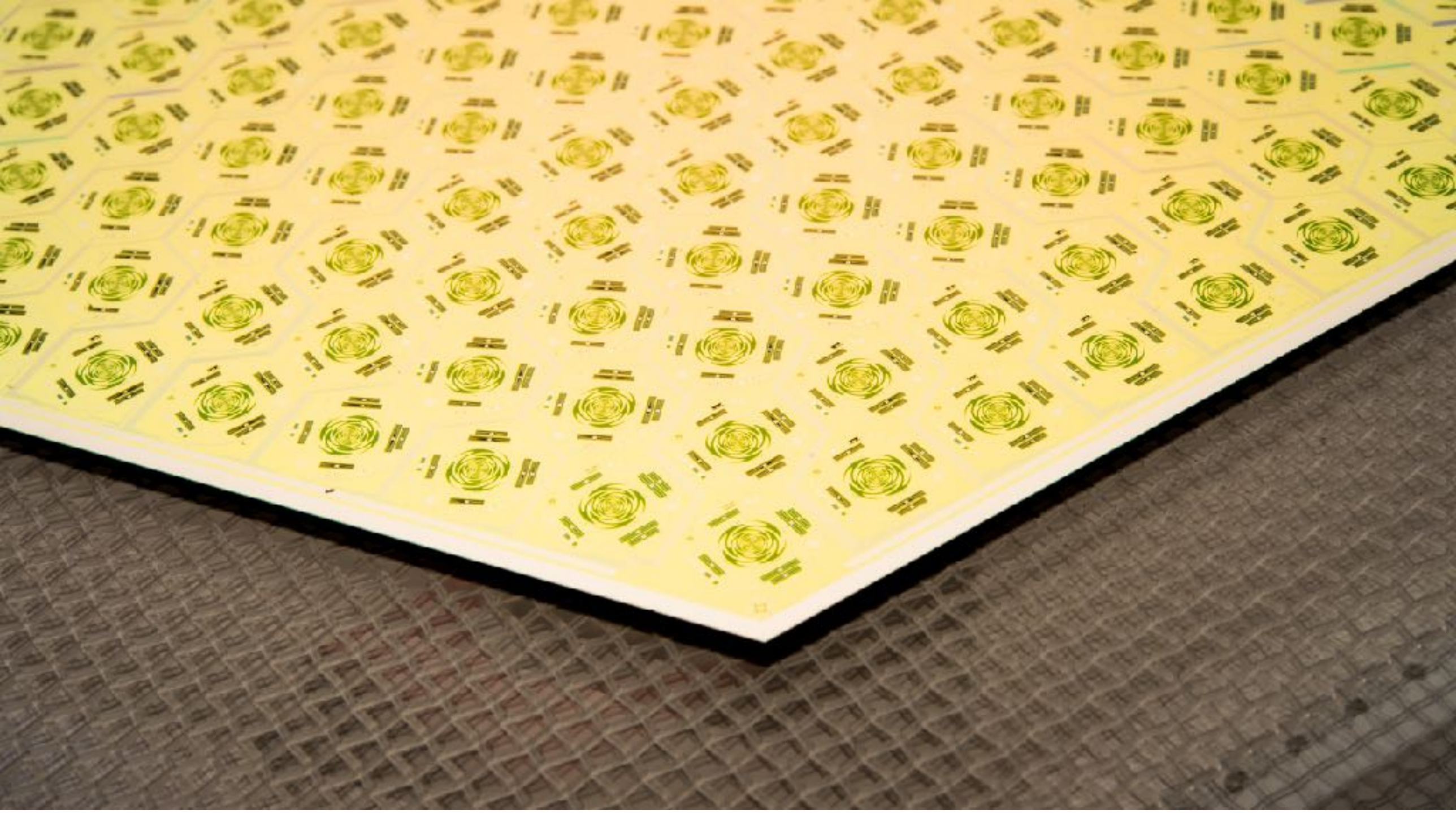


Detector Fabrication

KICP Summer School: CMB Detectors & Instrumentation
August 2017
Clarence Chang

Topics

- Basic structures of detector arrays
  - “antennas”
  - transmission line, signal manipulation, dissipation
  - power measurement
- Basics of fabrication
  - Lithography
  - Deposition
  - Etching
- Outline of a real fab process
- Testing implications

Detector targets

$$NEP_\gamma^2 \approx 2P_{opt}h\nu_0 + P_{opt}^2/\Delta\nu$$

$$NEP_G^2 = 4k_B T_b^2 G$$

$$NEP_\gamma \approx 4.8 \times 10^{-17}\,[W/\sqrt{Hz}] = 48\,[aW/\sqrt{Hz}]$$

$$NEP_G \approx \sqrt{4k_B(0.5K)^2(100pW/K)} \sim 37\,[aW/\sqrt{Hz}]$$

- Signal (i.e. photons): low signal loss, polarization isolation, bandpass definition
- Noise: tune other detector parameters so that fluctuations (noise) subdominant to photon noise

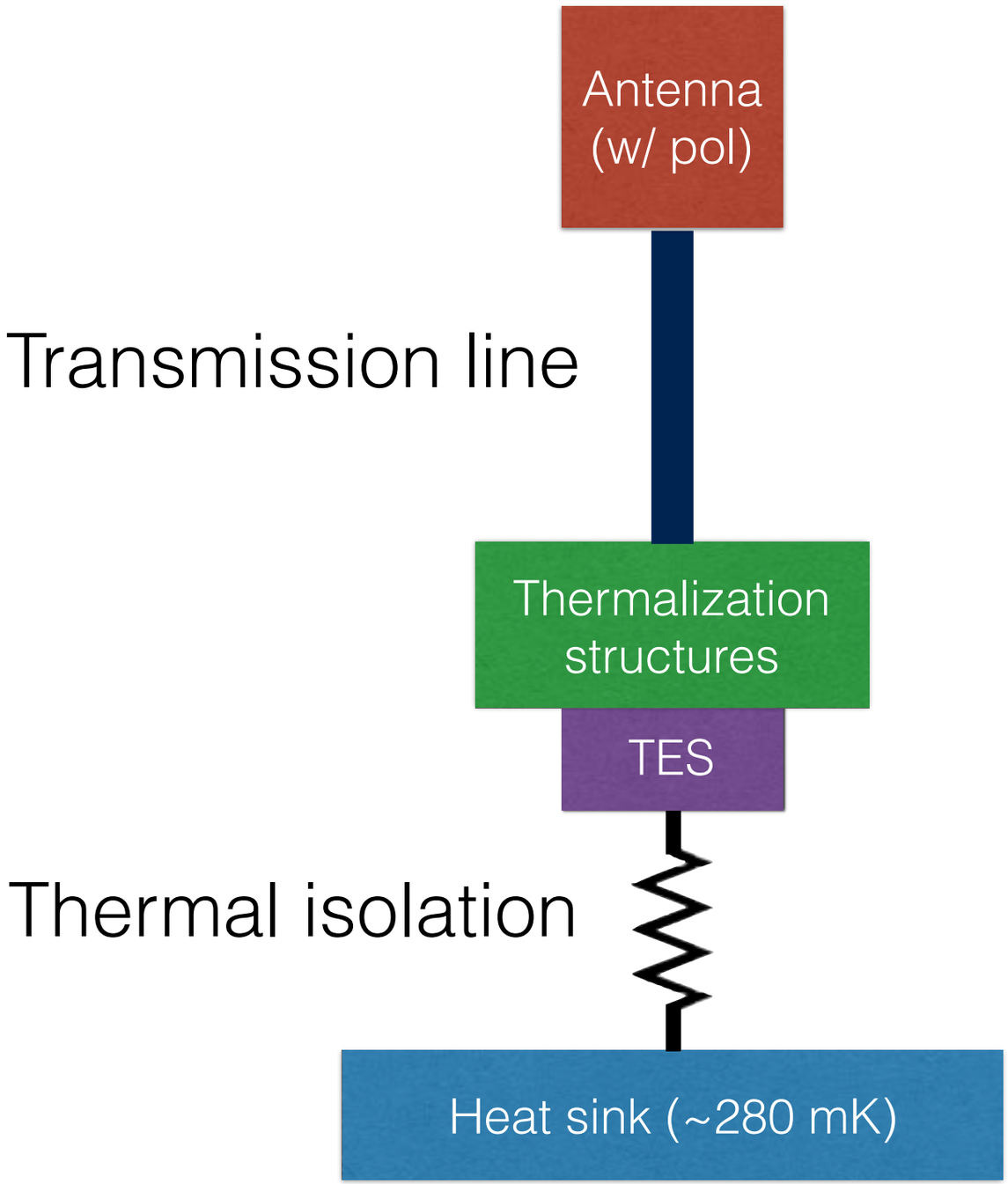
Detector targets

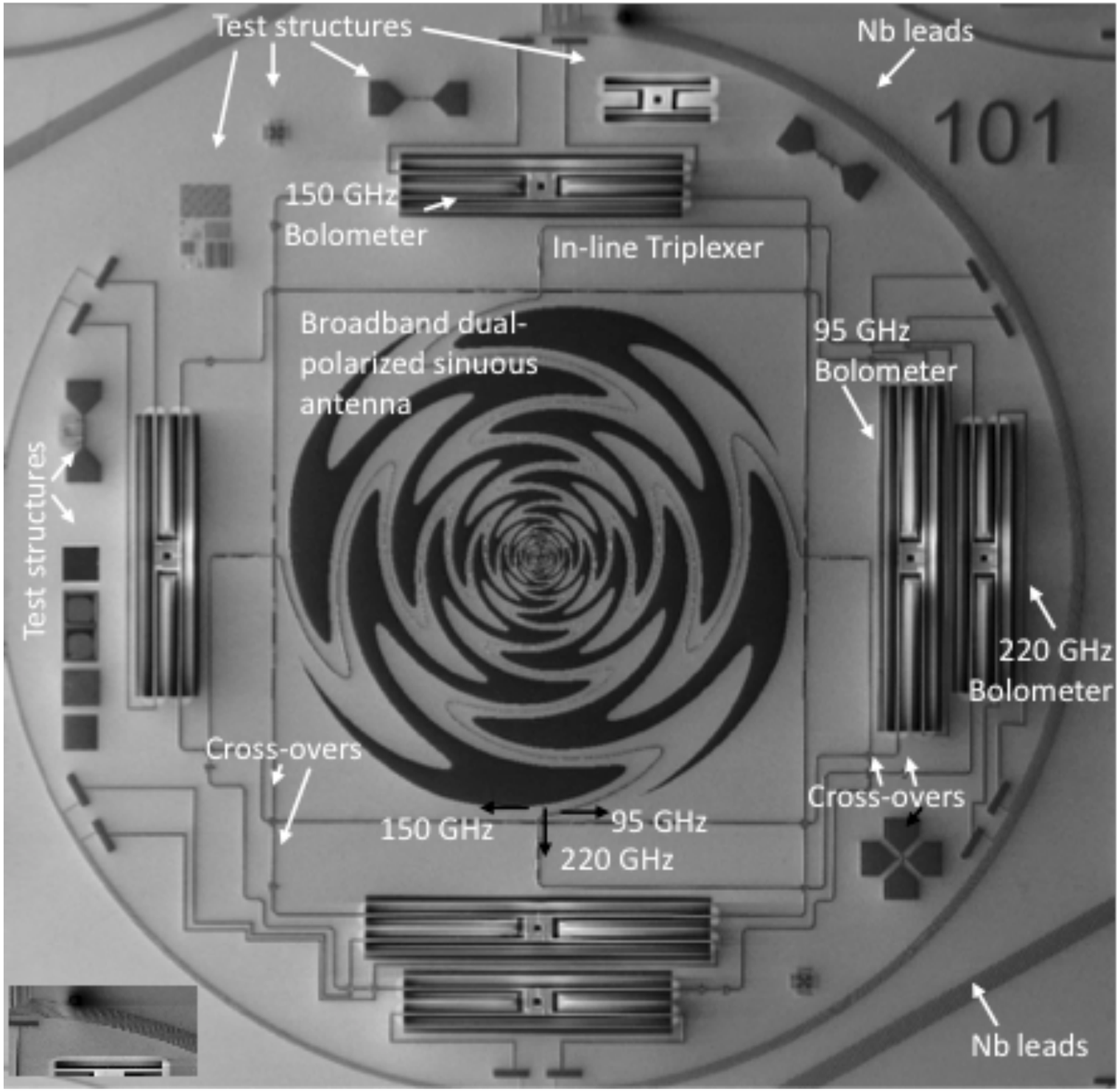
$$Noise_{map}[nK\ deg] \approx \frac{NET_{bolo}\sqrt{SkyArea(deg^2)}}{\sqrt{N_{bolo}\,t}}$$

