

Marker-Free Direct-Write Patterning of Transmon Chip

Onri Jay Benally

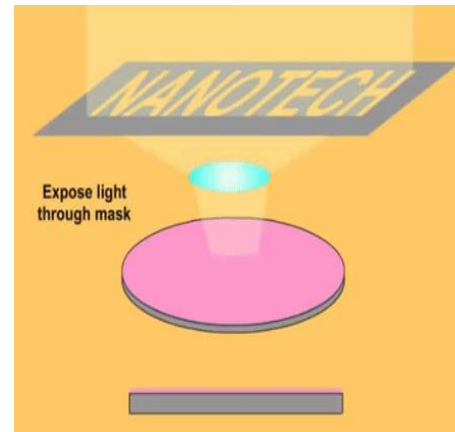
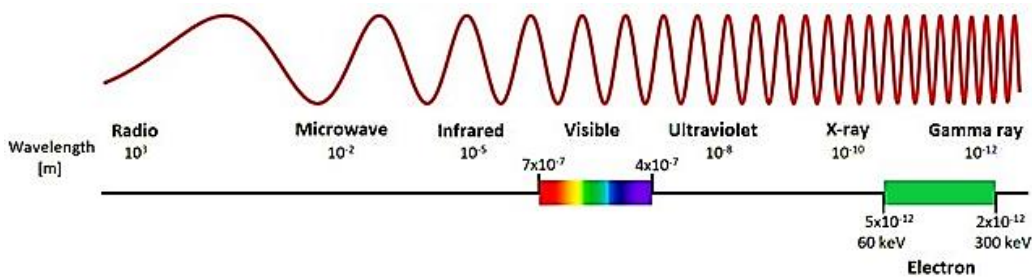
University of Minnesota

Department of Electrical & Computer Engineering

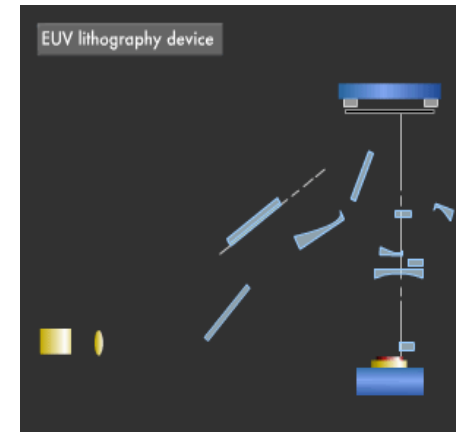
Principal Investigator: Prof. Jian-Ping Wang

Background

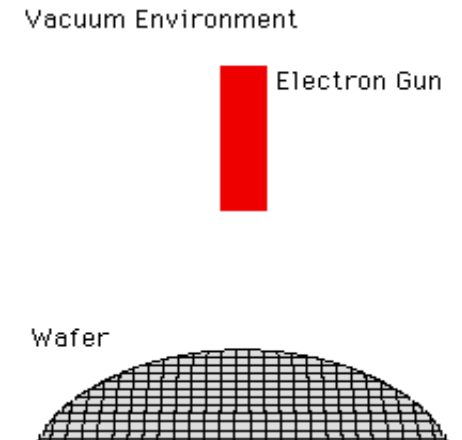
- Conventional optical lithography = **ultraviolet photon** exposure.
- Electron beam lithography = **electron** beam exposure.
- Ultimately, the *wavelength* of the energy being applied to a resist coating determines the feature size.
- It's possible to obtain 3-5 nm resolution with electron-beam lithography
 - Depends on your skill level (abstract).



