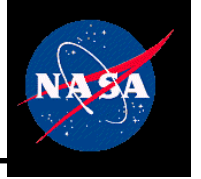




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Fabrication of Antenna-coupled Bolometers with Al/Ti/Au TES Readouts

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$$NEP_{bol} = \gamma [4kT^2G]^{1/2}$$

$$Q_{max} = \int G(T')dT' = S Q_0$$

$$NEP_{bol} = f [16kT_0SQ_0]^{1/2}$$

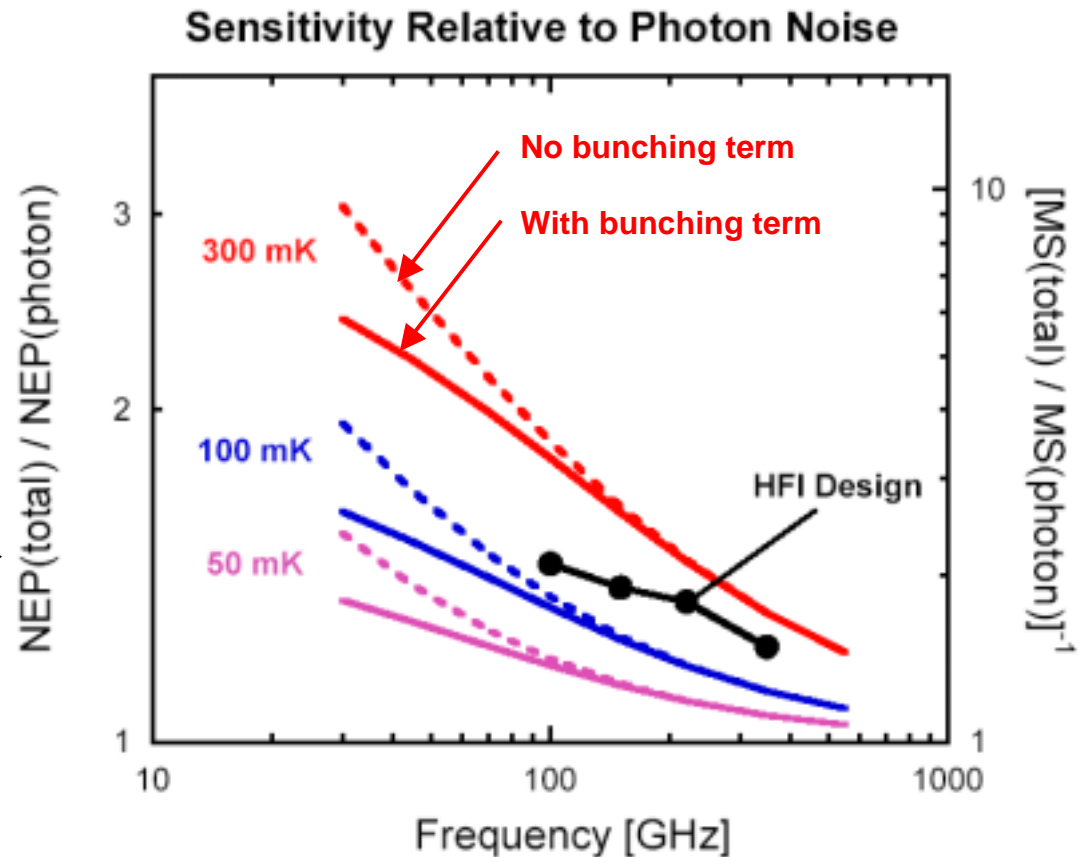
$$NEP_{photon} = [2h\nu Q_0(1+\varepsilon\eta/(e^x-1))]^{1/2}$$

Example:

Photons from CMB only

$\eta_{opt} = 50 \%$, $\Delta\nu/\nu = 30 \%$

TES bolometer with $S = 5$



NTD Ge bolometers have Johnson noise,
but more dynamic range due to rebiasing
Slightly better for this optimization

HEMTs

$T_A = 3h\nu/k$
 $\Delta\nu/\nu = 30\%$
 Q&U / feed

vs.

Bolometers

$\eta_{\text{opt}} = 50\%$
 $\Delta\nu/\nu = 30\%$
 $Q_{\text{max}}/Q_0 = 5$

1 % emissive 60 K telescope

Bolo NET = 0.5*(Planck NET)

- * No 4 K photons
- * No noise contingency
- * No technology development

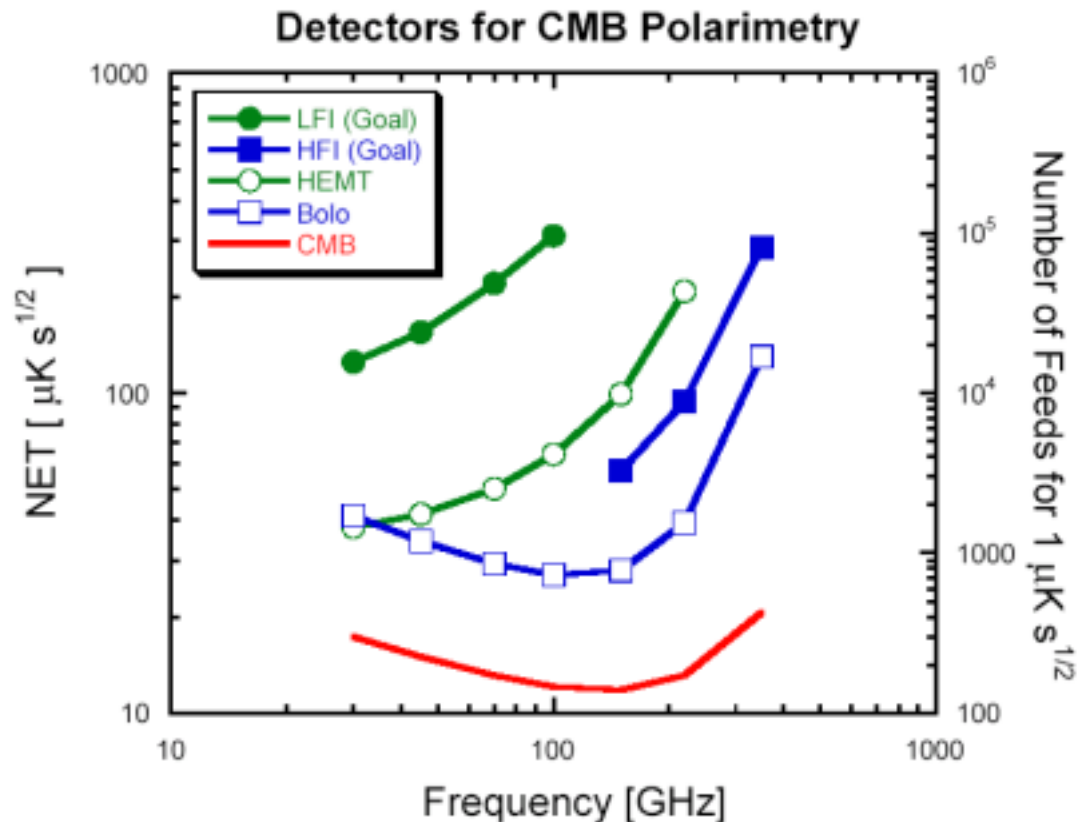
Absorber size the *only* issue
 for $\nu < 75$ GHz