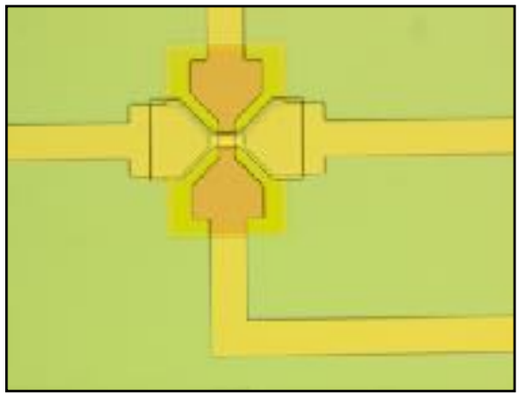
$$N_{bolo} = \left(\frac{300\mu K\sqrt{s}}{0.003\mu K\ deg}\right)^2 \frac{2000\ deg^2}{3\times 10^7\ s} \approx 600,000$$

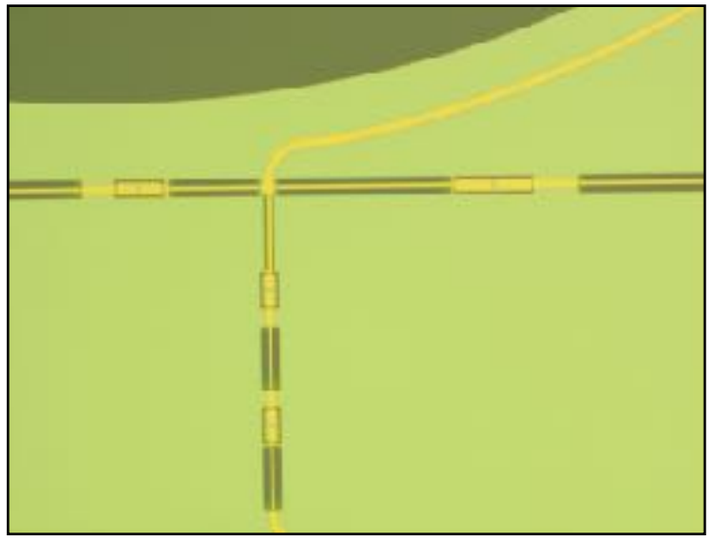
- Need to make lots of detectors

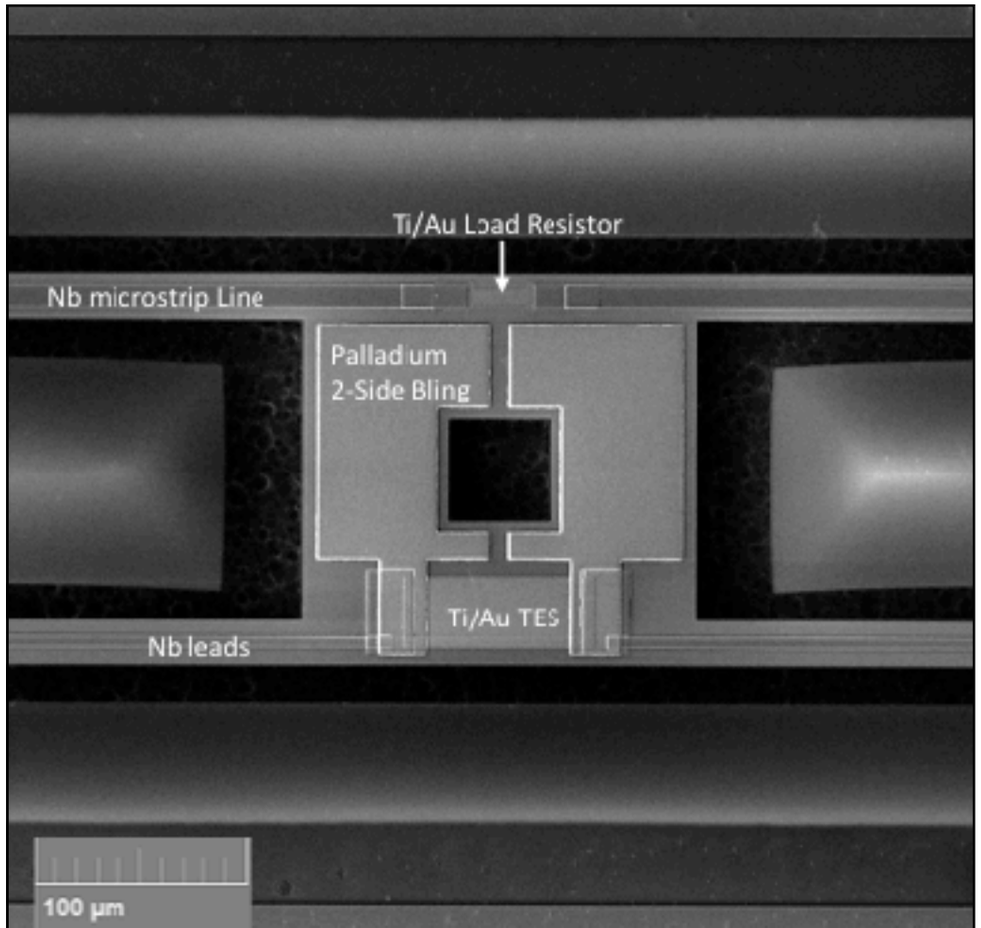
CMB Detector Block Diagram (TES)

