURE	50.000	50.000	
9	9.500000	3.400000	XN	UV	align		EXPOSURE	50.000	50.000	
10	0.300000	6.500000	XN	UV	align		EXPOSURE	50.000	50.000	
11	2.600000	6.500000	XN	UV	align		EXPOSURE	50.000	50.000	
12	4.900000	6.500000	XN	UV	align		EXPOSURE	50.000	50.000	
13	7.200000	6.500000	XN	UV	align		EXPOSURE	50.000	50.000	
14	9.500000	6.500000	XN	UV	align		EXPOSURE	50.000	50.000	
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16	2.600000	9.600000	XN	UV	align		EXPOSURE	50.000	50.000	
17	4.900000	9.600000	XN	UV	align		EXPOSURE	50.000	50.000	
18	7.200000	9.600000	XN	UV	align		EXPOSURE	50.000	50.000	
19	9.500000	9.600000	XN	UV	align		EXPOSURE	50.000	50.000	
20	6.500000	6.600000	XN	UV	var1_1550_flipped		EXPOSURE	50.000	50.000	
21	6.500000	6.600000	XN	UV	50um		EXPOSURE	50.000	50.000	
22	6.500000	6.650000	XN	UV	var1_1550		EXPOSURE	50.000	50.000	
23	6.600000	6.600000	XN	UV	var1_1550_flipped		EXPOSURE	50.000	50.000	
24	6.600000	6.600000	XN	UV	75um		EXPOSURE	50.000	50.000	
25	6.600000	6.675000	XN	UV	var1_1550		EXPOSURE	50.000	50.000	
26	6.700000	6.600000	XN	UV	var1_1550_flipped		EXPOSURE	50.000	50.000	
27	6.700000	6.600000	XN	UV	100um		EXPOSURE	50.000	50.000	
28	6.700000	6.700000	XN	UV	var1_1550		EXPOSURE	50.000	50.000	
29	7.000000	6.600000	XN	UV	var1_1550_flipped		EXPOSURE	50.000	50.000	
30	7.000000	6.600000	XN	UV	50um		EXPOSURE	50.000	50.000	
31	7.000000	6.650000	XN	UV	var1_1550		EXPOSURE	50.000	50.000	
32	7.100000	6.600000	XN	UV	var1_1550_flipped		EXPOSURE	50.000	50.000	
33	7.100000	6.600000	XN	UV	75um		EXPOSURE	50.000	50.000	
34	7.100000	6.675000	XN	UV	var1_1550		EXPOSURE	50.000	50.000	

*Nate Coirier

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eBeam Resists

Electron Beam Lithography has benefited greatly with improvements in the quality and process capability in resist materials.

This has enabled lithographic patterning into the sub-50 nm regime, often to single digit nanometer structures.

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Positive Resists

- **Positive tone "What exposed Goes!"**
- Upon exposure to Electron beam the polymer chains are cut and become more soluble in solvents.

Available at NUFAB

- Poly Methyl Methacrylate (PMMA) 990 A5, A2
- ZEP-520A

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High resolution positive resist

Single Layer 2 – 5 % 950K PMMA in Anisole

- Most users process at 60 to 300 nm thicknesses…
- **High resolution with moderate sensitivity**
- **Wide process latitude** with control of contrast curve using various developer concentrations. Responsive to different processing methods by time or temperature during develop
- **Great adhesion** to anything, but **not a good RIE mask**

Tips for New Users:

- Start with PMMA for initial test and then scale dose to other resist materials as you determine optimal exposure parameters for your devices
- Make a metal mask via lift off for RIE etch processes

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High resolution positive resist

Zeon Corp. ZEP-520 in Anisole

- I recommend using 100 to 250 nm Thin Film Thickness
- **High Sensitivity** and **High Contrast**
- **Sensitive to processing conditions** make it more difficult to work with for new and experienced users alike.
- **Adhesion** to Oxides, Nitrides, and most Glasses can be challenging
- **Not good for Lift Off -** Poor undercut at 50 kV
- **Excellent** Reactive Ion Etch (RIE) **Selectivity**, but avoid using O_2

