Antenna-coupled Transition Edge Polarization-sensitive Bolometer Arrays

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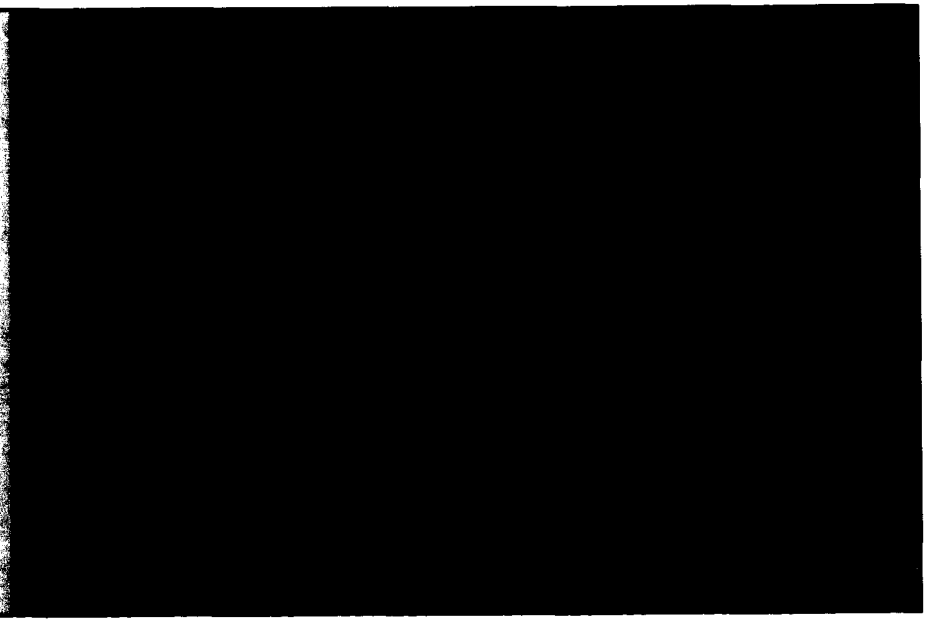
Motivation

Overview:

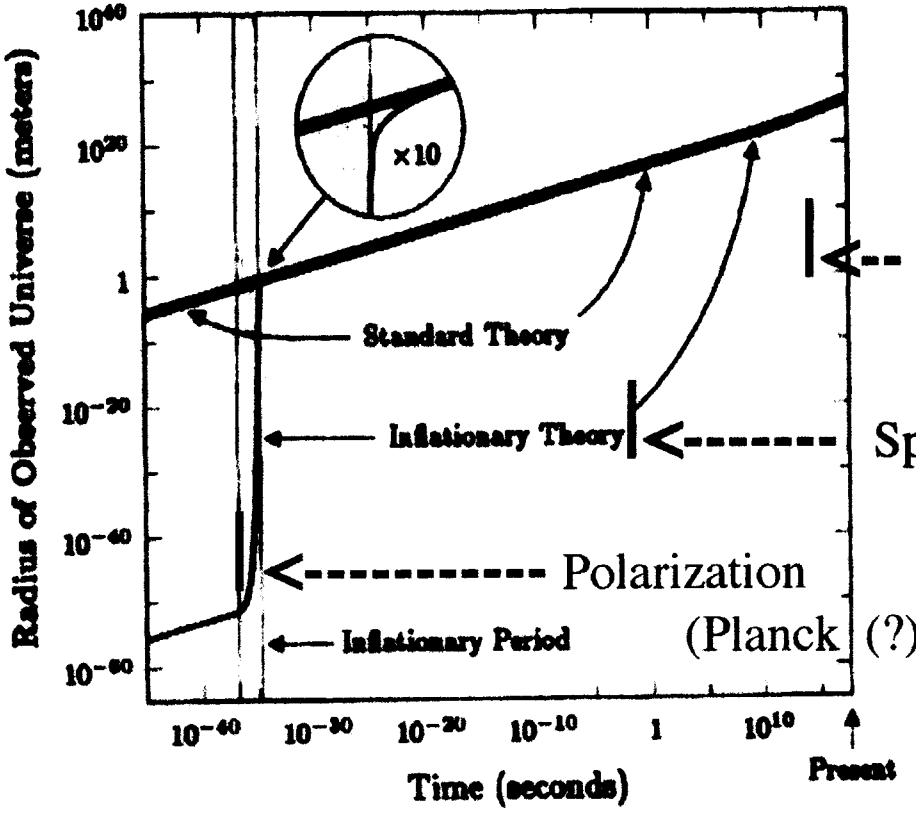
–Superconducting Transition Edge Sensors (TES) have demonstrated excellent performance both as bolometric and calorimetric detection systems. The basic device is a thin film of either a pure superconductor or more commonly a normal metal-superconducting multi-layer.

State-of-the-Art:

- **Calorimetry:** TES based calorimeters have demonstrated record performance in the x-ray regime with approximately 4eV energy resolution for 6keV photons and and are competitive with other technologies well into the visible regime.
- **Bolometry:** TES bolometers have achieved near phonon limited performance at submillimeter wavelength at temperatures in the 300mK range.



