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Authors
Verghese, S.
Richards, P.L.
Char, K.
et al.

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Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

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S. Verghese, P.L. Richards, K. Char, and S.A. Sachtjen

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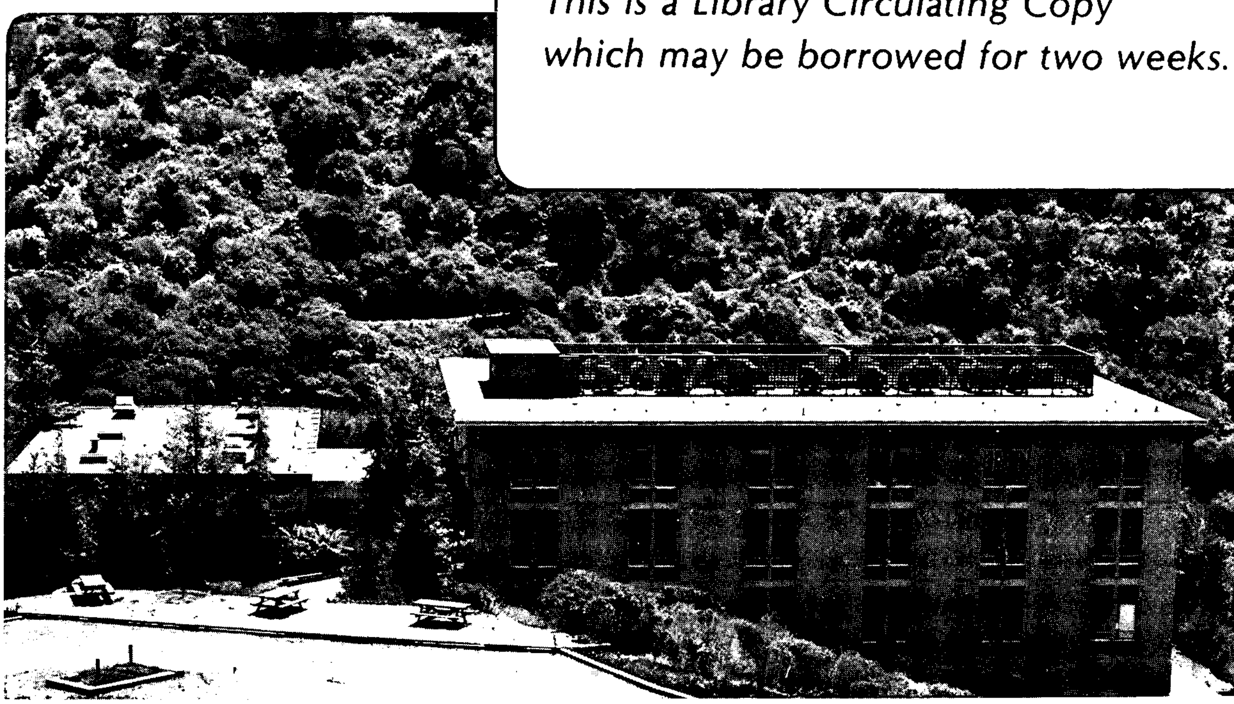

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S. Verghese and P.L. Richards

Department of Physics
University of California

and

Materials and Chemical Sciences Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

and

K. Char and S.A. Sachtjen

Conductus Inc.
Sunnyvale, CA 94086

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S. Verghese and P.L. Richards

Dept. of Physics, University of California and Materials
and Chemical Sciences Division, Lawrence Berkeley Laboratory,
Berkeley, CA 94720.

K. Char and S.A. Sachtjen

Conductus Inc., Sunnyvale CA 94086.

ABSTRACT

A sensitive high T_c superconducting bolometer has been fabricated with a YBCO thin film thermometer on a 20μm thick sapphire substrate. Electrical measurements showed no noticeable film degradation after bolometer fabrication. Optical measurements gave a noise equivalent power of $5 \cdot 10^{-11}$ W/Hz$^{1/2}$ at 10 Hz and a responsivity of 22 V/W. This performance is comparable to that of the very best pyroelectric detectors. Significant improvement appears possible.