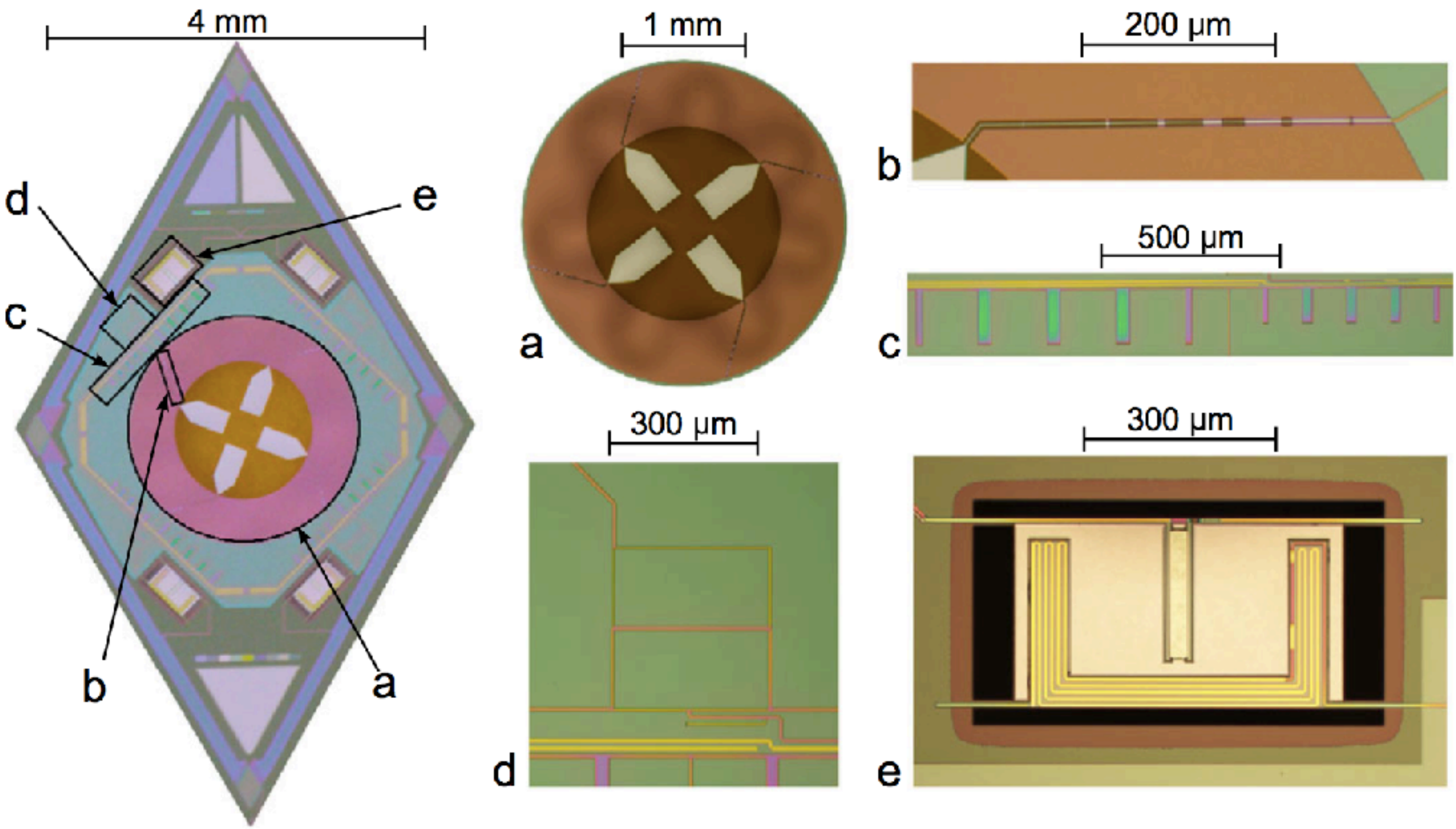


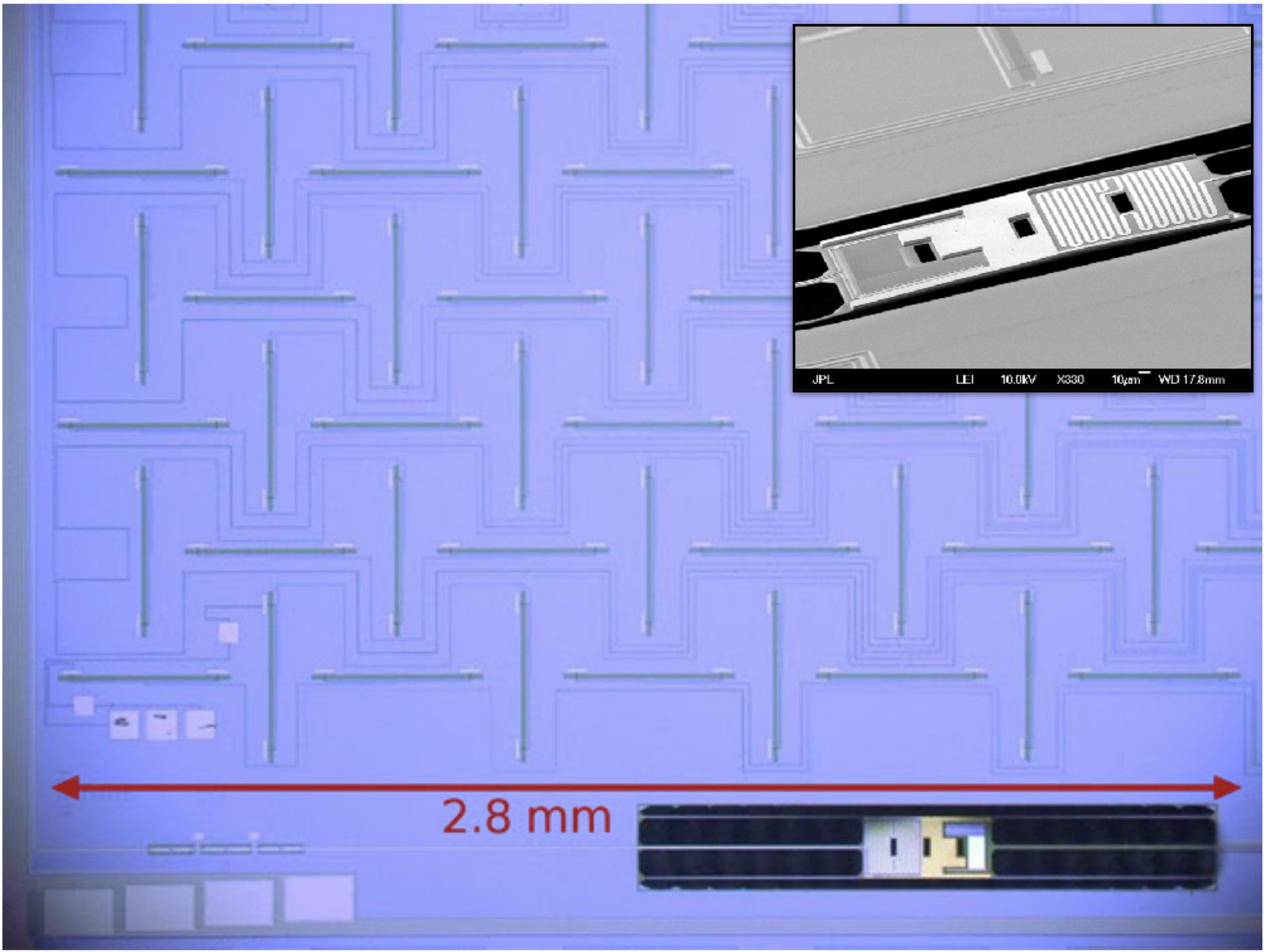

Test structures
Nb leads
101
150 GHz
Bolometer
In-line Triplexer
Broadband dual-
polarized sinuous
antenna
95 GHz
Bolometer
Test structures
220 GHz
Bolometer
Cross-overs
Cross-overs
150 GHz
95 GHz
220 GHz
Nb leads






Ti/Au Load Resistor
Nb microstrip Line
Palladium
2-Side Bling
Ti/Au TES
Nb leads
100 µm


4 mm
d
e
c
b
a
1 mm
a
200 µm
b
500 µm
c
300 µm
d
300 µm
e

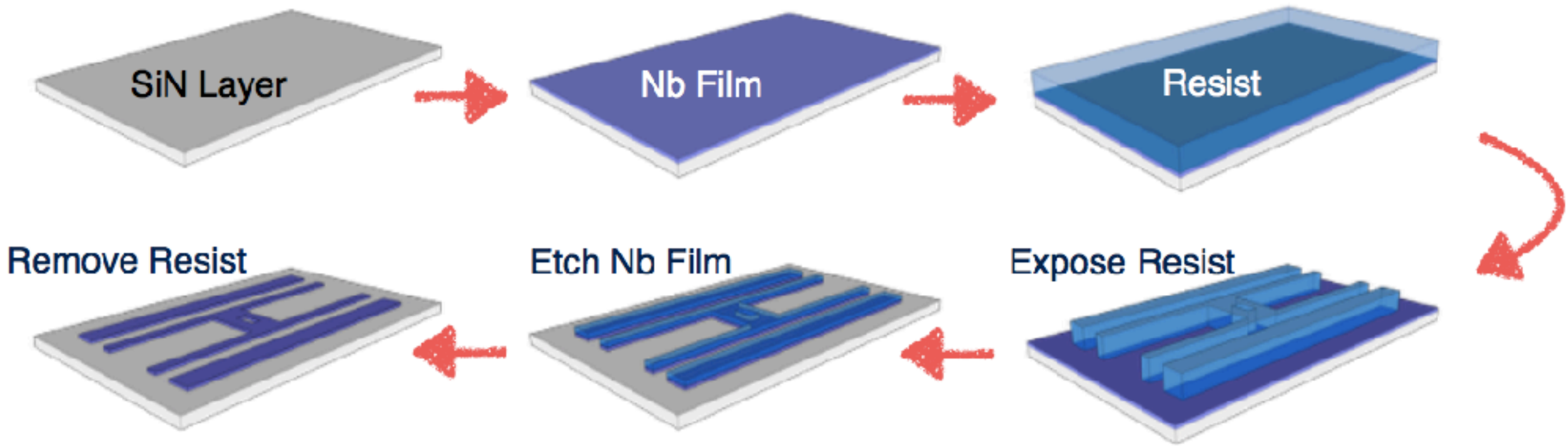

JPL
LEI
10.0kV
X330
10µm
WD 17.8mm
2.8 mm

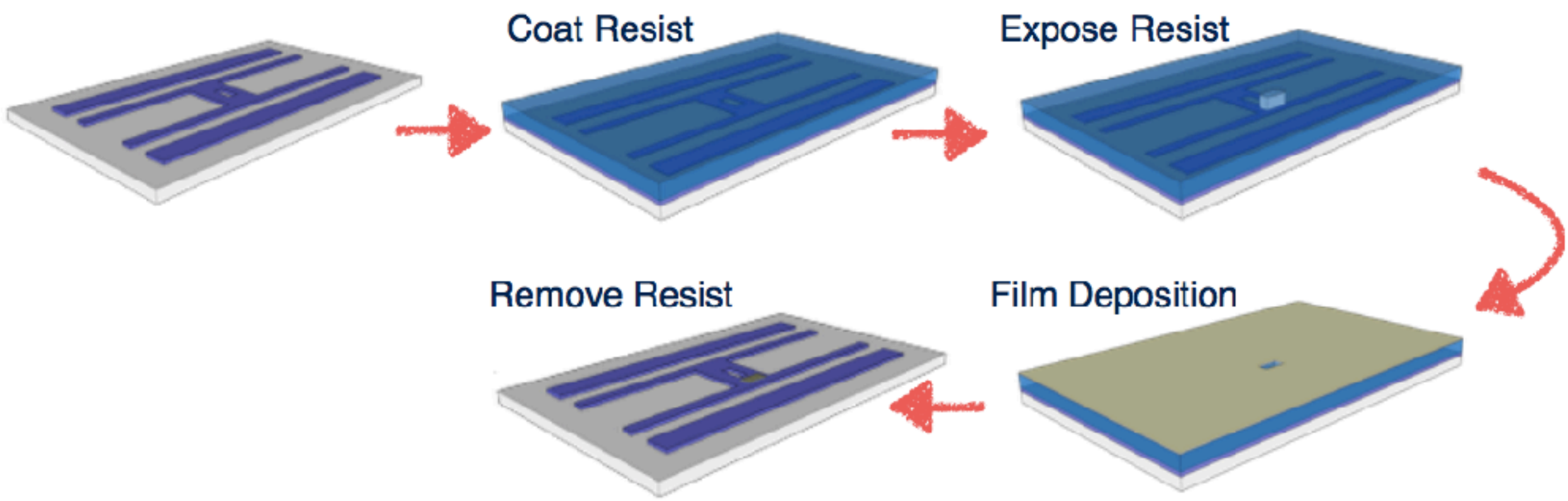
Detectors fabricated using thin film processing

- Lithography - generates patterns
- Deposition - add material
- Etching - remove material

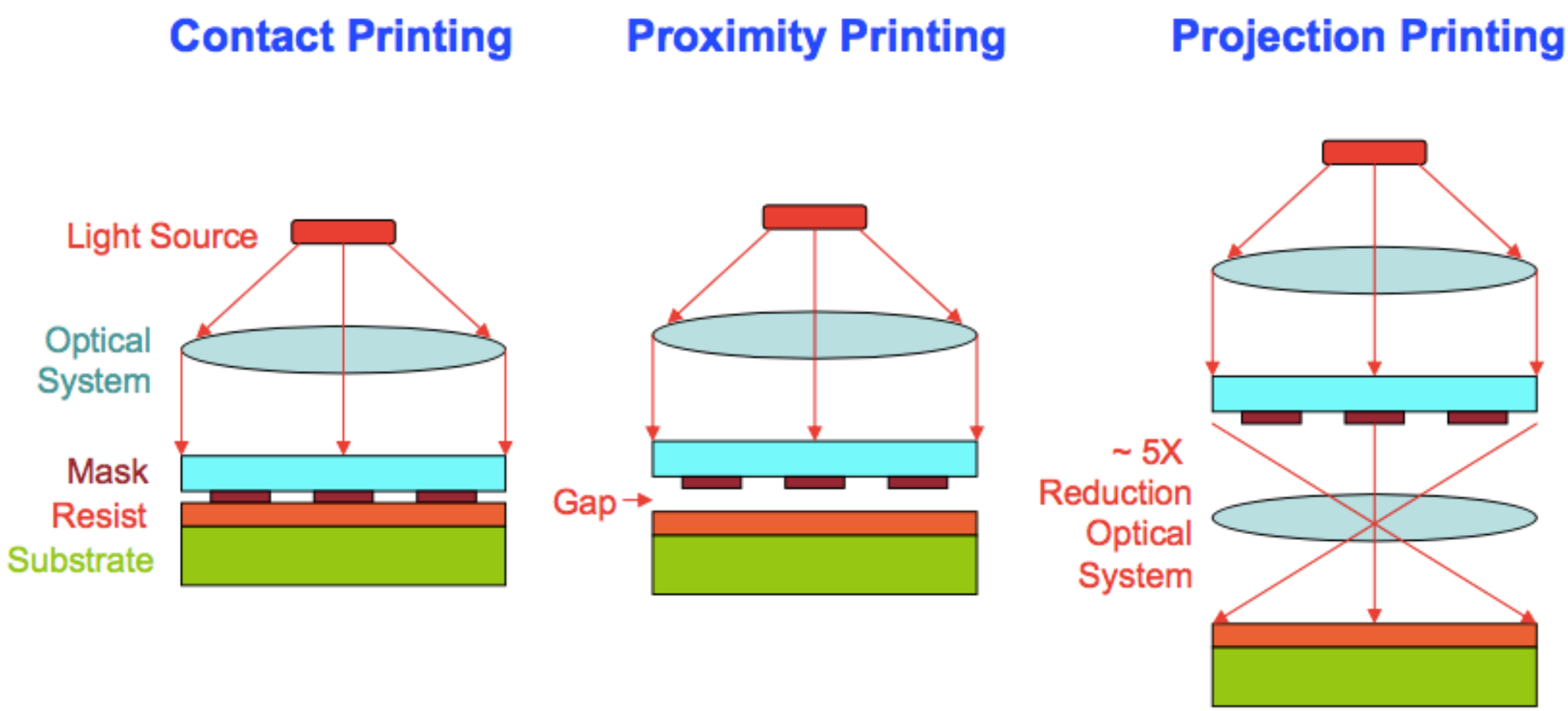
Optical Lithography

- Coat wafer with photoresist (PR)
- PR is a light-sensitive material whose chemical properties (solubility in “developer”) changes when exposed to light.
- Use a mask of your desired pattern to cover portions of the wafer.
- Illuminate the mask+PR+wafer to expose the PR.
- Develop to remove exposed PR (resist that is covered by mask is unexposed and remains).
- Do stuff.
- Strip away remaining resist.