"Seeing" inflation via the GW signal encoded in CMB polarization



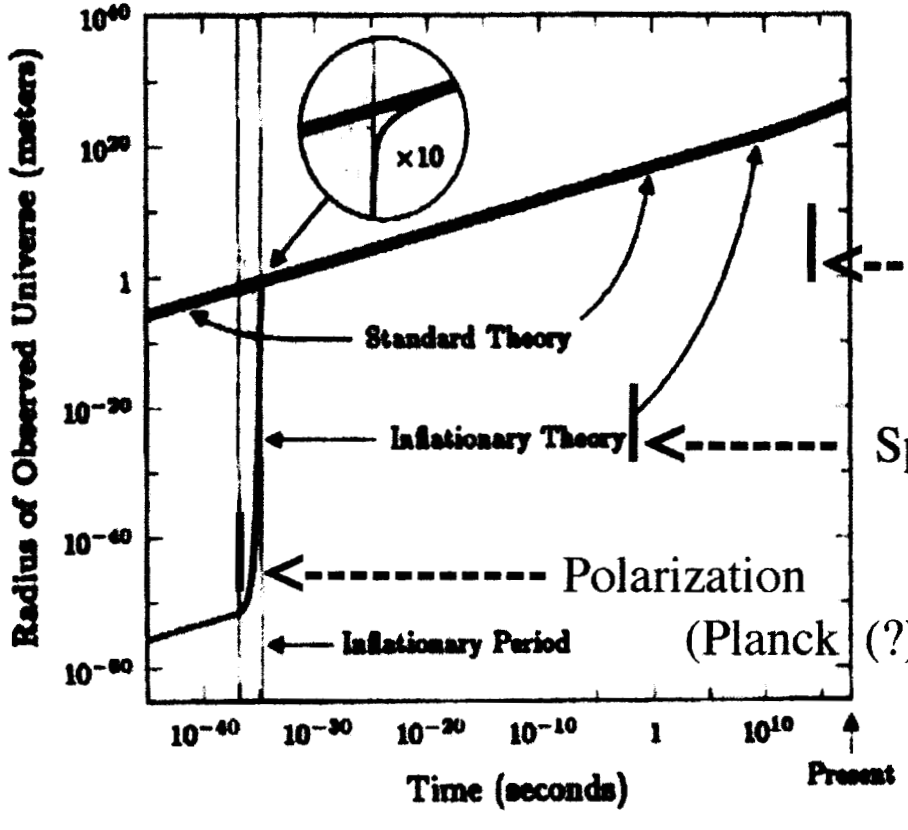
Anisotropy (MAP, Planck)

Spectrum (COBE/FIRAS)

Polarization (Planck (?), Future CMB mission)

CMB Polarization

"Seeing" inflation via the GW signal encoded in CMB polarization



Anisotropy (MAP, Planck)

Spectrum (COBE/FIRAS)

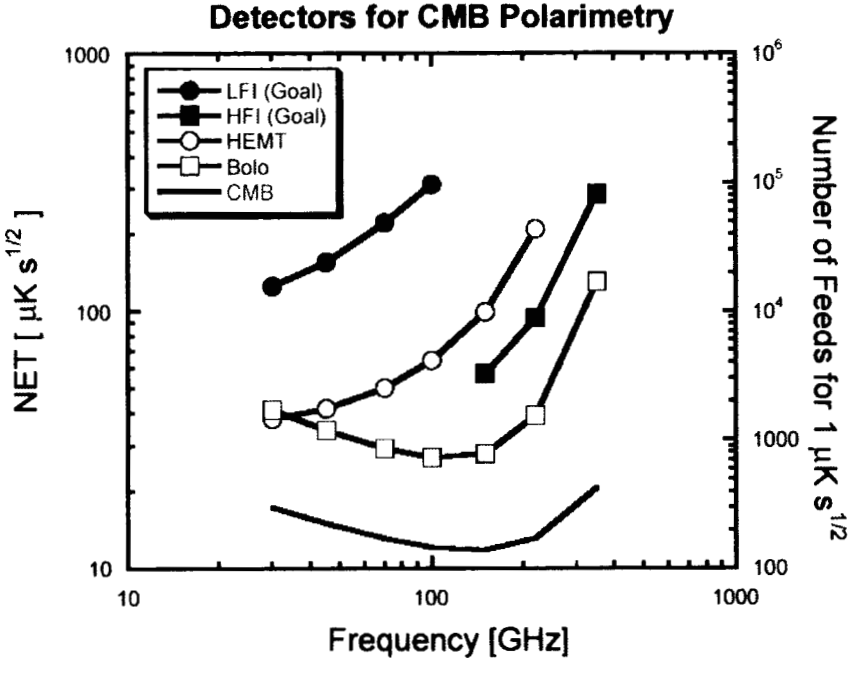
Polarization (Planck (?), Future CMB mission)

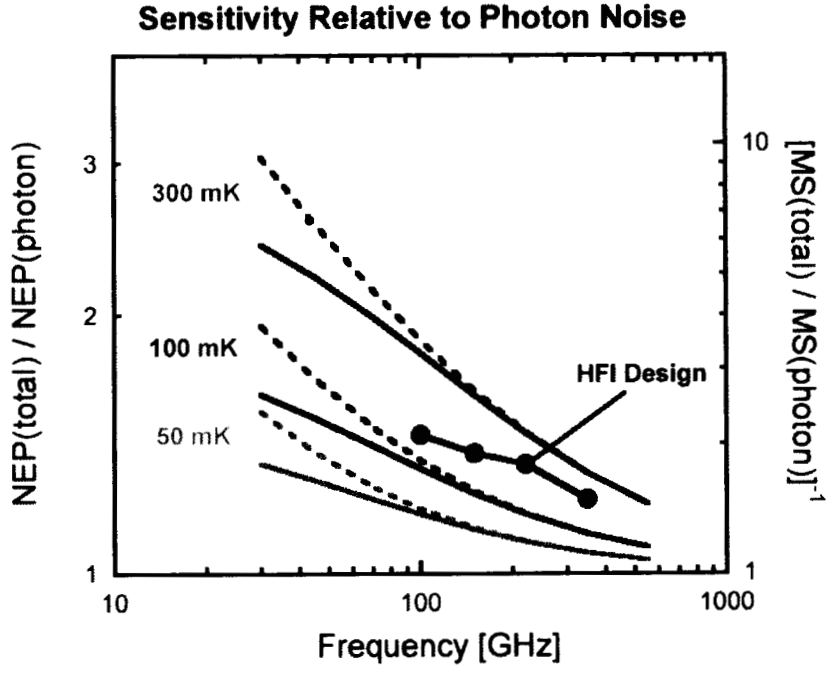
Design and Development

- Develop novel antenna and filter designs in superconducting Nb microstrip for coupling to direct detectors.
- Develop and test wide-band antenna, single-polarization, provides beam shaping, and eliminates coupling optics such as hyper-hemispherical lenses.
- Demonstrate single-band dual polarization antenna.
- Integrate RF components into a focal plane array

Future Focal Plane Sensitivity & Photon Noise

California Institute of Technology





What can we do today?