What can we do today?

250 feeds @ $40 \mu\text{K}\sqrt{\text{s}}$ per feed

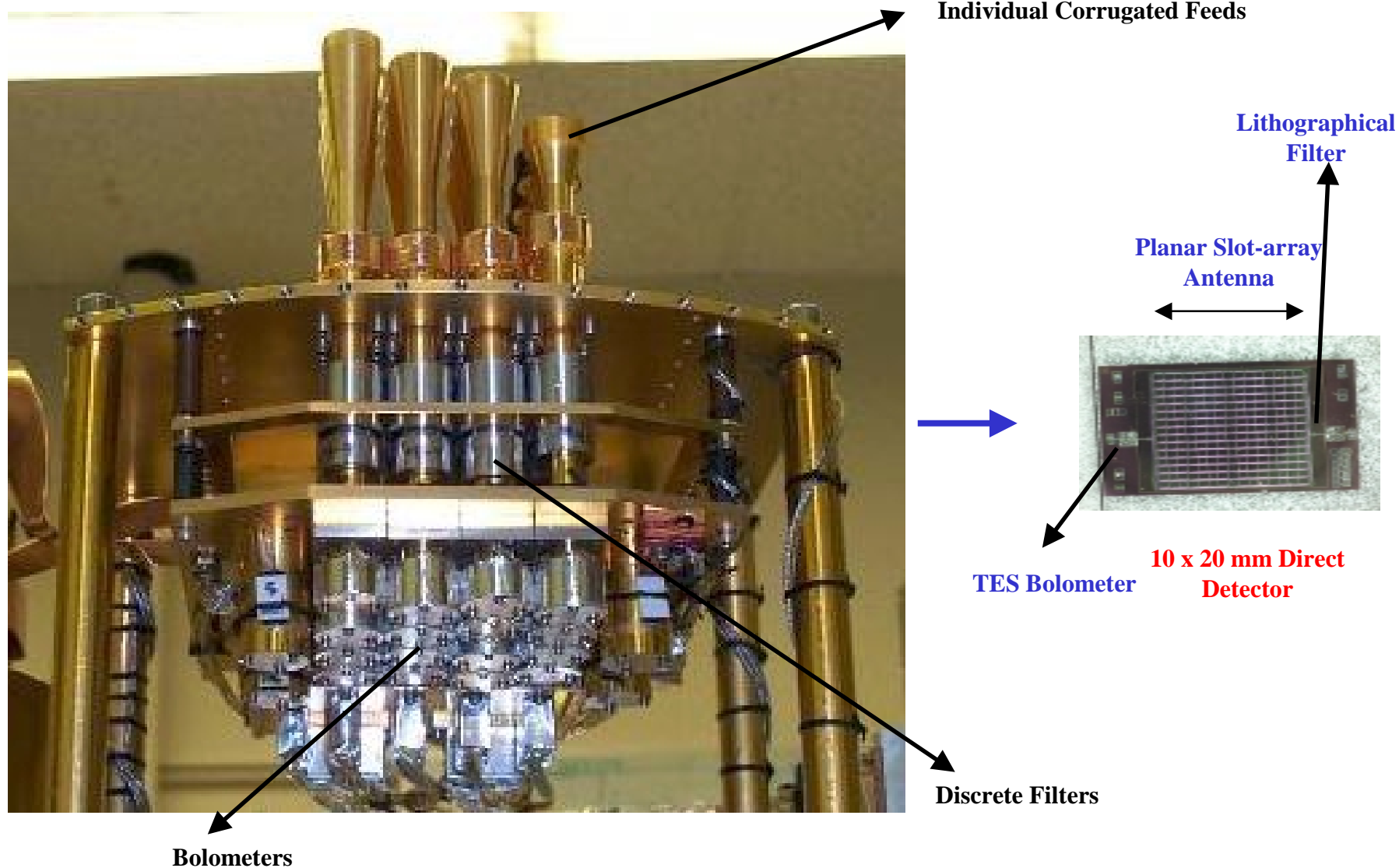
System NET = $2.5 \mu\text{K}\sqrt{\text{s}}$

