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

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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 <u>skill level</u> (abstract).
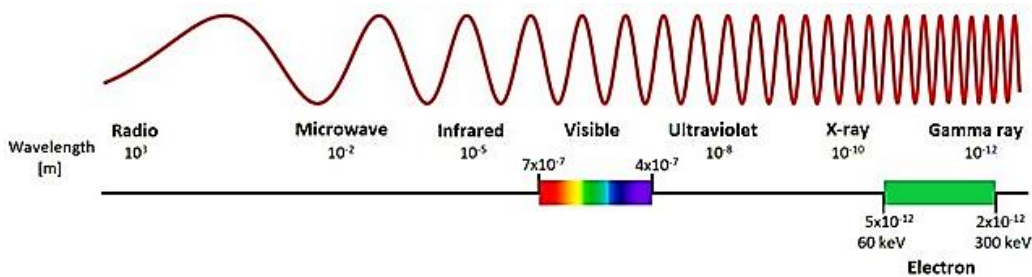
Maskless Ultraviolet Lithography
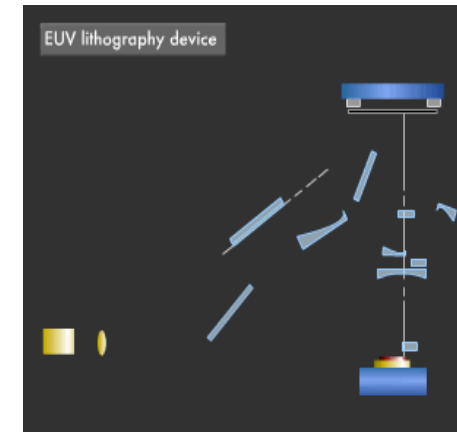
Maskless Extreme Ultraviolet Lithography
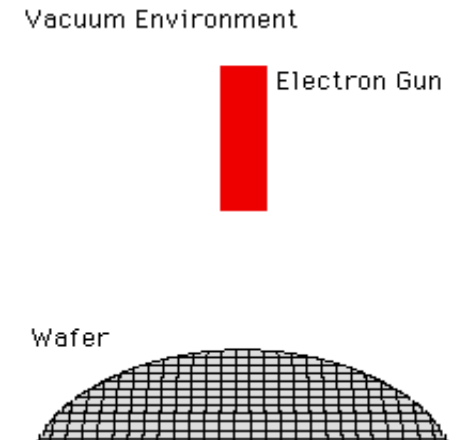
Maskless Electron Beam Lithography

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

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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.