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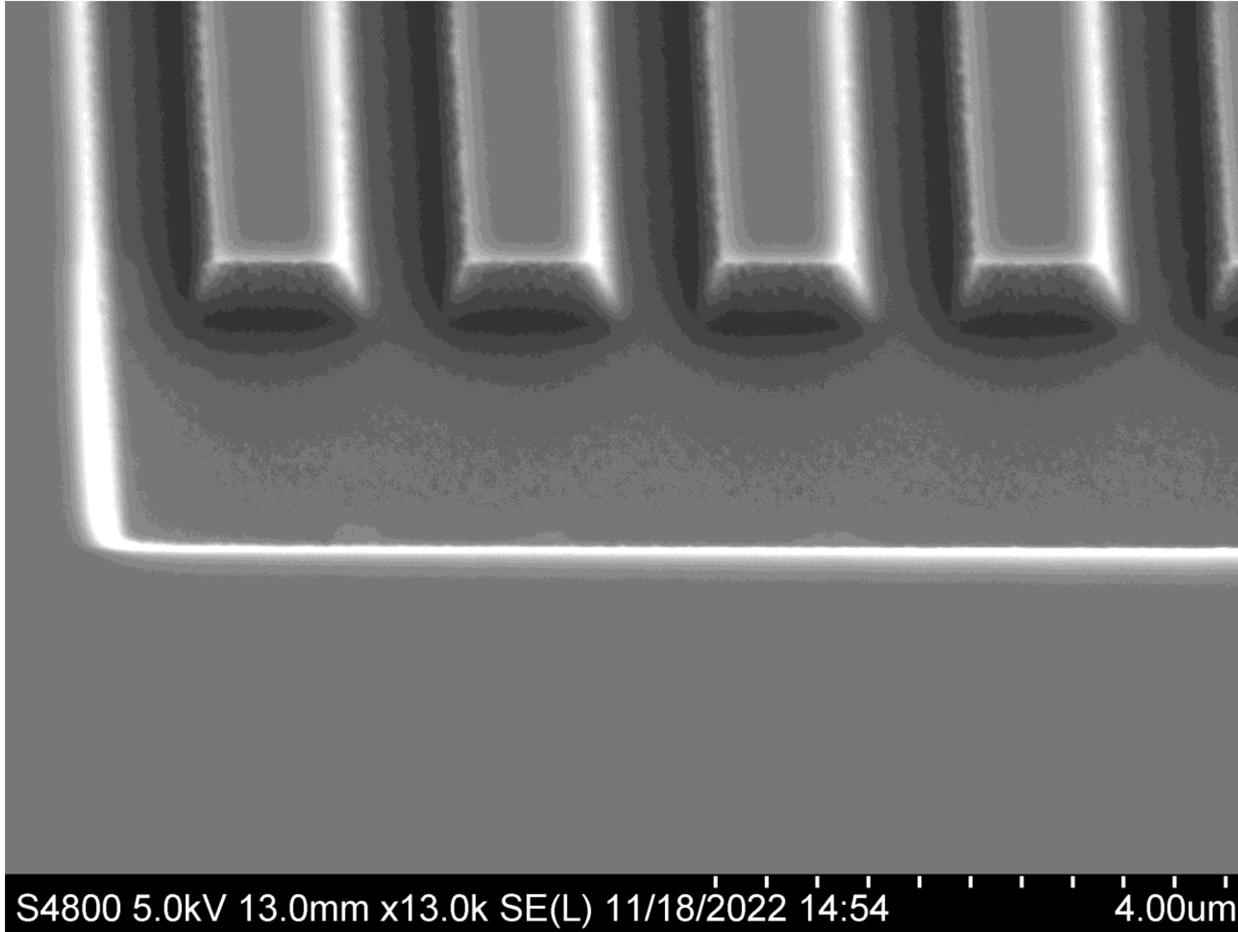

ZEP 520 200 nm
DRIE etch >400 nm deep

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Negative Resists

- **Negative Tone: “What exposed stays”**
- During exposure, the polymer chains cross link and become resistant to the developer, often strong bases, and remain on the wafer. Unpatterned areas wash away during development processing.

Available at NUFAB

- nLOF 2035 – diluted
- HSQ

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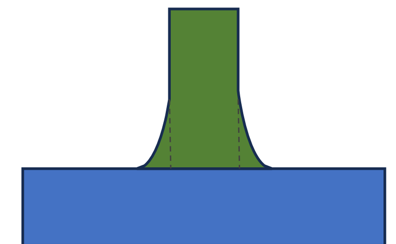
nLOF2035

- Negative photoresist that works well in EBL
- Needs dilution (SU8 developer)
- Cheap and available
- Good RIE resistance

- It is very sensitive to eBeam exposure – hard to do high resolution patterning <200nm