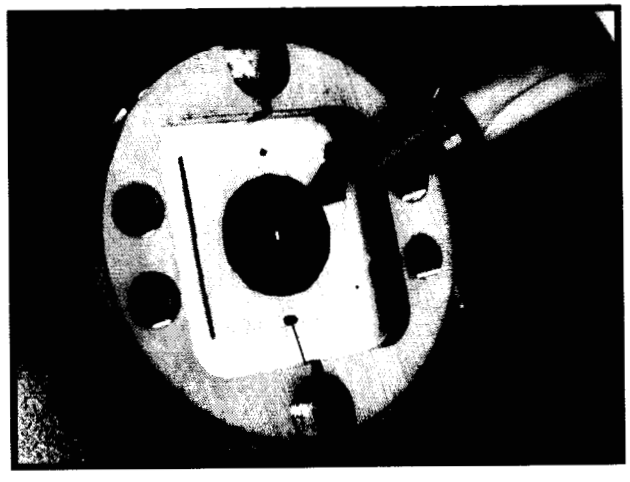
250 feeds @ 40 μK√s per feed

System NET = 2.5 μK√s

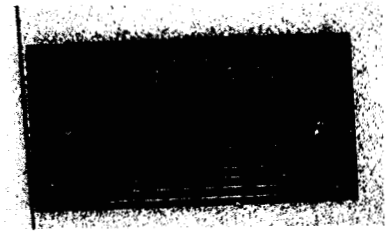
10 times more sensitive than Planck

But... Larger focal planes require a new architecture

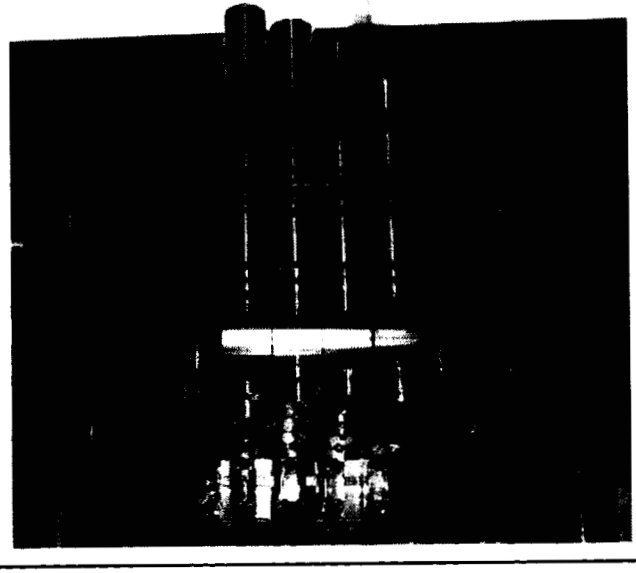
Size Matters?