SiN Layer
Nb Film
Resist
Expose Resist
Etch Nb Film
Remove Resist


Coat Resist
Expose Resist
Film Deposition
Remove Resist

Printing methods

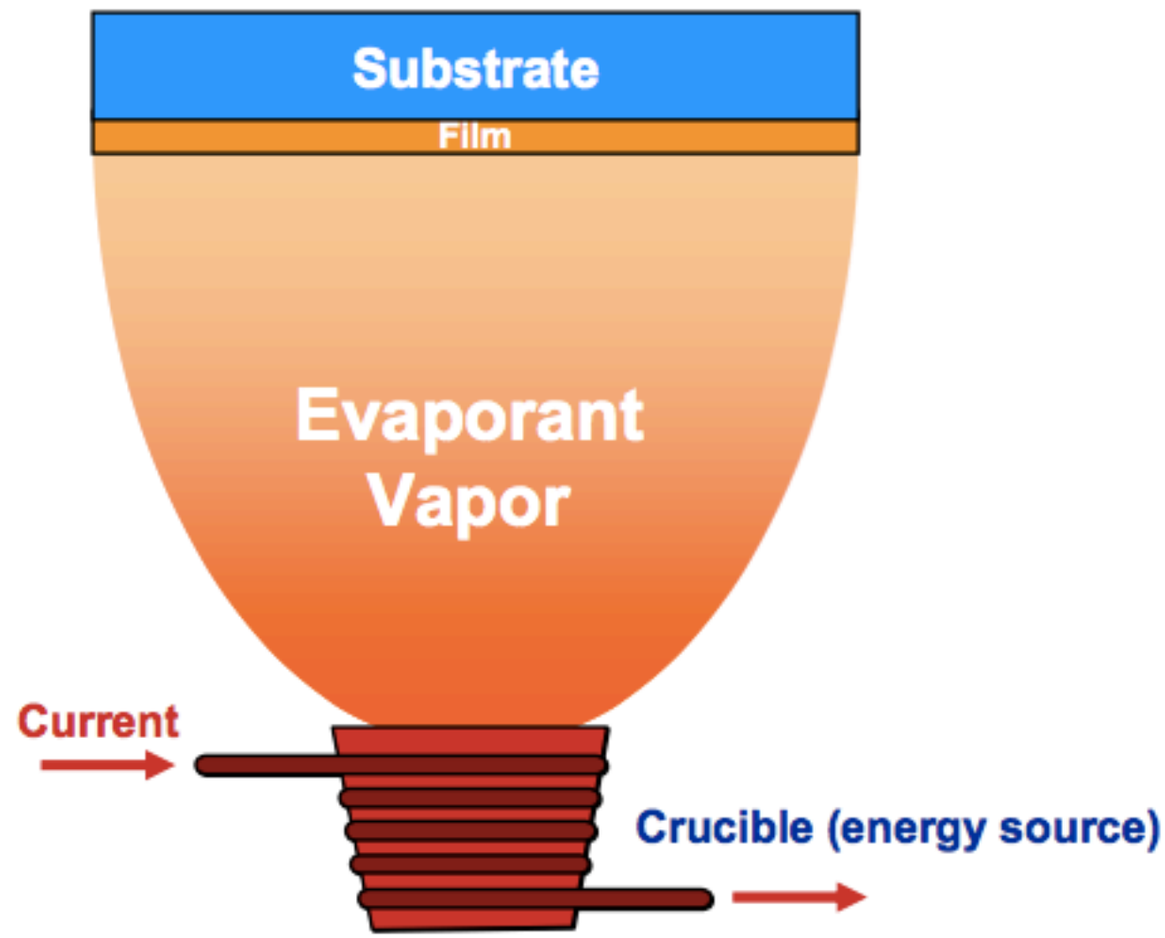


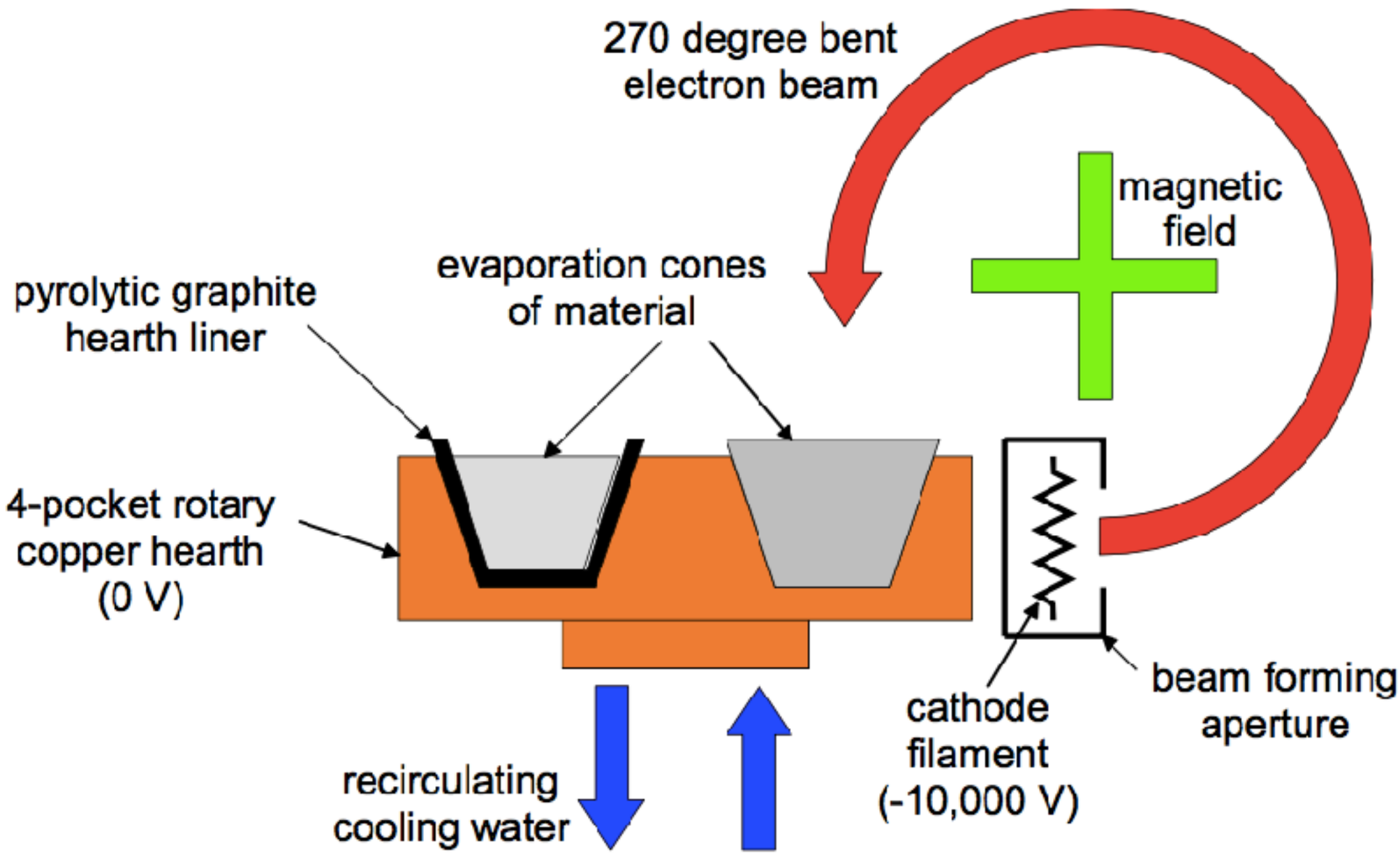
Detectors fabricated using thin film processing

- Lithography - generates patterns
- Deposition - add material
- Etching - remove material

Physical Vapor Deposition (PVD) - Evaporation

- Heat target material to high temperature.
- Material in the (hot) vapor moves to target and condenses to form thin film.
- Not all materials readily evaporated. Need to get things sufficiently hot.
  - resistance heating: limited to ~1800C. Can also heat crucible leading to contamination
  - e-beam: heat W filament, capture electrons with B-field and direct beam into target. Can achieve temperatures ~3000C.




270 degree bent
electron beam
magnetic
field
evaporation cones
of material
pyrolytic graphite
hearth liner
4-pocket rotary
copper hearth
(0 V)
recirculating
cooling water
cathode
filament
(-10,000 V)
beam forming
aperture

Physical Vapor Deposition (PVD) - Evaporation

- Heat target material to high temperature.
- Material in the (hot) vapor moves to target and condenses to form thin film.
- Not all materials readily evaporated. Need to get things sufficiently hot.
  - resistance heating: limited to ~1800C. Can also heat crucible leading to contamination
  - e-beam: heat W filament, capture electrons with B-field and direct beam into target. Can achieve temperatures ~3000C.
- Material transport is directional, challenging for uniform deposition over a large surface (needs large target, or large transport distance)
- Condensed material is “sticky,” leading to non-conformal films (good for lift-off, bad for step coverage)

Physical Vapor Deposition (PVD) - Sputtering

- Apply voltage across noble gas (typically Ar)
- Electrons accelerated by E-field
- At large enough voltages, scattering off Ar atoms can ionize strip outer electron. Secondary electron accelerated, process repeats
- Ar ions accelerated into target by E-field. At large voltages, KE of Ar ion can knock target atoms out of target.
- Free target atoms transported to substrate to form film

Physical Vapor Deposition (PVD) - Sputtering

- Most materials can be sputtered.
- Plasma ionization is inefficient (<0.01%). Presence of a lot of Ar gas limits sputtering deposition rate as target atoms scatter off the gas.
- Magnetron sputtering uses magnetic fields to confine electrons near target. Increases ionization efficiency. Can sputter with low gas concentrations and higher rates.
- Atoms have high mobility leading to more conformal films (good for step coverage, bad for lift-off)
- large targets -> more uniform

Detectors fabricated using thin film processing

- Lithography - generates patterns
- Deposition - add material
- Etching - remove material

Etching

- Chemical etching
  - etchant reacts with materials to form byproducts that are readily removed
  - immerse wafer in etchant (liquid, gaseous)
  - isotropic: process driven by diffusion, etchant removes material in all directions.
  - selective: not all materials undergo same chemistry with etchant. Rate of etching varies by material. Some materials may never be etched.
  - Can lead to undercuts