10 times more sensitive than Planck

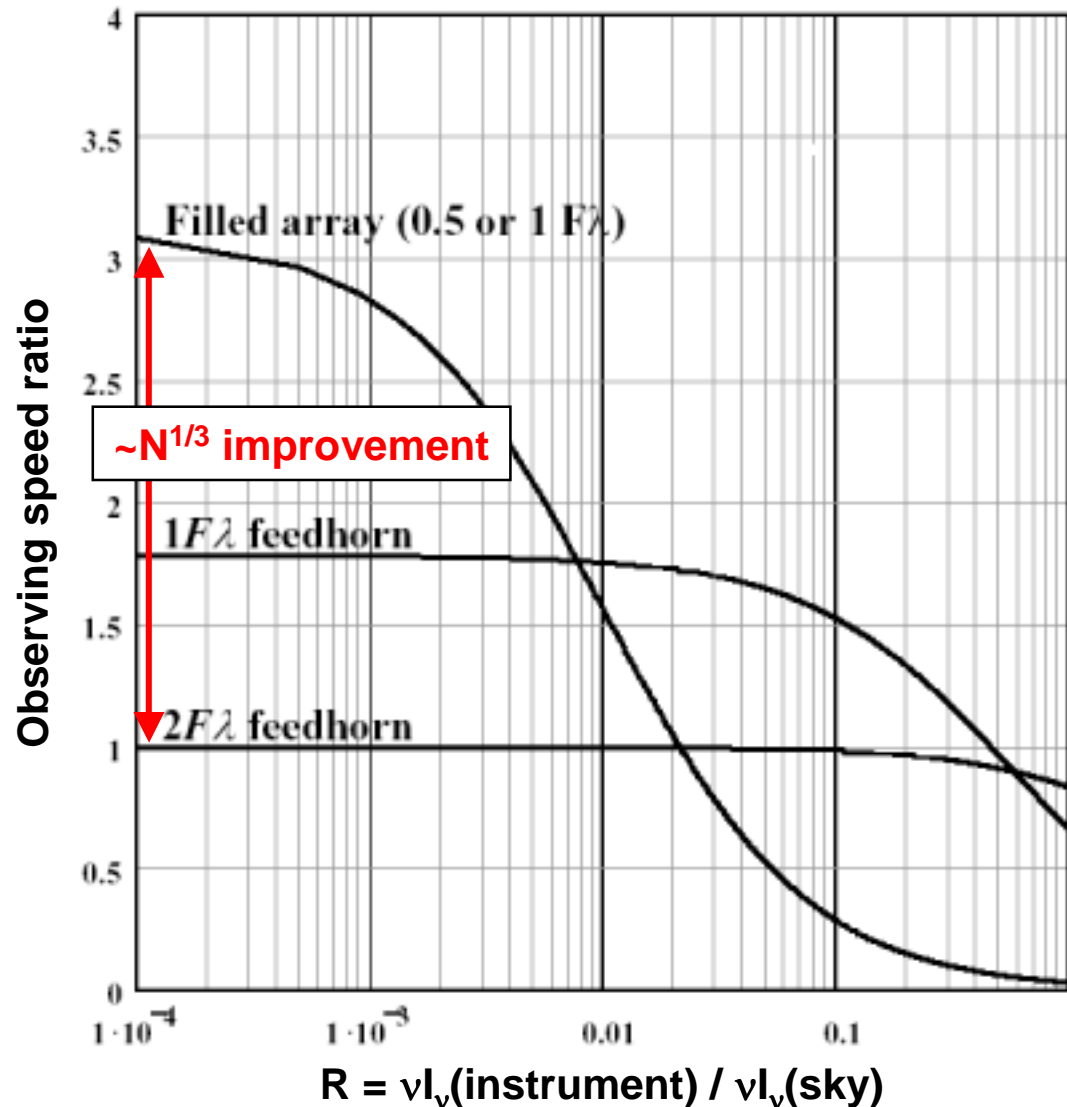


But... Larger focal planes require a new architecture

Building a Bigger Focal Plane Array



Directed Beams for Mm-wave Systems



**Background-limited filled array
vs. $2F\lambda$ feedhorn array:**

- $\sim 3x$ better mapping speed
- 16 times more detectors
- Simpler operating modes
- Requires straylight control

Millimeter-wave case:

- Sky is 2.7 K
- Need extreme control of beams even in a 2 K environment
- Sub-K re-imaging optics? Or
- Directed beams

See Griffin, Bock & Gear
Applied Optics 2002
Astro-ph 0205264

Challenges

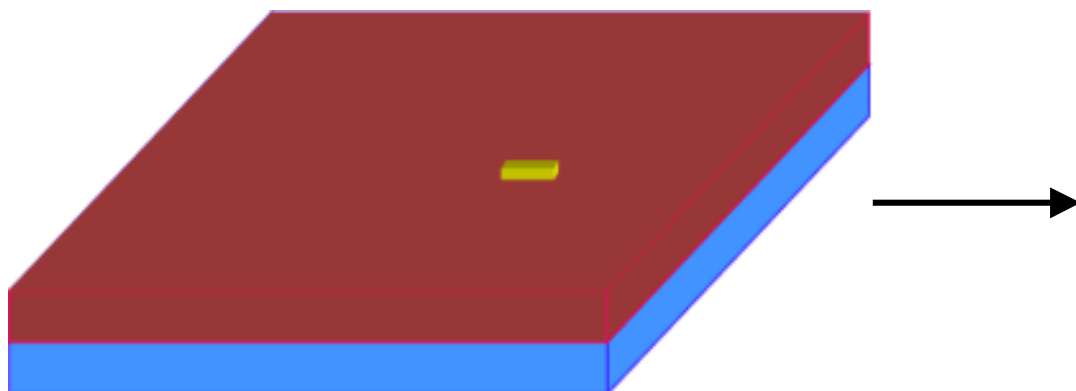
Challenges for Mm-wave Bolometers

- Need directed beams
- Massive focal planes
- Large pixels
- Straylight and filtering

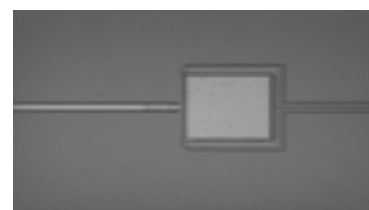
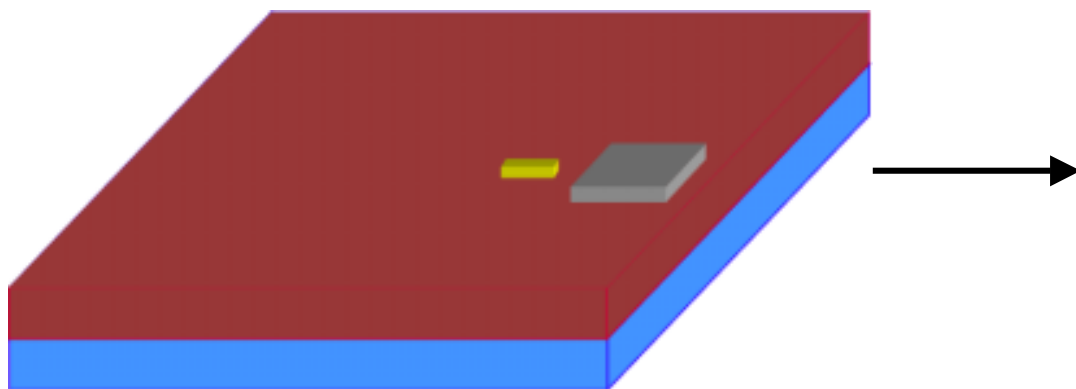
Microstrip-Coupled Bolometers

