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Optical and Thermal Properties of ANL/KICP Polarization Sensitive Bolometers for SPTpol

C.L. Chang · P. Ade · K. Aird · J. Austermann · J. Beall · D. Becker · B. Benson · L. Bleem · J. Britton · J. Carlstrom · H. Cho · T. de Haan · T. Crawford · A. Crites · A. Datesman · M. Dobbs · W. Everett · A. Ewall-Wice · E. George · N. Halverson · N. Harrington · J. Henning · G. Hilton · W. Holzapfel · S. Hoover · J. Hubmayr · K. Irwin · R. Keisler · J. Kennedy · A. Lee · E. Leitch · D. Li · M. Lueker · D.P. Marrone · J. Mcmahon · J. Mehl · S. Meyer · J. Montgomery · T. Montroy · T. Natoli · J. Nibarger · M. Niemack · V. Novosad · S. Padin · C. Pryke · C. Reichardt · J. Ruhl · B. Saliwanchik · J. Sayre · K. Schafer · E. Shirokoff · K. Story · K. Vanderlinde · J. Vieira · G. Wang · R. Williamson · V. Yefremenko · K.W. Yoon · E. Young

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Abstract We present recent optical and thermal characterizations of polarization sensitive mm-wave bolometers fabricated at Argonne National Lab. The devices are designed to measure the polarization of the Cosmic Microwave Background and consist of a Mo/Au TES suspended on SiN with a Pd-Au dipole absorber. The detector performance is excellent with $>85\%$ co-polar coupling, $<1\%$ cross-polar leakage, 36 GHz optical bandwidth, electrothermal loop gains of approximately 10, and NEP $\simeq 50\ \mathrm{aW\,Hz^{-1/2}}$.

Keywords Transition edge sensors · Bolometers · CMB

C.L. Chang (✉) · K. Aird · B. Benson · L. Bleem · J. Carlstrom · T. Crawford · A. Crites · W. Everett · A. Ewall-Wice · S. Hoover · R. Keisler · E. Leitch · J. Mehl · S. Meyer · J. Montgomery · T. Natoli · K. Story · R. Williamson
Kavli Institute for Cosmological Physics, Department of Physics, Enrico Fermi Institute, The University of Chicago, Chicago, IL 60637, USA
e-mail: clchang@kicp.uchicago.edu

C.L. Chang · J. Carlstrom
Argonne National Laboratory—HEP Division, Argonne, IL 60439, USA

P. Ade
Cardiff School of Physics and Astronomy, Cardiff University, Cardiff, UK

J. Austermann · N. Halverson · J. Henning
Department of Astrophysical and Planetary Sciences, University of Colorado, Boulder, CO 80309, USA

1 Introduction

Current and future studies of the Cosmic Microwave Background (CMB) focus on measuring the faint polarization signal of the CMB. Precision maps of this polarized signal will constrain the neutrino mass and probe the physics of Inflation. Transition Edge Sensor (TES) bolometers are leading the frontier in sensitivity for CMB polarization measurements. Argonne National Lab (ANL) and the Kavli Institute for Cosmological Physics have been collaborating to develop a TES bolometer for the SPTpol experiment. A single ANL/KICP Polarization Sensitive Bolometer pixel consists of two absorber coupled bolometers mounted in single-moded waveguide. Each bolometer couples to a single polarization mode in the wave guide through a lossy Pd-Au absorber suspended in the waveguide cavity on a SiN microbridge. Two bolometers are stacked orthogonally to measure the two independent polarization modes. The pixel couples to the telescope through a specially designed contoured smooth walled feedhorn [5, 6]. Details of the device design and fabrication are described in earlier publications [4, 7].

Prototype detectors demonstrated excellent optical properties, but also exhibited signs of thermal instability [2]. We have improved the detector design stabilizing

J. Beall · D. Becker · J. Britton · H. Cho · G. Hilton · J. Hubmayr · K. Irwin · D. Li · J. Nibarger · M. Niemack
NIST, Boulder, CO 80305, USA

T. de Haan · M. Dobbs · J. Kennedy · K. Vanderlinde
McGill University, Montreal, Quebec, Canada

A. Datesman · V. Novosad · G. Wang · V. Yefremenko
Argonne National Laboratory—MSD, Argonne, IL 60439, USA

E. George · N. Harrington · W. Holzapfel · A. Lee · C. Reichardt · E. Young
University of California, Berkeley, 151 LeConte Hall, Berkeley, CA 94720, USA