**Maskless Ultraviolet
Lithography**



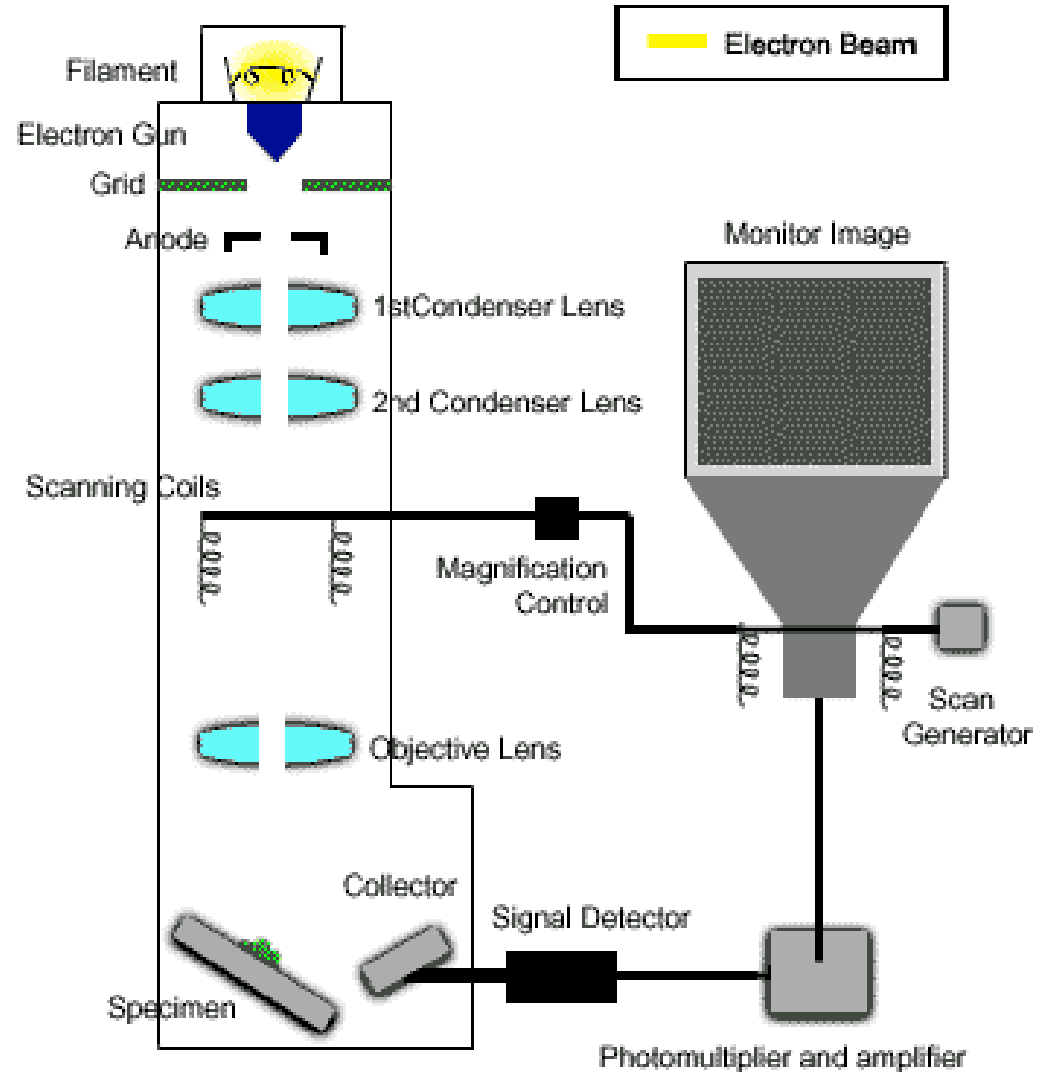
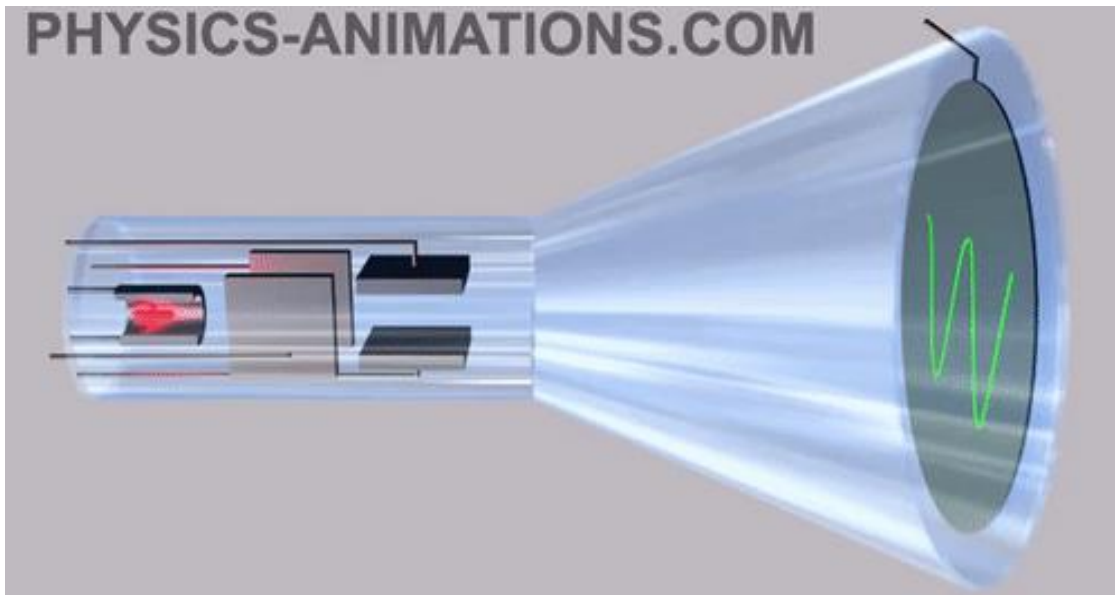
**Maskless Extreme
Ultraviolet
Lithography**