- Antennae defined beams
- Eliminate feedhorn optics
- Large antennae, small active area
Absorber volume reduced by $> 10^5$
- Integrated filters & phase switches
- Flexible planar architectures
- Compatible with new concepts
TES bolometer
Kinetic inductance

Direct Detector Fabrication

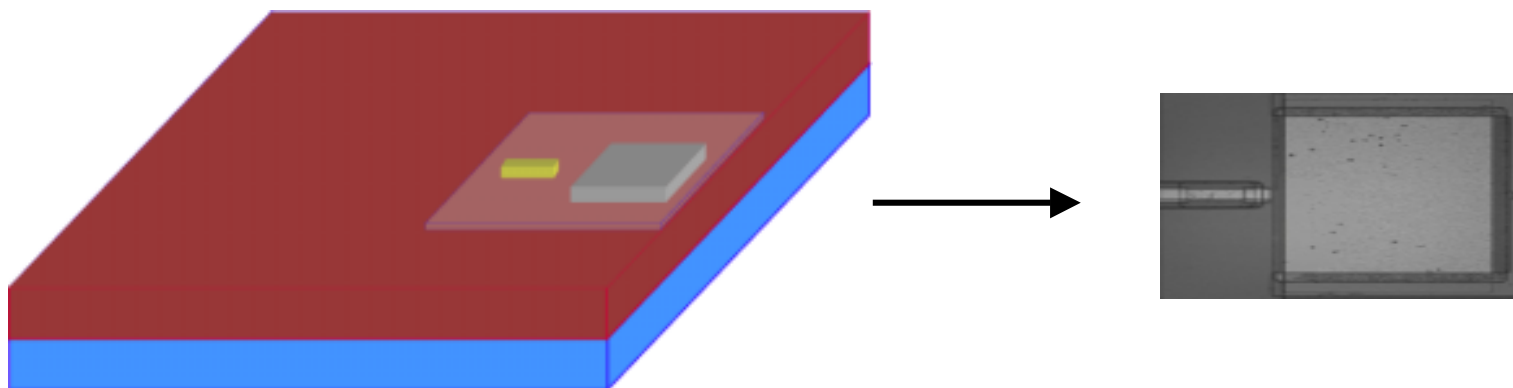


(a) Resistor deposition and lift-off

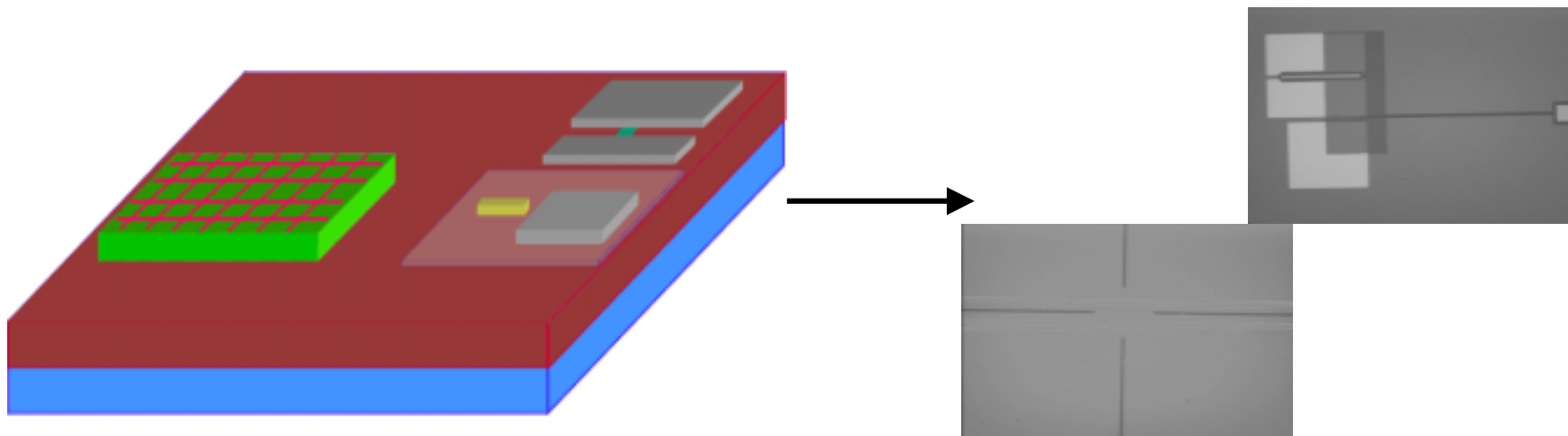


