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## High-$T_c$ Bolometers

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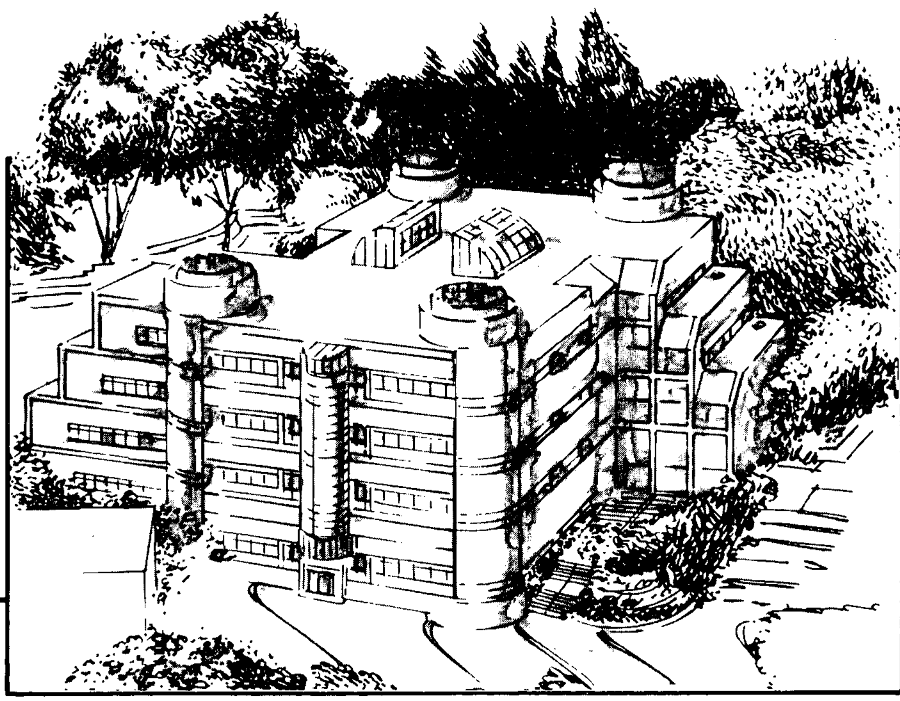

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Abstract. A description is given of recent work on high-$T_c$ superconducting bolometers for infrared and millimeter wavelengths. The first report describes measurements of the thermal boundary resistance between YBCO films and various substrates. This resistance is much larger than expected from the acoustic impedance mismatch model and gives a thermal time constant in the nanosecond range for typical YBCO films. Then, there are reports on the design and experimental performance of two different types of high-$T_c$ bolometric detectors. One is a conventional bolometer with a gold-black absorber. The other is an antenna-coupled microbolometer. Finally, there is a description of the ultimate performance expected from high-$T_c$ bolometers on Si and $Si_3N_4$ membrane substrates, with comparisons to other detectors used for thermal imaging.

## 1. Introduction

Many workers have measured the response of high-$T_c$ films (especially $YBa_2Cu_3O_7$) to infrared radiation. All experiments show one or more types of thermal response when the infrared signal is large. We are designing, fabricating and testing bolometric detectors for infrared and millimeter waves based on this thermal response. We are also exploring relevant physical properties of 123 films such as thermal boundary resistance and noise.

## 2. Summary

We have made direct measurements of the thermal boundary resistance, $R_{bd}$, between high quality epitaxial films of $YBa_2Cu_3O_{7-\delta}$ and a variety of substrates with and without buffer layers (Nahum et al. 1991(b)). The boundary resistance was deduced from measurements of the electrical resistance changes in three parallel strips of $YBa_2Cu_3O_{7-\delta}$ when one was electrically heated. Results are available only for temperatures above the superconducting transition with this method.