Prone to scum and skirting

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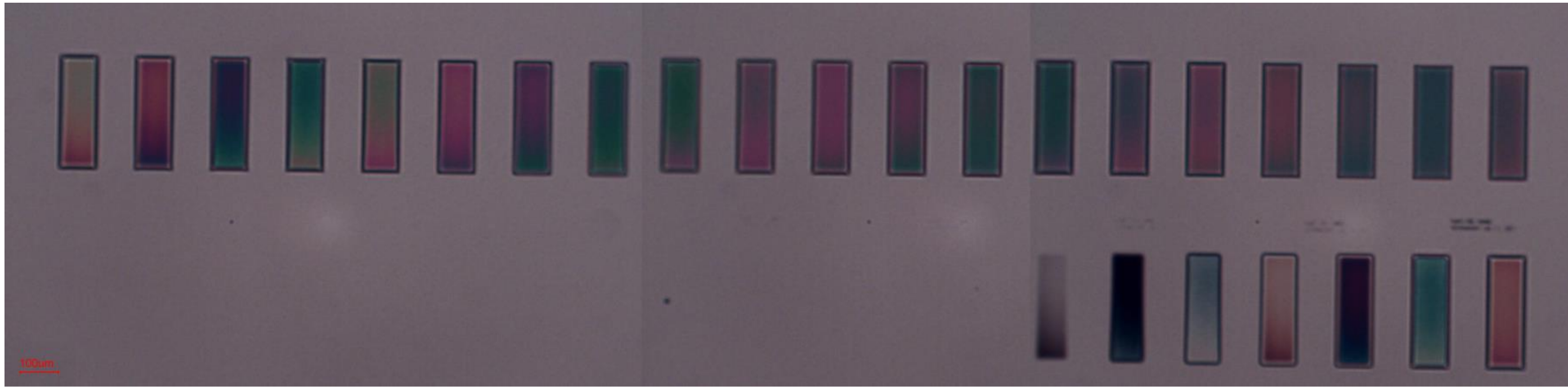
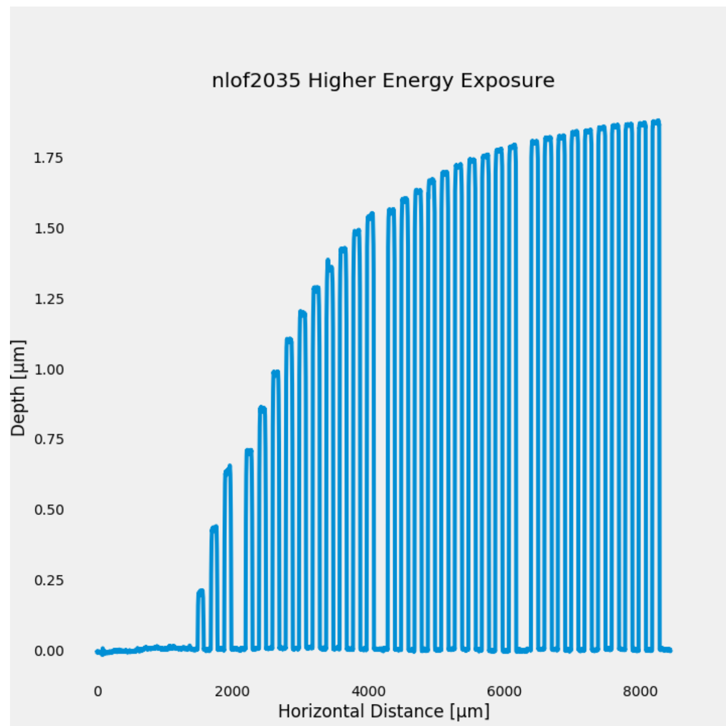
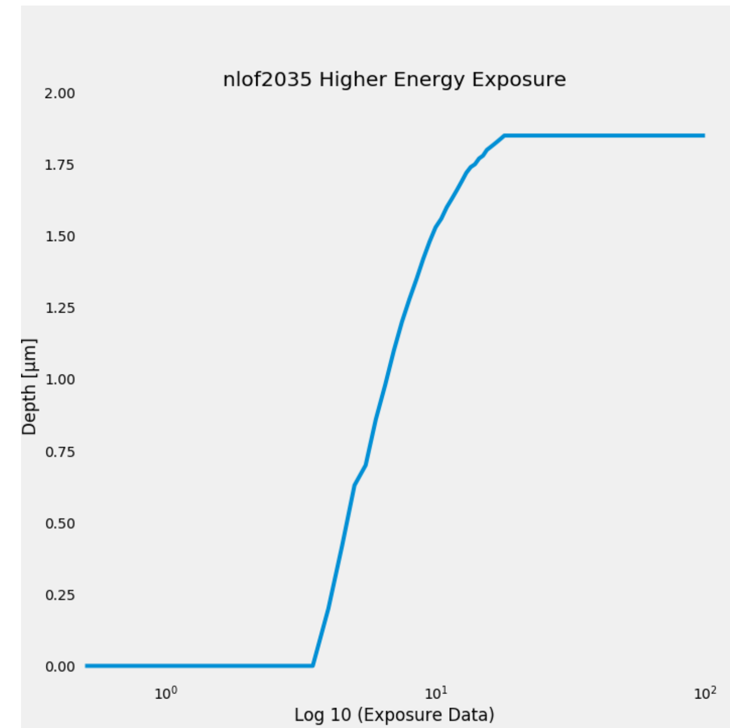
Contrast curves







