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

\[ \text{Noise}_\text{map}[nK \text{ deg}] \approx \frac{\text{NET}_\text{bolo} \sqrt{\text{Sky Area}(\text{deg}^2)}}{\sqrt{N_{\text{bolo}} t}} \]

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

- Need to make lots of detectors
CMB Detector Block Diagram (TES)

- Antenna (w/ pol)
- Transmission line
- Thermalization structures
- TES
- Thermal isolation
- Heat sink (~280 mK)
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.
Printing methods
Detectors fabricated using thin film processing

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- 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 ~1800°C. 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 ~3000°C.
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- 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
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<th>Layer</th>
<th>Material</th>
<th>Comment</th>
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<tr>
<td>1</td>
<td>Silicon</td>
<td>LSN (1µm)</td>
</tr>
<tr>
<td>2</td>
<td>Nb (300nm)</td>
<td>Silicon</td>
</tr>
<tr>
<td>3</td>
<td>Nb</td>
<td>LSN (1µm)</td>
</tr>
<tr>
<td>4</td>
<td>SiO₂</td>
<td>Silicon</td>
</tr>
<tr>
<td>5</td>
<td>Nb</td>
<td>SiO₂</td>
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<tr>
<td>6</td>
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<tr>
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<tr>
<td>12</td>
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<td>SiO₂</td>
</tr>
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</table>

The diagram shows a complex microstrip line structure with labeled components such as Nb lead pads, Nb bond pads, Nb microstrip line, broadband sinuous antenna, and TES bolometer.
The diagram shows a layout of layers and materials, including SiO₂, Nb, and LSN (1µm). The layers are labeled with locations 1 to 16. Each layer includes different components such as Nb leads, Nb braid-pads, Nb Microstrip line, Broadband sinuous antenna, and TES bolometer. The diagram also includes labels for 95 GHz, 150 GHz, 220 GHz, and 260, 271. The scale is marked as 2 mm.
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”)