Investigation of semiconducting YBaCuO thin films: A new room temperature bolometer

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We explore the application of the semiconducting phases of YBaCuO thin films as a bolometer for uncooled infrared detection. For this study, four different structures were built with different types of buffer layers: YBaCuO on a Si substrate with and without a MgO buffer layer, and on an oxidized Si substrate with and without a MgO buffer layer. These films were all amorphous without a detectable long range order. For comparison, crystalline tetragonal YBa2Cu3O6.5 and YBa2Cu3O6.3 thin films on a LaAlO3 substrate were included into the study. All six films exhibited semiconducting resistance versus temperature characteristics. The bolometer figures of merit, responsivity, and detectivity were calculated from the measured temperature coefficient of resistance (TCR) and the inherent noise characteristics of the temperature sensing element. The room temperature TCRs for all four amorphous films were greater than 2.5% K⁻¹. The highest TCR of 4.02% K⁻¹ was observed on the amorphous YBaCuO thin film deposited on MgO/Si without a SiO2 layer. The TCR of the tetragonal films, on the other hand, remained 2% K⁻¹ or less in the same temperature range. Noise measurements performed in the 1–100 Hz frequency range revealed a quadratic dependence on the bias current as would be expected from ohmic electrical characteristics. The Johnson and 1/f regions were clearly identified in the noise spectrum. From TCR and noise measurements, we estimated the amorphous semiconducting YBaCuO bolometers would have a responsivity as high as 3.8×10⁷ V/W and a detectivity as high as 3.6×10⁹ cm Hz¹/²/W for 1 μA bias current and frame frequency of 30 Hz if integrated with a typical air-gap thermal isolation structure.

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INTRODUCTION

Since the discovery of high-\(T_c\) superconductivity in YBa2Cu3O6+x, most research has concentrated on the characteristics of superconducting phases (\(x\sim 1\)) below its critical temperature (\(T_c \sim 90\) K). Several groups have built YBaCuO superconductor microbolometer arrays employing silicon micromachining techniques.¹–³ These have shown detectivities as high as 6×10⁶ cm Hz¹/²/W but require cooling to liquid nitrogen temperatures for operation. They are also potentially unstable because of the positive value of the temperature coefficient of resistance (TCR), which causes thermal runaway and pushes the device temperature above the effective temperature range of operation where \(dR/dT\) is high, mainly the superconducting transition region.⁴

The structural,⁵,⁶ electrical,⁵,⁷–⁹ and optical⁵,¹⁰,¹¹ properties of YBa2Cu3O6+x can be varied by adjusting the oxygen content \(x\). The oxygen deficient phase of YBa2Cu3O6+x (\(x \leq 0.5\)) is a semiconductor that crystallizes in a tetragonal structure.⁵ Our previous studies have shown that the room temperature resistivity of this material has a high and relatively constant TCR, \(\beta = (1/R)(dR/dT) \geq 2.5\%\) K⁻¹.¹² Amorphous YBaCuO thin films deposited on silicon wafers with a MgO buffer layer have exhibited TCRs as high as 3.1% K⁻¹ over a 60 K range around room temperature and a noise voltage of 0.75 μV/Hz¹/² at a frequency of 30 Hz and a bias current of 1 μA. The projected responsivity of 5.5×10⁶ V/W and detectivity of 1.3×10⁹ cm Hz¹/²/W were shown to be possible in Ref. 12 if these structures are integrated with a typical thermal isolation structure. This article reports on an order of magnitude improvement in detectivities. Our previous work on the implementation of oxygen-poor YBaCuO as uncooled infrared detectors is developed in a much broader perspective by comparing differently prepared amorphous samples as well as crystalline tetragonal YBaCuO.

In an effort to integrate the YBaCuO thin films with existing silicon micromachining technology, we investigate the electrical and material characteristics of YBaCuO thin films on SiO2 grown on silicon substrates with and without a MgO buffer layer. Since \(c\)-axis epitaxial YBaCuO had generally been considered to be better suited for bolometric applications,¹³ the degree of crystallinity is also varied. Measurements of resistivity, TCR, noise, and degree of crystallinity of six different YBaCuO thin films are presented.