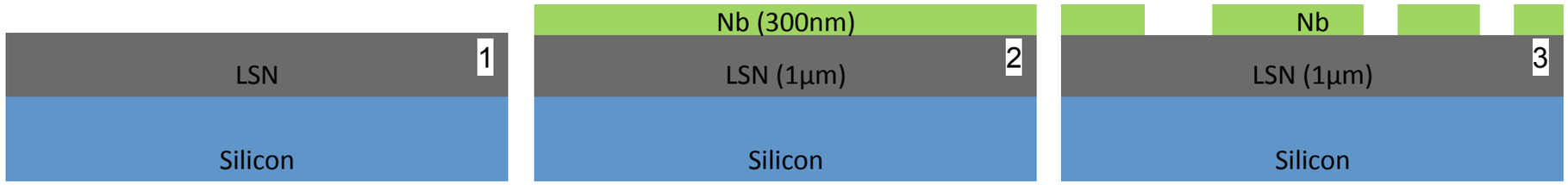
Etching

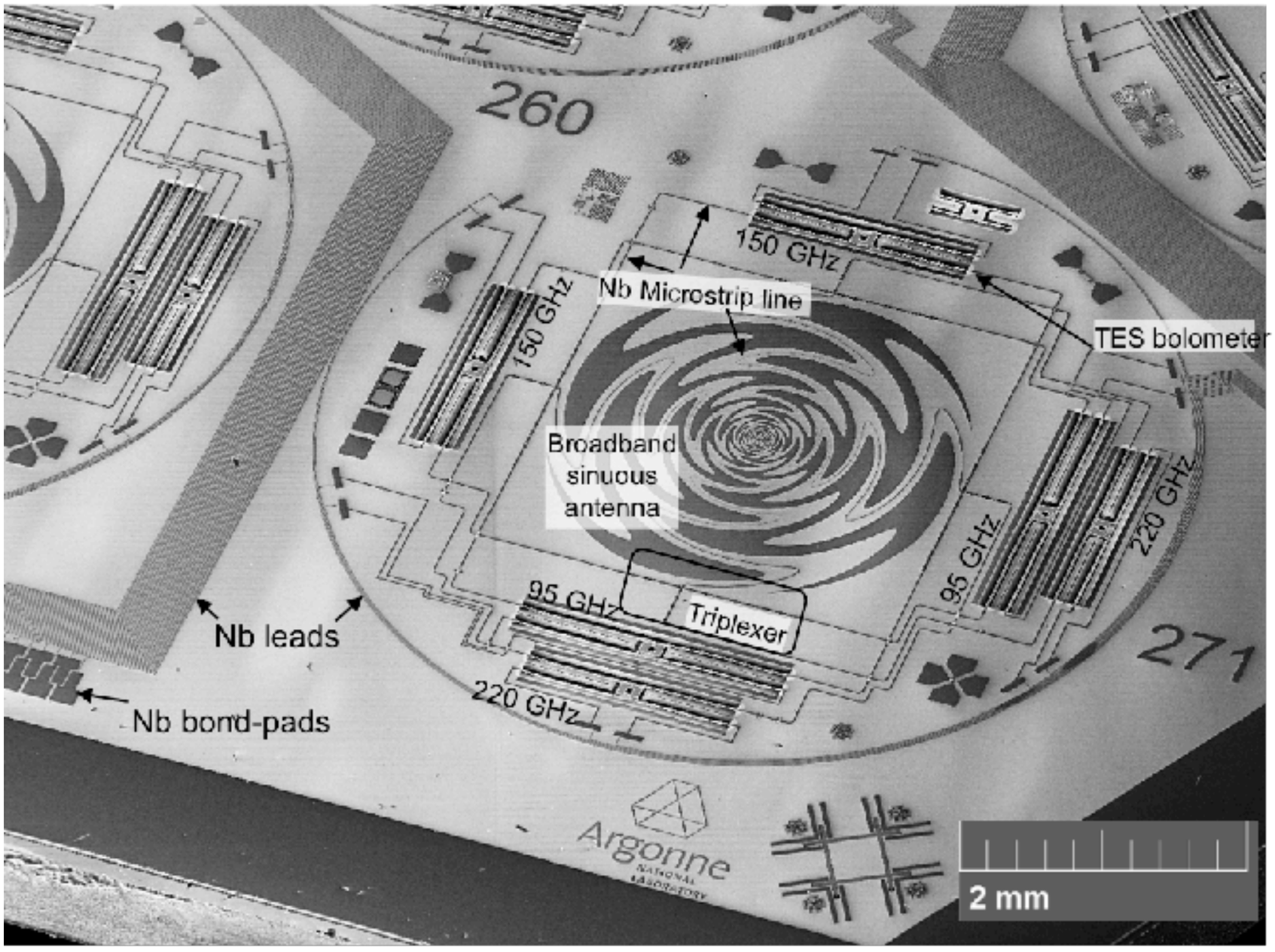
- Mechanical etching
  - bombard wafer with high KE ions.
  - Ions collide with wafer material, sufficiently high KE will knock material off the wafer. (sputtering!)
  - an-isotropic: process driven by field, ion transport is directional
  - non-selective: very little dependence on substrate material.
  - Good at transferring mask pattern (very little undercut), but slow.

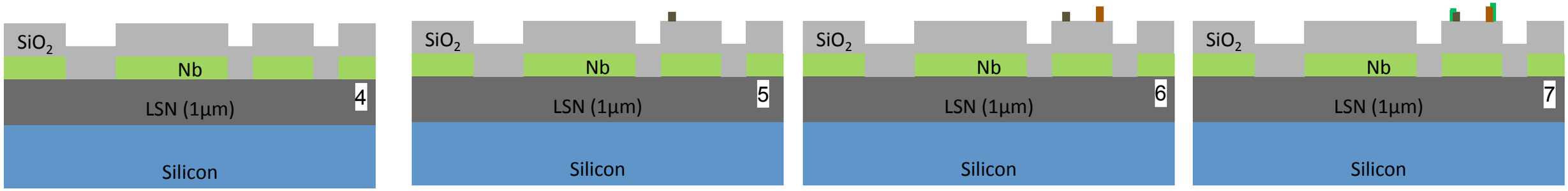
Etching

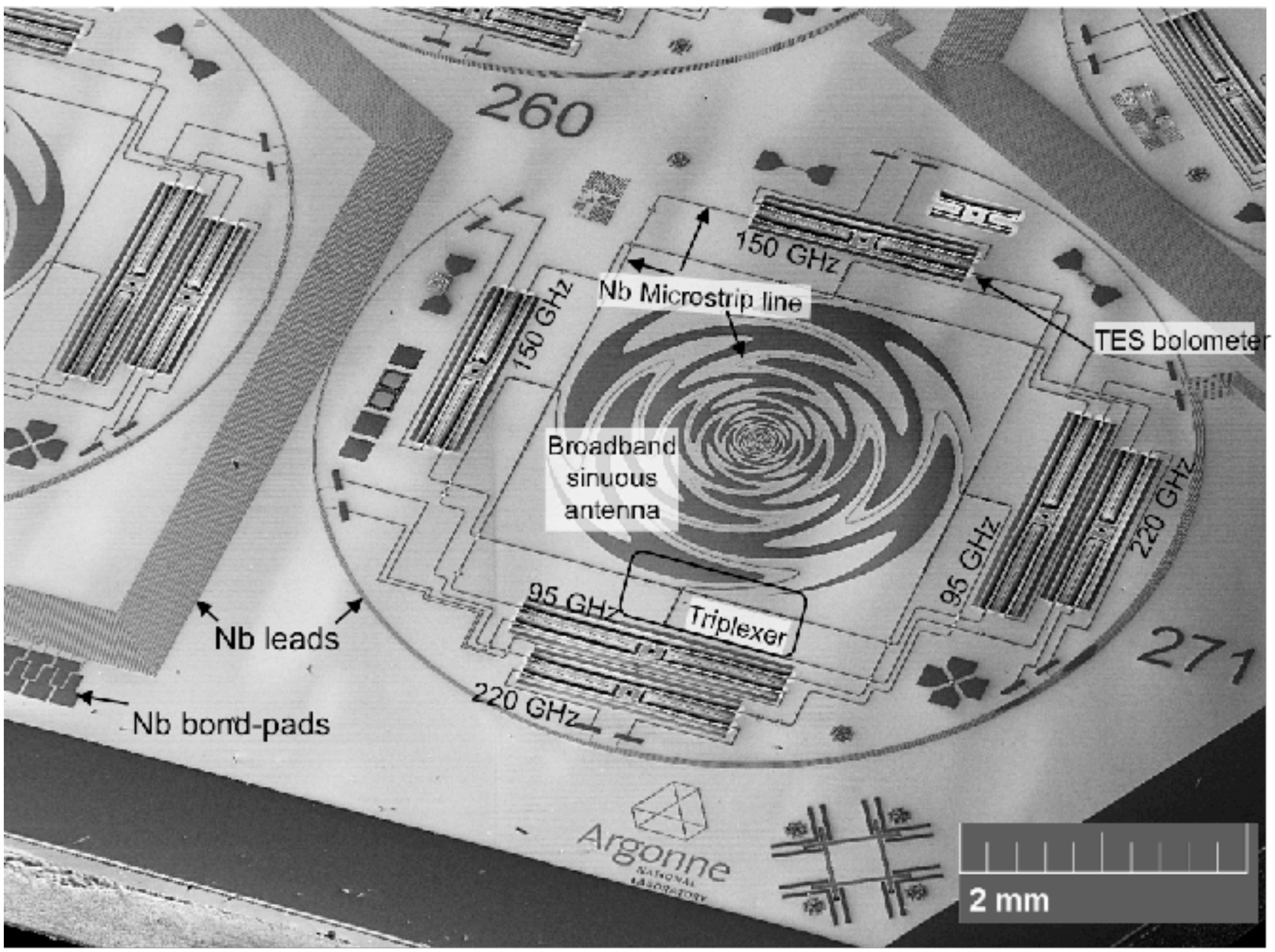
- Reactive Ion Etching (RIE)
  - inject a reactive gas (etchant)
  - apply voltage to produce a plasma ionizing atoms in the gas. Gas ions are chemically active (radicals)
  - bombard wafer with radicals.
  - sputtering and chemical reactions take place
  - Inductively Coupled Plasma (ICP) enables separate tuning of plasma concentration and kinetic energy.
  - Can achieve a range of etch selectivities and isotropy.

Example process: 3G


LSN
1
Silicon
Nb (300nm)
LSN (1µm)
2
Silicon
Nb
LSN (1µm)
3
Silicon


260
150 GHz
Nb Microstrip line
TES bolometer
150 GHz
Broadband
sinuous
antenna
95 GHz
220 GHz
95 GHz
Triplexer
Nb leads
Nb bond-pads
220 GHz
271
Argonne
2 mm