1. INTRODUCTION

The sensitivity of infrared detectors that operate above liquid ^{4}He (LHe) temperatures degrades with increasing wavelength. For wavelengths $\leq 20\mu$m conventional liquid nitrogen-cooled (LN) photovoltaic infrared detectors such as HgCdTe are widely used. For longer wavelengths, however, there is no satisfactory cooled detector technology above LHe temperatures, and room temperature detectors such as Golay cells or pyroelectric detectors are used. A bolometer which operates at the transition temperature of a high T_c superconductor may offer greater sensitivity at these longer wavelengths[1,2]. This paper describes the design, fabrication, and evaluation of such a bolometer based on epitaxial $YBa_2Cu_3O_7$ (YBCO) on a 20μm thick Al_2O_2 substrate.

2. THEORY AND DESIGN

A bolometer consists of a radiation absorber with an electrical resistance thermometer coupled to a heat sink via a thermal conductance. The minimum heat capacity C is limited by materials consideration. The minimum thermal conductance G to the heat sink is limited by the background power loading and by the response time $\tau = C/G$. The responsivity for a signal modulated at angular frequency ω can be written as

$$S(\omega) = I\frac{dR(T)}{dT}\,|G+i\omega C|^{-1} = \frac{IR}{G\delta T(1+\omega^2\tau^2)^{1/2}} ,$$

where δT is half the transition width and R is the resistance at the operating point near the midpoint of the transition. We neglect the effects of the positive thermal feedback from the current bias which reduces the thermal conductance to an effective value $G - I^2R/\delta T$. To maintain thermal stability we arbitrarily constrain the current by the condition $I^2R \leq 0.3G\delta T$.

The noise equivalent power (NEP) is calculated by summing the important sources of incoherent noise in quadrature.

$$NEP = \left[4kT_c^2G + \frac{4kT_cR}{|S|^2} + \frac{e_n^2+(i_nR)^2}{|S|^2} + \frac{V_{1/f}^2}{|S|^2}\right]^{\frac{1}{2}} .$$

Ideally, the dominant contributions of a fully optimized bolometer are the first and second terms, phonon shot noise and Johnson noise respectively. Parameters for an optimized bolometer are determined by equating these two contributions. The contribution of the last two terms, amplifier noise and 1/f noise in the high T_c film respectively, should be smaller in a well designed bolometer. A high T_c bolometer on a $1\times1\times0.02$ mm^3 Al_2O_3 substrate with $\delta T = 0.5K$ and $\omega/2\pi = 10Hz$ could have an NEP $\approx 10^{-11}$ $W/Hz^{1/2}$. For comparison, a pyroelectric detector[3] optimized for 10 Hz operation has NEP $\approx 1-5\cdot10^{-10}$ $W/Hz^{1/2}$.

3. CONSTRUCTION

We chose sapphire as a bolometer substrate for its high Debye temperature and strength. Earlier work[4] indicated high quality c-axis films could be grown directly on $\{\bar{1}012\}$ Al_2O_3 by laser ablation. When current biased, these films have excess noise at the resistive transition. The best bolometer made from such films had NEP $\approx 5\cdot10^{-9}$ $W/Hz^{1/2}$ at 10 Hz. Films without this excess noise were obtained by *in situ* laser ablation of 3000Å of YBCO on top of a 500Å thick buffer layer of $SrTiO_3$ on the Al_2O_3 substrate. The

6×6 mm^2 chip was then waxed face down to a polishing block and lapped to 20μm thickness. Electrical contact pads were made by sputter cleaning the YBCO surface in a 1:5 O_2 + Ar background and then sputter depositing 2000Å of Ag. The chip was diced into 1×1 mm^2 bolometer chips and finally the contacts were annealed in O_2 at 500°C for 1 hr.

Electrical leads of 25μm diameter copper wire were attached to the two silver contact pads with Ag paint. The bolometer chip was suspended by the electrical leads in a temperature regulated brass ring. The bolometer assembly was then mounted on the cold plate of an optical cryostat for electrical and optical characterization.