BACKGROUND

The responsivity \(R_T\) of a bolometer, i.e., the output signal voltage per incident infrared (IR) power, is given by¹⁴
where $I_b$ is the bias current, $R$ is the dc resistance, $\eta$ is the absorptivity, $G$ is the thermal conductance between sensitive element and the substrate, $\omega$ is the angular modulation frequency of the incident radiation, and $\tau$ is the thermal response time which is given by $C/G$, $C$ is the heat capacity (thermal mass) of the sensitive element. Therefore, a microbolometer requires a temperature sensitive element that displays a high TCR and a structure that has a low thermal conductance and thermal mass. Silicon micromachining techniques can be employed to create an air-gap bridge under the sensitive element to provide low thermal conductance and thermal mass.

Another important figure of merit is the detectivity $D^*$ which is determined by the ratio of the responsivity $R_V$ to the noise voltage of the detector $V_n$:

$$D^* = \frac{R_V \sqrt{\Delta f \cdot A}}{V_n},$$

where $\Delta f$ is the amplifier bandwidth, and $A$ is the area of the detector. $V_n$ is determined by the sum of the contributions due to the background noise produced by the blackbody emissions of the surroundings, the temperature fluctuation noise due to thermodynamic fluctuations in the isolated thermal mass, and the noise generated by the thermometer or sensitive element. The noise generated by the thermometer includes Johnson noise and the low frequency (mostly 1/f) noise of the material.

The per-unit-bandwidth noise voltage in Eq. (2) is obtained from the measured voltage noise power spectral density $S_V$ using the relation $V_n / \sqrt{\Delta f} = \sqrt{S_V}$.

### RESISTANCE AND TCR MEASUREMENTS

A total of six YBaCuO thin films were studied. The four amorphous films, samples a, b, c, and d, were made at Southern Methodist University (SMU). The other two films, samples e and f, were single crystal, tetragonal, and made at the University of Rochester. The films made at SMU were rf sputtered onto 4 in. Si wafers at ambient temperature on different buffer layers as shown in Table I. Single crystal YBa$_2$Cu$_3$O$_{6+x}$ thin films were in situ magnetron sputtered at 750 °C on LaAlO$_3$ substrates. As-deposited films were superconducting with $T_c \approx 90$ K and they were subsequently oxygen depleted by heating in a 10 mTorr Ar ambient at 450 °C for sample e and at 680 °C for sample f. Samples a–e were 7×10 mm$^2$; sample f was 10×10 mm$^2$. All the films studied were 2000 Å thick.

Electron microprobe, x-ray diffraction, and Raman spectroscopy analyses were performed on the films to analyze the physical stoichiometry and microstructure. Table I shows the structure and compositions of each sample. All four samples made at SMU were barium deficient from the Y:Ba:Cu = 1:2:3 ratio. This phenomenon was also observed by Wördnenweber et al. who examined the properties of their multiphase Y$_{1.2}$Ba$_{0.8}$CuO$_3$ and found that it was actually a mixture of YBa$_2$Cu$_3$O$_{6+y}$ and Y$_2$BaCuO$_5$. It is quite possible that our samples a–d also consist of a mixture of these two phases. Samples a–d were found to be mostly amorphous (polycrystalline at very fine scale) as determined by the broad peaks of x-ray diffraction and Raman scattering measurements. The oxygen content of the amorphous films was estimated by the electron microprobe analysis. The tetragonal samples were crystalline and their cell parameters, obtained from x-ray diffraction pattern, were used to estimate the oxygen content. More information on the material characterization and carrier transport properties of these thin films is provided in an upcoming publication.

For the electrical measurements, gold leads were attached by ultrasonic bonding. The standard four-probe method with a 3 mm probe spacing was used to measure the resistance and voltage noise of samples a–d. The voltage-probe spacing was slightly larger in sample f. In calculating the resistivities and sheet resistances from the measured data, the standard corrections were applied for the finite (rectangular) sample size and thickness, as well as (when applicable) for the unequal probe spacing.