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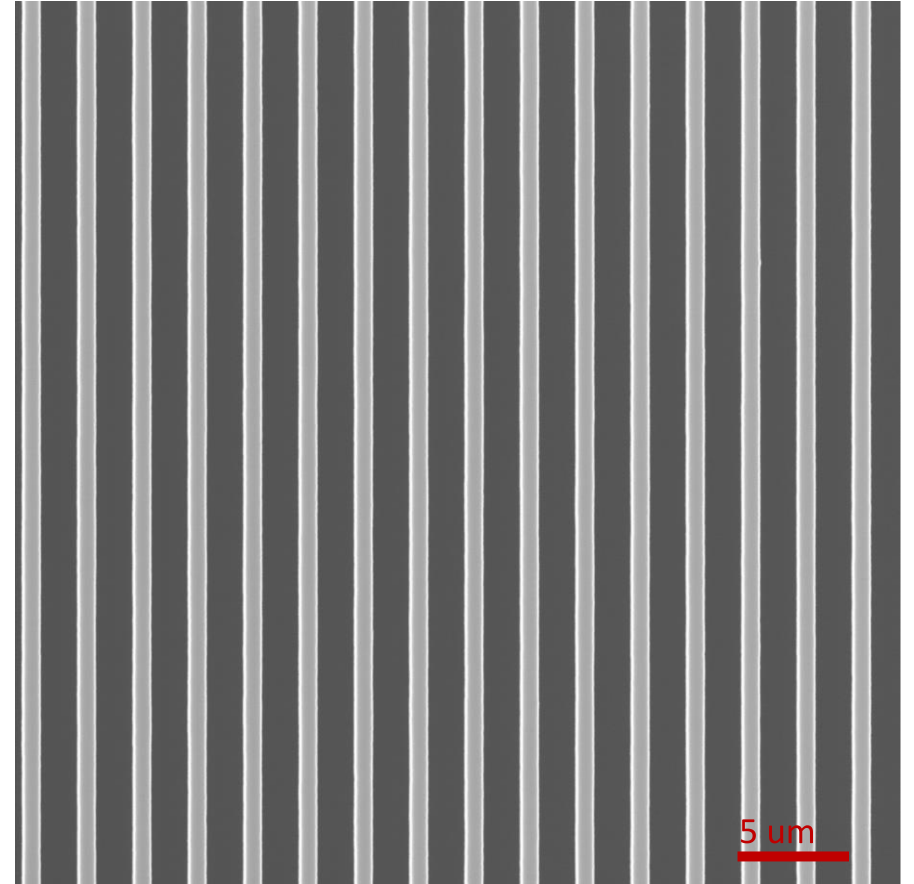
To achieve quality results, consider these:

- Substrate Preparation and Cleaning.
- Resist Thin Film Application
- Exposure Parameters
- Development Technique
- Pattern Inspection / Metrology
- Pattern Transfer



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Cleaning is essential for sample to sample consistency

- **Silicon wafers**, esp. with Oxides, Nitrides, Quartz and Glasses: Solvents/Nanostrip/O2plasma or to remove organics, HF dip to remove native oxides, and metallic (ionic) contaminates. Skip the oxide strip on Quartz and Glasses.
- **Group III/V and II/VI substrates: combination of solvent cleans followed by a short acid or base dip and DI water rinse and dry.**
  e.g., Nanostrip or 100:1 NaOH:DI water, then Spin Rinse Dry.
- **2DEG materials, Graphene / Metal Dichalcogenides are fragile, just spin on your resist to protect films from the environment.**
- **After Cleaning consider dehydration bake.**
- **Tips for New Users:** Clean your wafers immediately before coating.