**Maskless Electron
Beam Lithography**

1. Venturi, *PhD Thesis* (2017)
2. Taken from: thumbs.gfy.com
3. Taken from: *Wikimedia Commons*

Bonus: Basic Operating Principle of Electron-Beam-Based Technology



Equipment Advantages & Disadvantages

- **Advantages:**

- Relatively high-resolution lithography.
- Maskless procedure allows for indirectly importing AutoCAD drawings.
- Fast design modification.
- Vacuum environment leads to better control of contamination.
- Markers can be avoided.

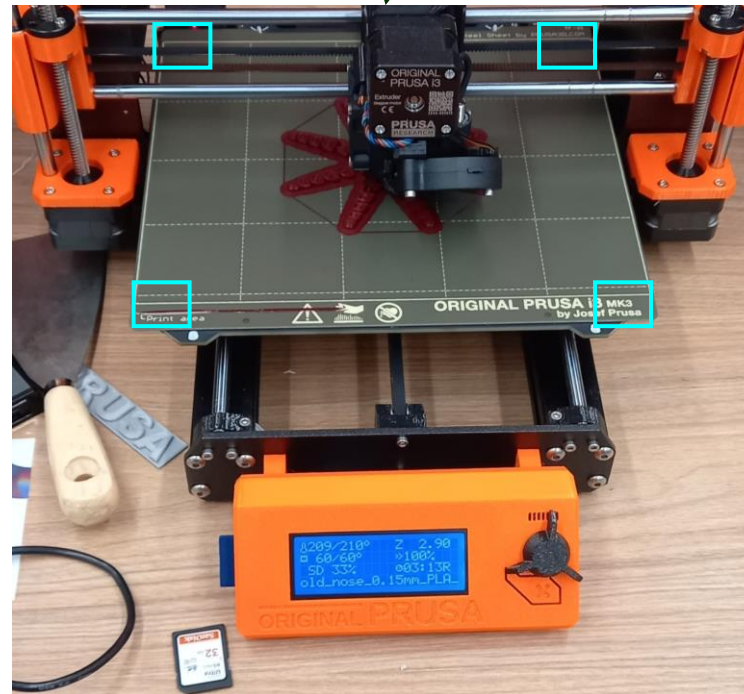