The four amorphous YBaCuO samples showed different room temperature resistivities ranging from 6.5 to 32.4 Ω cm that were comparable to the values obtained on bulk semiconducting YBa$_2$Cu$_3$O$_{6+x}$ ($x \approx 0.3–0.5$) by Parfionov and Konovalov, but lower than those obtained by Yu and Heeger on single crystal YBa$_2$Cu$_3$O$_{6+x}$. It is, however, much higher than the values observed by others on YBa$_2$Cu$_3$O$_{6+x}$ ($x \approx 0.3$) samples. Since resistivity is a very sensitive function of oxygen content and processing conditions, it is not unusual to have such a wide range of reported values. This is seen for the two crystalline samples, e and f, where resistivity changes from 0.48 Ω cm ($x \approx 0.5$) to 50.40 Ω cm ($x \approx 0.3$), respectively.

The resistance versus temperature ($R–T$) of four amorphous YBaCuO samples biased with 1 μA current is shown in Fig. 1(a). The curves clearly depict semiconducting char-

<table>
<thead>
<tr>
<th>Sample</th>
<th>Structure</th>
<th>Y:Ba:Cu:O ratio</th>
<th>Crystal type</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>YBaCuO (200 Å)–MgO (350 Å)–Si</td>
<td>1:0.5:2:0.4:5</td>
<td>Amorphous</td>
</tr>
<tr>
<td>b</td>
<td>YBaCuO (200 Å)–Si</td>
<td>1:0.3:2:3:4:6</td>
<td>Amorphous</td>
</tr>
<tr>
<td>c</td>
<td>YBaCuO (200 Å)–SiO$_2$ (8000 Å)–Si</td>
<td>1:0.4:2:4:4:6</td>
<td>Amorphous</td>
</tr>
<tr>
<td>d</td>
<td>YBaCuO (200 Å)–MgO (350 Å)–SiO$_2$ (8000 Å)–Si</td>
<td>1:0.5:2:4:4.8</td>
<td>Amorphous</td>
</tr>
<tr>
<td>e</td>
<td>YBaCuO (200 Å)–LaAlO$_3$</td>
<td>1:1.8:2:4:6.5</td>
<td>Tetragonal</td>
</tr>
<tr>
<td>f</td>
<td>YBaCuO (200 Å)–LaAlO$_3$</td>
<td>1:2:0:2:6:3</td>
<td>Tetragonal</td>
</tr>
</tbody>
</table>
acteristics, i.e., an increasing resistance with decreasing temperature. We were not able to perform measurements below 250 K since the resistance values were above what we could reliably measure with our present equipment. The TCR versus temperature that was obtained from Fig. 1~a! using point-by-point differentiation is shown in Fig. 1~b! for the same samples. As explained in an earlier publication, the resistance of the samples decreased with increasing current due to high TCR and a small Joule heating effect on the films. Due to this slight nonlinearity of the $I$–$V$ curves, resistivity and TCR showed small differences at different bias currents. The results are summarized in Table II. The highest room temperature TCR was obtained on samples a and d which were deposited on MgO buffer with (a) or without (d) an underlying SiO$_2$ layer. A MgO buffer layer apparently eliminates the interaction between YBaCuO and the SiO$_2$ layer or Si substrate. The highest TCR was obtained on sample a at 268 K when biased with 0.1 $\mu$A. These values are better than the 2% K$^{-1}$ TCR value that was obtained on a Honeywell room temperature bolometer.

The resistivity and TCR values versus temperature for the single crystal oxygen-deficient YBa$_2$Cu$_3$O$_{6.5}$ thin films e and f are shown in Fig. 2. In general, the tetragonal samples yielded lower TCR values than the amorphous ones. Although sample f had a rather large $dR/dT$ since it also had a large resistivity, the resultant TCR was still less than 2% K$^{-1}$ at room temperature. As would be expected, the less oxygenated samples displayed a higher resistivity and an absolute value of TCR. The observed resistivity and TCR values on our tetragonal samples agree with the results obtained by

