Journal logo

Antenna-Coupled Transition Edge Polarization-sensitive Bolometer Arrays

Minhee Yun[a*], James Bock[a], Henry Leduc[a], Peter Day[a], and Moon Kim[b]

[a]*Jet Propulsion Laboratory, 4800 Oak Grove Dr., Pasadena, CA 91109, U.S.A.*

[b]*Department of Material Science and Engineering, University of North Texas, Denton, TX 76203, U.S.A*

Elsevier use only: Received date here; revised date here; accepted date here

Abstract

We have fabricated antenna-coupled superconducting transition edge sensor (TES) arrays for far-infrared and millimeter-wave applications. The advantage of antenna coupling is that the large optical coupling structure required for far-infrared/millimeter wavelengths is not thermally active. The sensor can thus be as small as lithographic techniques permit. By eliminating large absorbers, this technology enables bolometers working at frequencies as low as 30 GHz, covering the entire spectral region of interest for future space-borne studies of cosmic microwave background polarization. We developed a focal plane architecture with dual-polarization sensitivity in a single spectral band, or single-polarization sensitivity in multiple spectral bands. We use TES layers consisting of Al/Ti/Au/Ti thin films and Nb electrical contacts on a low-stress Si_3N_4 membrane. © 2001 Elsevier Science. All rights reserved

Keywords: Bolometer; TES: Antenna-coupled array
PACS: 95.85.Bh ;95.55.Aq

1. Introduction

The microstrip-coupling bolometers provide several advantages compared to conventional absorption onto a black surface[1-2]. One of the advantages is that the large optical coupling structure required for far-infrared millimeter wavelengths is not thermally active. Additionally, integrated microstrip-coupled bolometer arrays provide compact optical packaging of detectors, filters, and antennas. The very low-level loss in the superconducting Nb microstrip will allow for quasi-optical structures that have no analog in conventional detector technology.

We have fabricated single-, double-element antennas, filters, and detectors. Simple junction detectors, for now, allow rapid characterization of the

* Corresponding author. Tel.: 1-818-354-3413; fax: 1-818-393-4540; e-mail: Minhee.Yun@jpl.nasa.gov.

optical components. The test experiments are ongoing in the present time. Once these components are tested and proven, we will develop these structures into focal plane arrays. The device consists of a dual slot microstrip antenna coupled to an Al/Ti/Au voltage-biased transition edge superconducting bolometer. In order to obtain sharp and reproducible superconducting transition temperatures, we use Ti as an diffusion barrier layer to avoid alloy formation at the interface causing transition temperature change during the operation of the bolometer. We have investigated transition temperatures as a function film composition in this work.

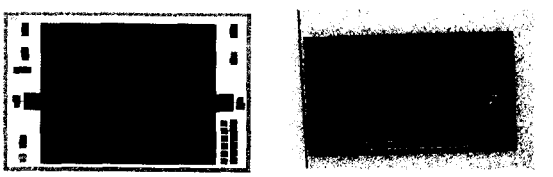
2. Fabrication

Figure 1 shows the fabrication steps for antenna-coupled transition edge polarization-sensitive bolometer arrays. Ti-Au metal films are then deposited on Si_3N_4 layer , using a liftoff technique to form a resistor (Fig. 1(a)). The resistor is designed to terminate the microstrip lead and can be used to simulate optical power. Al (28 nm), Ti (28 nm), Au (28 nm), and Ti (4 nm) layers are deposited by e-beam evaporation to obtain the TES sensor (Fig. 2(a)). The Ti layer is used to avoid interfacial diffusion between Al and Au preventing transition temperature change during the operational life time [3]. The SiO was deposited on the top of metal to protect from the Nb etching. Due to the Nb etch back process using reactive-ion etch, it is necessary to protect metal layers underneath of Nb layer using SiO. Nb is sputtered for ground plane and shunt resistor (Fig. 1(b)). Figure 1 (b) shows a shunt resistor after Nb etch process using reactive-ion etch. Another SiO evaporation is needed for separation of Nb superconducting lead from the ground plane by 400 nm of SiO dielectric material (Fig. 1(b)). Figure 1(b) also shows a 100-GHz filter after lift-off process. The wafer is then sputtered for the Nb microstrip lead and patterned using e-beam lithography for fine patterning. The thickness of the Nb layer deposited as a microstrip lead is same as ground plane thickness, 300 nm. The wafer is patterned to define a microstrip lead (Fig. 1(c)), and etched. Transporting signals across bolometers through superconducting microstrip transmission lines is a key implementation of microstrip-coupled bolometers. The microstrip lead passes a filter bank and terminates at a normal film resistor.