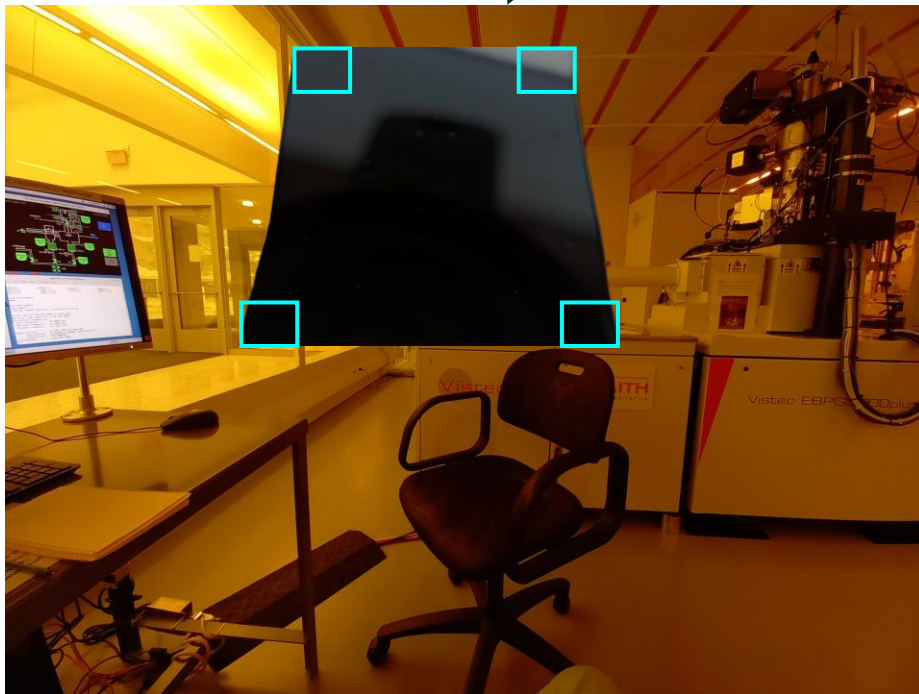
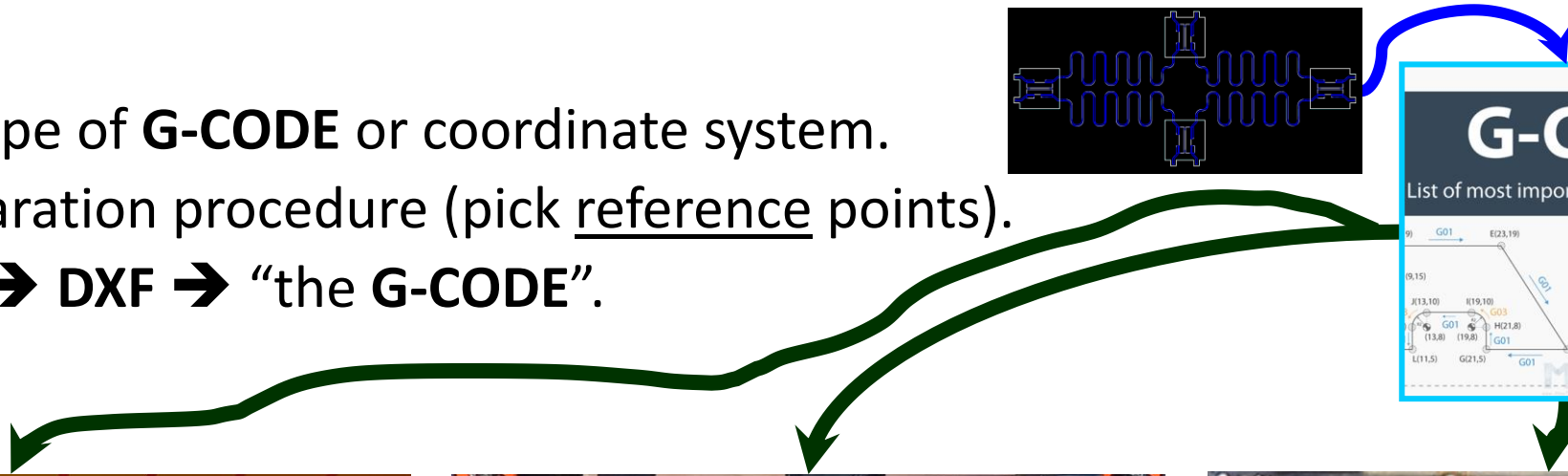
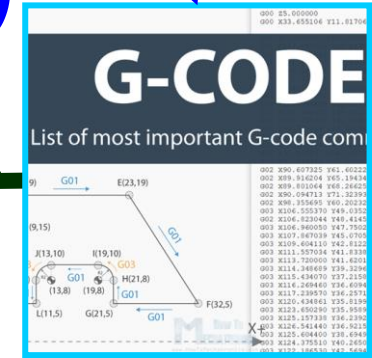
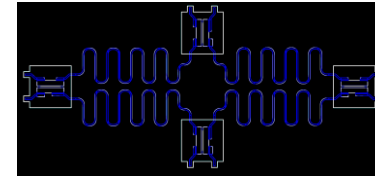
- **Disadvantages:**

- Vacuum environment required.
- Charge build-up, even during SEM inspection.
- Low throughput.
- Proximity effects.

E-Beam vs. 3D Printing vs. CNC Machining

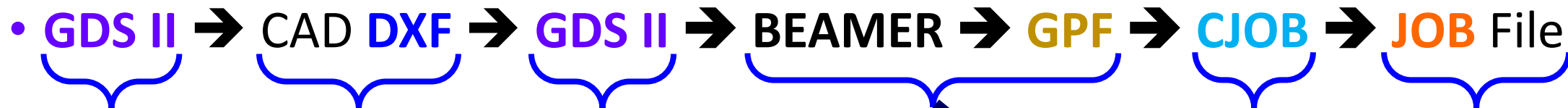
- Similarities:

- Uses of a type of **G-CODE** or coordinate system.
- Initial preparation procedure (pick reference points).
- CAD **DWG** → **DXF** → “the **G-CODE**”.