(b) TES (Al/Ti/Au) deposition and lift off

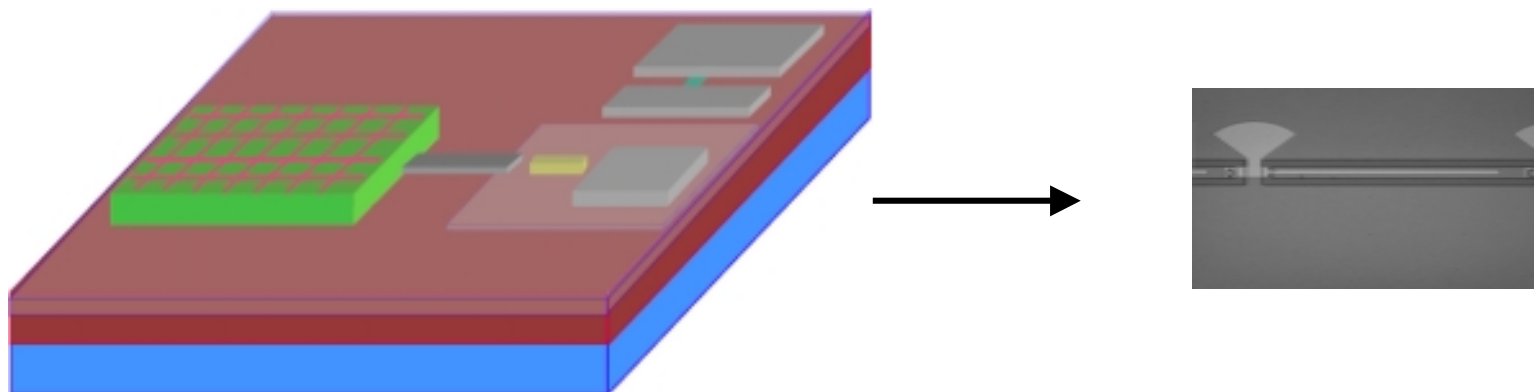
Direct Detector Fabrication



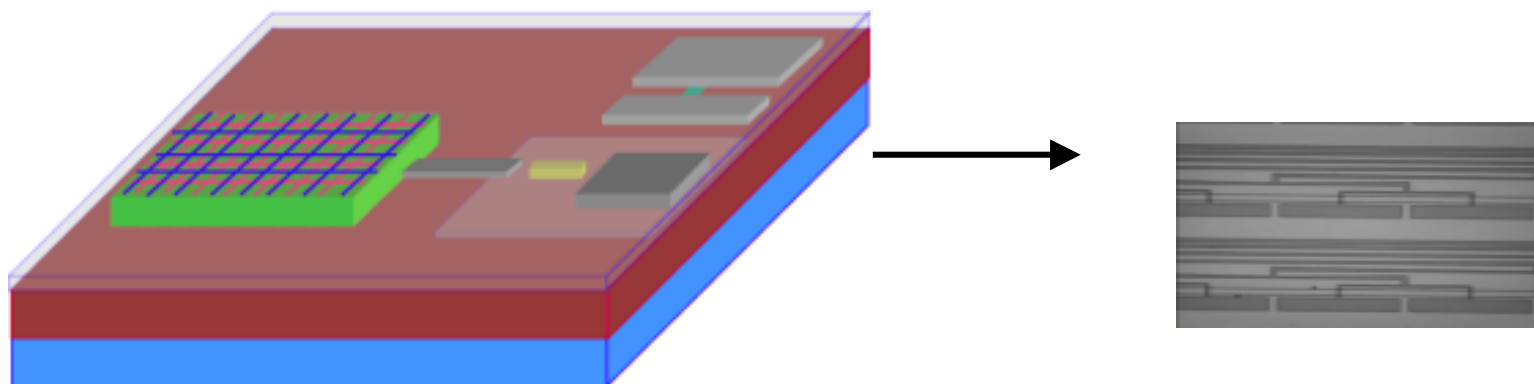
(c) The first SiO deposition to protect TES layers



(d) Nb Ground plane deposition and etch. Shunt resistor formation

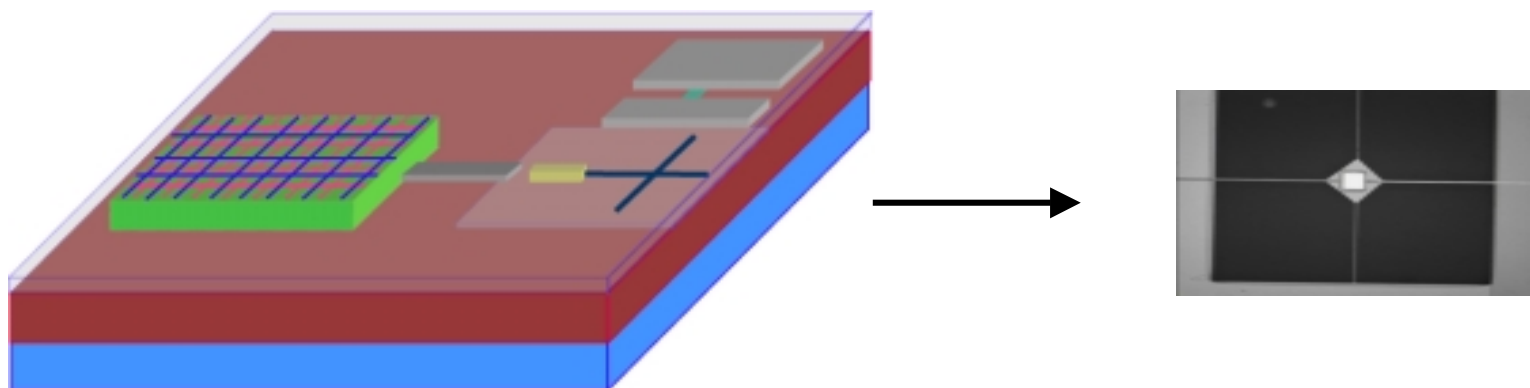


(e) SiO deposition and lift-off to form vias

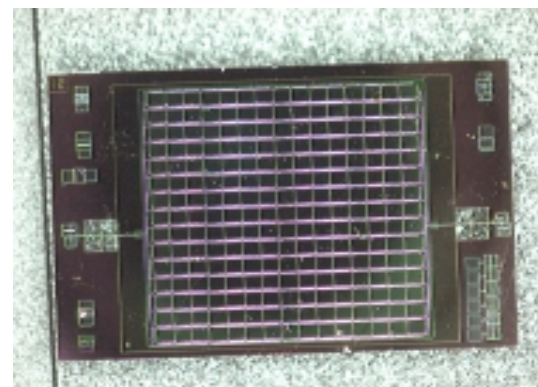
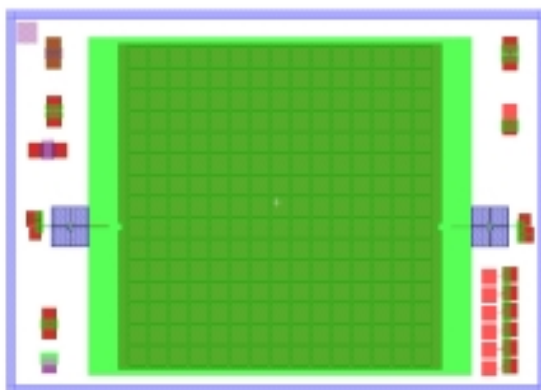


