Marker-Free Direct-Write Patterning of Transmon Chip

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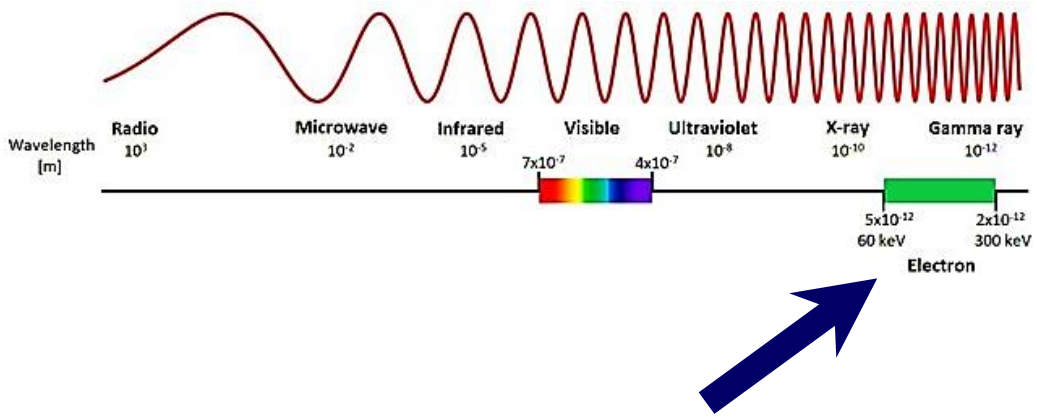
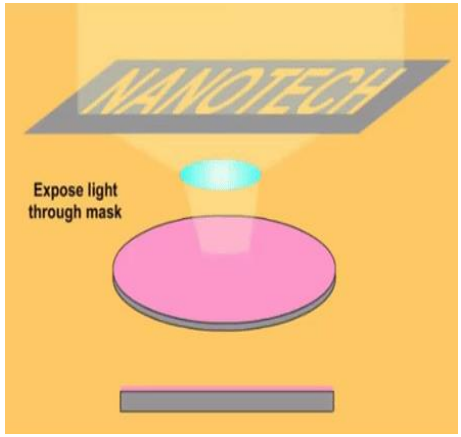
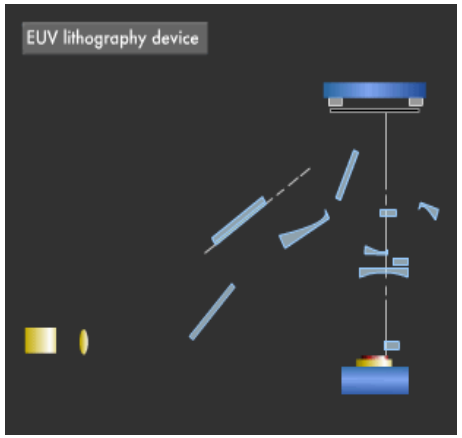
Background

- 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).