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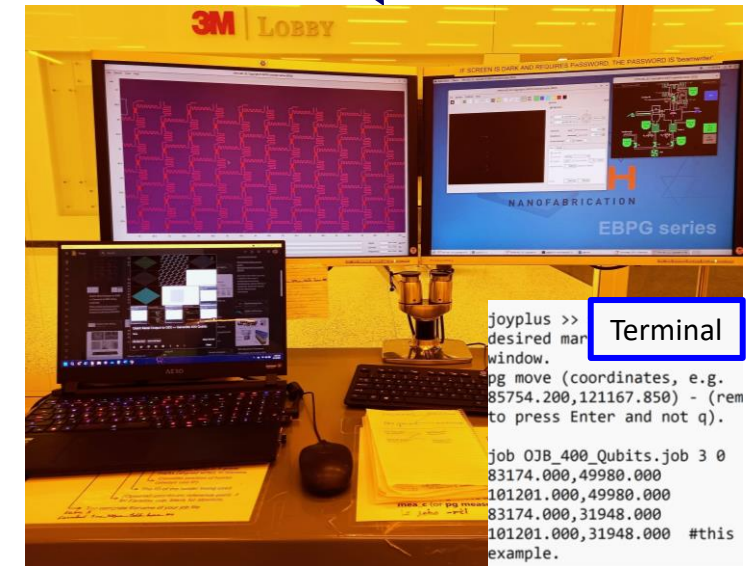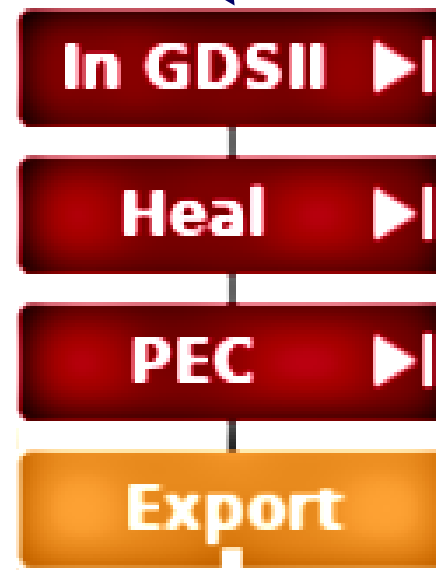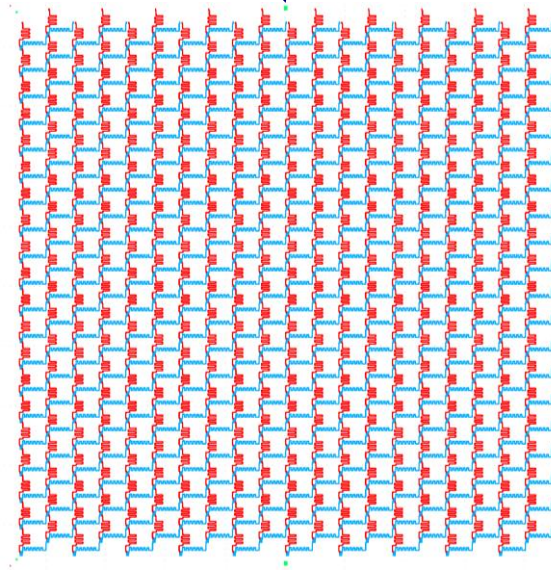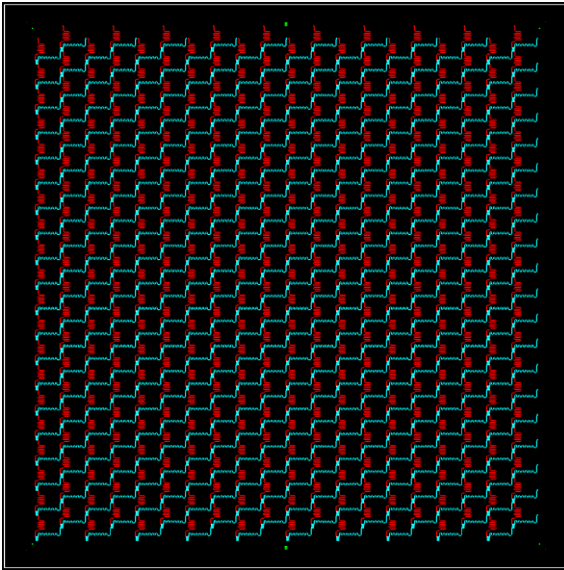Driven to Discover®

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.)
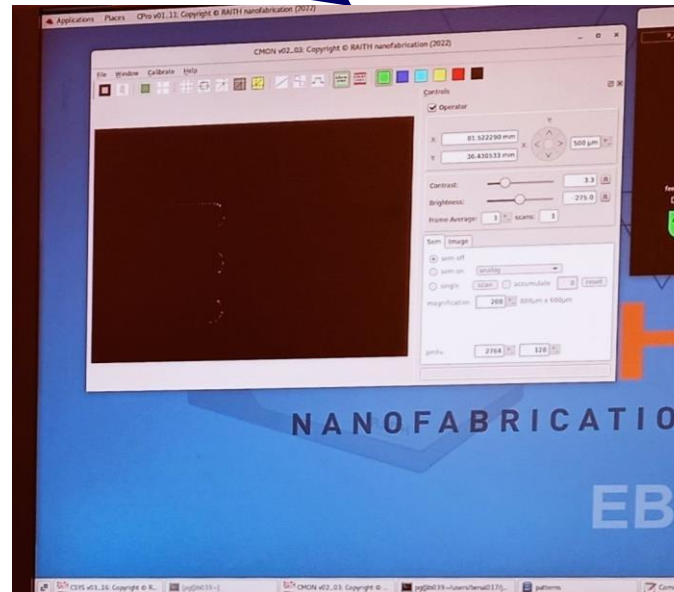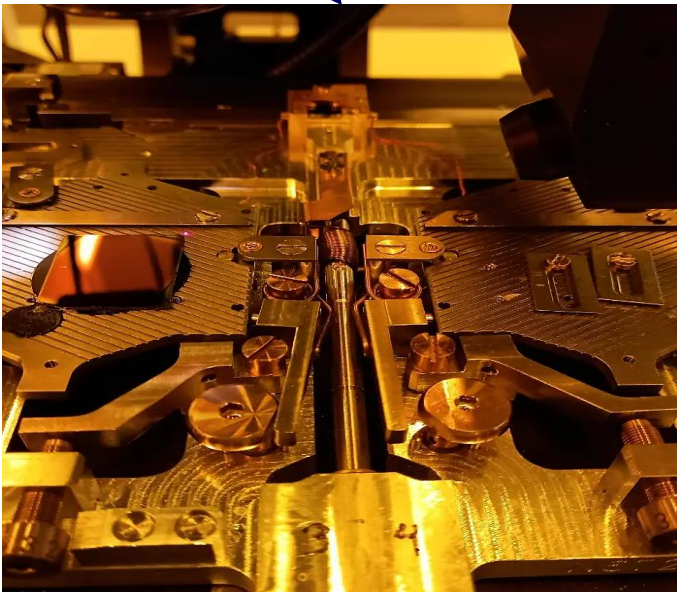
During final setup, machine actually uses this one.