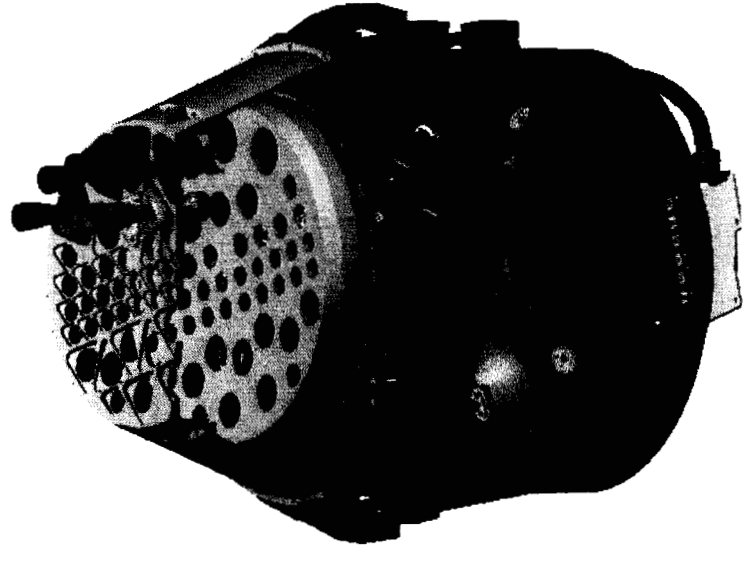


HFI Bolometer



10 x 20 mm Direct Detector

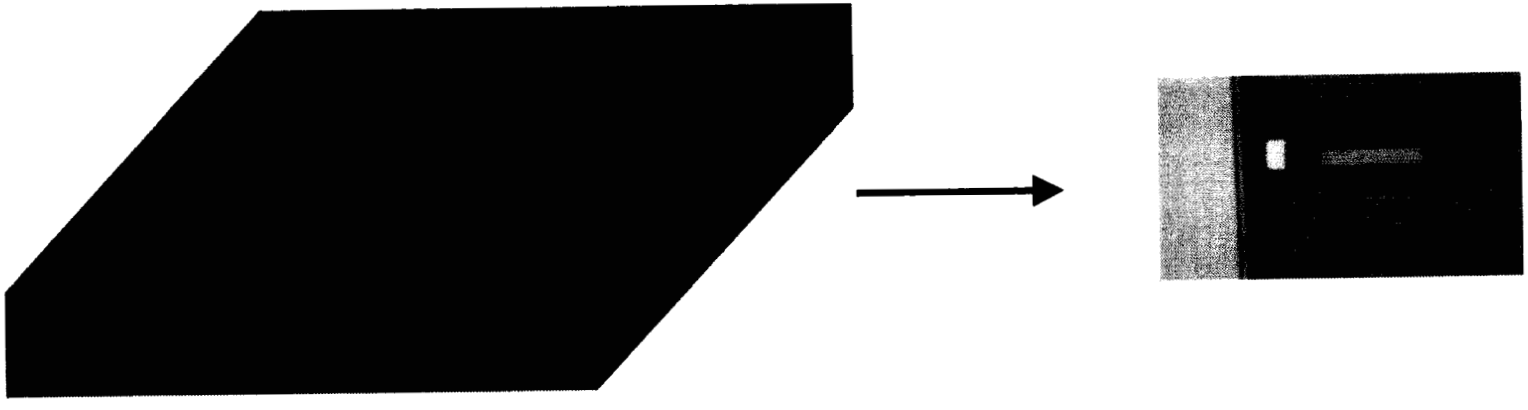




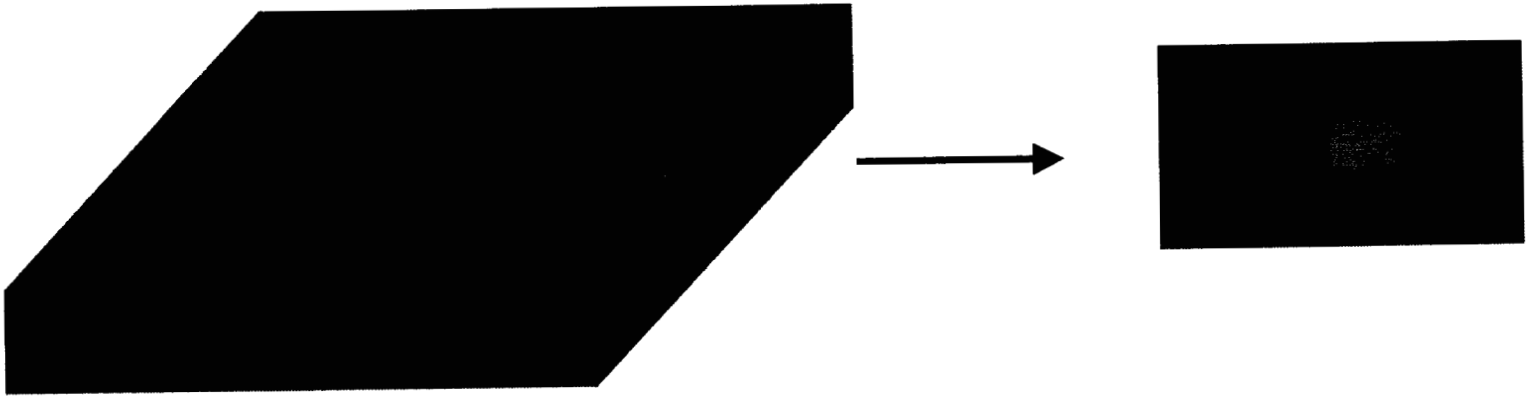
Challenges

Challenges for Mm-wave Bolometers	Microstrip-Coupled Bolometers
• Need directed beams • Massive focal planes • Large pixels • Stray light and filtering	• Antennae defined beams • Eliminate feedhorn optics • Large antennae, small active area Absorber volume reduced by > 10^3 • Integrated filters & phase switches • Flexible planar architectures • Compatible with new concepts TES bolometer Kinetic inductance