Design Process Flow to Test Pattern Quality

- Design file conversion is a bit extensive.



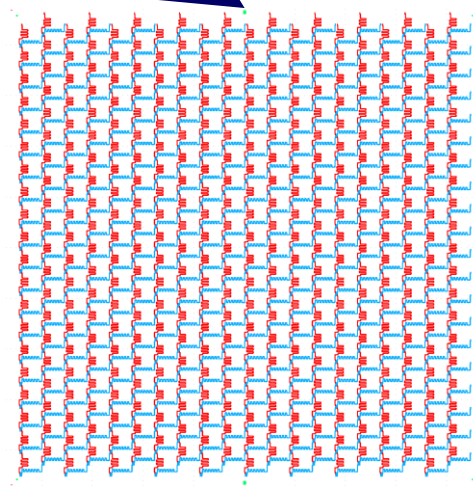
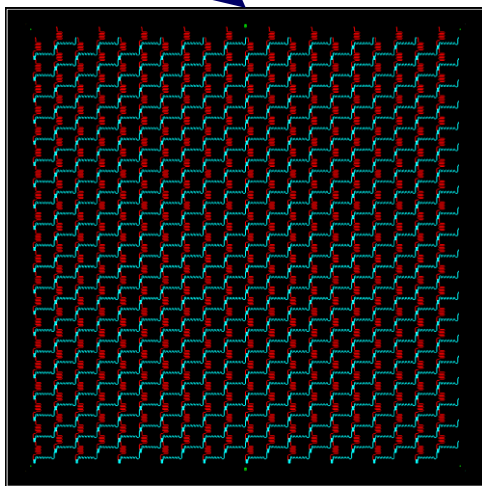
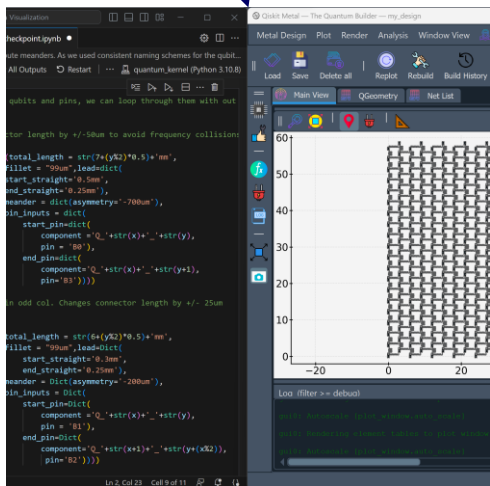
Export GDS file from Qiskit Metal.

For modifiable polygons & layer separation. (Pattern editors allow GDS-to-DXF conversion & some degree of layer separation).

At this point, each layer should be labeled based on their feature sizes, ready for lithography software.

Additional Parameters (dosage, sub. size, etc.)

During final setup, machine actually uses this one.



Maskless Direct Writing Using “Joyplus”