SiO2
Nb
LSN (1µm)
Silicon
4
5
6
7


260
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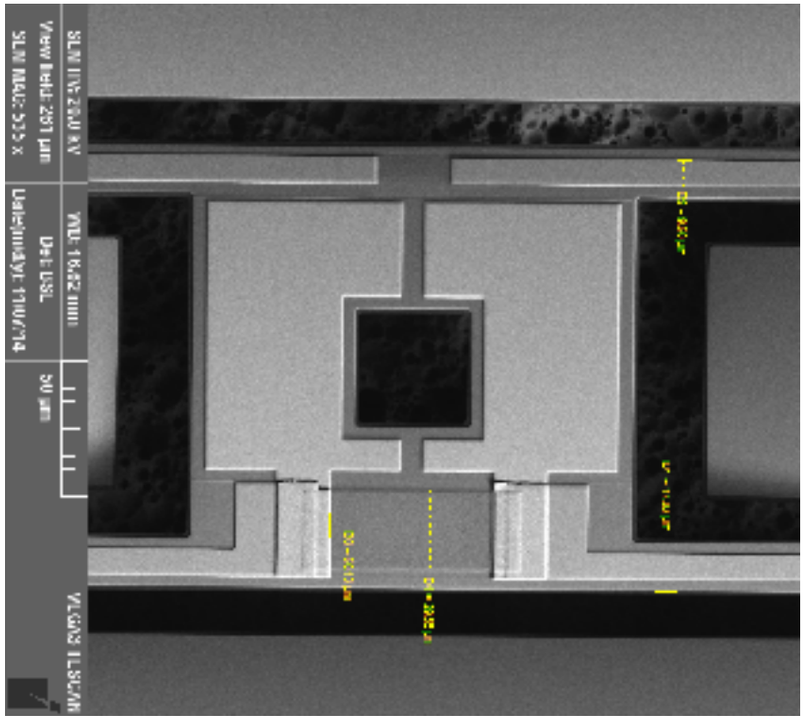
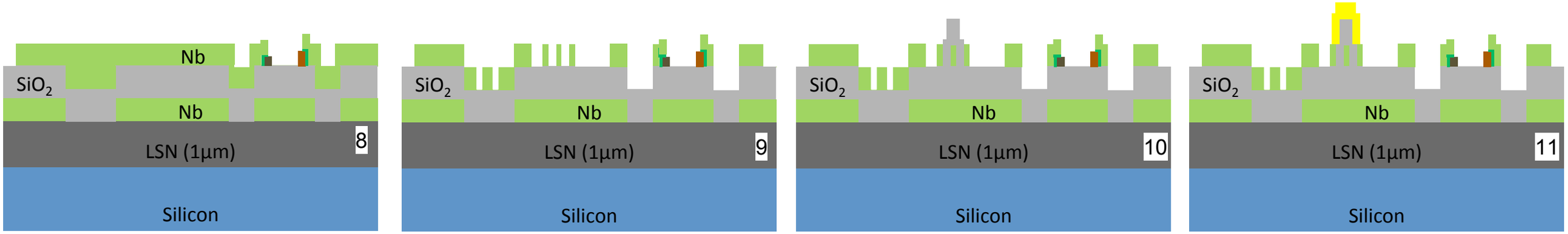
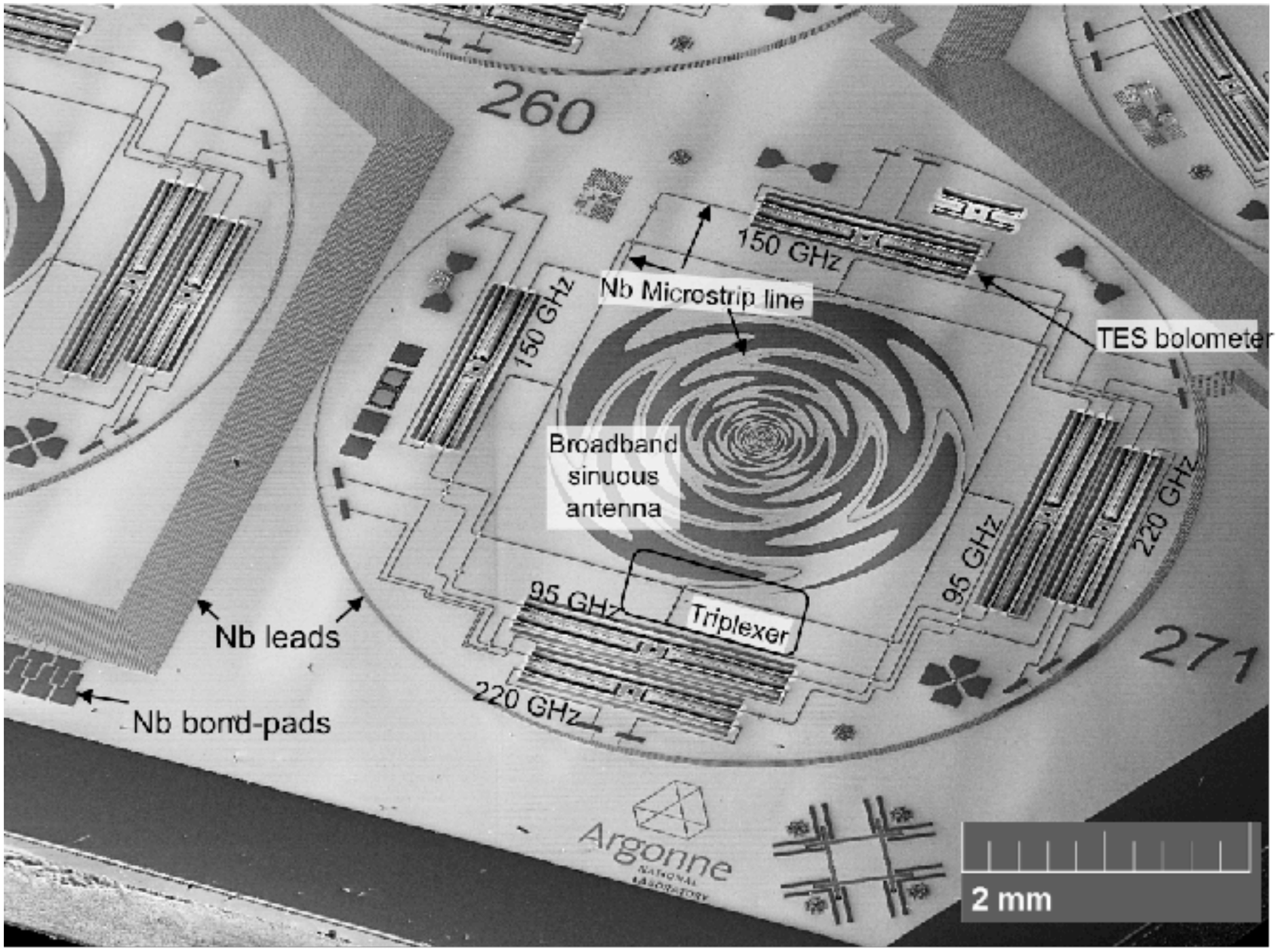



Nb
SiO_2
Nb
LSN (1µm)
8
Silicon
SiO_2
Nb
LSN (1µm)
9
Silicon
SiO_2
Nb
LSN (1µm)
10
Silicon
SiO_2
Nb
LSN (1µm)
11
Silicon


260
150 GHz
Nb Microstrip line
TES bolometer
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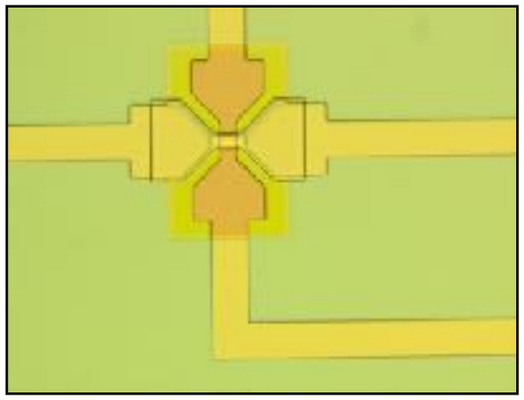
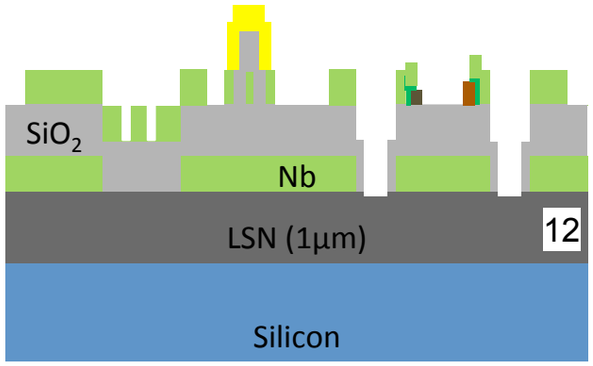
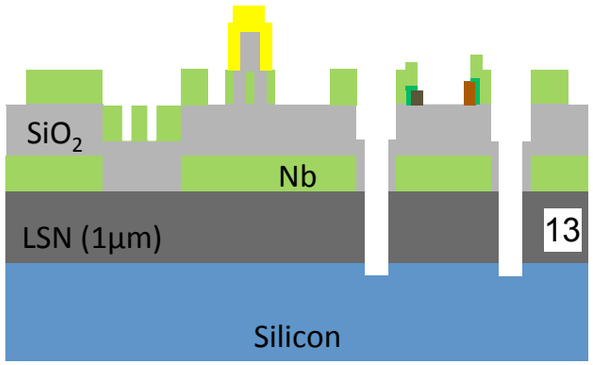
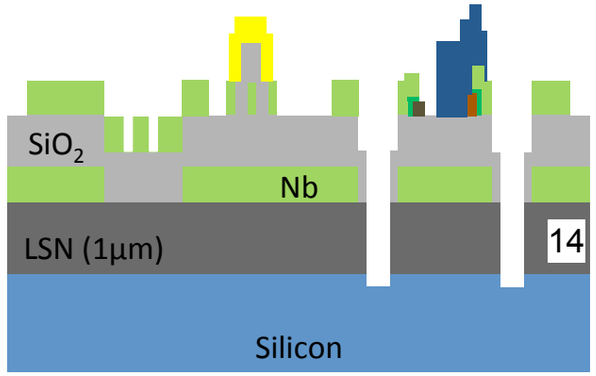
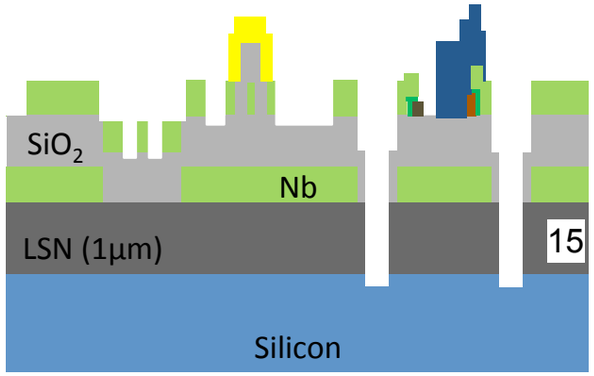
sinuous
antenna
95 GHz
220 GHz
95 GHz
Triplexer
Nb leads
Nb bond-pads
220 GHz
271
Argonne
2 mm