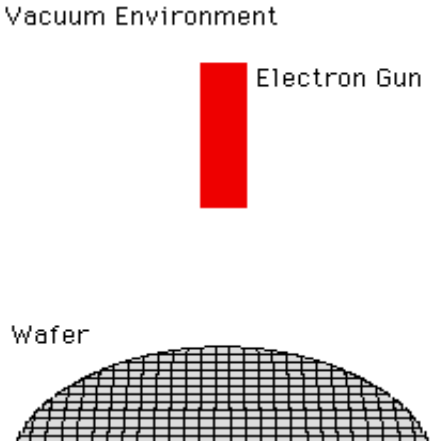




Maskless Ultraviolet Lithography



Maskless Extreme Ultraviolet Lithography



Maskless Electron Beam Lithography

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

Equipment Advantages & Disadvantages

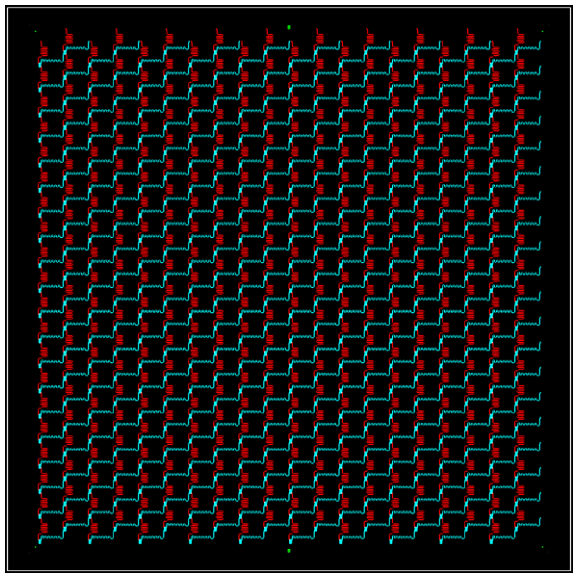
- Advantages:
  - Relatively high-resolution lithography.
  - Maskless procedure allows for indirectly importing AutoCAD drawings.
  - Fast design modification.
  - Vacuum environment leads to better control of contamination.
  - Markers can be avoided
- Disadvantages:
  - Vacuum environment required.
  - Charge build-up, even during SEM inspection.
  - Low throughput.
  - Proximity effects.

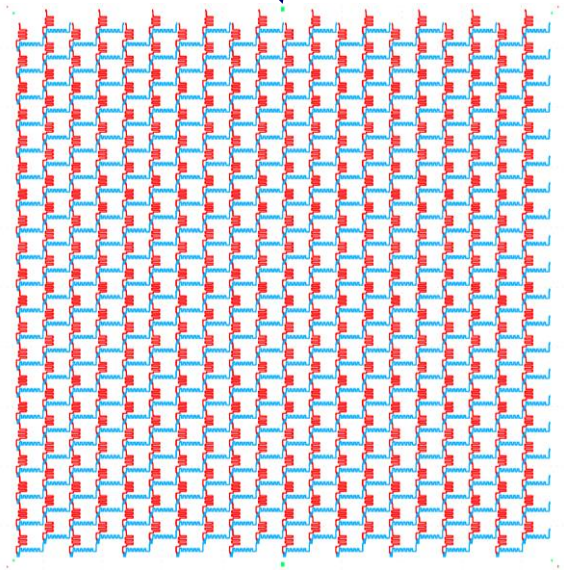
Design Process Flow to Test Pattern Quality

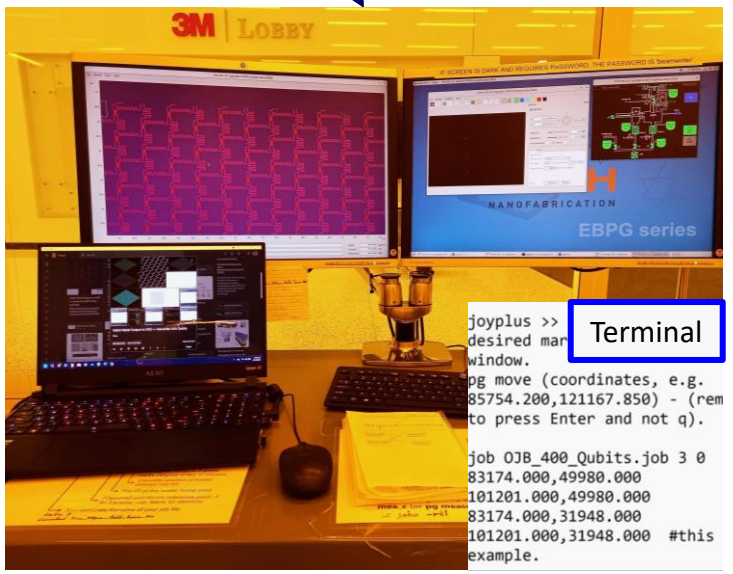
- Design file conversion is a bit extensive.
- CAD **DWG** → **DXF** → **GDS II** → **BEAMER** → **GPF** → **CJOB** → **JOB File**

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

During final setup, machine actually uses this one.