Direct Detector Fabrication

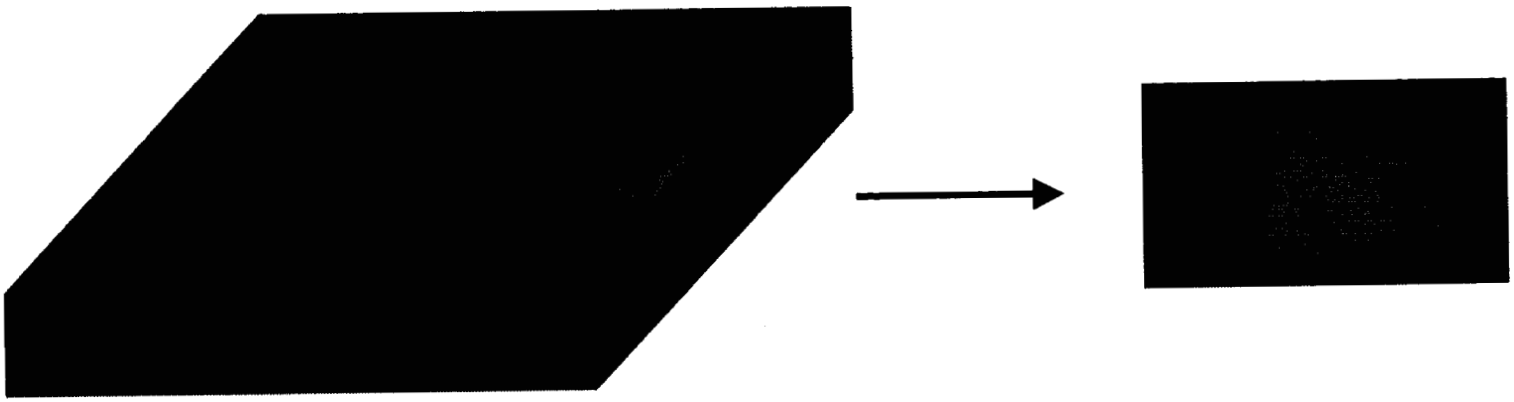


(a) Resistor deposition and lift-off

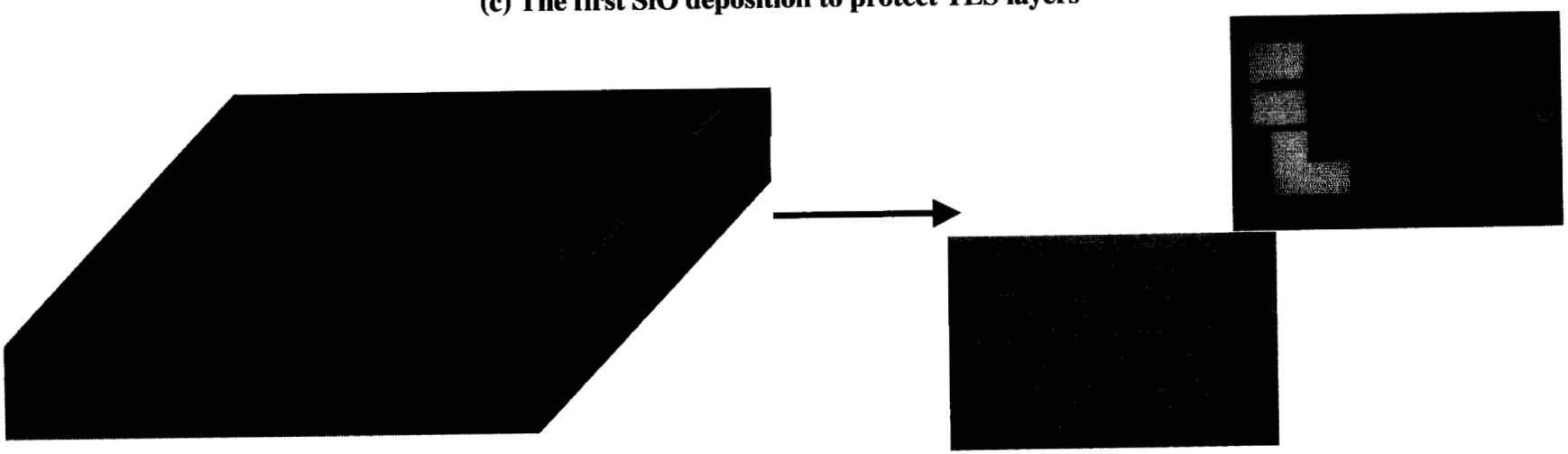


(b) TES (Al/Ti/Au) deposition and lift off

Direct Detector Fabrication

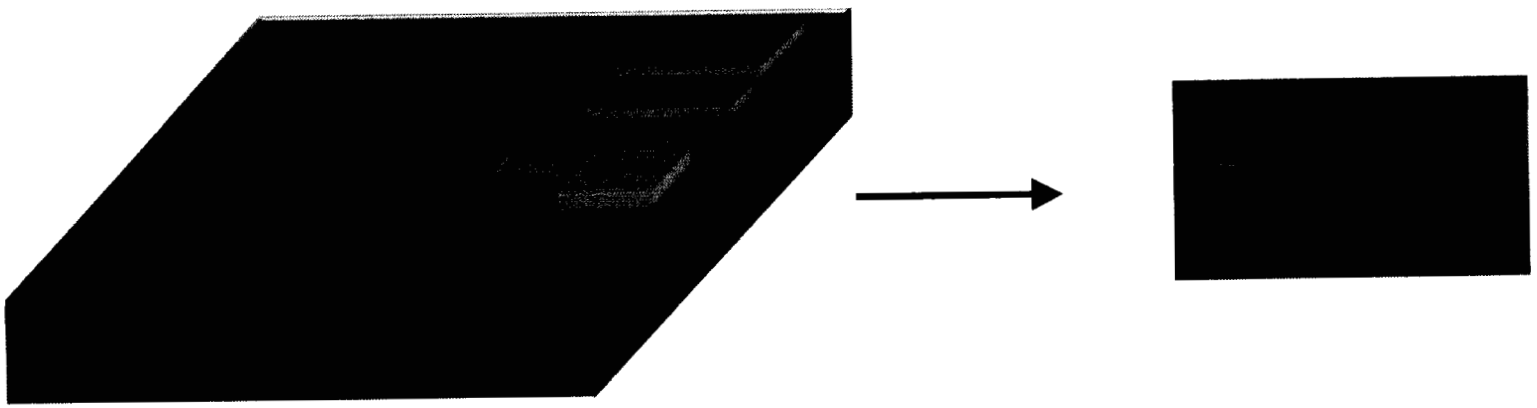


(c) The first SiO deposition to protect TES layers

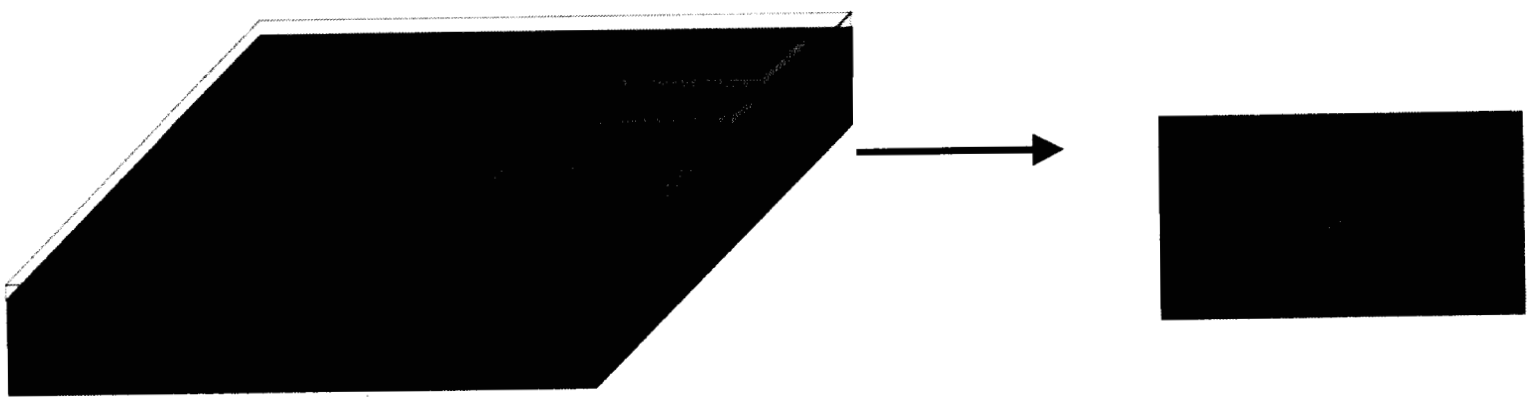