(f) E-beam patterning for Nb microstrip and etch back

Direct Detector Fabrication

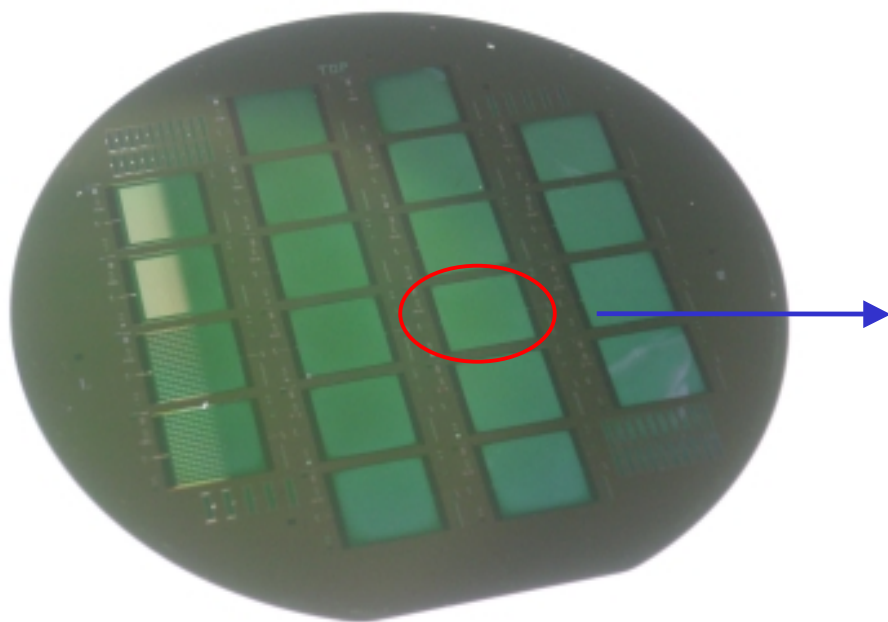


(g) Front, backside nitride etch and backside deep trench etch

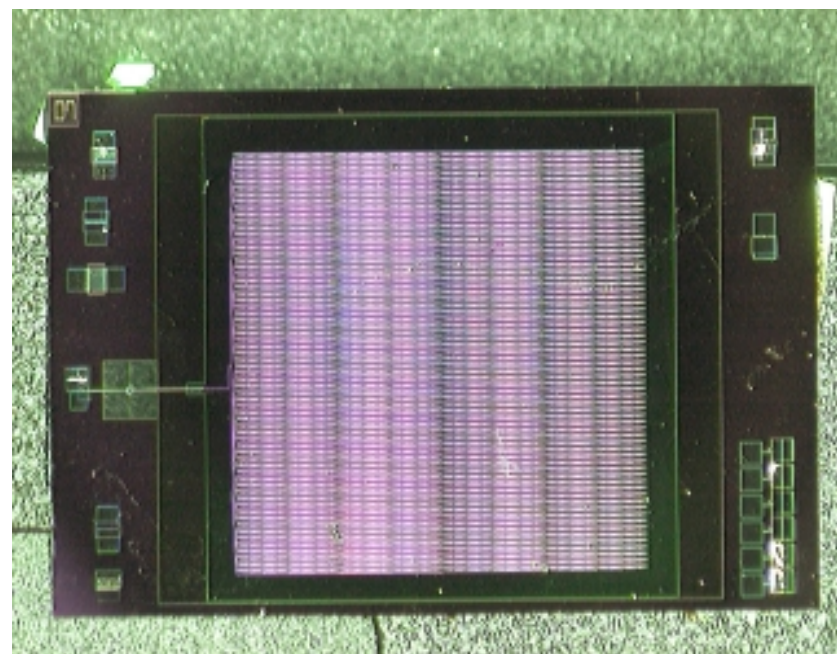


(h) Top-view after final release and cleaning each array and double antenna-coupled Transition Edge Polarization-sensitive Bolometer