<table>
<thead>
<tr>
<th>Sample</th>
<th>$\rho$ ($\Omega$ cm)</th>
<th>$dR/dT$ (k$\Omega$/K)</th>
<th>TCR (%)</th>
<th>$T$ (K)</th>
<th>$I$ ($\mu$A)</th>
<th>$I$–$V$ curve</th>
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<tr>
<td>a</td>
<td>32.42</td>
<td>24.2</td>
<td>3.39</td>
<td>4.02</td>
<td>268</td>
<td>0.1 Nonlinear</td>
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<tr>
<td>b</td>
<td>6.53</td>
<td>3.8</td>
<td>2.64</td>
<td>3.92</td>
<td>258</td>
<td>1.5 Slightly nonlinear</td>
</tr>
<tr>
<td>c</td>
<td>8.33</td>
<td>4.9</td>
<td>2.67</td>
<td>3.22</td>
<td>258</td>
<td>0.5 Slightly nonlinear</td>
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<tr>
<td>d</td>
<td>12.91</td>
<td>8.4</td>
<td>2.95</td>
<td>3.40</td>
<td>263</td>
<td>0.5 Slightly nonlinear</td>
</tr>
<tr>
<td>e</td>
<td>0.48</td>
<td>0.053</td>
<td>0.50</td>
<td>0.56</td>
<td>258</td>
<td>Independent of applied current</td>
</tr>
<tr>
<td>f</td>
<td>50.40</td>
<td>37.8</td>
<td>1.86</td>
<td>2.04</td>
<td>258</td>
<td>Independent of applied current</td>
</tr>
</tbody>
</table>

FIG. 1. (a) The resistance and resistivity vs temperature for the amorphous YBaCuO thin films (samples a–d) biased with 1 $\mu$A current. (b) TCR for the same samples as obtained from (a).

FIG. 2. The resistivity of tetragonal samples e (△=YBa$_2$Cu$_3$O$_{6.5}$) and f (■=YBa$_2$Cu$_3$O$_{6.3}$) as a function of temperature. The inset shows TCR for the same films. The bias current was 100 $\mu$A for sample e and 0.1 $\mu$A for sample f. The resistivity remained independent of the bias current as expected from linear $I$–$V$ curves.
Zubkus et al.\textsuperscript{8} and Parfionov and Konovalov\textsuperscript{19} on bulk ceramic samples of YBa$_2$Cu$_3$O$_{6+x}$ with similar oxygen contents.

**NOISE MEASUREMENTS**

We measured the voltage noise spectral density $S_\nu$ in the frequency range of 1–100 Hz using a HP 3562A dynamic signal analyzer. Figure 3 shows typical voltage power spectral densities, depicting Johnson and 1/f components, measured at $T=295$ K with different bias currents. A detailed discussion can be found elsewhere.\textsuperscript{12} The bias current dependence of the 1/f noise component was measured between 0.5 to 7 $\mu$A and revealed an $I^\alpha$ ($\alpha$ is ranging from 1.7 to 2.3) power dependence on bias current at all frequencies for samples a, b, c, d, and f. Since the resistance of sample e was much lower, the bias current dependence of the 1/f noise power spectral density was measured between 50 and 300 $\mu$A and revealed an $I^{1.64}$ dependence. Figure 4 shows the normalized voltage noise power spectral density $S_\nu/V^2$ at 30 Hz for all samples biased with 1 $\mu$A, except for sample e that was biased with 100 $\mu$A. At 30 Hz, all samples, except sample e, exhibit 1/f noise when biased with 1 $\mu$A at room temperature. The inherent noise of sample e was so low that, at these conditions, only Johnson noise was observed. At the same bias and temperature, but at a higher frequency of 500 Hz, Johnson noise was the only component observed on samples a–d. Sample f, on the other hand, still had a considerable amount of 1/f noise at 500 Hz.

Since the 1/f noise component depends quadratically on the current, $S_\nu/V^2$ provides a good comparison between the noise characteristics of different samples. Among the amorphous samples, a and d exhibit the lowest room temperature noise. It is interesting to note that these are the same samples that have the highest TCR and therefore should yield the highest responsivity and detectivity values, the two most important figures of merit for an infrared detector. The common aspect between samples a and d is the presence of a MgO underlying layer, which seems to be desirable for bolometric applications of YBaCuO.