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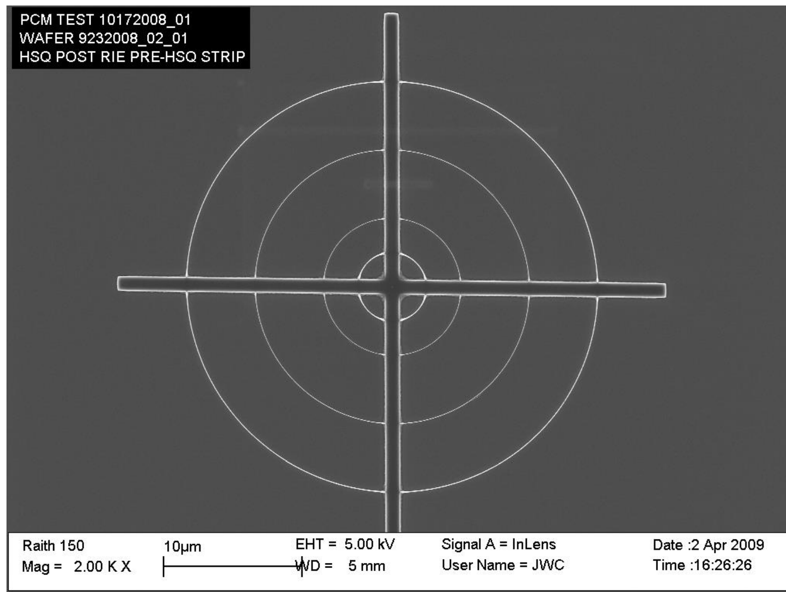
Consider including QC patterns with your designs

- Focus and stigmator check targets
- Contrast curve patterns
- Stitch and overlay accuracy patterns



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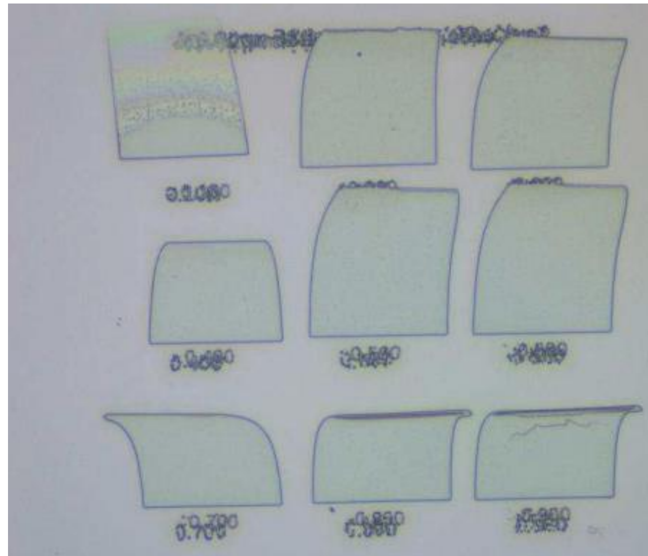
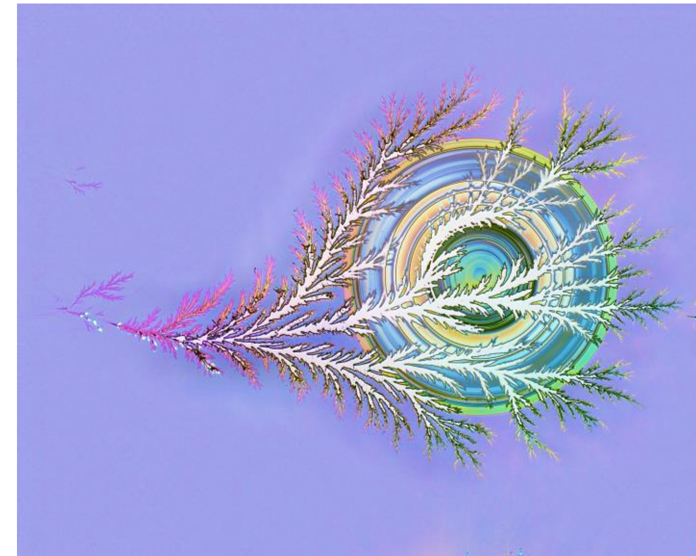
Insulating substrates





Use charge dissipation layers
NUFAB offers **DischargeH2O** – a water soluble conductive polymer
Very effective up to 1 nA beam current

5-8 nm Au deposition on the resist also works great!