(d) Nb Ground plane deposition and etch. Shunt resistor formation

Direct Detector Fabrication

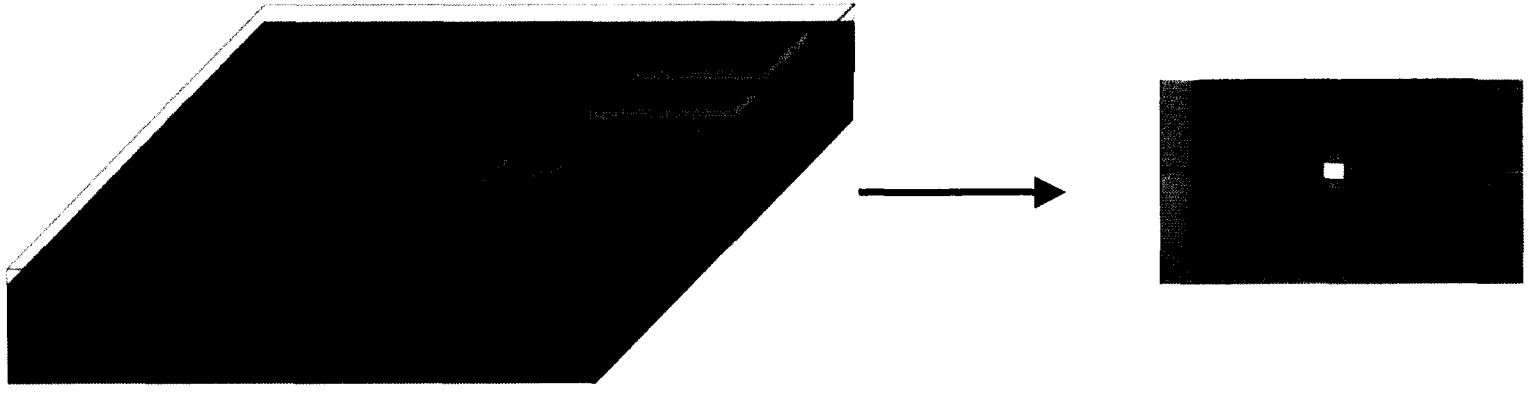


(e) SiO deposition and lift-off to form via



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

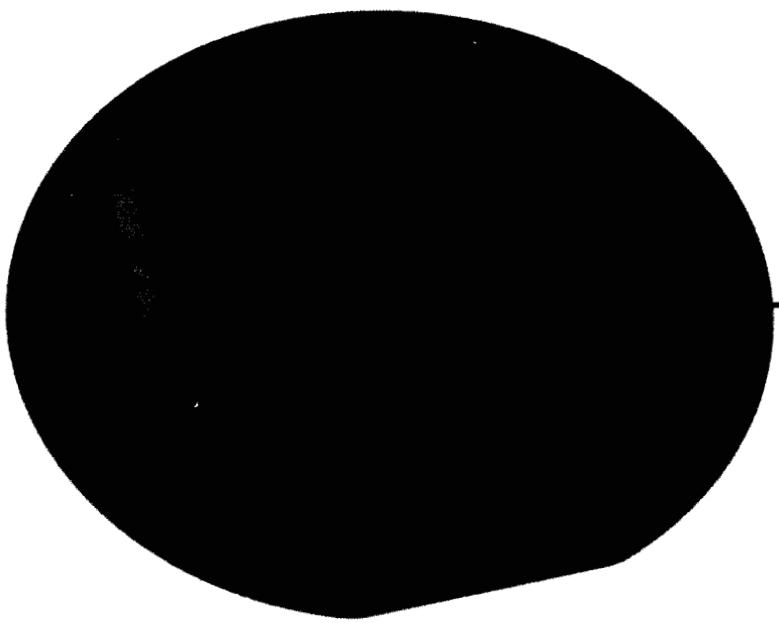
Direct Detector Fabrication



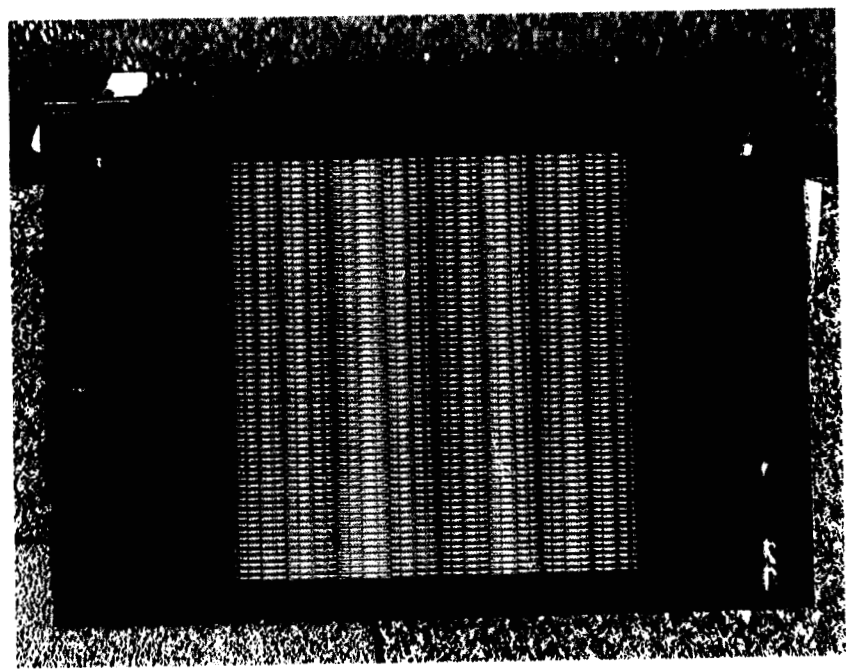
(g) Front, backside nitride etch and backside deep trench etch