**DISCUSSION**

Although our YBaCuO samples have not yet been integrated into thermal isolation structures, the measured $dR/dT$ and noise values can be used to estimate the responsivity and detectivity. In order to estimate $R_V$, we used typical room temperature values for a 50 $\mu$m$\times$50 $\mu$m Si$_n$N$_m$ suspended structure\textsuperscript{12,24} with an effective detector area of 35 $\mu$m$\times$35 $\mu$m$=1.2\times10^{-5}$ cm$^2$ ($G=6.7\times10^{-8}$ W/K, $C=0.7\times10^{-9}$ J/K, $\tau=C/G=10^{-2}$ s) with an IR absorber (\textit{\eta}=1). For a bias current of 1 $\mu$A and frame frequency of 30 Hz, the responsivity of our room temperature ($T=295$ K) bolometers estimated by Eq. (1) is shown in Table III. The sheet resistance $R_s$ of each film is used for $R$. As expected from the high $dR/dT$ among the amorphous samples, the ones deposited on MgO (a and d) have the best projected $R_V$. Although sample f has a rather low TCR due to its very high resistivity, the $dR/dT$ value is high, yielding a respectable responsivity. All semiconducting YBaCuO samples, except sample e, show superior responsivity (up to two orders of magnitude higher) compared to their reported superconducting counterparts, $R_V=1.5\times10^5$ V/W by Johnson et al.,\textsuperscript{25} $R_V=6500$ V/W by Bang et al.,\textsuperscript{26} and $R_V=2900$ V/W by Rice et al.\textsuperscript{12}

Since the responsivity scales with the applied current, a question might arise whether the 1 $\mu$A bias current would be a realistic current to use in an actual detector based on a thin film of such high resistance. Isolated structures might require a lower current than 1 $\mu$A to avoid excessive overheating. In order to estimate the actual temperature of the isolated structure with $G=6.7\times10^{-8}$ W/K, $C=0.7\times10^{-9}$ J/K biased with 1 $\mu$A at room temperature, the standard heat balance equation, was used\textsuperscript{27}

$$\frac{dT}{dt} = \frac{I^2 R_s(T) - G(T - T_{sub})}{C} \tag{3}$$

Here $T_{ solub}$ is the substrate temperature. For the worst case, sample e ($R_s=1600$ k$\Omega$), the equilibrium sample temperature increase was found to be only 13 K. Thus 1 $\mu$A bias current should not cause any problem in the operation of the bolom-
eter since the TCR is negative (no thermal runaway) and stable over a large temperature range. In fact, most likely higher bias currents can be used in actual devices to achieve higher responsivities without any overheating considerations.

A better measure of bolometric performance is the detectivity $D^*$ since it also includes the noise properties of the thin film. The estimation of $D^*$ is more involved. The measured noise using a 3 mm probe spacing has to be scaled to a typical detector area of $1.2 \times 10^{-5}$ cm$^2$. If we use the Hooge relation, $S_V = \alpha_h V^2/f N$, for 1/f noise and scale the 1/f noise magnitude by the total number of independent fluctuators $N$, taken as the total number of carriers that is proportional to the sample volume, then we obtain an unrealistically high 1/f noise magnitude. However, this is an improper approach since it takes into consideration only the bulk contribution to the 1/f noise, an unlikely scenario for thin films as proven by van der Ziel. Since, at this point, the origin of the fluctuations in our films is unknown, a better method is to scale the measured noise magnitudes by the value of the thin film sheet resistance. This is done using Ohm’s law to scale $S_V$ for a smaller device of 35 $\mu$m $\times$ 35 $\mu$m with the same sheet resistance, biased at the same current level, yielding a proportionately smaller voltage and therefore noise voltage. In effect, $S_V$ is scaled with respect to the resistance of the film since $S_V \propto V^2 \propto R^{-2}$ for a constant bias current.