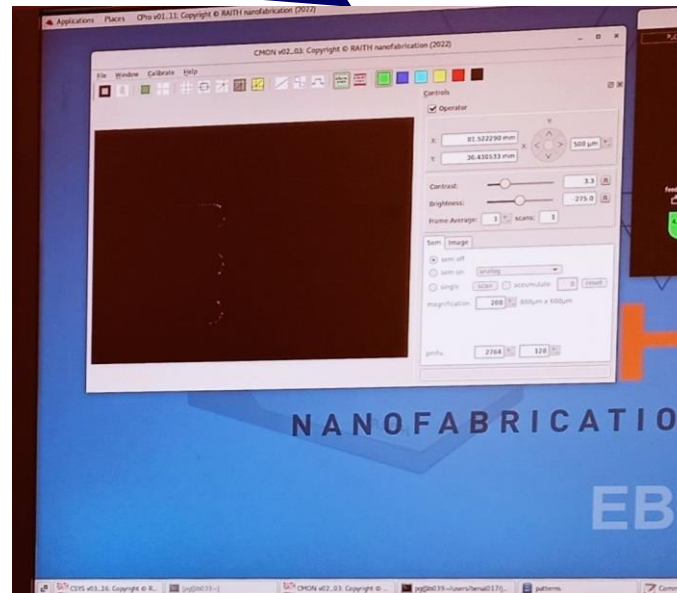
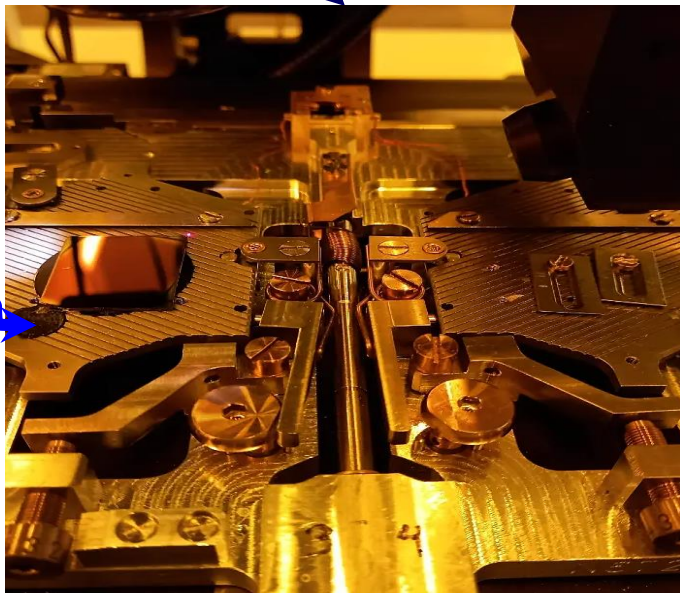
- Doses:
 - For relatively larger features (**pads & stripes**): $450 \mu\text{C}/\text{cm}^2$.
 - For smaller features (**pillars & junctions**): $825\text{-}875 \mu\text{C}/\text{cm}^2$.

- Basically:

- Locate 4 Points → SEM-Aided ‘Marker’ Location → Record Final Marker Position → **Confirm & Write!**

Confirm
&
Write!

Conductive carbon tape

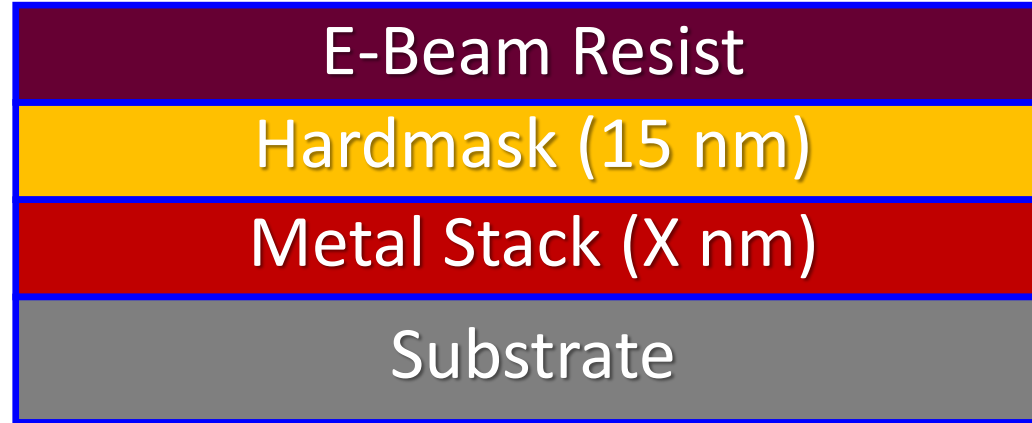


```
joyplus >> follow prompt to center  
desired marker locations on SEM  
window.  
pg move (coordinates, e.g.  
85754.200,121167.850) - (remember  
to press Enter and not q).  
  
job OJB_400_Qubits.job 3 0  
83174.000,49980.000  
101201.000,49980.000  
83174.000,31948.000  
101201.000,31948.000 #this is an  
example.
```

Basic Flow Summary of “Joyplus” for E-Beam

- Enter relative coordinates >> locate desired marker reference points >> record real coordinates found >> enter (pg move position) of real coordinates >> type (joyplus) >> confirm real coordinates of marker locations by inspecting SEM scan >> press Enter.
- You may now continue with job file locations and other parameters for stage selection >> copy-paste job command into terminal >> press Enter >> watch 1st few steps of exposure >> Done!

