eBeam Lithography at NUFAB

NUANCE Tech Talk Series
Serkan Butun

*250 nm brick pattern
The NUANCE Center
www.nuance.northwestern.edu
(Tech, Silverman, Hogan, Cook | Northwestern University)

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Electron Probe Instrumentation Center
SEM, TEM, FIB, EDS, EELS, EBSD, eBL, sample prep
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Keck Interdisciplinary Surface Science
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Northern University Atomic and Nanoscale Characterization Experimental Center
Exploring Inner Space
NUFAB Tech FG70 and Cook 4026

Class 100 Clean Room Facility
Quantum Devices, Biomechanical Devices, Electronics, Semiconductor Fabrication, MEMS, NEMS, Plasmonics, Metamaterials, and more ….
Metalens, 2 mm diameter, Al liftoff on Glass
I Tanriover, Aydin Group

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

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

Waveguide Launcher, N Coirier, Mohseni Group
Minimum line width, periodicity
In this talk...

- EBL background

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

NUFAB
NORTHWESTERN UNIVERSE
MICRO/NANO FABRICATION FACILITY

300 nm

NUANCE
Nano and Materials
Characterization Experimental Center

0.5 mm
What is eBeam Lithography

- Patterning with electrons.
- Allows patterning sub 10 nm scale
- Serial process – patterns are exposed pixel by pixel
Raith Voyager 100

- 3 nm beam size
- 50 kV column
- 20 bit 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

Step size

Line spacing

What EBL exposes
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
Raith Circle  

Polygon
Effect of accelerator voltage

500 nm PMMA

10 kV

50 kV

Si

Better undercut

Collapsing

Better resolution
Two writing techniques

Stitch and go
Most common

FBMS
Long interconnects
Waveguides
FBMS examples

3 mm across
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
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 (gdstoolkit, ezdxf)

I do not recommend using AutoCAD and dxf files!
Scripting - gdstk
Raith_GDSII package by Univ of Alberta

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

*Nate Coirier
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.
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
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
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

- **Excellente** Reactive Ion Etch (RIE) **Selectivity**, but avoid using $O_2$
ZEP 520 200 nm
DRIE etch >400 nm deep
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
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
Contrast curves
To achieve quality results, consider these:

- Substrate Preparation and Cleaning.
- Resist Thin Film Application
- Exposure Parameters
- Development Technique
- Pattern Inspection / Metrology
- Pattern Transfer
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.
Consider including QC patterns with your designs

- Focus and stigmator check targets
- Contrast curve patterns
- Stitch and overlay accuracy patterns
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!
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
Positive Bilayer for lift off process

PMMA 495 A3-A5 - Substrate
Spin 1

PMMA 990 A2
PMMA 495 A3-A5 - Substrate
Spin 2

EBL

Substrate

Substrate

Substrate

Develop

Metal dep

Lift off
5 nm Cr
70 nm Au

80 nm gap

70 nm Pt

PMMA 495 A3
2000 RPM – 180°C for 90s

PMMA 990 A2
2000 RPM – 180°C for 90s

LTO substrate

Develop
MIBK:IPA 1:3
Room temperature 90 s

Ebeam evaporation for metals
Negative Bilayer process

Spin 1

PMMA A2-A5
Substrate

Spin 2

HSQ, nlof2035, Ma-N
PMMA A2-A5
Substrate

EBL

Develop

PMMA A2-A5
Substrate

O2 plasma

Metal dep and Liftoff

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

Leverage the expertise of James Conway

James Conway
Raith Senior Application Scientist
James.Conway@raithamerica.com

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

Questions?