Table III lists the calculated room temperature detectivities for 30 and 500 Hz from Eq. (2) using the responsivity calculated above and the measured noise magnitudes for 1 $\mu$A bias current. The 30 Hz frequency is important since it is the frame frequency for infrared detection cameras. The frequency 500 Hz, on the other hand, roughly corresponds to the white noise, mainly Johnson noise, regime for most of our thin films. At 30 Hz, 1/f noise component dominates all samples except for sample e that shows only Johnson noise. At 500 Hz all samples show only Johnson noise except for sample e.

For comparison, the ratio $\beta(S_V/V^2)^{1/2}$ at 30 Hz for all six samples is shown in Table III. Again, among the amorphous samples, a and d outperform the samples without a MgO underlying layer. This time, however, sample e shows a high figure of merit, comparable to that of sample a. This indicates that, if the detectivity of sample e is optimized by a higher level bias (e.g., $I_b \approx 100$ $\mu$A), tetragonal YBa$_2$Cu$_{6}$O$_{5.5}$ might be as suitable as a temperature sensitive material as amorphous YBaCuO thin films.

The 1/f noise voltage $V_n$ scales linearly with the applied bias as expected from noise theory and Ohm’s law. Johnson noise, on the other hand, is a thermal equilibrium noise source and depends only on the device resistance and temperature. Since the responsivity also scales linearly with bias current, the detectivity increases linearly with $I_b$ at low bias levels and, once the 1/f noise exceeds the Johnson noise level, detectivity saturates and does not show any further increase with increasing bias current. Thus, the value of $I_b$ at the edge of $D^*$ saturation can be regarded as the optimized current bias. Since sample e shows only Johnson noise at 30 Hz and 1 $\mu$A bias current, its projected detectivity in Table III is below the optimized value, which would be reached at a higher bias current in the 1/f noise regime. Therefore, the above analysis underestimates the maximum performance achievable by sample e.

Perhaps a better measure of merit is the ratio $\beta(S_V/V^2)^{1/2}$ where $S_V/V^2$ is the voltage normalized 1/f noise power spectral density. This ratio is directly proportional to $D^*$ and can be obtained by substituting Eq. (1) into Eq. (2):

$$D^* = \frac{\beta \eta \sqrt{A}}{(S_V/V^2)^{1/2} G(1 + \omega^2 \tau^2)^{1/2}}.$$  

For comparison, the ratio $\beta(S_V/V^2)^{1/2}$ at 30 Hz for all six samples is shown in Table III. Again, among the amorphous samples, a and d outperform the samples without a MgO underlying layer. This time, however, sample e shows a high figure of merit, comparable to that of sample a. This indicates that, if the detectivity of sample e is optimized by a higher level bias (e.g., $I_b \approx 100$ $\mu$A), tetragonal YBa$_2$Cu$_{6}$O$_{5.5}$ might be as suitable as a temperature sensitive material as amorphous YBaCuO thin films.

Despite the fact that both amorphous and tetragonal, oxygen-poor YBaCuO samples promise high responsivity and detectivity, the amorphous films are preferred since they do not require a high-temperature deposition/annealing process as do the crystalline samples. This enables direct integration of the amorphous films in existing complementary metal-oxide-semiconductor (CMOS) technology without additional high-temperature processing steps.

**Table III.** Calculated responsivity and detectivity of the semiconducting YBaCuO bolometers with an area of $1.2 \times 10^{-5}$ cm$^2$. Samples a–d are amorphous. Samples e and f are tetragonal YBa$_2$Cu$_{6}$O$_{5.5}$ and YBa$_2$Cu$_{6}$O$_{5.5}$, respectively. All values are for $T = 295$ K.