4. MEASUREMENTS

The bolometer responsivity was directly measured by comparison with a commercial pyroelectric detector and was also calculated from electrical measurements. Figure 1 shows the resistive transition of the completed bolometer for a 1mA current bias. Comparison with measurements made immediately after YBCO deposition showed no noticeable degradation. The steepest part

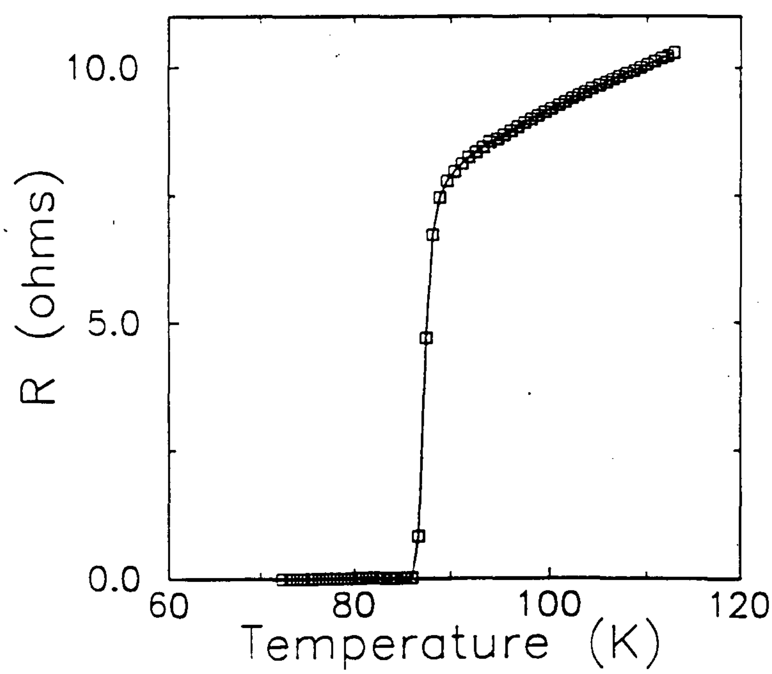

Figure 1: Resistance versus temperature for the bolometer measured at 1mA. This curve was not noticeably degraded by bolometer fabrication.

of the resistive transition has a slope dR/dT = 6.2 Ω/K where R = 3Ω. Figure 2 shows the dependence of the bolometer resistance on electrical heating by the bias current. We checked that the non-linearity was from heating and found that the film was ohmic at constant temperature. The thermal conductance G = 270 μW/K was obtained from the slope at small I^2R and from R(T).

The bolometer time constant τ = 55 msec was obtained by measuring the roll off as a function of chopping frequency. We infer a value C = 15 μJ/K from the measured values of G and τ. This value is consistent with the computed value C = 12 μJ/K and gives us confidence in the G calculated from Figure 2. From the measured values of G, dR/dT, and τ, we calculate a responsivity of 26 V/W at 10Hz and I = 4mA.

The spectral response of the bolometer is determined by the radiation absorber attached to it. For simplicity, we used the YBCO film as the absorber of 632 nm He-Ne laser light. Figure 3 compares the response to chopped laser light with the slope of the resistive transition. These data are consistent with bolometric response. The peak signal corresponds to an optical responsivity of 22 V/W.