(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

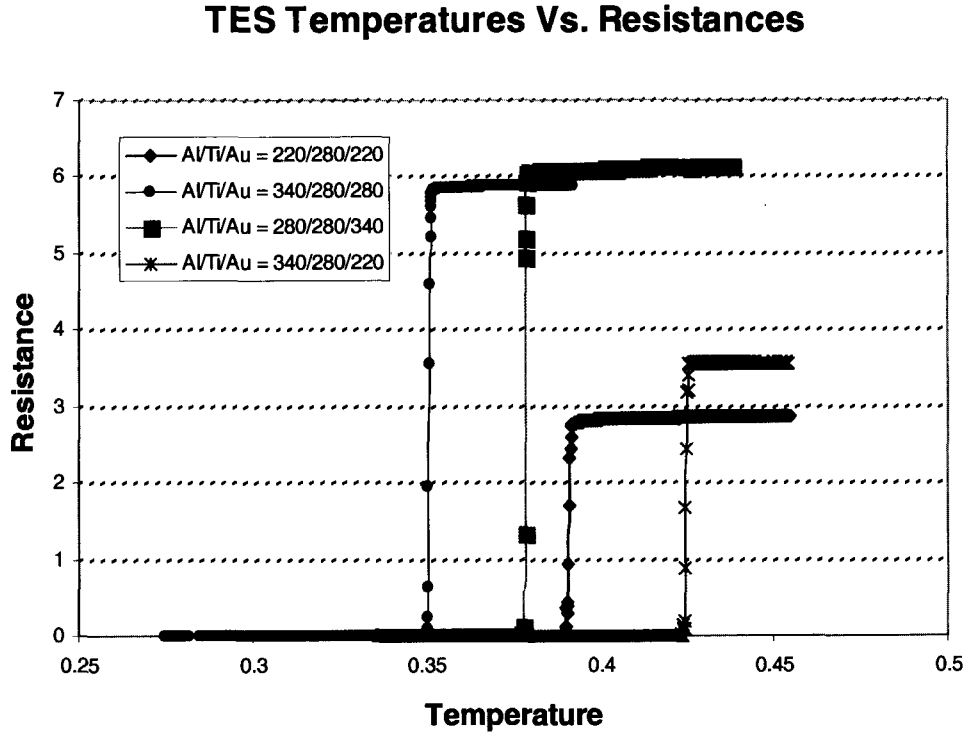


Figure. Transition temperatures as a function of Al/Au thicknesses

TES Temperatures

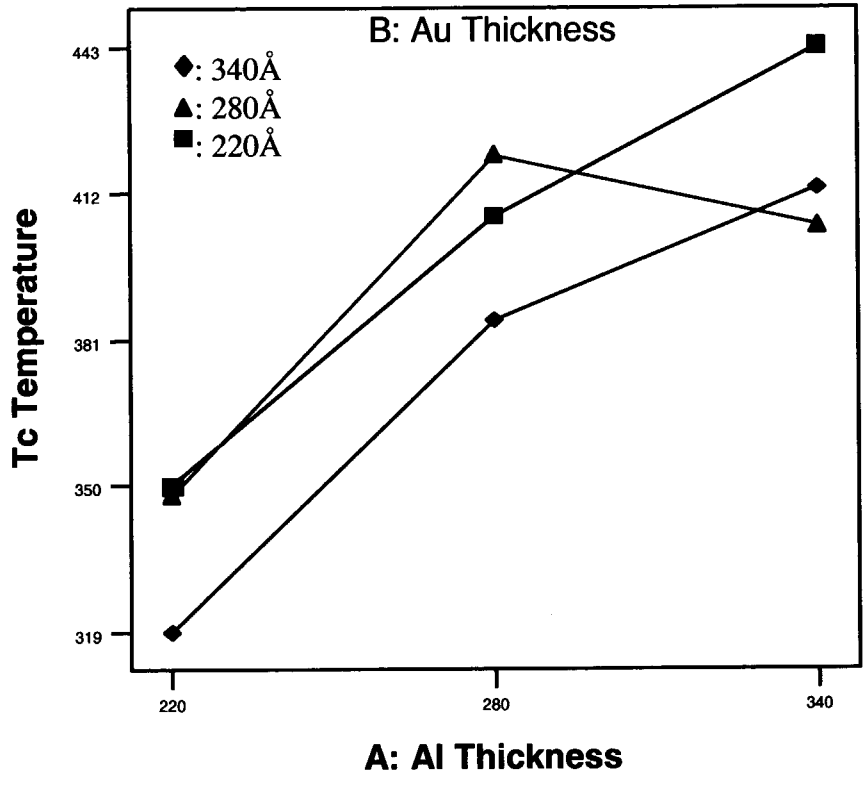


Figure. TES temperature plot dependence on Al and Au thicknesses

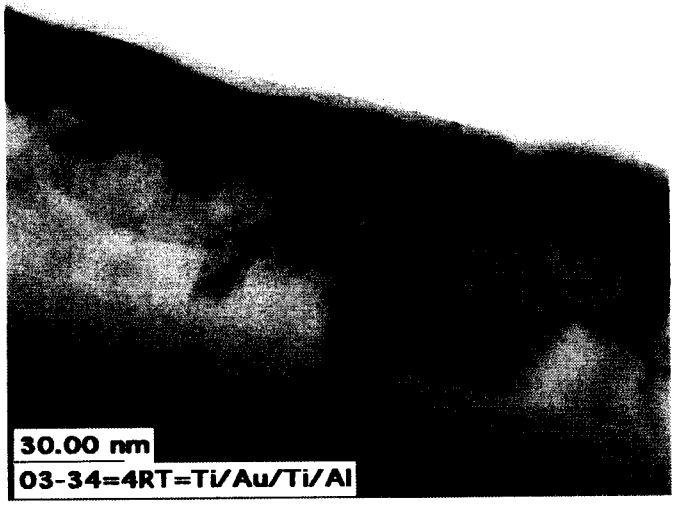
Statistical Analysis

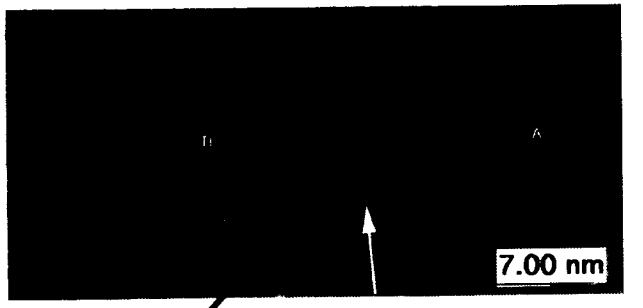
Table1 . Contribution of the Al (A), Au (B) and interaction (C) effects on TES temperature.

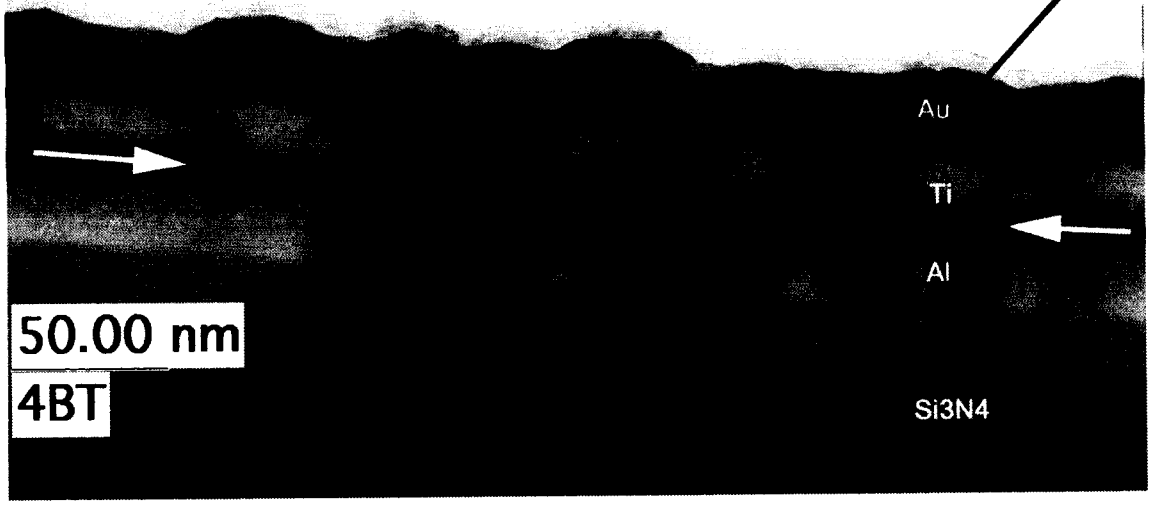
Term	DF (Degree of freedom)	Sum Square	Mean square	% Contribution
A	2	11106.90	5553.44	84.543
B	2	1194.89	597.44	9.095
C	4	835.78	208.94	6.362

