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A DEMONSTRATION OF 1×8 LINEAR ARRAY YBCO TRANSITION EDGE IR BOLOMETER*

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A high-T_c superconducting array microbolometer has been fabricated by using a YBCO film. Optical measurements gave moderate performance as individual detector, but singnificant improvement appears possible.

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I. INTRODUCTION

The discovery of high-T_c superconductors has prompted a large amount of research into potential applications[1]. To date, a high-T_c superconductor infrared microbolometer may offer practical applications[2, 3]. This paper describes the design, fabrication, and evaluation of such a device with an 8-element array from Y-Ba-Cu-O thin films. Detectors for visible and infrared light, and for mm-waves, have a wide range of applications in space, military and optical communication industries.

II. PRINCIPLE OF OPERATION

The microbolometer is based on sputtering $YBa_2Cu_3O_7$ (YBCO) on ZrO_2 substrate. It is a superconducting resistor maintained at the transition edge between the normal and superconducting states (Fig. 1). Incident radiation absorbed by the resistor increases its temperature, thereby increasing its resistance. The responsivity R of a microbolometer at the bias current I_b, i.e. the signal output per unit radiant power input, is given by

$$R = I_b \alpha Re \eta / G(1+\omega^2\tau^2)^{1/2} , \quad (1)$$

where R is the resistance, η the optical absorptance, G the thermal conductance from the

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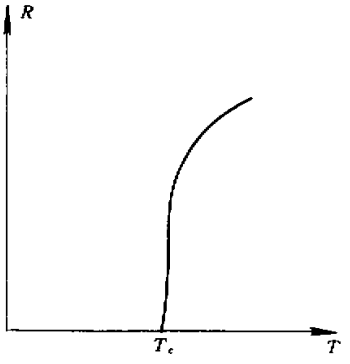

Fig.1. Variation of resistivity of YBCO films vs temperature (schematic).

absorber to its surroundings, and ω is the angular frequency of the incident radiation. The temperature coefficient of the resistance is given by

$$\alpha = \frac{1}{Re}\frac{\mathrm{d}Re}{\mathrm{d}T}. \tag{2}$$

The response time is given by $\tau = C/G$, where C is the heat capacity of the absorber. Thus the responsivity is frequency independent at low modulation frequencies and reduces with frequency at higher frequencies. Equation (1) shows that the key to developing highly sensitive bolometers are to obtain as high as possible a temperature coefficient, a very low heat capacity C and low thermal conductance G.

The noise-equivalent power (NEP) is defined as the incident radiant power required to generated a signal voltage equal to the noise voltage. Its formulation is to divide the noise voltage by the responsivity, i.e.

$$\mathrm{NEP} = \frac{(4k_B T_d \Delta f)^{1/2} \cdot G(1 \quad {}^2\tau^2)^{1/2}}{I_b \alpha \eta Re^{1/2}}, \tag{3}$$

where k_B is Boltzmann's constant, T_d the operating temperature, and Δf the measurement bandwidth. The detectivity D^* of a bolometer depends upon the noise mechanism. All resistive materials, including superconductors at the transition edge, exhibit Johnson noise, whose voltage V_J is given by

$$V_J = (4k_B T_d Re\Delta f)^{1/2}. \tag{4}$$

Superconductors may also offer other forms of excess noise, for exsample, the $1/f$ power law noise. The D^* is defined as

$$D^* = (A_D \cdot \Delta f)^{1/2} R / V_n, \tag{5}$$

where A_D is the area of the absorber and V_n is the noise voltage.

III. CONSTRUCTION AND TECHNOLOGY OF THE DEVICE

The YBCO films were fabricated in a dc magnetron sputtering system in working gases of argon and oxygen. During sputtering the ZrO_2 substrates were heated and after sputtering the film was *in situ* annealed in pure oxygen with a standard atmosphere.