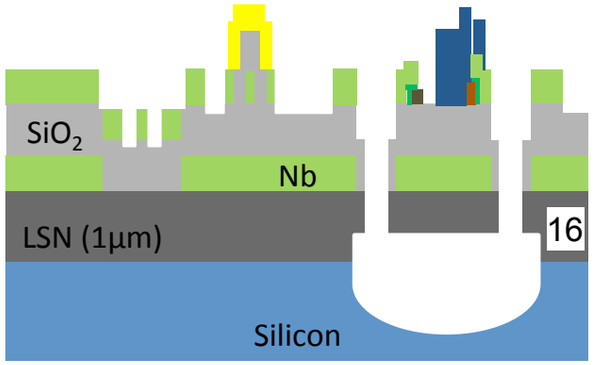


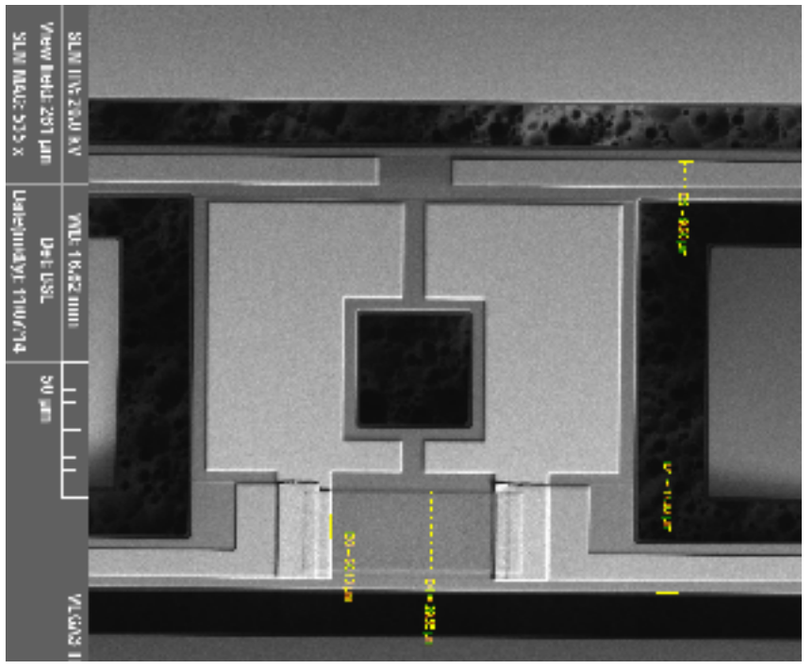

SiO2
Nb
LSN (1µm)
Silicon
12

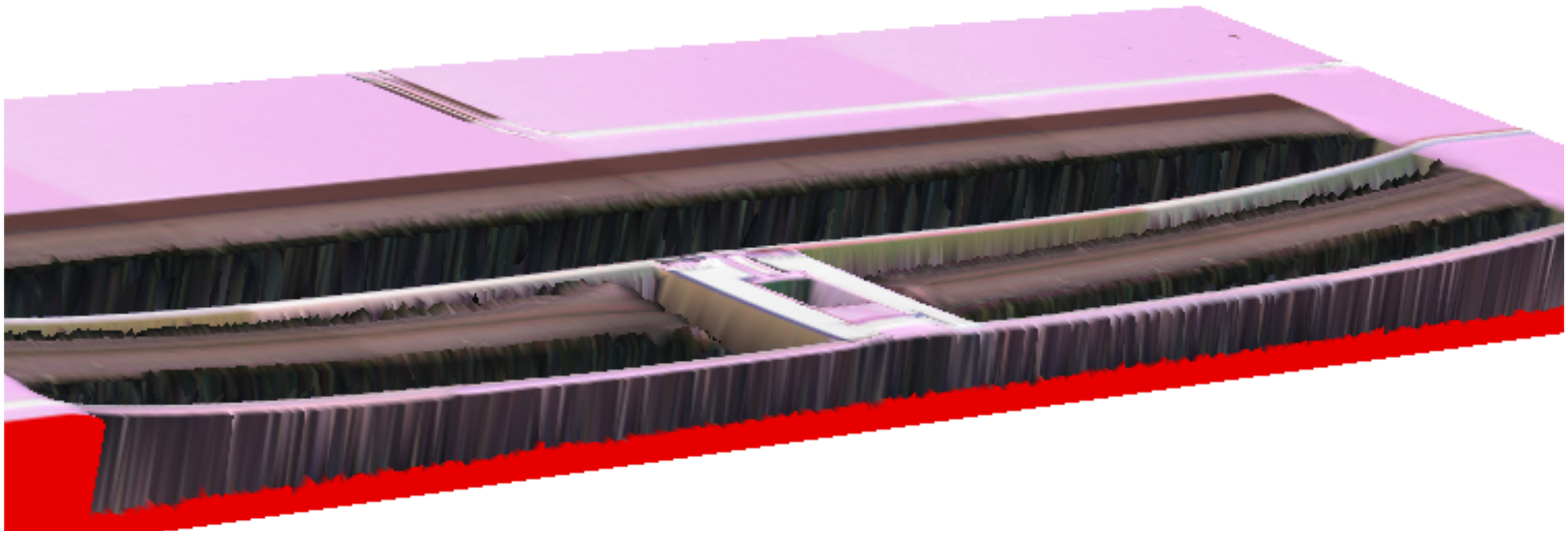

SiO2
Nb
LSN (1µm)
Silicon
13

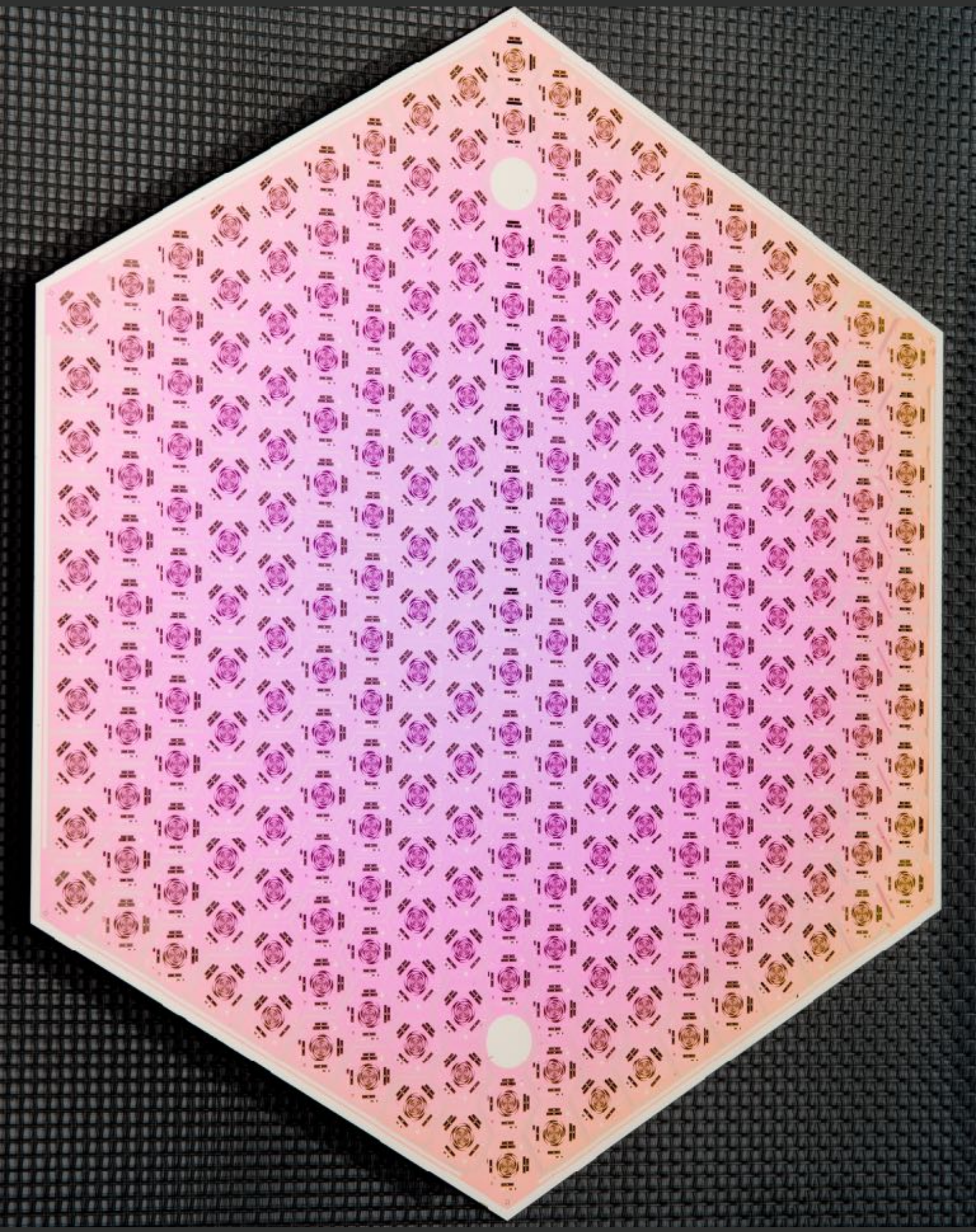

SiO2
Nb
LSN (1µm)
Silicon
14


SiO2
Nb
LSN (1µm)
Silicon
15


SiO2
Nb
LSN (1µm)
Silicon
16

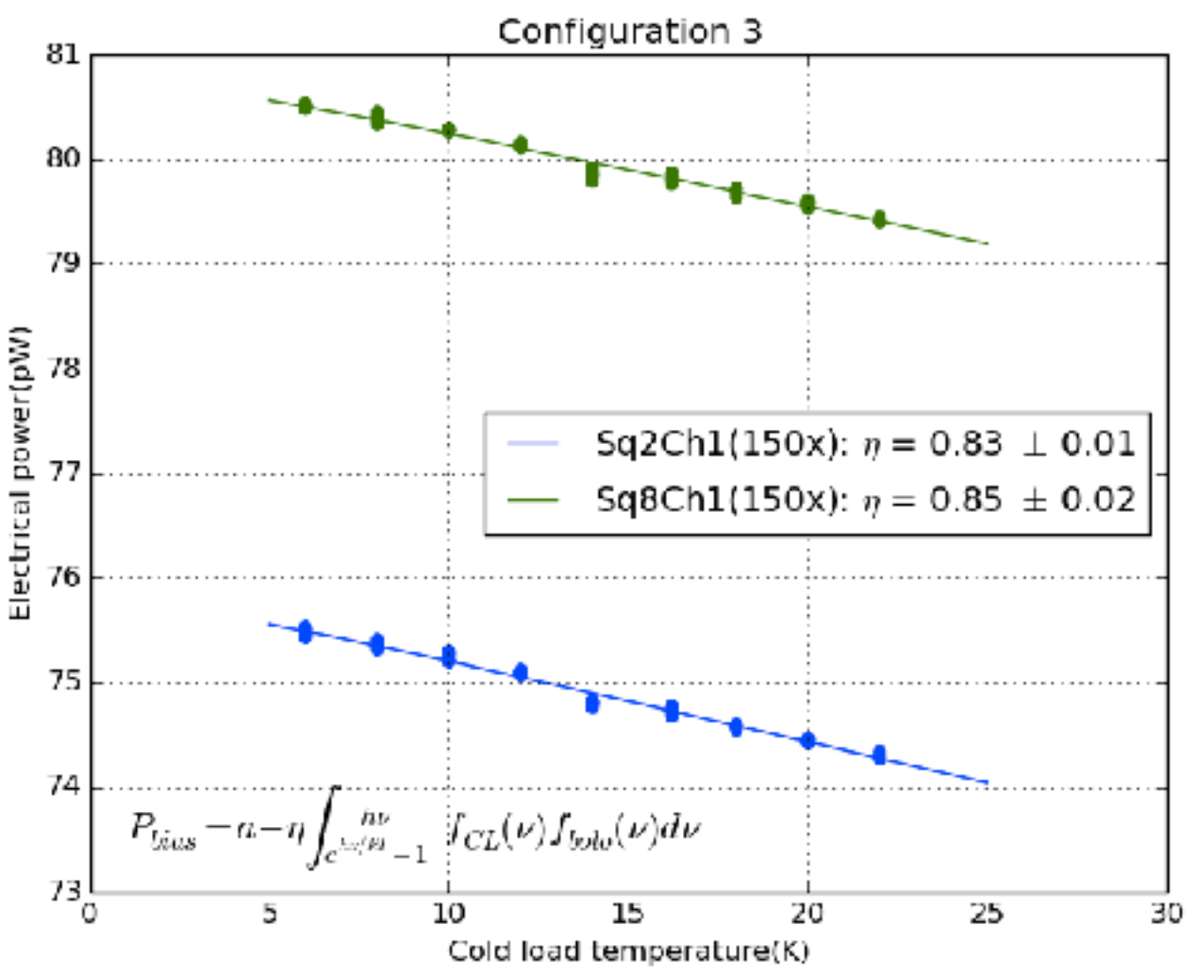


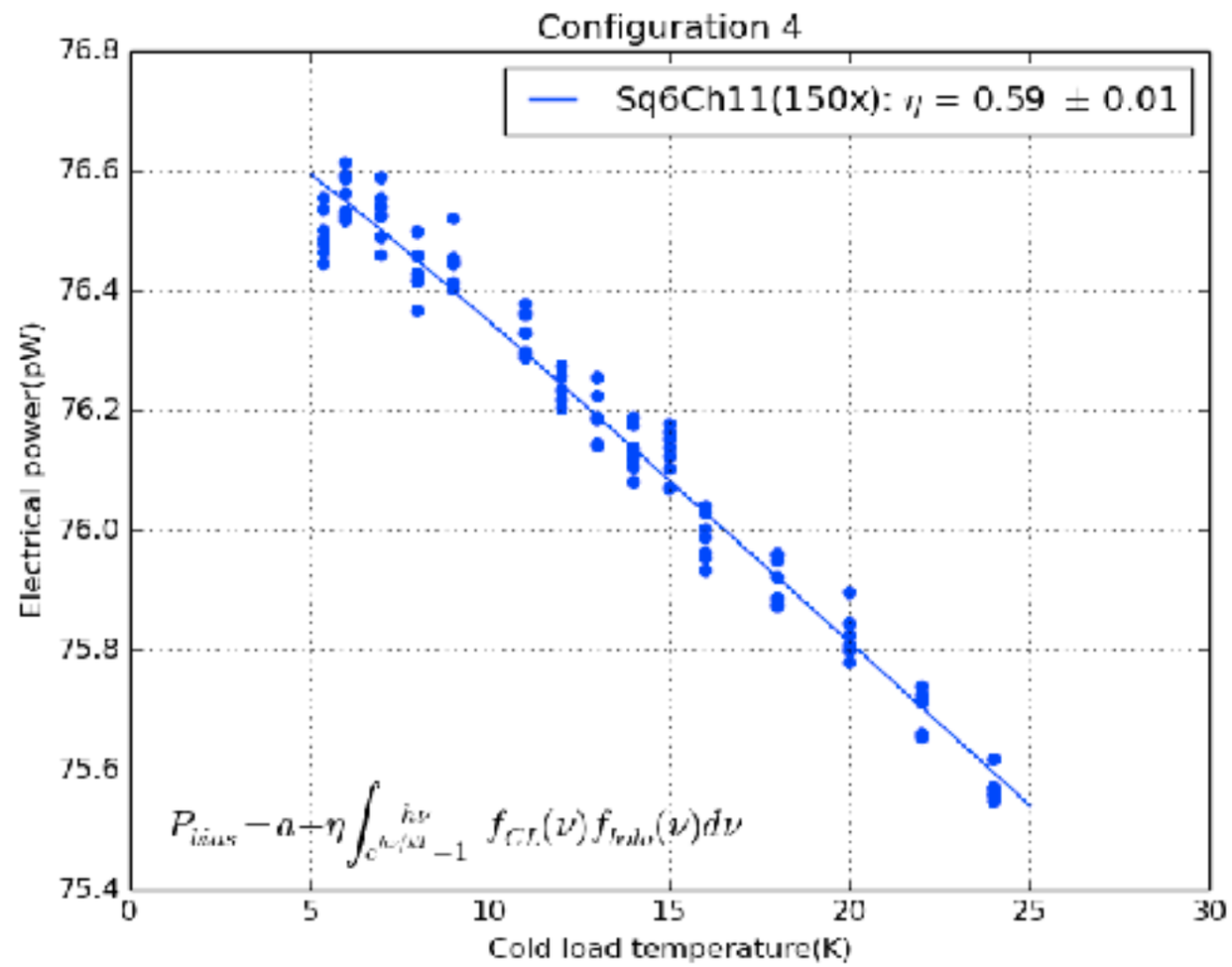




What am I measuring? Does it connect to fab?

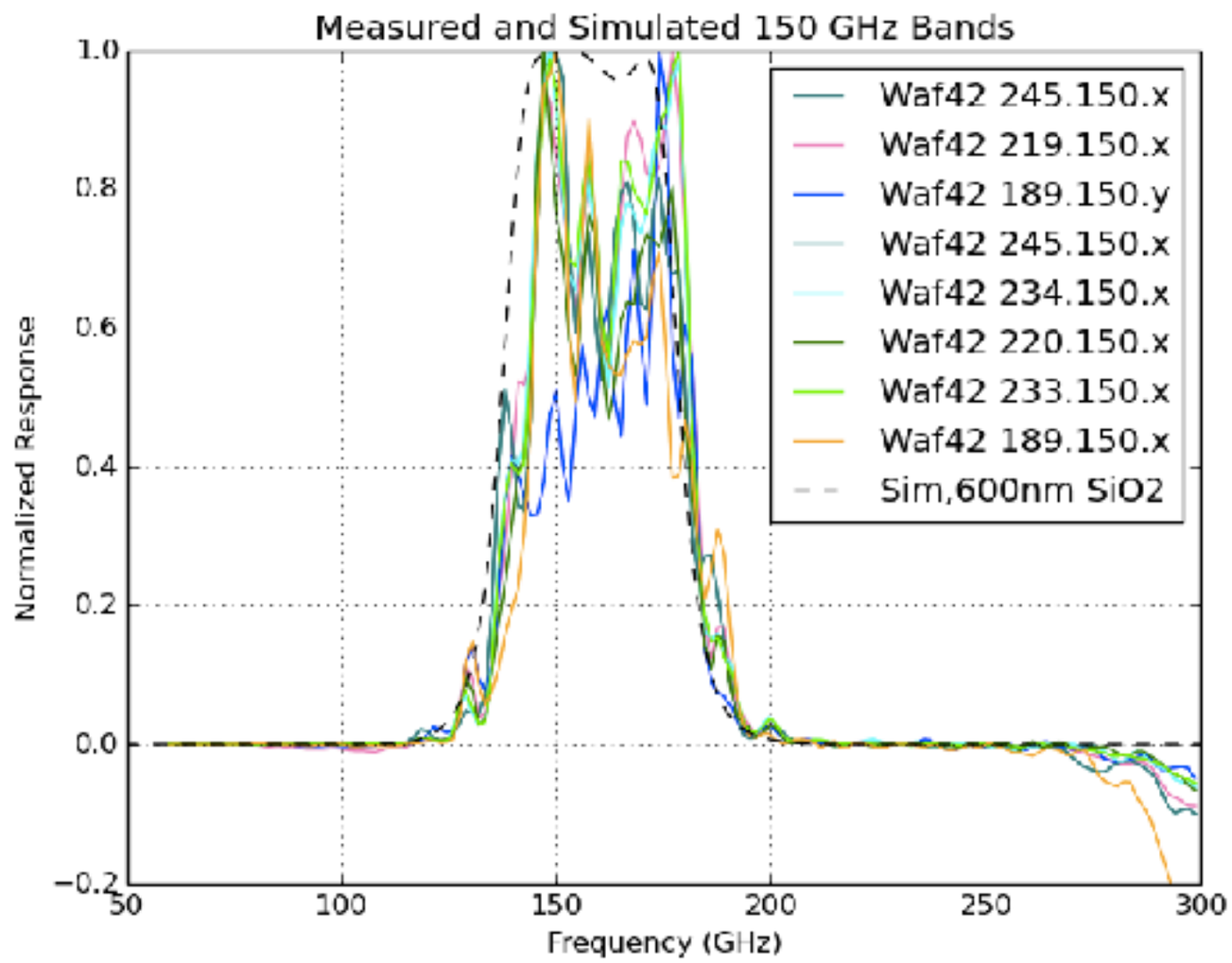
Cold load