M. Lueker · S. Padin · E. Shirokoff · J. Vieira
California Institute of Technology, Pasadena, CA 91125, USA

D.P. Marrone
Steward Observatory, University of Arizona, 933 North Cherry Avenue, Tucson, AZ 85721, USA

J. Mcmahon
University of Michigan, Ann Arbor, MI, USA

T. Montroy · J. Ruhl · B. Saliwanchik · J. Sayre
Case Western Reserve University, Cleveland, OH 44106, USA

C. Pryke
University of Minnesota, Minneapolis, MN 55455, USA

K. Schafer
School of the Art Institute of Chicago, Chicago, IL 60603, USA

K.W. Yoon
Stanford University, Palo Alto, CA 94305, USA

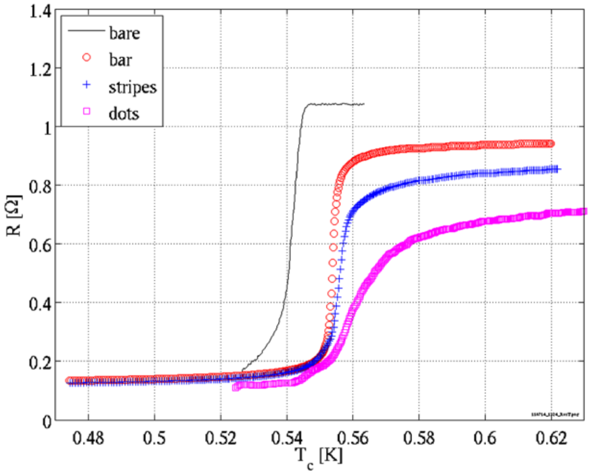

Fig. 1 (Color online) $R(T)$ curves showing the impact of various Nb structures fabricated directly on a Mo/Au TES. There are four curves corresponding to a reference sample with no Nb structures and three patterns consisting of a single 3 μm-wide Nb bar across the width of the TES, three 3 μm-wide Nb stripes separated by 18 μm, and 3 μm Nb dots at a 11 μm pitch. The Nb for all the structures is 120 nm-thick

the detector performance through use of a well coupled thermal heat capacity along with reduction in the detector electro-thermal loop gain. The loop gain is reduced by softening the superconducting transition of the Mo/Au TES through the use of Nb structures patterned directly on the TES. Figure 1 shows the $R(T)$ for four TES films from the same wafer but with different Nb structures. It is clear that the structures increase T_c, reduce Rn, and reduce $\alpha = d\log R/d\log T$. The three α modification studied are a single long Nb bar across the TES, three shorter stripes, and Nb dots at an 11 μm pitch. The dots configuration gave the most stable detector performance.

2 Experimental Methods

We have characterized the optical and electro-thermal properties of the ANL/KICP polarization sensitive bolometers through a number of experiments similar to those conducted on earlier prototypes [2]. Measured optical properties include the total optical efficiency referred to the aperture of the feedhorn, the detector bandwidth, and the pixel polarization isolation and registration. Measured non-optical properties include electro-thermal time constants, electro-thermal gain, and noise equivalent power (NEP).

The optical coupling efficiency of the detector was characterized using a cryogenic variable temperature blackbody whose temperature is varied from 4–30 K. Varying the load temperature changes the optical power incident on the detector. We estimate the optical efficiency by the ratio of the change in Joule heating versus changing optical load.

It is difficult to make laboratory optical measurements with non-cryogenic sources since detectors with our nominal saturation powers (∼30 pW) are overwhelmed by the 300 K radiative loading. However, since the ANL/KICP detectors continue to have optical response well above T_c [2] (only with reduced sensitivity), we attempted a couple of optical measurements under 300 K loading. The two measurements performed under these conditions are spectroscopy and polarization isola-