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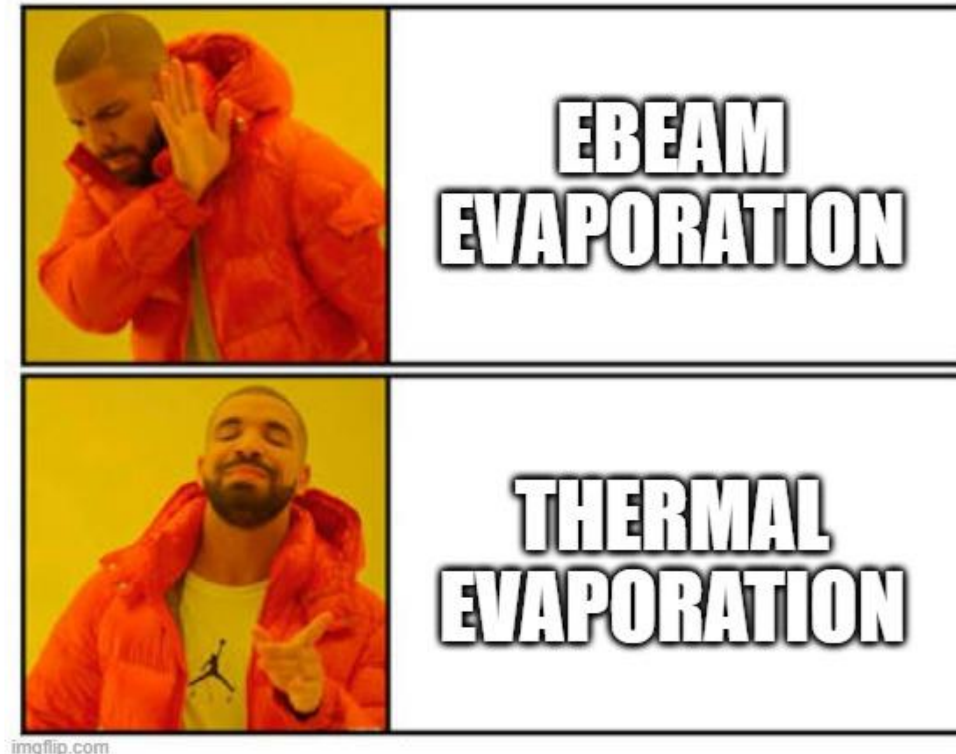
Lift off issues

Ebeam Evaporation is not ideal
Bremsstrahlung Radiation (xrays) crosslinks PMMA makes it difficult to strip

Consider Thermal Evaporation instead

Put icepacks over the Thermal evaporator to keep the sample cool



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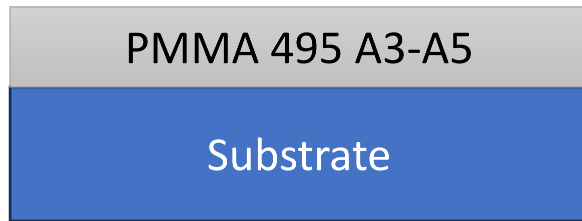
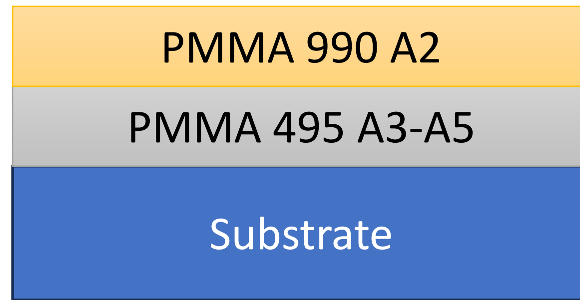
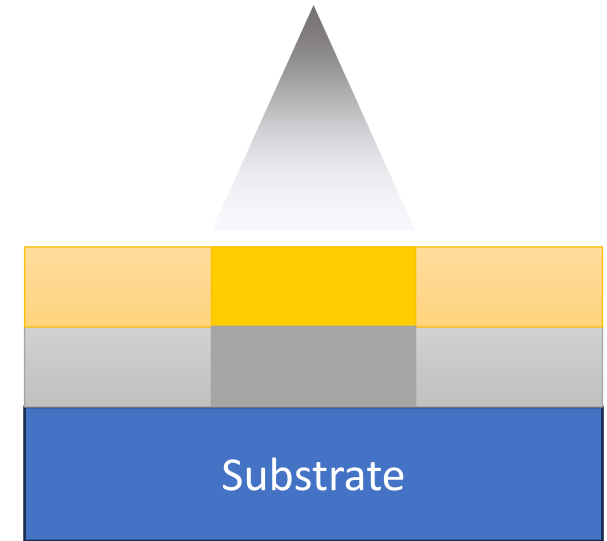
Positive Bilayer for lift off process