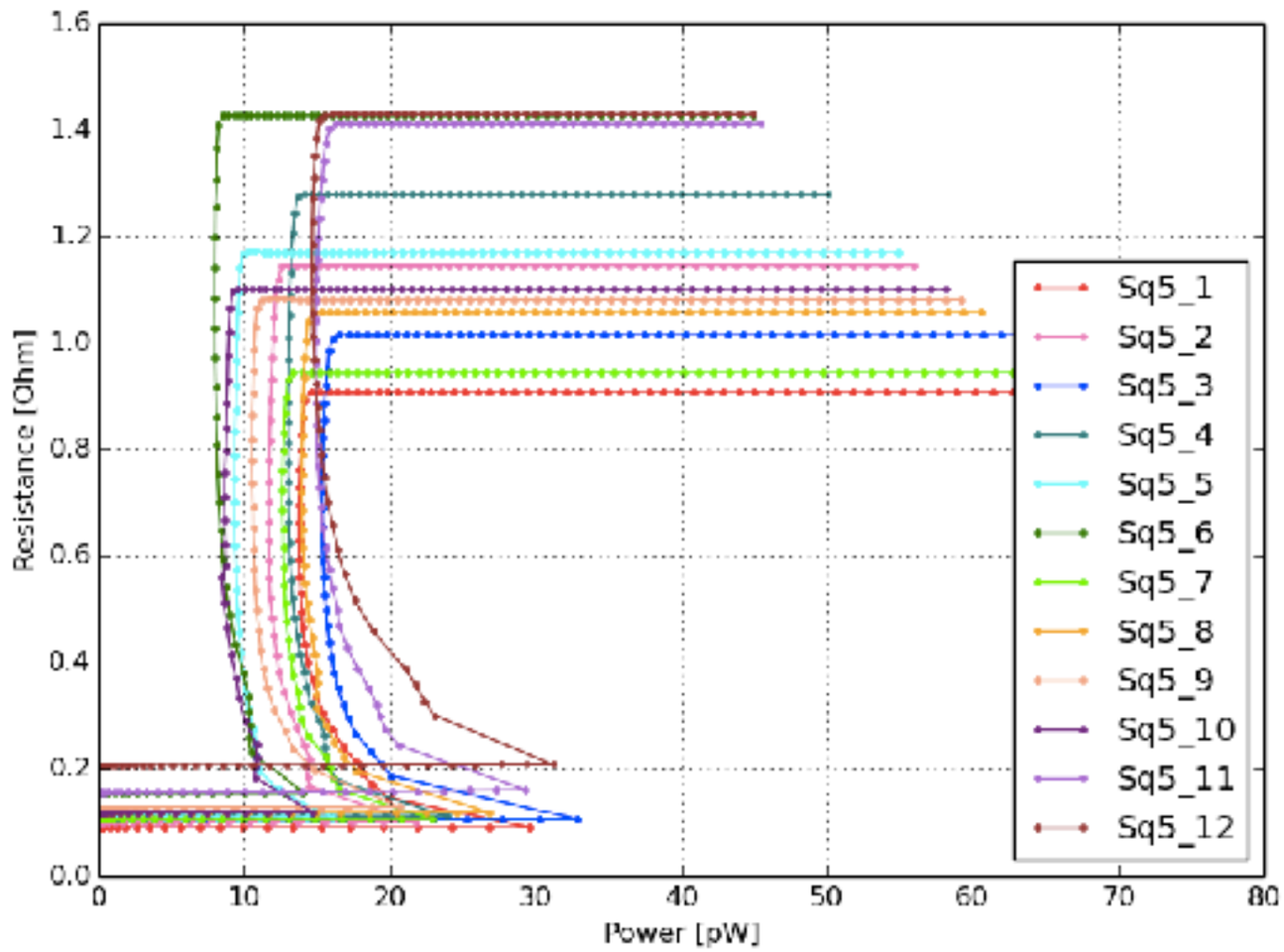
- Microstrip loss from poor superconductor, lossy dielectric, undesired material near stripline.
- Poor efficiency, but low loss microstrip indicates problem with coupling or reflections in circuit.

Bandpass



- Bad bands could be the result from varying dielectric thickness/constant, varying Nb properties (KI), fab errors (lith, etching).

IV (Psat/G)



- Bad Psat: poor control of TES Tc, problems with leg fabrication (materials properties varying, incomplete release e.g. “pillars”)