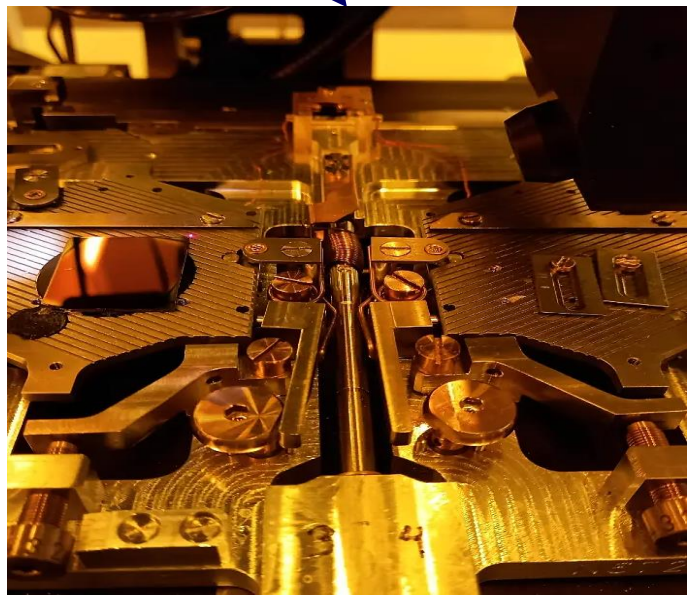


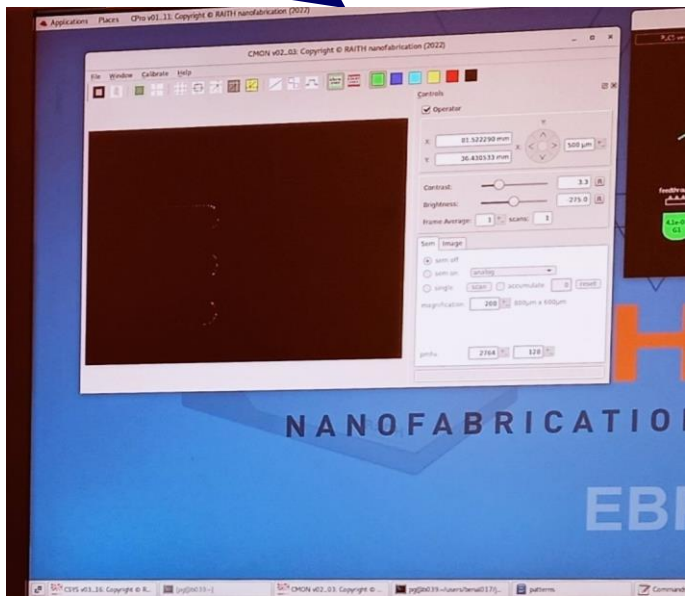


Maskless Direct Writing Using “Joyplus”

- Doses:
  - For relatively larger features (**pads** & **stripes**): 450 µC/cm^2.
  - For smaller features (**pillars**): 825-875 µC/cm^2.
- Basically:
  - Locate 4 Points → SEM-Aided ‘Marker’ Location → Record Final Marker Position → Confirm & Write!

(joyplus)





