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Talk given at the International Conference
on Submillimeter Waves and their
Applications, Atlanta, GA, June 5-7, 1974

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JOSEPHSON JUNCTION BOLOMETER

John Clarke, G. I. Hoffer, and P. L. Richards

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John Clarke, G. I. Hoffer, and P. L. Richards
Department of Physics, University of California
and
Inorganic Materials Research Division,
Lawrence Berkeley Laboratory,
Berkeley, California 94720

ABSTRACT

A bolometer for use in the submillimeter and far infrared is described. The temperature sensitive element is an SNS Josephson junction. The electrical NEP is 5×10^{-15} W/Hz$^{1/2}$ and the detectivity, D^*, is 10^{14} cm Hz$^{1/2}$ W^{-1}.

*This work sponsored by the U.S. Atomic Energy Commission.

We have developed a new type of superconducting bolometer in which a superconductor-normal metal-superconductor (SNS) Josephson junction is used as the temperature sensitive element. The critical current, I_c, of an SNS junction[1] varies with temperature according to the equation

$$I_c = I_o \exp -(T/T_o)^{1/2}, \qquad (1)$$

where T is the temperature and $T_o \approx 0.01$ to 0.1°K. (This equation is valid for a junction with the normal metal in the dirty limit, as is the case for our junctions.) The rate at which the critical current changes with temperature is

$$\frac{\partial I_c}{\partial T} = -\frac{I_c}{2\sqrt{TT_o}}. \qquad (2)$$

When the junction is biased at a finite voltage by a current just greater than I_c, the voltage is also a function of temperature and varies at a rate

$$\frac{\partial V}{\partial T} = \frac{\partial V}{\partial I_c} \cdot \frac{\partial I_c}{\partial T} \approx -R_d \frac{\partial I_c}{\partial T}. \qquad (3)$$

R_d is the dynamic resistance of the junction at the bias point, typically about 10^{-5} Ω. If we assume that the dominant source of noise in the bolometer system is Johnson noise in the SNS junction, then the minimum detectable temperature change is found from Eq. (3) to be

$$\delta T = \frac{2\sqrt{TT_o}}{R_d I_c} (4kTR_d B)^{1/2}, \qquad (4)$$

where B is the measurement bandwidth. The thermal time constant of the bolometer is

$$\tau = \frac{C}{G}, \qquad (5)$$

where C is the heat capacity of the bolometer and G is ther thermal conductance linking the bolometer to its surroundings. If the bolometer is operated at a frequency much less than $1/\tau$, then the electrical noise equivalent power is

$$\text{NEP} = G\delta T. \qquad (6)$$

(The thermal feedback effect due to changes in Joule heating in the bolometer element, which can affect the apparent value of G, is negligible in the SNS bolometer.)

The bolometer configuration is shown in Fig. 1. A Pb/CuAl/Pb junction is evaporated on to a 4×8×0.125 mm sapphire substrate. In addition to the junction, the substance has on it a CuAl film which is used as a heater. The substrate is supported by nylon threads, approximately 15 μ in diameter, which are glued to the substrate with General Electric 7031 varnish. The threads are connected to a brass ring, the segments of which are electrically isolated. Pb is then evaporated on to the threads, providing electrical contact to the junction and heater. This assembly is mounted in the vacuum can of a liquid helium cryostat, and the voltage across the junction is measured by means of an rf SQUID with a voltage resolution of about 10^{-15} V/√Hz.

The bolometer was evaluated as follows. The I-V characteristic was measured in order to determine R_d. The temperature dependence of I_c was determined, and from this a value for T_o was obtained. Then a current was passed through the heater and the resulting temperature rise determined from the observed change in I_c. In this manner the thermal conductance, G, was measured. Also, the output voltage resulting from a given heater power input was noted, and this, combined with the observed level of the noise voltage, gave the NEP. (The temperature of the liquid helium bath drifted slowly so that it was necessary to chop the heater current at a low frequency in order to take the measurements.) Finally, τ was determined by switching off the heater current and observing the exponential decay of the voltage signal.

