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Composite bolometer based on $Bi_2Sr_2CaCu_2O_{8+x}$ single crystals

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Abstract

We describe the properties of a prototype bolometer operating at liquid nitrogen temperature based on a $Bi_2Sr_2CaCu_2O_{8+x}$ single crystal 15 μm thick grown by the flux method. The use of thin single crystals having low thermal capacities was suggested by the request of decreasing the response time τ of the device. Preliminary results indicate that single-crystal-based far infrared bolometers can be competitive with the commercial detectors operating at room temperature.

1.Introduction

At present the most sensitive radiation detectors in the far infrared (FIR) range ($\lambda > 100\mu m$) are bolometers based on doped semiconductors, operating liquid ^{4}He temperatures. Such detectors show sensitivities close to the photon noise limit. However the use of the semiconducting bolometers for laboratory spectroscopy and in space astronomy is somewhat hindered by the need of liquid helium refrigeration. Besides LHe cooled detectors, only relatively low performance room temperature detectors are available (Golay cells and pyroelectrics).

The discovery of high T_c superconducting materials (HTS) having sharp resistive transitions in the temperature range from 70 K to 110 K provided the opportunity to develop FIR bolometric detectors operating at intermediate temperatures. Such detectors could have a number of applications, ranging from laboratory FIR spectroscopy to observation of the earth atmosphere in the millimetric windows and to planetary photometry from space vehicles.

To date, the most widely investigated HTS material has been $YBa_2Cu_3O_{7-x}$ (YBCO). A YBCO-based bolometer has already been fabricated. It has an area of 3x3 mm^2 and a noise equivalent power (NEP) of 3.0 10^{-10} W/Hz$^{1/2}$ [1].

Recently the employment of a $Bi_2Sr_2CaCu_2O_{8+x}$ (BSCCO 2212) film as thermometer in a composite FIR bolometer has been proposed[2]. It has been shown that the quality parameter $\alpha = \frac{1}{R}\frac{dR}{dt}$ of the resistive transition in BSCCO 2212 films of good quality are in the range of a few K^{-1}, therefore comparable with the α values reported for good quality YBCO films[3]. Measurements of the noise voltage spectrum were also carried out on a BSCCO epitaxial film: the main contribution was found to originate from the excess 1/f noise, of about 1 nV/Hz$^{1/2}$ at 10 Hz. Such value is again comparable with the excess noise at the same frequency found in good quality epitaxial YBCO films. However the

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NEP at a frequency of 10 Hz resulted to be about $1x10^{-8}$ W/Hz$^{1/2}$. Such high value of the NEP is due to the high effective response time $\tau = 1.5s$, which in turn is ascribed to the high thermal capacity of the $NdGaO_3$ substrate used to grow the BSCCO film.

In order to overcome this problem, we propose here to use a thin BSCCO 2212 single crystal as thermometer in a composite bolometer operating at liquid nitrogen temperature. Single crystals of BSCCO 2212 can be grown by the flux method as c-oriented platelets[4]. Single crystal slices only a few microns thick can be then obtained by simply delaminating the as-grown crystals. Such slices have electrical properties comparable with those of the epitaxial films on $NdGaO_3$ substrates, but a much smaller thermal capacity.

2.Experimental

BSCCO single crystals were grown by the flux method and then delaminated. A platelet 2x2x.015 mm^3 was chosen for the bolometric characterization. For such platelet, a thermal capacity of $56\mu J/K$ was estimated, i.e. much smaller than that (600 $\mu J/K$) estimated for the film and the substrate. Two silver pads, .2x.2 mm^2 area and about 200 nm thick were thermally evaporated on the crystal surface. The sample was then annealed in air at 400 °C for 1h to decrease the contact resistance. The resistance of each contact, after this thermal treatment, resulted to be about 20 $m\Omega$ while the resistance of the crystal just above the transition was about 1.5 Ohm. The sample was glued by GE7031 varnish to two nylon threads (60 μm diameter) fixed to a copper ring. Thermal and electrical connections were ensured by four copper wires (50 μm diameter) glued to the pads by silver paint. The thermal capacity of the sample, including the copper wires, was estimated to be about 160 $\mu J/K$.

The static responsivity S(0) was then calculated measuring the I-V characteristic (load curve) using the electrical equivalent formula $S(0) = (Z - R)/2V$ where Z is the dynamic impedance calculated from the load curve[5]. The sample was cooled to the transition temperature by a mechanical refrigerator. Load curves were measured at different temperatures along the resistive transition of the crystal. It must be noticed that, due to the presence of a temperature gradient inside the cold chamber and to the poor thermal coupling between the sample and the heat sink, the measured transition temperature is lower than the real value (about 80K). The static responsivity S(0) was then calculated as a function of the bias current I_b (see fig.1).