(a) Resistor and TES (Al/Ti/Au) deposition and lift off

(b) TES, Nb Ground plane deposition and etch. Shunt resistor and SiO deposition and lift-off to form via

(c) E-beam patterning for Nb microstrip and Front, backside nitride etch and backside deep trench etch



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

Figure 1. Fabrication steps for Antenna-coupled Transition Edge Polarization- sensitive Bolometer Arrays

The final processing step is a deep-trench reactive-ion etching (DRIE) through the wafer etch. Figure 1(d) shows a top-view after final release and cleaning each array, and a digital image of double antenna-coupled transition edge polarization-sensitive bolometer.

3. TES

The principles of transition edge sensor (TES) have been described by Irwin [4].The resistance of the devices was measured as a function of temperature down to 0.3 K. Figure 3 shows the

measured TES temperature versus resistance for various devices with different metal thicknesses. As the temperature is lowered, gradually TES layers become superconducting, lowering the overall resistance. The trends of the transition temperature decrease with increasing Au thicknesses at constant Al thickness. The transition temperature changes dependent on Au thickness range from 40 mK or less at any Al thickness. On the other hand, the transition temperature varies up to 100 mK with Al thicknesses. The lowest and highest measured transition temperatures occurred at 22 nm for Al and 34 nm for Au, and at 34 nm for Al and 22 nm for Au, respectively.

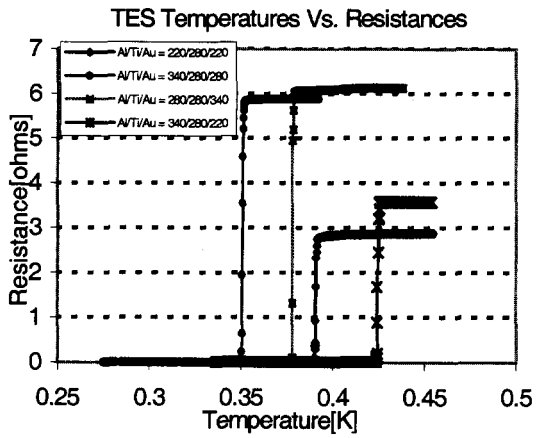


Figure 2. Transition temperatures as a function of Al/Au thicknesses

4. Characterization

The key to the successful implementation of the microstriped-coupled bolometer is the ability to transport signals across macroscopic distances via a superconducting microstrip transmission line. Loss measurement on Nb superconducting films with an SiO dielectric layer is presented in a parallel contribution [5].

The test experiments are ongoing. Our initial tests of an antenna-coupled bolometer will include complex impedances of TES and then more thorough characterization of the devices. We will also obtain the information on heat capacities and thermal conductance at 300 mK. We will also test the thermal isolation of the Nb transmission lines and Si_3N_4 support structures to determine the ultimate NEP at low temperatures. In particular, a multi-band polarimeter would allow for a Cosmic Microwave Background polarimetry follow-up mission to Planck with orders of magnitude improvement in sensitivity.

5. 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. 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. Finally, the 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.

Acknowledgments

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

References

[1] J. J. Bock, A. Goldin, C. Hunt, A. Lange, H. Leduc, P. K. Day, A. Vayonakis, and J. Zmuidzinas, LTD 9th (2001), 243
[2] A. Goldin, J. J. Bock, C. Hunt, A. Lange, H. Leduc, P. K. Day, A. Vayonakis, and J. Zmuidzinas, LTD 9th (2001), 251
[3] C. L. Hunt, J. Bock, P. K. Day, A. Goldin, A. Lange, H. Leduc, and J. Zuidzinas, SPIE (2002), Hawaii, USA, pp318
[4] K. D. Irwin, Appl. Phys., 66, (1995), 1998
[5] A. Vayonakis, C. Luo, H. G. Leduc, R. Schoelkopf, J. Zmuidzinas, LTD 9th (2001), pp309