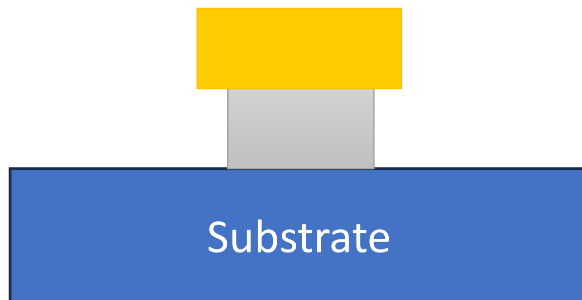
Spin 1



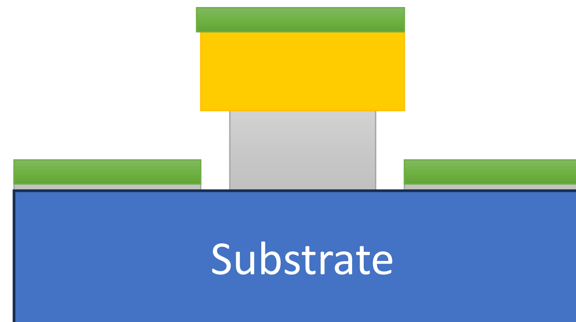
Spin 2



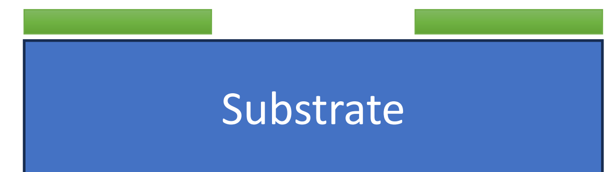
EBL



Develop



Metal dep



Lift off

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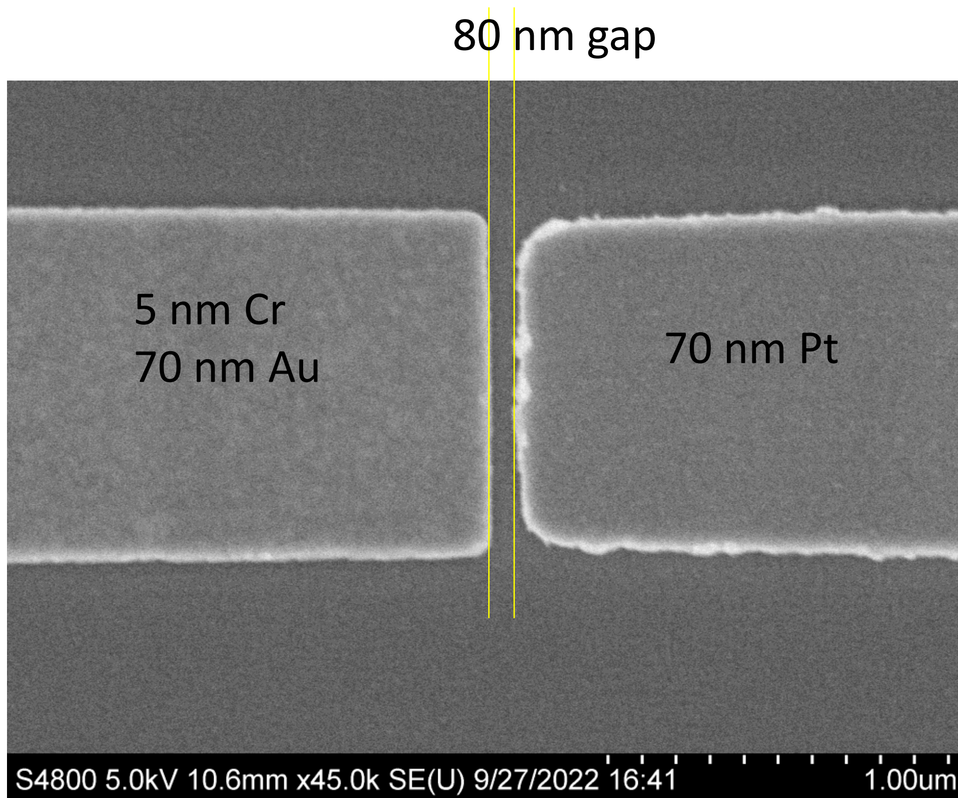

