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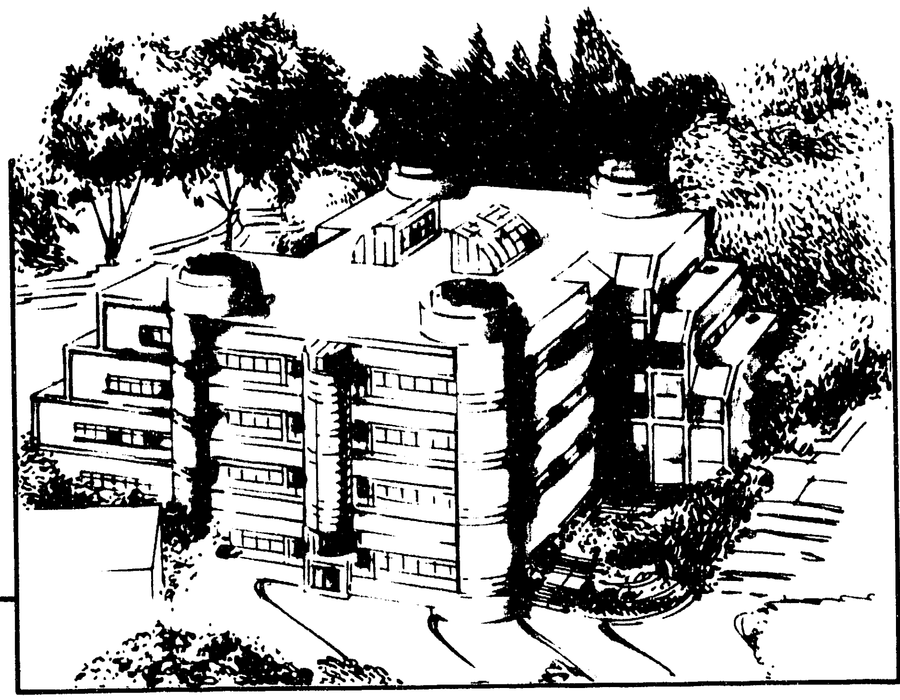

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DESIGN OF HIGH-T_c BOLOMETERS ON SILICON MEMBRANES FOR A FAR INFRARED IMAGING ARRAY

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ABSTRACT

We discuss the design of high-T_c superconducting bolometers for use in a far infrared imaging array from wavelengths $30 - 100\,\mu$m. Useful opportunities exist for imaging and spectroscopy with bolometer arrays made on micro-machined silicon membranes.

BOLOMETER DESIGN

The high-T_c bolometer has useful sensitivity for wavelengths $\lambda > 20\,\mu$m where the sensitivity of semiconducting detectors at or above 77K is poor and room-temperature thermal detectors such as the pyroelectric detector are presently used. Such bolometers consist of an infrared radiation absorber thermally coupled to a high-T_c superconducting thermometer operated at its resistive transition, both weakly coupled to a liquid-nitrogen-cooled heat sink at 77K. Some of the authors have recently built composite high-T_c bolometers cooled by liquid nitrogen with $D^* = 1 - 4 \times 10^9$cm Hz$^{1/2}$W^{-1} for wavelengths $20 - 300\,\mu$m [1]. The areas of these bolometers were chosen from 1 to 10 mm^2 to match the throughput of laboratory Fourier transform spectrometers. Arrays of much smaller bolometers are potentially useful for thermal imaging [2]. The lower heat capacity of such small bolometers relaxes the requirement on thermometer sensitivity. Here, we consider micro-machined bolometers on silicon membranes which are potentially useful for imaging from wavelengths $30 - 100\,\mu$m. We analyze the thermal geometry and propose to use the same $YBa_2Cu_3O_{7-\delta}$ (YBCO) film as both the thermometer and the radiation absorber.

For practical reasons, bolometers for use in large format imaging arrays must be produced by optical lithography and micromachining. Silicon is well suited to such fabrication techniques and is a substrate which is compatible with the deposition of high quality YBCO films. For a given optical system, the area of a pixel which couples optically to N spatial modes is proportional to the wavelength squared