Our measurements indicate that $R_{bd}$ is weakly dependent on temperature and, for all the measured samples, has a value of $0.9\text{-}1.4\times10^{-3}$Kcm$^2$/W at 100K, which is a factor ~20 larger than the prediction of the acoustic mismatch model. The thermal response of these films to pulsed power is dominated by the heat capacity of the film and the boundary resistance. The resulting thermal response time of ≈1ns for typical $YBa_2Cu_3O_{7-\delta}$ films is observed in many experiments with pulsed laser sources.

A design analysis has been given for a bolometric infrared detector that uses the resistive transition of a high-temperature superconductor as the temperature sensing element, and liquid nitrogen as the coolant (Richards et al. (1989)). It was shown that for highly oriented c-axis films, the measured low-frequency noise causes little or no degradation of the performance. With the incoming radiation chopped at 10 Hz, noise equivalent powers (NEP) in the range $(1\text{-}20)\times10^{-12}$ W Hz$^{-1/2}$ should be achievable. These values compare favorably with the NEP of other detectors operating at or above liquid nitrogen temperatures for wavelengths greater than 20 μm.

A sensitive high-$T_c$ superconducting bolometer has been fabricated on a 20 μm thick sapphire substrate with a YBCO thin film transition edge thermometer (Verghese et al. 1990 and 1991(a)). Optical measurements with a He-Ne laser gave a noise equivalent power of $2.4\times10^{-11}$ W/Hz$^{1/2}$ at 10 Hz and a responsivity of 17 V/W, in good agreement with electrical bolometer measurements. Gold black smoke was then deposited on the back side of the assembled bolometer as an absorber. Spectral measurements on a Fourier transform spectrometer showed that the bolometer has useful sensitivity from visible wavelengths to beyond -100 μm. This performance is clearly superior to that of a commercial room temperature pyroelectric detector. Some improvement appears possible.

We propose an antenna-coupled microbolometer based on the resistive transition of a high-$T_c$ superconducting film as a detector for far infrared and millimeter waves (Hu and Richards 1989). Such microbolometers can be mechanically stronger, more easily fabricated, and much faster than conventional bolometric infrared detectors. A design analysis shows that a noise equivalent power of $2.5\times10^{-12}$ W Hz$^{-1/2}$ is achievable for modulation frequencies up to 10 kHz. The superconducting film must be of high quality with narrow resistive transition and low $1/f$ noise.

We have fabricated and measured the performance of antenna-coupled microbolometers (Nahum et al. 1991(a) based on the resistive transition of a high-$T_c$ superconducting film for use as detectors of far-infrared and millimeter waves. A planar lithographed antenna (log-periodic or log-spiral) is used to couple the radiation to a thin YBCO film with dimensions ≈6×13 μm$^2$, which are much smaller than the wavelength to be measured. This film acts both as the resistor to thermalize the RF currents and as a transition edge thermometer to measure the resulting temperature rise. Because of its small size, both the thermal conductance from the film into the bulk of the substrate and the heat capacity of the thermally active region are small. Consequently, the microbolometer has low noise, fast response and a high voltage responsivity. We have measured a phonon noise-limited electrical NEP of $4.5\times10^{-12}$WHz$^{-1/2}$ at 10 kHz modulation frequency and a responsivity of 478 V/W at a bias of 550 μA. Measurements of the optical efficiency are in progress.

We discuss the design of high-$T_c$ superconducting bolometers for applications such as infrared imaging arrays (Verghese et al. 1991(b)). The dependence of bolometer sensitivity on excess voltage noise in the thermometer is a function of the detector area and thus of the wavelength to be detected. We use measurements of the voltage noise in thin films of $YBa_2Cu_3O_7$ on Si, $Si_3N_4$, and sapphire substrates to predict the performance of different bolometer architectures. Useful opportunities exist for bolometers made on both Si and $Si_3N_4$ membranes. We also describe a readout scheme for two-dimensional arrays of bolometers in which real-time signal integration is performed on chip.

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