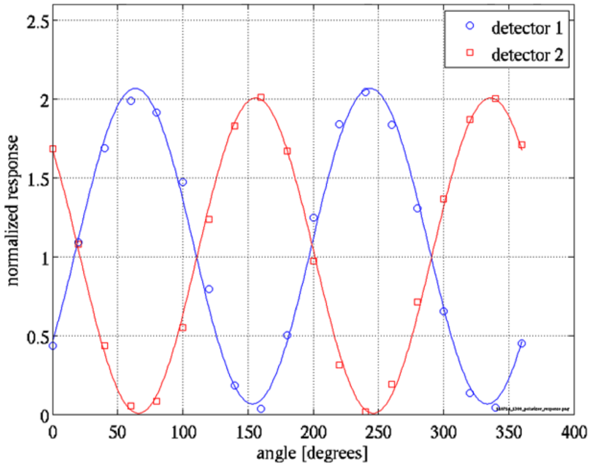

Fig. 2 (Color online) Polarization response of the two bolometers in a single detector pixel to a rotating chopped polarized source. *Lines* are only guides and are not a fit to the data. The data indicates that the bolometers are nearly orthogonal in their alignment with a relative angle of 90.6°. Cross-polarization is limited to <1.6%

tion/registration. The detector's spectral performance was measured using a symmetric polarizing Michelson Fourier Transform Spectrometer (FTS) operating from 45–3000 GHz with a resolution of 2 GHz. The polarization isolation and registration was determined by measuring the response of both detectors to a rotating linearly polarized blackbody. In the course of making these measurements, we discovered that some glue had become attached to the legs of one of the bolometers. This glue caused the detector to have an anomalously high thermal conductance. As such, the detector was not saturated and it was possible for us to bias this detector into its transition despite the high background loading. Spectra was obtained for this bolometer, but no spectra was obtained for its cross-polar detector. For the polarization isolation/registration measurement, data was obtained for both bolometers, but the response from the clean (no glue) detector is smaller due to its being saturated. However, determination of the pixel's polarization isolation and registration does not require that the detector responses be well matched, so we can still robustly compare their relative response.

Non-optical properties of ANL/KICP detectors were measured using a digital frequency domain multiplexing (DfMUX) readout [3]. The detector electro-thermal time constant and loop gain were measured as a function of depth in the transition [1]. Noise was also measured.

With the exception of the optical efficiency estimate, all measurements correspond to detectors whose transitions have been modified using the Nb dot structures. The optical efficiency measurement was conducted using a detector with the single long Nb bar. We do not expect a difference in optical performance for the different modification structures since the TES is located outside of the waveguide.

3 Results

Our measurements indicate that the detectors have ∼36 GHz of bandwidth (Fig. 3) and 85% optical efficiency (Fig. 4). Figure 2 shows the normalized response of the

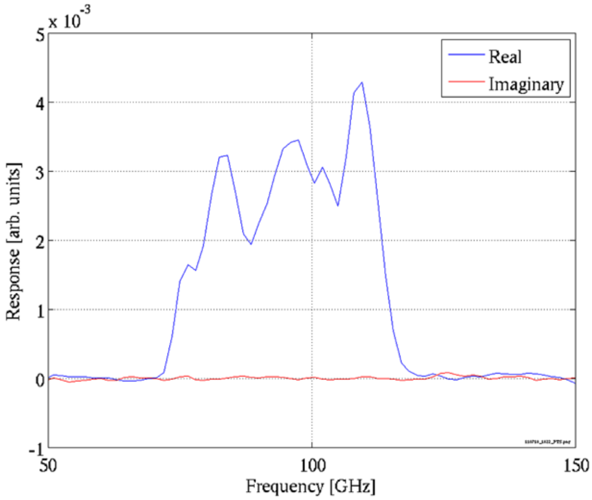

Fig. 3 (Color online) Spectra for one of the bolometers in a detector pixel showing ∼36 GHz of optical bandwidth. The peaks and troughs in the spectrum are artifacts arising from standing waves in the optical setup

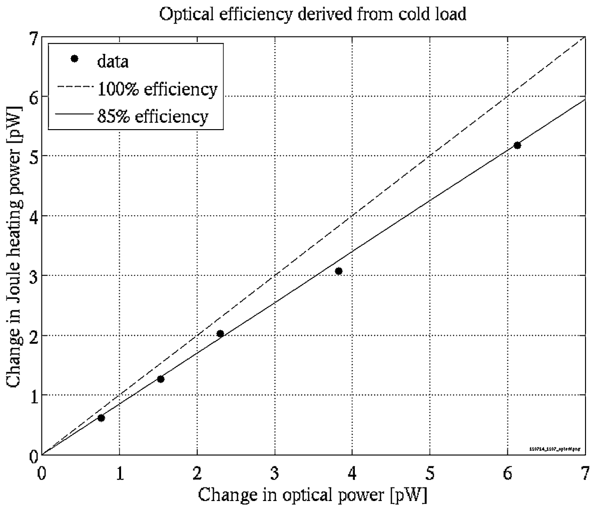

Fig. 4 The change in Joule heating for changes in optical power incident on the detectors. The optical power is modulated by changing the temperature of a nearly black cryogenic load. The expected optical power is calculated for a Rayleigh-Jeans source assuming a 36 GHz optical bandpass (comparable to the spectra measured in Fig. 3) for which the coupling is single-moded. The measured change in Joule heating indicates an optical coupling efficiency of ∼85%