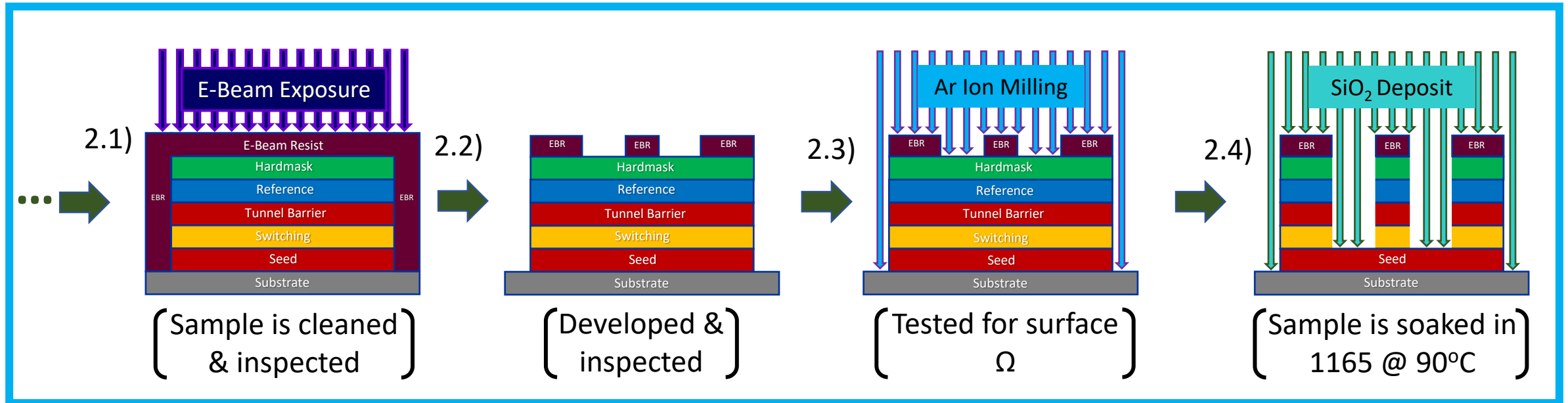
Stack Composition



**Sample can contain any stack
(deposited on substrate)
for hardmask testing purposes**

Hardmask layer can help reduce dimension size or increase the density of device drive lines & other fine features as needed.