The film thickness was about 0.3 μm. The zero resistance transition T_c of the film ranged from 85 K to 90 K with a critical current density J_c (77 K) = 1×10^5 A/cm^2. The film was patterned into meander line structure by means of optical lithography. The line width was 30 μm, and the total length was 2000 μm. An advantage of the method of con-

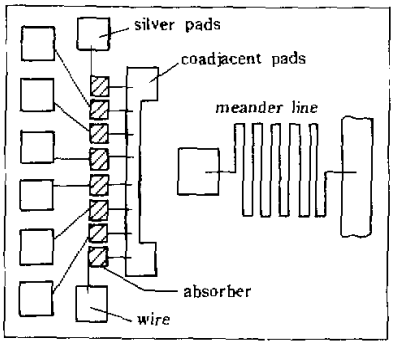

Fig.2. Diagram of the eight elements of the device.

struction is the extension to microbolometer arrays. Figure 2 shows the processed pattern made by silicon microstructure technology. The microbolometer is an 8-element linear array. The resistance of each absorber is about 3 kΩ at room temperature, which is a match for the preamplifier. The total device was a 1 mm × 2 mm.

The electrical connections were made by suiting the thermosonic wire bonding (gold wire) to film silver pads on the microbolometer. The fabricated linear array devices were placed in a LN-cooled metal Dewar with optical access via an optical window of ZnS. The operational temperature, by using an accurate temperature controller, was maintained at the transition temperature.

IV. RESULTS AND DISCUSSION

A standard blackbody at 500 K was used to measure the signal to noise ratio and responsivity of the microbolometer. The best performance of an 8-element microbolometer had $D^* = 4.3 \times 10^9$ cm · $Hg^{1/2}$ · W^{-1} at 10 Hz. Table 1 summarizes the main performences of an 8-element linear array microbolometer.

From Table 1, it can be seen that the performances of the absorbers are different. This is believed to be due to both the non-uniform of the film and the substrate used. Since the responsivity of an absorber is proportional to dR/dT, a sharper superconducting transition will result in a higher responsivity. The thermal properties of the substrate and the contact resistance between the film and the substrate are also important. It is believed that the performances of the microbolometer can be increased further by optimizing the geometry and thermal characteristics[4-6]. A potential application is for large 2-D staring focal plane arrays.

Table 1. Main performances of an 8-element microbolometer (YBCO, T_c=90 K, f=10 Hz).

2# device absorbers No.	V_s (mV)	V_n (mV)	V_s/V_n	R (V/W)	NEP ($W \cdot Hz^{-1/2}$)	D^* ($cm \cdot Hz^{1/2} W^{-1}$)	note
1	3.4	0.2	17	245	7.4×10^{-11}	2.7×10^{8}	
2	3.8	0.2	19	274	6.6×10^{-11}	3.0×10^{8}	
3	2.5	0.07	35.7	180	2.5×10^{-11}	8.0×10^{8}	
4	2.2	0.05	44	159	2.9×10^{-11}	7.0×10^{8}	
5	2.0	0.1	20	144	6.3×10^{-11}	3.2×10^{8}	
6	3.5	0.2	17.5	253	7.2×10^{-11}	2.8×10^{8}	
7, 8							wire failed
3# device absorbers							
1	6.0	0.8	7.5	433	1.7×10^{-10}	1.1×10^{8}	
2	10.4	0.7	14.9	750	8.5×10^{-11}	2.4×10^{8}	
3	7.5	0.8	9.4	541	1.3×10^{-10}	1.5×10^{8}	
4	6.0	0.3	20	433	6.3×10^{-11}	3.2×10^{8}	
5	6.5	0.5	13	469	9.7×10^{-11}	2.1×10^{8}	
6	10.0	1.5	6.7	722	1.9×10^{-10}	1.1×10^{8}	
7	6.5	0.3	21.7	469	5.8×10^{-11}	3.4×10^{8}	
8							wire failed

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