$$A = \lambda^2 N/\Omega, \tag{1}$$

where Ω is the solid angle of the field of view of the pixel. Many considerations enter the choice of the constant of proportionality N/Ω. The goal of this design is an imaging array with f/6 optics ($\Omega = 0.02$ sr) which has useful sensitivity for wavelengths $30 - 100\,\mu$m and is diffraction-limited ($N = 1$) at $\lambda = 100\,\mu$m. From (1), the pixel size is 0.7×0.7 mm. Using handbook values [3], we estimate the heat capacity for a $0.5\,\mu$m thick Si membrane to be $C = 1.5 \times 10^{-7}$ J/K. For a thermal conductance $G = 5 \times 10^{-5}$ W/K, the thermal response time is $\tau = C/G = 3$ ms. Such a thermal conductance can be achieved with two $1000 \times 90 \times 0.5\,\mu$m legs of Si which support the membrane. Figure 1 is a diagram of such a bolometer with the width of the Si legs exaggerated for clarity. The limit to the noise equivalent power (NEP) from thermal fluctuations for this bolometer is NEP $= 3 \times 10^{-12}$ W/Hz$^{1/2}$. For the YBCO/YSZ/Si films we have measured [2], voltage noise in the thermometer would limit the sensivitity of the bolometer. The predicted noise equivalent power of a Si membrane bolometer using such a thermometer is NEP $= 5 \times 10^{-12}$ W/Hz$^{1/2}$ which corresponds to $D^* = 1.4 \times 10^{10}$ cmHz$^{1/2}$W^{-1}. This detectivity is significantly better than the $D^* = 2 \times 10^9$ cmHz$^{1/2}$W^{-1} of the best Schwartz-type thermopiles used in this wavelength range [4].

MEMBRANE FABRICATION

We have fabricated $0.5\,\mu$m thick Si membranes which are supported by two $1000 \times 100 \times 0.5\,\mu$m legs. The membrane was defined with an etch-stop layer produced by selective ion implantation of 180 keV BF_2^+ at a dose of 10^{16} cm^{-2}. After a 60s anneal at 1000°C, the Si samples were etched in a solution of 80°C KOH. There are some disadvantages to the boron etch stop. The boron concentration results in a degenerately doped Si membrane which

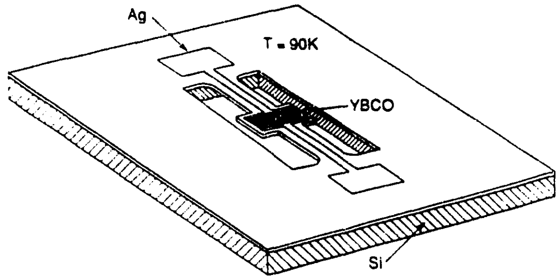

Figure 1: *Diagram of a membrane bolometer. The bolometer consists of a YBCO film which functions as the radiation absorber and as the thermometer. The silicon membrane is isolated from the heat sink by two thin legs. Radiation is incident on the Si membrane from the back side.*

is under tensile stress and may be difficult to fabricate reproducibly to the dimensions needed for sensitive high-T_c bolometers. Also, a degenerately doped Si membrane has a high infrared conductivity which renders thin film infrared absorbers ineffective. We are presently investigating an electrochemical etch-stop which uses a reverse-biased $p-n$ junction to slow the Si etch rate in KOH [5]. This technique requires much lower ion implantation doses of $\sim 10^{12}\,\mathrm{cm}^{-2}$.

RADIATION ABSORBER

In earlier work on sapphire composite bolometers, some of the authors used a resistive bismuth film as a radiation absorber from $50 - 1000\,\mu$m [1]. A 30 nm Bi film deposited on the back of the Si bolometer would have a surface resistance $R_s \approx 150\Omega$ and could absorb $\sim 50\%$ of the radiation incident through the Si substrate. An alternative scheme is to use a YBCO film on the front of the bolometer as both the thermometer and the absorber of infrared radiation incident from the back. Data on the infrared conductivity [6] of a 48 nm thick YBCO film about T_c suggest that a 20 nm thick YBCO film would have $R_s \approx 150 - 120\Omega$ for wavelengths of $30 - 100\,\mu$m respectively. This corresponds to an absorption efficiency of $53\% - 45\%$ for radiation at normal incidence. Such a scheme could also reduce the thermometer noise since the volume of the film would be large and a DC resistance $> 100\Omega$ is required for adequate coupling to a readout amplifier.

We have discussed the design of an imaging array of high-T_c Si membrane bolometers which could be useful over wavelengths $30 - 100\,\mu$m. Measurements of electrical noise in YBCO films on Si substrates and an analysis of the thermal geometry of a bolometer which is diffraction-limited at $\lambda = 100\,\mu$m predict $D^* = 1.4 \times 10^{10}\,\mathrm{cmHz}^{1/2}\mathrm{W}^{-1}$ for a single pixel. Applications for arrays of silicon membrane bolometers exist in space observations of bright sources such as planets using radiatively cooled systems or systems cooled with a single stage Stirling cycle refrigerator.

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