Generic E-Beam Patterning Flow for Tunnel Junction



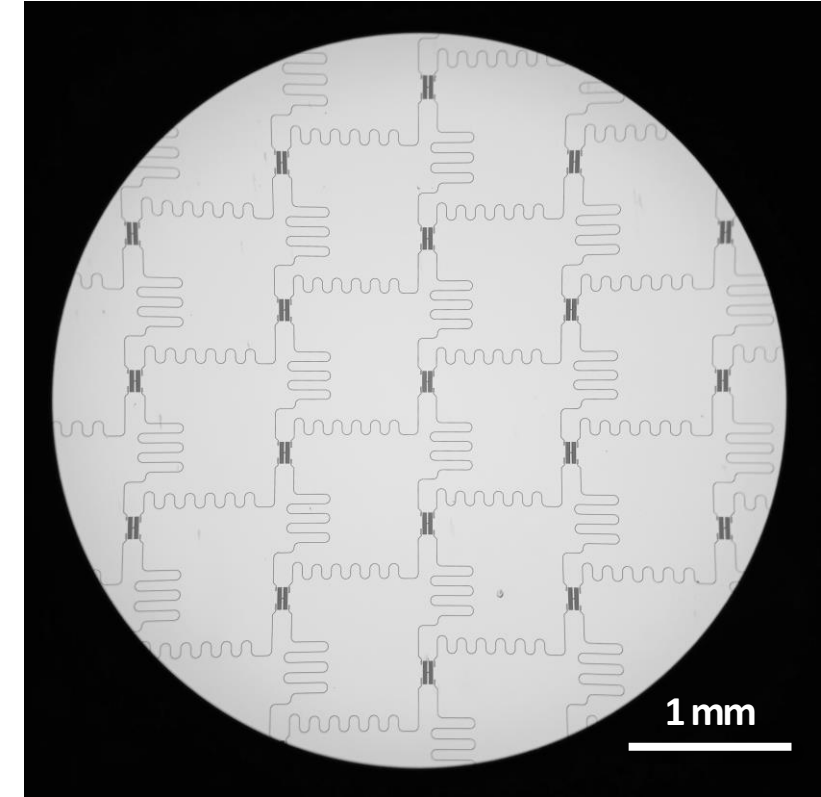
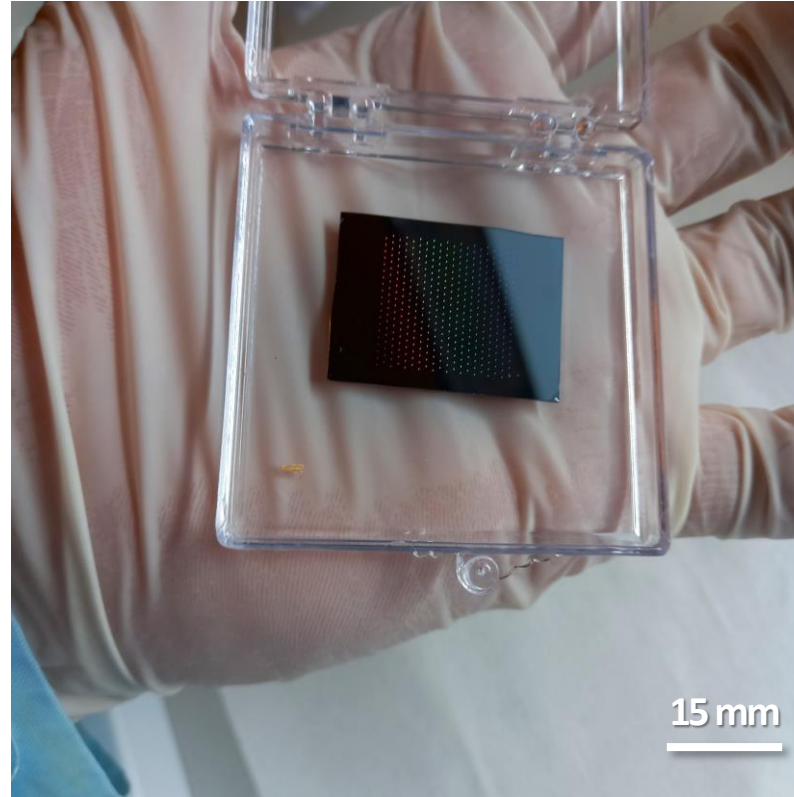
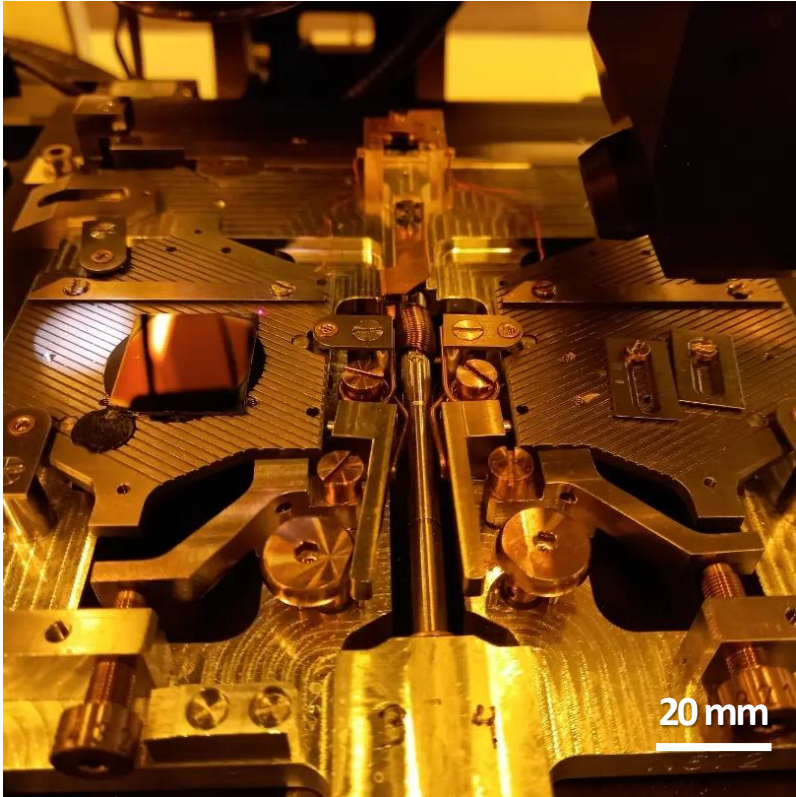
Here, the seed layer doubles as an adhesion layer

PR: Photoresist
 Ω : Resistance

EBR: Electron-Beam Resist
1165: Strong Solvent

* For more details on basics of thin films for quantum chips, see "Onri's_Quantum_Hardware_Tutorial_Part_2_of_5" on GitHub.

Results



On the sample holder, conductive carbon tape is used to stick sample to grounded metal to prevent charge build-up. Charge build-up deflects the electron-beam & causes undesired patterns on the chip.

Results (Continued)