The best NEP was obtained at 1.7°K. The various bolometer parameters were as follows:

I_c = 10 mA
$R_d = 10^{-5}$ Ω
T_o = 0.06°K
$G = 10^{-8}$ W/°K
τ = 3 sec
NEP = 5×10^{-15} W/√Hz.

If Eqs. (4) and (6) are used to calculate the NEP, the result is

$$(\text{NEP})_{\text{calc.}} = 2 \times 10^{-15} \text{ W}/\sqrt{\text{Hz}}.$$

The fact that the observed noise was somewhat above the expected Johnson noise suggests that there may be an additional shot noise[2] contribution.

The large value of τ and the excess heat capacity that it implies are attributed to the GE varnish. We have developed an alternative method for attaching the threads to the substrate. A thin film of In is deposited on the threads and the substrate. These are then placed in contact and pressed together to cold weld the In films. We expect that this technique will bring τ down to 0.1 sec.

The area of our bolometer is much larger than that of the germanium bolometers with lowest NEP. The figure of merit used to compare bolometers of different area is $D^* = 10^{14}$ cm W^{-1} Hz$^{1/2}$ while for germanium bolometers D^* is about a factor of 30 smaller.

A radiation absorbing layer will be required on the bolometer, and for this purpose we plan to use a thin conducting film. Preliminary measurements in the frequency range 1 to 50 cm^{-1} indicate that thin (~ 250 Å) Bi films on sapphire have an absorption close to the theoretical value of $n/(n + 1) = 3/4$, where n is the index of refraction of sapphire.

If the bolometer is filled at f/1 with radiation from a blackbody in the Rayleigh Jeans limit, then the smallest blackbody temperature interval that can be detected at a frequency $\nu = 10$ cm^{-1}, for a predetection bandwidth ν_1 of 1 cm^{-1}, and a post detection bandwidth ν_2 of 1 Hz, is $\Delta T \approx 2 \times 10^{-4}$ K. If a single mode microwave heterodyne radiometer[3] is used for the same measurement, the system noise temperature required for

equivalent performance is $\Delta T(\nu_1/\nu_2)^{1/2} \sim 30K$.

References

1. J. Clarke, "Supercurrents in Lead-Copper-Lead Sandwiches," Proc. Roy. Soc., Series A, Vol. 308, pp. 447-471, January 28, 1969.

2. A. J. Dahm et al., "Linewidth of the Radiation Emitted By a Josephson Junction," Phys. Rev. Letters, Vol. 22, pp. 1416-1420, June 30, 1969.

3. R. H. Dicke, "The Measurement of Thermal Radiation at Microwave Frequencies," Rev. Sci. Instr., Vol. 17, pp. 268-275, July 1946.

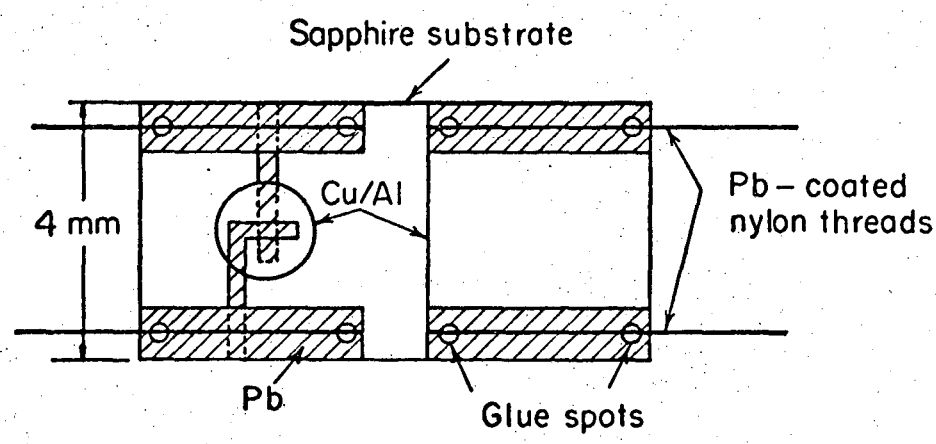

Fig. 1. Bolometer element with Pb/CuAl/Pb junction on the left, and CuAl heater on the right.

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