Terminal

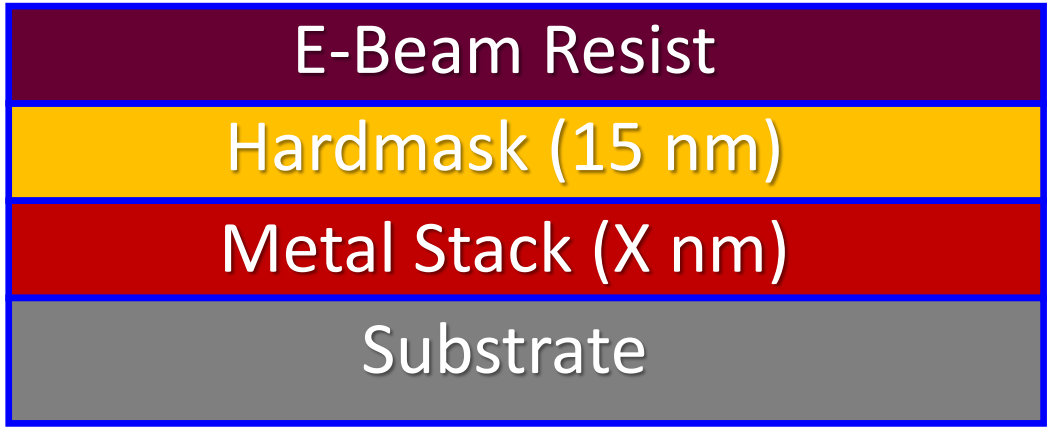
```
joyplus >> follow prompt to select
desired marker locations on SEM
window.
pg move (coordinates, e.g.
85754.200,121167.850) - (remember
to press Enter and not q).

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 teminal >> press Enter >> watch 1st few steps of exposure >> Done!

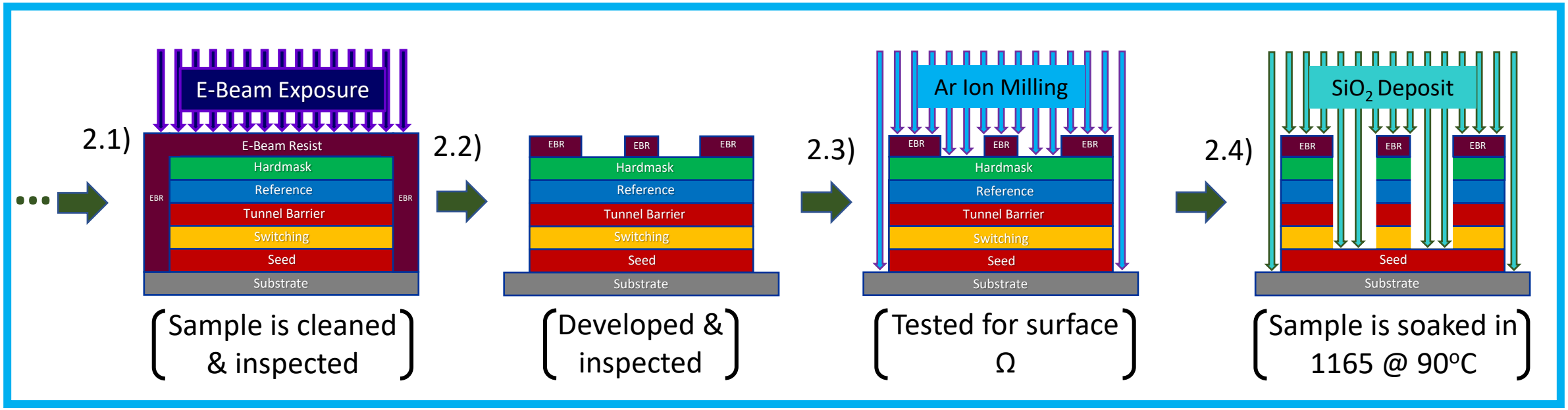
Stack Composition



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