PMMA 990 A2
2000 RPM – 180C for 90s

PMMA 495 A3
2000 RPM – 180C for 90s

LTO substrate

Develop
MIBK:IPA 1:3
Room temperature 90 s

Ebeam evaporation for metals

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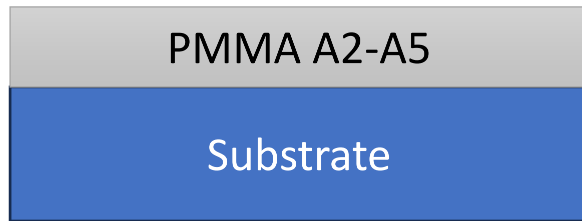
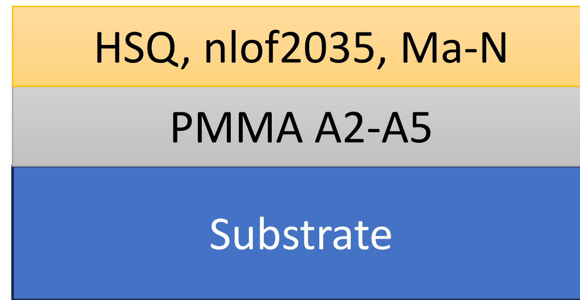
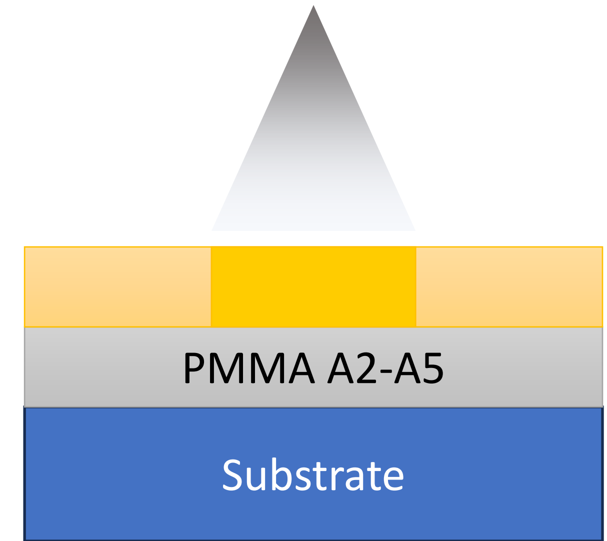
Negative Bilayer process



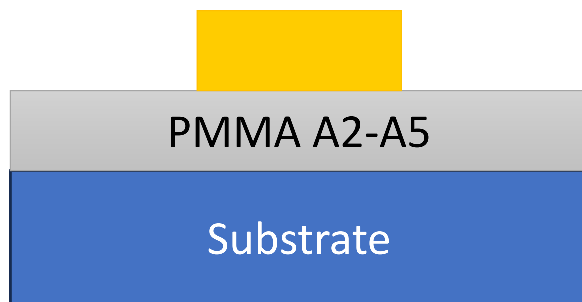
Spin 1



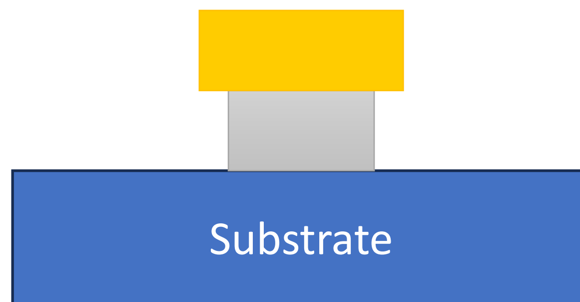
Spin 2



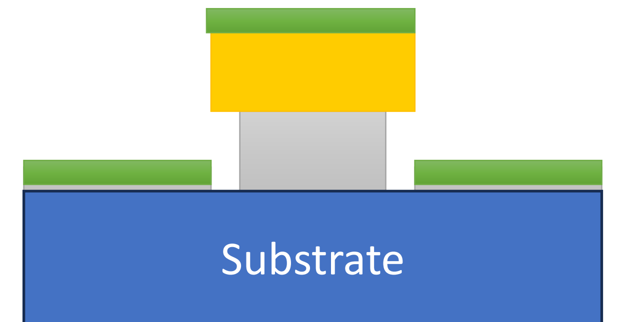
EBL



Develop



O2 plasma



Metal dep and Liftoff

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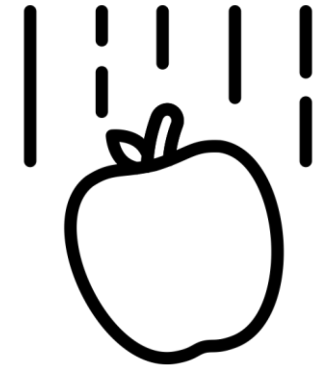
If I’ve seen further, it’s by standing on the shoulders of giants.

I. Newton

Leverage the expertise of James Conway



James Conway
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James.Conway@raithamerica.com

Office Hours: Tuesdays, Wednesdays, and Fridays from 9:30 AM to 10:30 AM PST"

Thank you!

Questions?

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