two crossed detectors in a single pixel to a rotating grid. From this data, the relative registration of the two arms is estimated to be 90.6° with cross polar coupling $<1.6\%$. All of these results are consistent with our expectations from simulations [4].

Figures 5 and 6 present dark detector data. Figure 5 shows that at typical operating depths of 0.69Rn, the detectors have electro-thermal time constants of ∼0.9 ms and electro-thermal gains of ∼9. The noise shown in Fig. 6 is consistent with a noise model consisting of readout electronics noise, Johnson noise, and thermal carrier noise. The white noise level of the spectrum is 57 aW $\mathrm{Hz}^{-1/2}$, corresponding to background limited noise power for the SPTpol experiment.

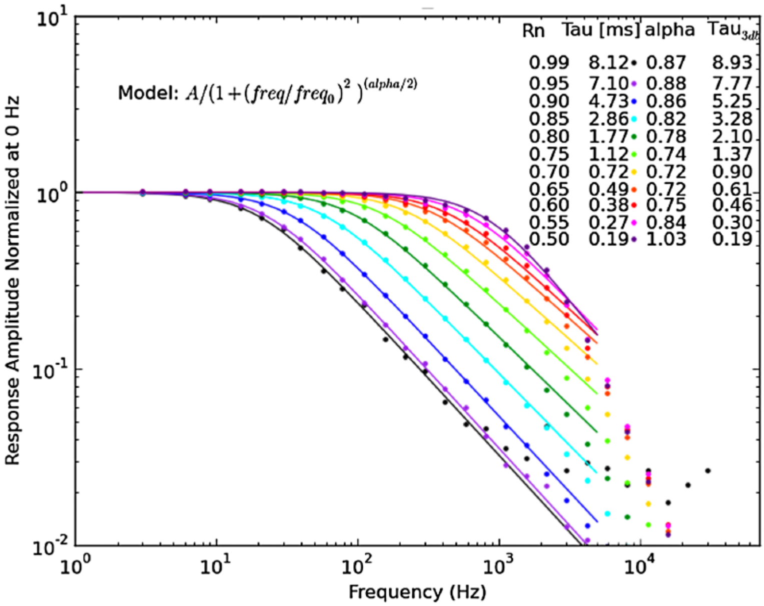

Fig. 5 (Color online) The thermal response [1] of a ANL/KICP bolometer at various depths in the transition. At an operating depth of 0.69Rn, the detector has a thermal time constant of 0.9 ms corresponding to an electro-thermal gain of ~9 and exhibits no signs of thermal instability

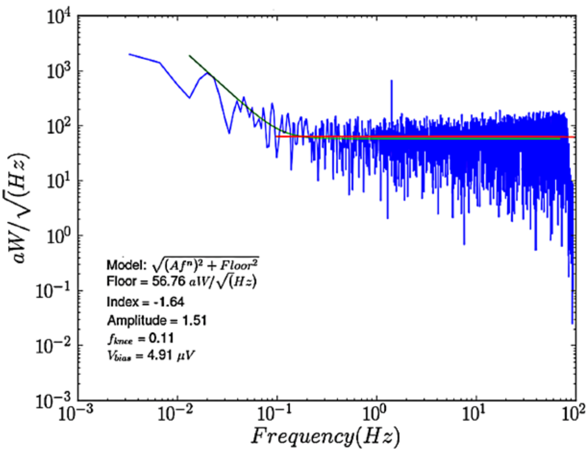

Fig. 6 (Color online) Dark noise equivalent power at 0.69Rn for an ANL/KICP detector with 33 pW saturation power. The noise is modeled (*green line*) as a low frequency component together with a white noise floor. Above 0.1 Hz, the noise is dominated by the white noise (*red line*) which is 57 aW $\mathrm{Hz}^{-1/2}$ and is consistent with noise contributions from the readout system, Johnson noise, and thermal carrier fluctuations. This noise spectrum is nearly background limited for typical observing conditions expected for SPTpol

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