In GDSII ▶|

Heal ▶|

PEC ▶|

Export

Terminal

Maskless Direct Writing Using "Joyplus"

- Doses:
  - For relatively larger features (**pads** & **stripes**): 450 µC/cm².
  - For smaller features (**pillars**): 825-875 µC/cm².

- Basically:
  - Locate 4 Points ➔ SEM-Aided 'Marker' Location ➔ Record Final Marker Position ➔ **Confirm & Write!**

  (joyplus)

Terminal

```
joyplus >> follow prompt
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!
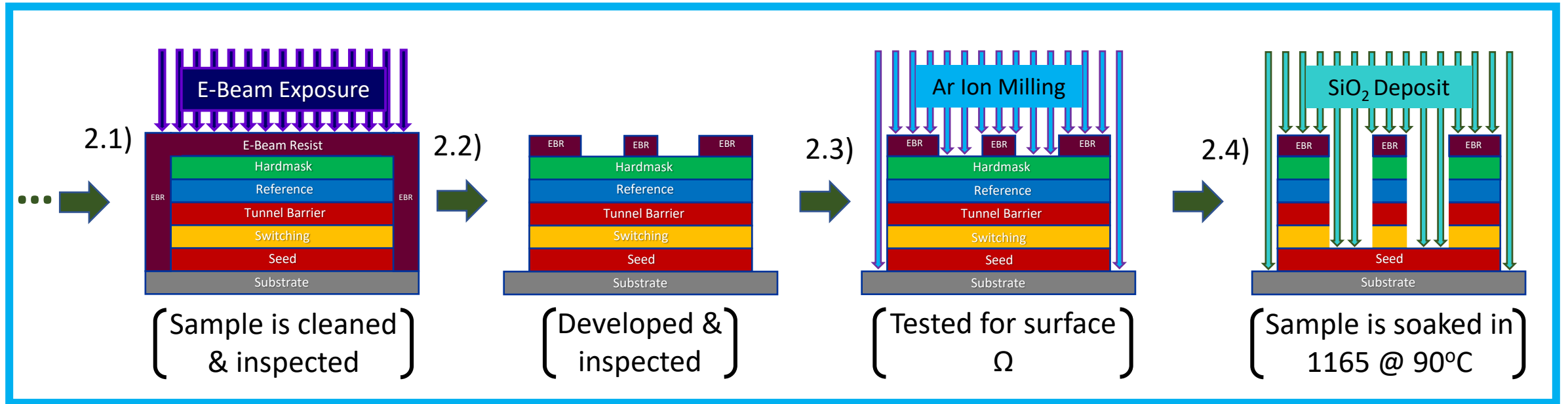
Stack Composition

E-Beam Resist
Hardmask (15 nm)
Metal Stack (X nm)
Substrate