TES Layer

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



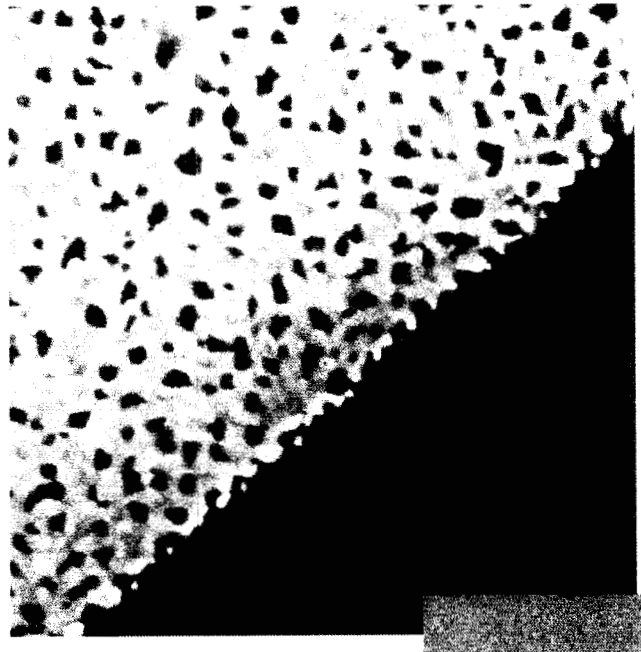


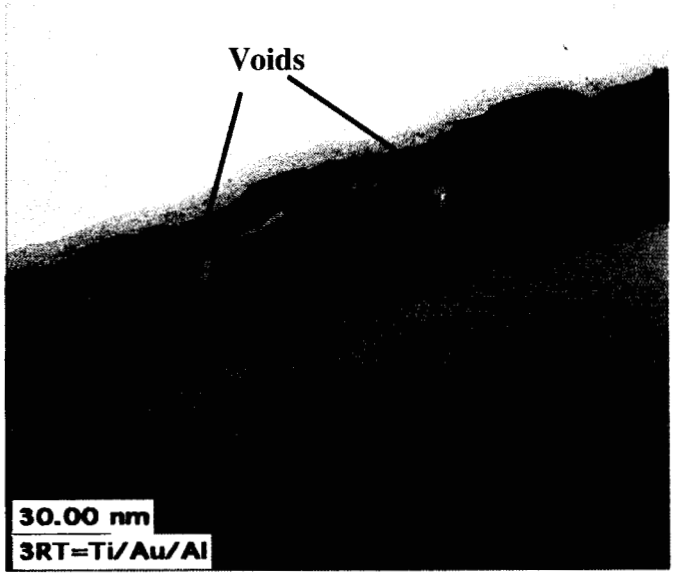


Al/Ti/Au/Ti processed at 150 °C for 60 min

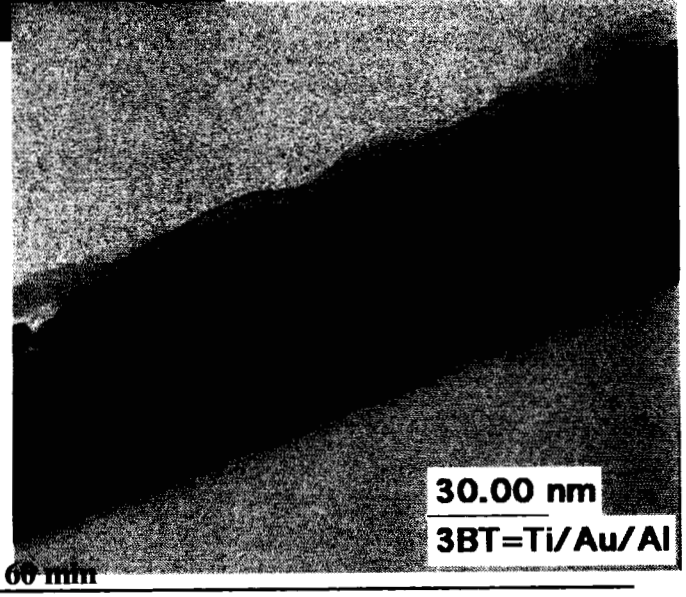
TES Layer

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





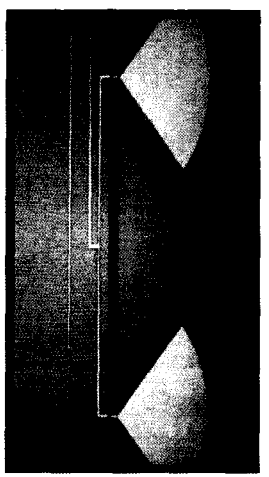
Al/Au/Ti at room temperature



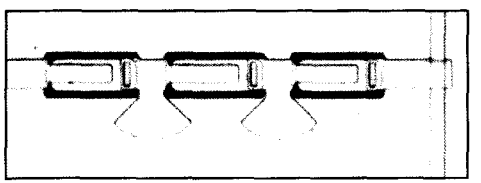
Al/Au/Ti processed at 150 °C for 60 min

Future Work

- Complete characterization and testing of antennas and filters



Wide-band antenna



25 % BW filter

- Compare performance to model predictions
- Measure optical performance coupled to direct detector
- Identify required materials and process developments required to produce multifrequency arrays.

Summary

- We have successfully fabricated antenna-coupled transition edge polarization-sensitive bolometer arrays 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. The contribution of Al, Au, and interaction of Al/Au are 84.54%, 9.09%, and 6.36%, respectively.
- 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 analyzing and testing the Nb microstrip antenna-coupled bolometer arrays for multi-color polarization-sensitive focal plane.

Acknowledgement

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