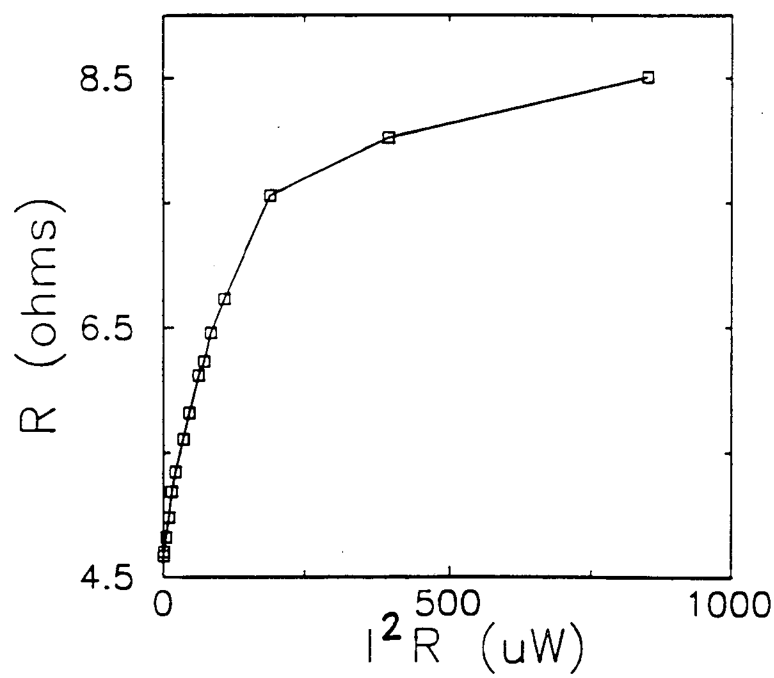

Figure 2: Resistance of the bolometer as a function of electrical heating from the bias current. The nonlinearity of this curve is from the temperature rise and the shape of R(T).

We measured the voltage noise in the film for current biases up to 4mA. The excess 1/f noise was so small that we were limited by the 1.2 $nV/Hz^{1/2}$ voltage noise in our bipolar amplifier at 10Hz. Using the measured noise we compute optical NEP = $5 \cdot 10^{-11}$ $W/Hz^{1/2}$. At the maximum current allowed by the stability condition (I = 4mA), the excess 1/f noise in the film was still below amplifier noise. Assuming that the excess noise stays less than Johnson noise, the NEP and responsivity could be improved to 10^{-11} $W/Hz^{1/2}$ and 110 V/W at 10Hz by increasing the resistance R to at least 200 Ω. This could be done by patterning a meander strip in the YBCO film.

We have designed, fabricated, and tested the first high T_c bolometer with higher sensitivity than competing room temperature detectors. At a 10 Hz chopping frequency, the lowest NEP is $5 \cdot 10^{-11}$ $W/Hz^{1/2}$ and the responsivity is 22 V/W. Matching the film resistance to the amplifier should further increase the bolometer's sensitivity.

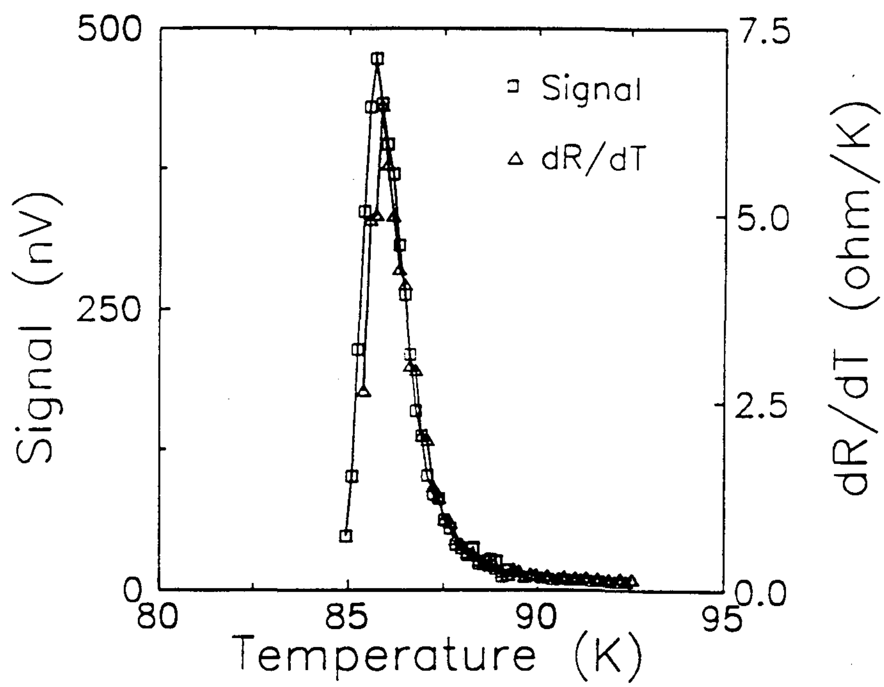

Figure 3: Voltage response of the bolometer to chopped laser light and dR/dT. The shape of the two curves indicates that the response is bolometric.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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3. See, for example the P-41 detector, Molectron Corp., Sunnyvale, CA.

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LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
1 CYCLOTRON ROAD
BERKELEY, CALIFORNIA 94720