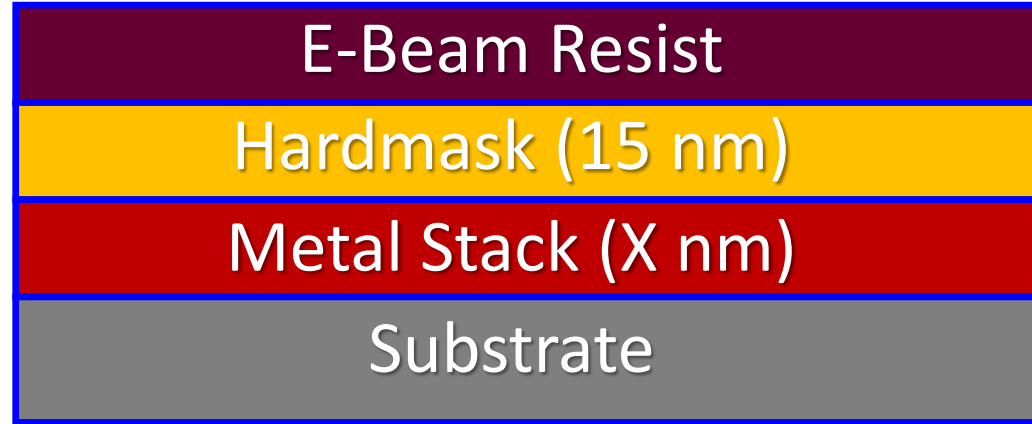
Sample can contain any stack (deposited on substrate) for hardmask testing purposes
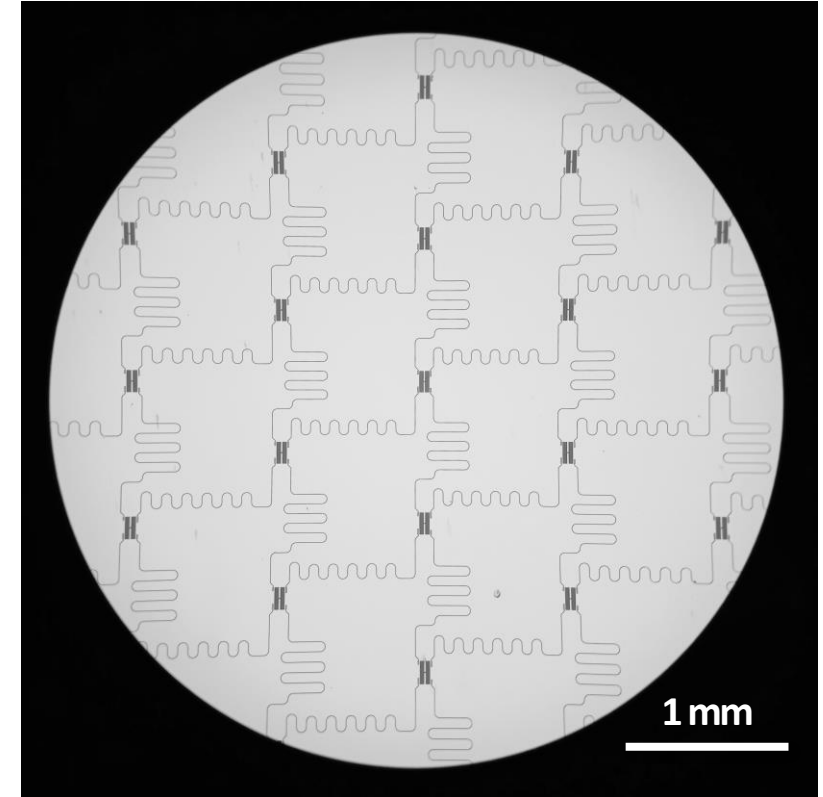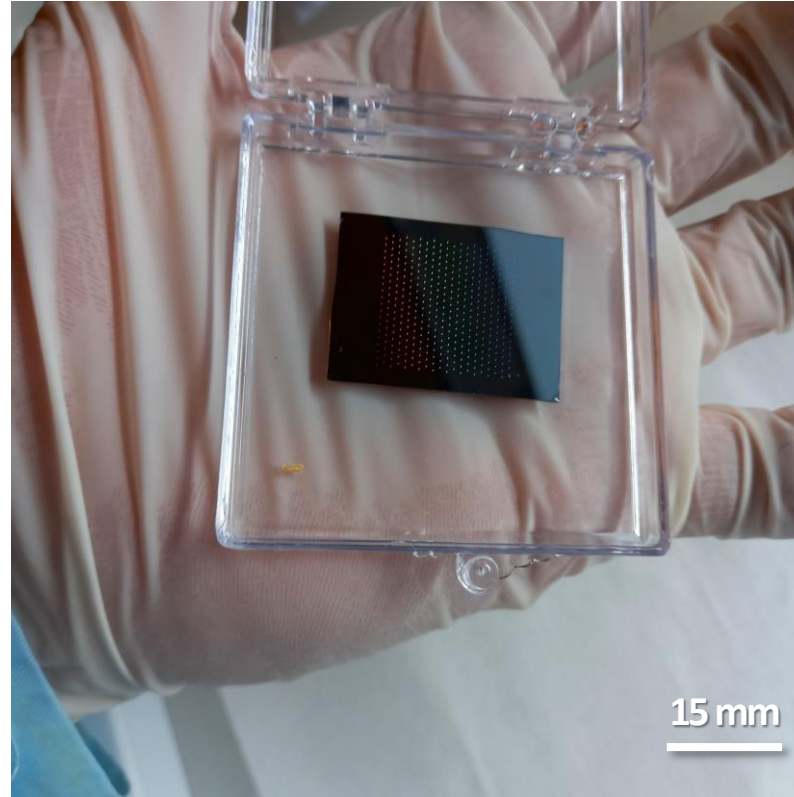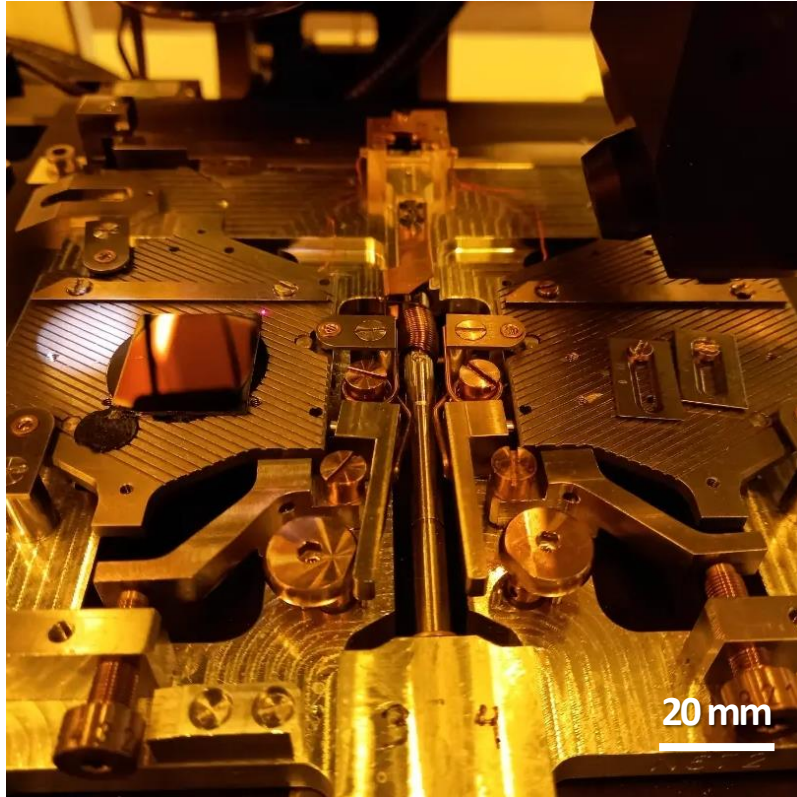
Hardmask layer will help us reduce or increase the density of device drive lines & other fine features as needed.

Generic E-Beam Patterning Flow for Tunnel Junction

2.1)
E-Beam Exposure
E-Beam Resist
Hardmask
Reference
Tunnel Barrier
Switching
Seed
Substrate
EBR
(Sample is cleaned & inspected)

2.2)
EBR EBR EBR
Hardmask
Reference
Tunnel Barrier
Switching
Seed
Substrate
(Developed & inspected)

2.3)
Ar Ion Milling
EBR EBR EBR
Hardmask
Reference
Tunnel Barrier
Switching
Seed
Substrate
(Tested for surface Ω)

2.4)
SiO_2 Deposit
EBR EBR EBR
Hardmask
Reference
Seed
Substrate
(Sample is soaked in 1165 @ 90°C)

Seed layer doubles as an adhesion layer

PR: Photoresist   EBR: Electron-Beam Resist
Ω: Resistance   1165: Strong Solvent

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Results

20 mm

15 mm

1 mm

On the sample stage, carbon tape is being used to prevent charge build-up

Results (Continued)

1 mm