Direct Detectors



Completed bolometer arrays on the 4" Si wafer



Single antenna-coupled Transition Edge Polarization-sensitive Bolometer

TES Temperatures Vs. Resistances

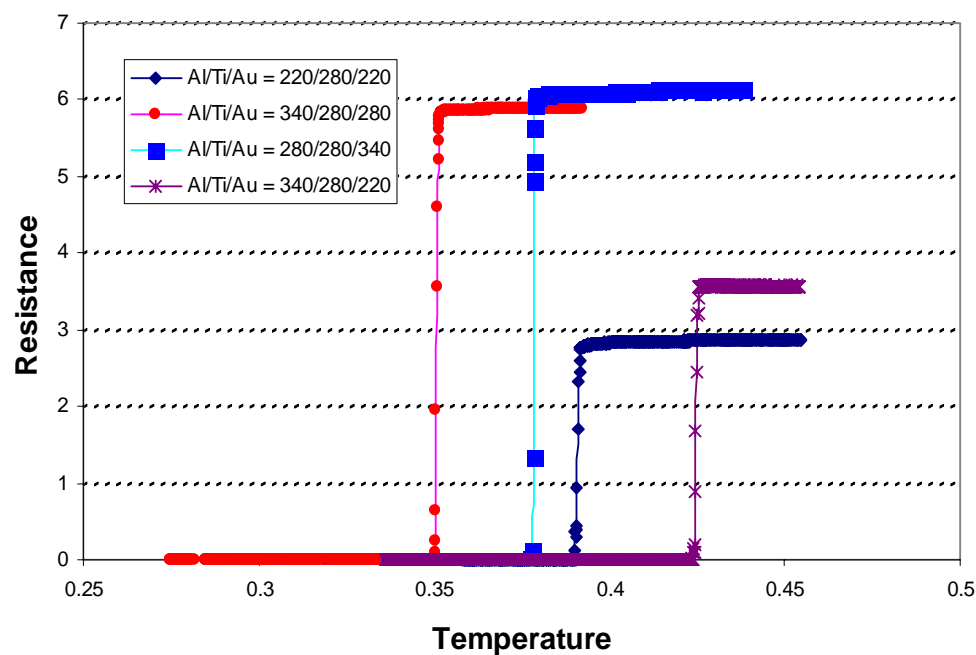


Figure. Transition temperatures as a function of Al/Au thicknesses

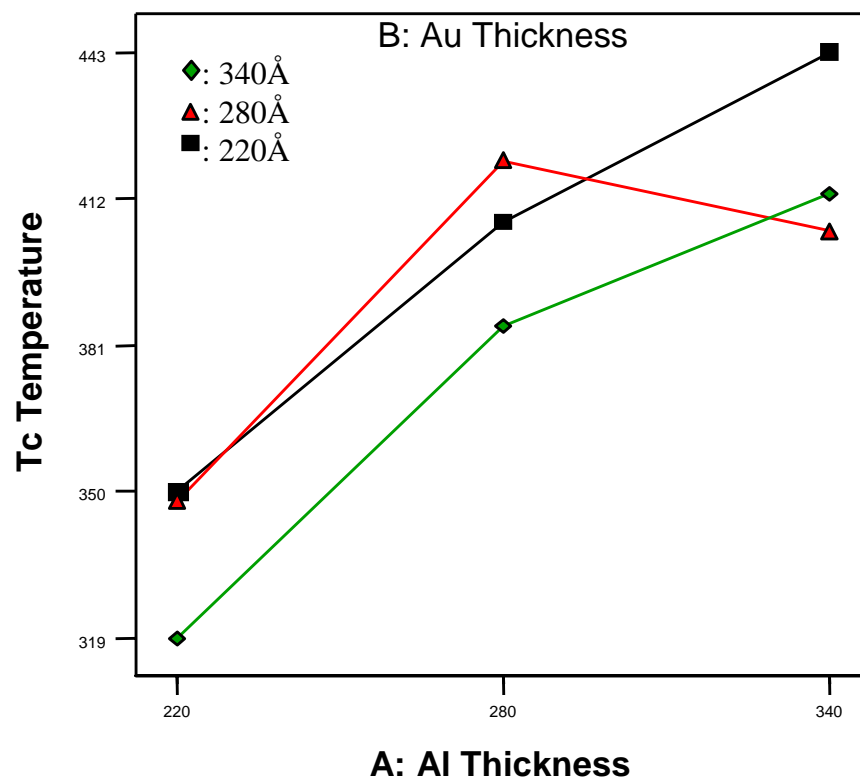
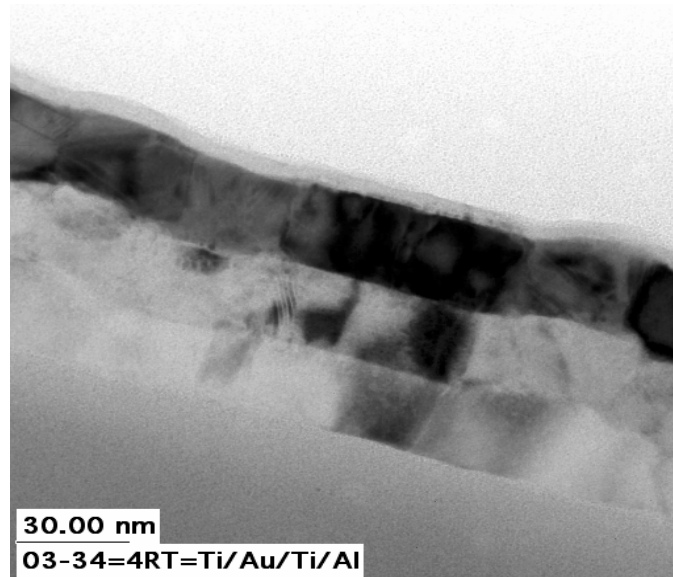
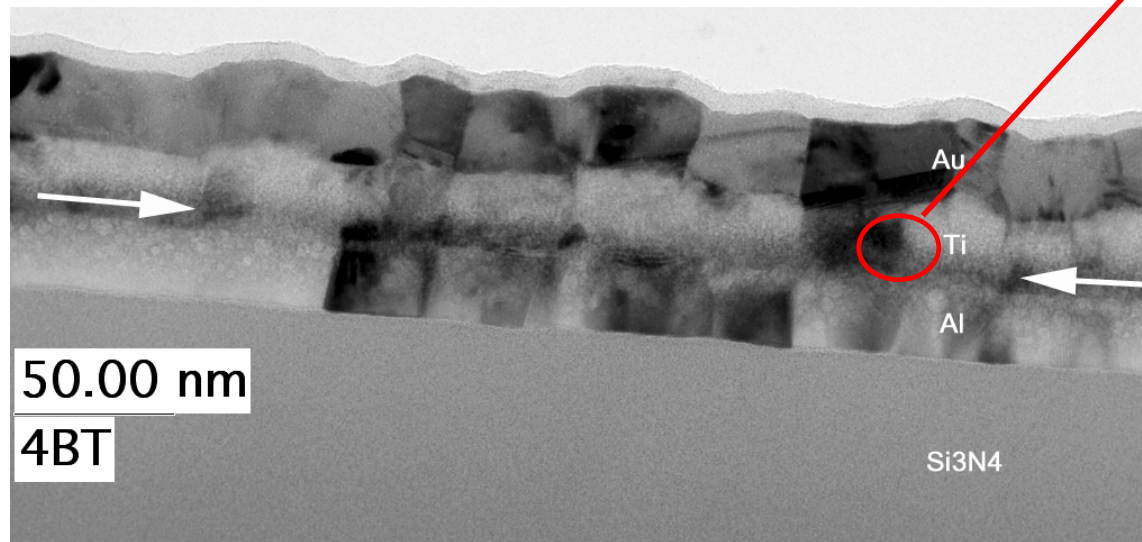
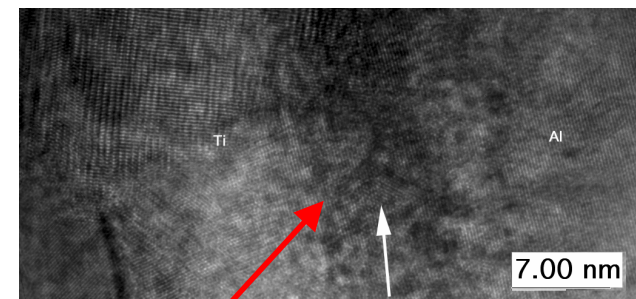