Hardmask layer will help us reduce or increase the density of device drive lines & other fine features as needed.

Generic E-Beam Patterning Flow for Tunnel Junction

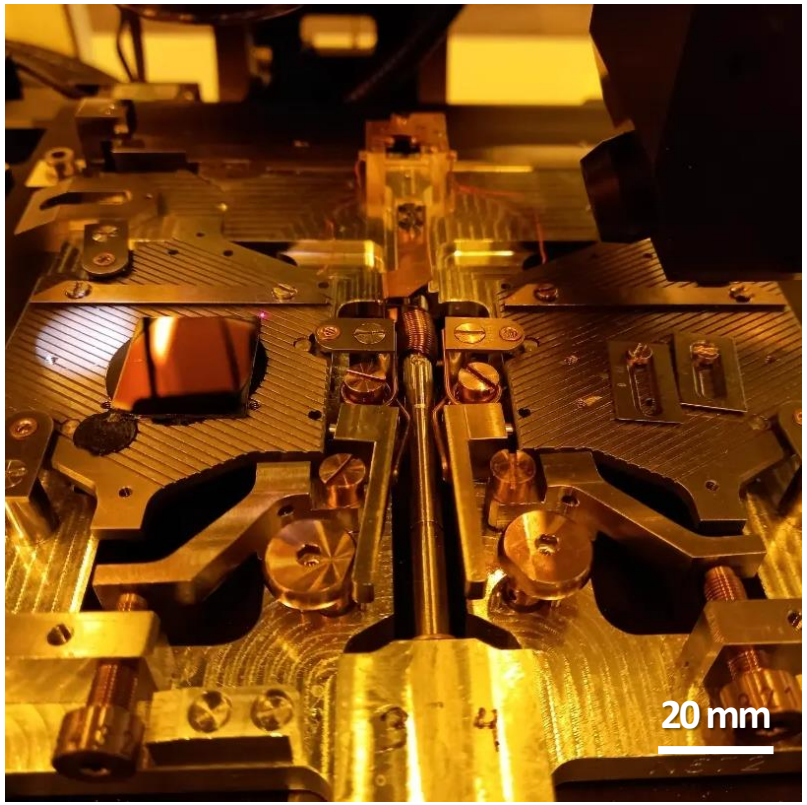


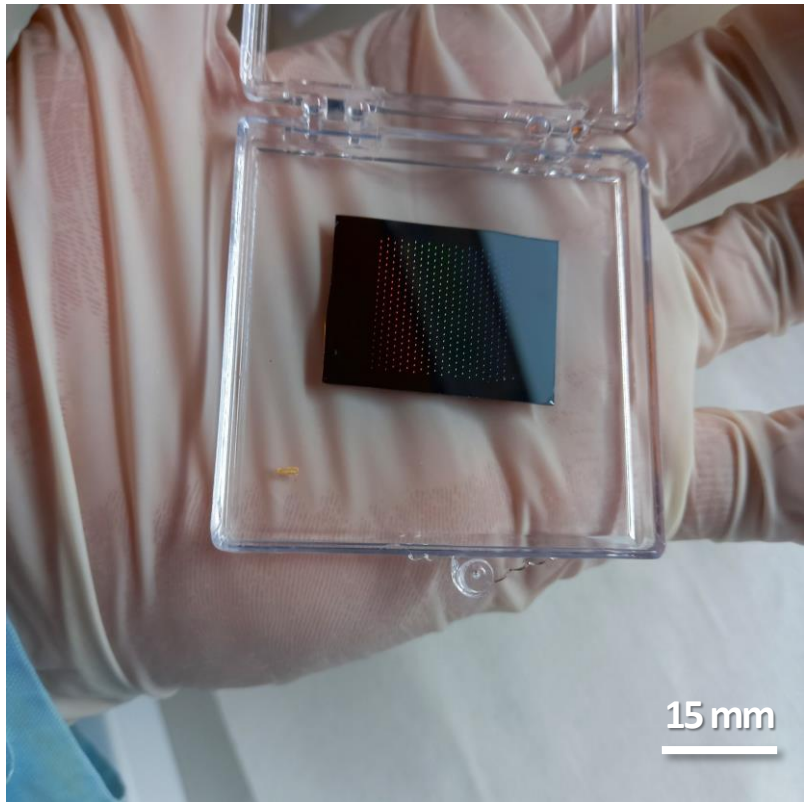
Seed layer doubles as an adhesion layer

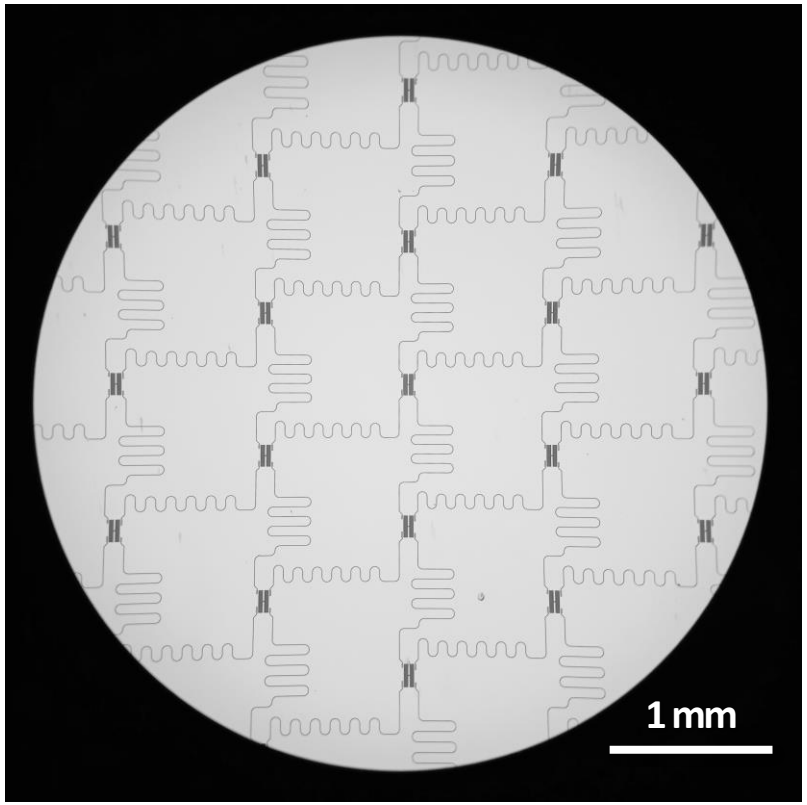
PR: Photoresist
Ω: Resistance

EBR: Electron-Beam Resist
1165: Strong Solvent

Results







On the sample stage, carbon tape is being used to

Results (Continued)