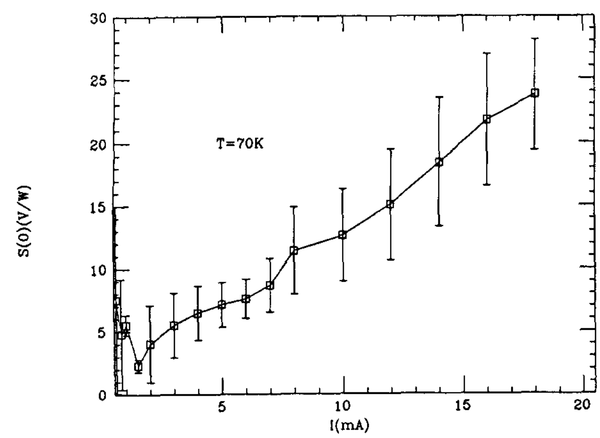

Figure 1. Electrical responsivity at zero frequency versus bias current at 70 K corresponding to the midpoint of the transition. The full line through the experimental points is a guideline for the eye.

The static responsivity S(0) was found to be almost independent on the temperature between 68 K and 71 K. Typical values of S(0) were about 12 V/W for I_b in the range of 10-20 mA: such values are in good agreement with those estimated from the purely thermal formula $S(0) = \alpha R I_b / G$. In Ref. 2 a large deviation from a purely thermal behaviour was observed at low bias currents due to critical current effects. Such non thermal effect does not appear in the data reported in fig.1. This finding can be attributed to the much larger value of the critical current density in bulk single crystals relative to thin films.

The effective time constant τ of the bolometer was estimated recording the variation of voltage versus time after the application of an electrical power step. A value of τ of about 2.2 s was found, much larger than the value of 600 ms expected from the thermal capacity estimated above and the thermal conductance of the copper wires. This effect is not well understood, however we suggest that it could be ascribed to the thermal capacity of the silver paint, nylon threads and GE7031 varnish.

Measurements of the voltage noise spectrum have been carried out on the same single crystal platelet. The dc output voltage from the device was amplified and then analysed by a fast Fourier transform digital spectrum analyser. The noise spectrum was measured as a function of the bias current at four different temperatures along the transition curve. A noise spectrum taken below the transition temperature showed that the contribution from silver contact is negligible and independent from the bias current. Fig.2 shows the temperature behaviour of the resistance and of the voltage noise for four different frequencies, after subtracting the contribution from the amplifier. A bias current of 10 mA was applied. It can been seen that the excess noise is dominant with respect to both the phonon and Johnson terms. The behaviour of the excess noise vs. temperature shown in Fig.2 is in agreement with noise measurements carried out on YBCO films[6]. The excess noise at 10 Hz for I_b=10 mA can be estimated to be about $1-2nV/\sqrt{Hz}$ over the whole temperature range of the transition. The noise equivalent power (NEP) for the device was finally estimated using the measured values of the static responsivity and the noise spectrum measurements and, in the best case, resulted to be about $8x10^{-9}W/\sqrt{Hz}$ at a frequency of 10 Hz and for a bias current of 10 mA. Such value is not far from those of commercial FIR detectors operating at room temperature as Golay cells and pyroelectrics. However a noticeable improvement of the NEP of the bolometer can be readily obtained optimizing the design: the spurious contributions to the thermal capacity can be reduced by eliminating the nylon threads and the GE7031 varnish and decreasing both the length and the diameter of the copper wires. Furthermore thinner crystals could be used.
Work is in progress in this direction.

3. Acknowledgements

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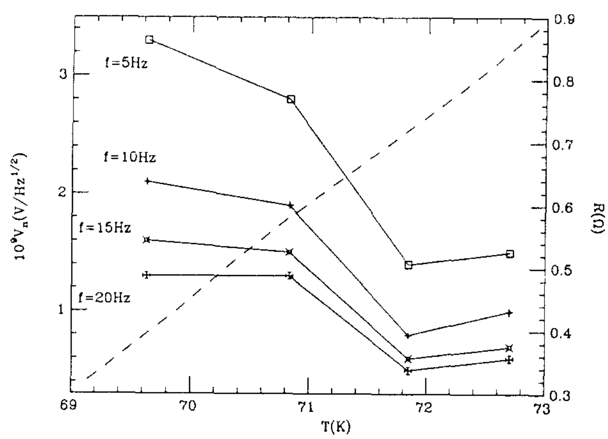

Figure 2. Voltage noise versus temperature at four different frequencies. The dashed line represents the resistive transition of the film (scale on the right side of the figure).

References

1) S.Verghese, P.L.Richards, K.Char, D.H.Fork, T.H.Geballe, in press on IEEE Transaction on Superconductivity.
2) A.Bottiglione, M.Epifani, G.Balestrino, E.Milani, M.Montuori, L.Maritato, A.Ruosi, R.Scafuro, to be published.
3) S. Verghese, P.L.Richards, K.Char, S.A.Sachtjen, IEEE Trans. Magn., 27 (1991) 3077.
4) G.Balestrino and P.Paroli, J. Crystal Growth, 92 (1988) 674.
5) R.C.Jones, J. Opt. Soc. Am., 43 (1953) 1.
6) P.L.Richards, J.Clarke, R.Leoni, P.H.Lerch, S.Verghese, M.R.Beasley, T.H.Geballe, P.H.Hammond, P.Rosenthal, S.R.Spielmann, Appl. Phys. Lett., 54 (1989) 3.