Figure. TES temperature plot dependence on Al and Au thicknesses

TES Layer Diffusion



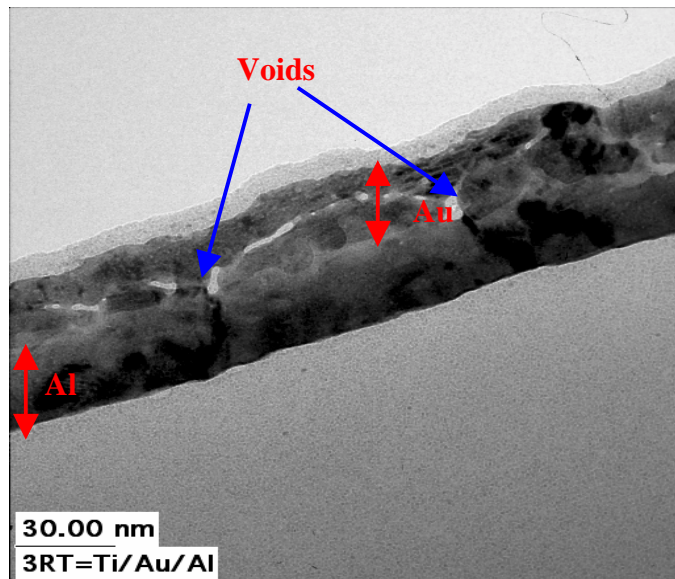
Al/Ti/Au/Ti (28 nm/28 nm/28 nm/4 nm)
at room temperature



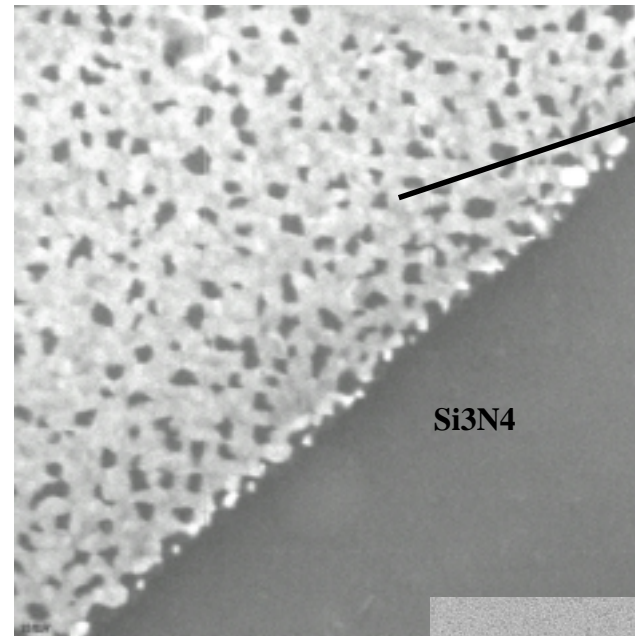
Al/Ti/Au/Ti processed at 150 °C
for 60 min

TES Layer

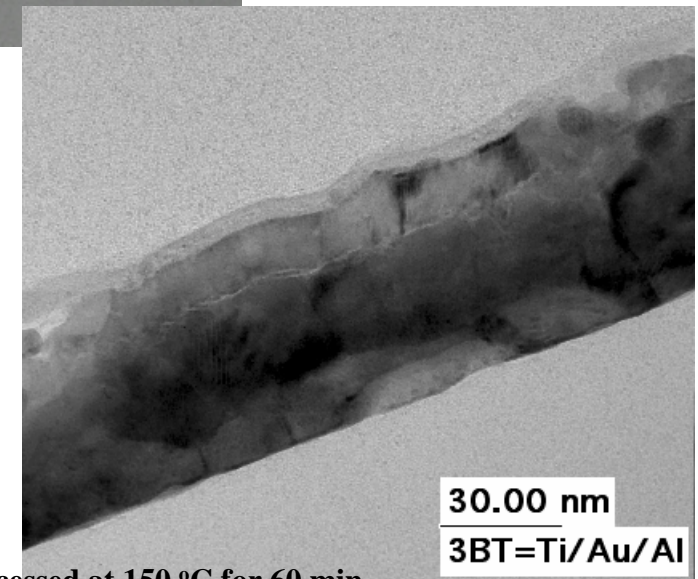
A SEM image of voids between Au grains resulting from secondary and non-uniform nucleation.



Al/Au/Ti at room temperature

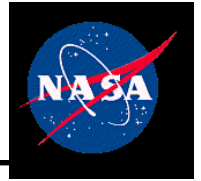


Ti/Au islands resulting from non-uniform nucleation



Al/Au/Ti processed at 150 °C for 60 min

Summary



- We have successfully fabricated antenna-coupled transition edge polarization-sensitive bolometer using micro-electro-mechanical systems (MEMS) techniques.
- Our Al/Ti/Au/Ti TES demonstrated excellent physical properties to help constant transition temperature during the operation.
- Using statistical engineering methods, we show that the factors important in the TES sensing temperature are, in decreasing order of importance, Al, Au thicknesses, and interaction between Al/Au layers. We have demonstrated the use of an atomically thin Ti interlayer to prevent inter-diffusion between Al and Au layers. The Ti layer deposited at the interface also helps adhesion of a Au layer and avoids void formation. Ti layer contributes to hold down the change in transition temperature.
- We are testing the Nb microstrip antenna-coupled bolometer arrays for multi-color polarization-sensitive focal plane.



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Acknowledgement



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