<table>
<thead>
<tr>
<th>Sample</th>
<th>$R_1$ (V/W)</th>
<th>$R_2$ (V/W)</th>
<th>Measured voltage noise ($10^{-7}$ V/Hz$^{1/2}$)</th>
<th>Measured voltage noise ($10^{-7}$ V/Hz$^{1/2}$)</th>
<th>$D^*$ (cm Hz$^{1/2}$/W)</th>
<th>$D^*$ (cm Hz$^{1/2}$/W)</th>
</tr>
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<tbody>
<tr>
<td>a</td>
<td>3.83 x 10$^4$</td>
<td>2.60 x 10$^4$</td>
<td>8.13</td>
<td>3.05</td>
<td>1.63 x 10$^4$</td>
<td>2.95 x 10$^4$</td>
</tr>
<tr>
<td>b</td>
<td>6.02 x 10$^4$</td>
<td>4.09 x 10$^4$</td>
<td>3.94</td>
<td>1.07</td>
<td>5.30 x 10$^4$</td>
<td>3.20 x 10$^4$</td>
</tr>
<tr>
<td>c</td>
<td>7.76 x 10$^4$</td>
<td>5.27 x 10$^4$</td>
<td>6.17</td>
<td>0.923</td>
<td>4.36 x 10$^4$</td>
<td>1.98 x 10$^4$</td>
</tr>
<tr>
<td>d</td>
<td>1.33 x 10$^5$</td>
<td>9.03 x 10$^4$</td>
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<td>1.33</td>
<td>1.08 x 10$^5$</td>
<td>2.35 x 10$^5$</td>
</tr>
<tr>
<td>e</td>
<td>8.40 x 10$^5$</td>
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<td>0.202</td>
<td>0.202</td>
<td>1.44 x 10$^5$</td>
<td>9.78 x 10$^5$</td>
</tr>
<tr>
<td>f</td>
<td>3.13 x 10$^5$</td>
<td>2.42 x 10$^5$</td>
<td>2.43</td>
<td>2.43</td>
<td>4.72 x 10$^5$</td>
<td>1.31 x 10$^5$</td>
</tr>
</tbody>
</table>

*All samples, except e, exhibit 1/f noise at 30 Hz when biased at 1 $\mu$A. Sample e shows only Johnson noise.

†At 500 Hz, on the other hand, all samples except for f exhibit only Johnson noise. Sample f still shows a significant 1/f noise component. Calculated detectivities reflect the measured noise values.

...
with existing CMOS technology is essential if YBaCuO thin films are going to be used as sensitive elements in microbolometers and IR imagers since the sensors have to be directly built on silicon wafers so that signal processing can be performed on the same chip.

The detectivities predicted in this work are still about an order of magnitude lower than those obtained on cryogenic HgCdTe photon IR detectors, but uncooled YBaCuO offers the advantage of working at room temperature.

CONCLUSION

In summary, amorphous semiconducting YBaCuO thin films deposited on Si with a MgO buffer layer promise excellent room temperature bolometric response, with a temperature coefficient of resistance up to 4% K−1 and a noise voltage less than a fraction of 1 μV/Hz 1/2 at 30 Hz. Responsivities of the order of 3.8×10 3 V/W and detectivities of 1.6×10 9 cm Hz 1/2 /W are possible if these thin films are integrated into typical air-gap microbolometer structures. Since crystallinity is not needed, high-temperature processing is not required, making this material ideal for direct integration into existing CMOS technology such that signal processing can be accomplished on the IR focal plane.

ACKNOWLEDGMENTS

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24 S. Borrello (private communication).
27 E. I. Shaheen, Basic Practice of Chemical Engineering (Houghton Mifflin, Boston, 1975).
30 If Hooge’s relation is used to further scale the measured noise from an area of 7 mm×3 mm to 1.2×10 −3 cm 2, the projected noise voltage for sample a would be 108 μV/Hz 1/2 at 30 Hz, giving an estimated D * of about 5×10 6 cm Hz 1/2 /W. However, it is our conviction that, in our thin films, the 1/f noise does not scale with the number of carriers in the volume of the sample since in such films interface effects play the dominant role. In order to verify this theory, we performed noise power spectral density measurements on 60 μm×60 μm and 40 μm×40 μm samples of YBaCuO similar to sample a in composition, sheet resistance, and TCR. The noise voltage V 1/f was found to be 0.9–2 μV/Hz 1/2 at 30 Hz and 0.8 μA bias. These values support the suggestion that the noise voltage scales with sample resistance, as predicted by Ohm’s law, but not with respect to volume, as implied by Hooge’s formula.