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

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July 10, 2003
Photon Noise and Thermal Reserve

\[ \text{NEP}_{\text{bol}} = \gamma [4kT^2G]^{1/2} \]

\[ Q_{\text{max}} = \int G(T')dT' = S Q_0 \]

\[ \text{NEP}_{\text{bol}} = f [16kT_0 SQ_0]^{1/2} \]

\[ \text{NEP}_{\text{photon}} = [2h\nu Q_0(1+\epsilon\eta/(e^x-1))]^{1/2} \]

Example:
Photons from CMB only
\[ \eta_{\text{opt}} = 50 \%, \Delta \nu/\nu = 30 \% \]
TES bolometer with \( S = 5 \)

NTD Ge bolometers have Johnson noise, but more dynamic range due to rebiasing
*Slightly better for this optimization*
### Future Focal Plane Sensitivities

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

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

| 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 $\mu$K\(\sqrt{s}\) per feed
- System NET = 2.5 $\mu$K\(\sqrt{s}\)
- 10 times more sensitive than Planck

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**But… Larger focal planes require a new architecture**

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LTD 10, Genoa, Italy
Building a Bigger Focal Plane Array

Individual Corrugated Feeds

Lithographical Filter

Planar Slot-array Antenna

10 x 20 mm Direct Detector

TES Bolometer

Discrete Filters

Bolometers

California Institute of Technology

LTD 10, Genoa, Italy
Directed Beams for Mm-wave Systems

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

- ~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

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<th>Challenges for Mm-wave Bolometers</th>
<th>Microstrip-Coupled Bolometers</th>
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<tr>
<td>• Need directed beams</td>
<td>• Antennae defined beams</td>
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<tr>
<td>• Massive focal planes</td>
<td>• Eliminate feedhorn optics</td>
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<tr>
<td>• Large pixels</td>
<td>• Large antennae, small active area</td>
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<td>• Straylight and filtering</td>
<td>Absorber volume reduced by $&gt; 10^5$</td>
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<td>• Integrated filters &amp; phase switches</td>
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<td>• Flexible planar architectures</td>
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<td>• Compatible with new concepts</td>
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<td>Kinetic inductance</td>
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**LTD 10, Genoa, Italy**
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 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
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**
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
A SEM image of voids between Au grains resulting from secondary and non-uniform nucleation.

Ti/Au islands resulting from non-uniform nucleation

Al/Au/Ti at room temperature

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.
Acknowledgement

This research was performed at the Jet Propulsion Laboratory, an operating division of the California Institute of Technology, under a contract with the National Aeronautics and Space Administration.