A Superconducting Bolometer as a High Sensitivity Detector for Molecular Beams

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The construction, operation and calibration of a superconducting bolometer is reported. Operated as a molecular beam detector the bolometer has, for Argon, a maximum sensitivity of $7 \cdot 10^6$ molecules sec^{-1} corresponding to a N.E.P. of $3 \cdot 10^{-13}$ Watt $Hz^{-\frac{1}{2}}$.

The use of a liquid He cooled Ge infrared detector as a high sensitivity bolometer detector for molecular beams has been recently reported [1] and its usefulness in molecular scattering experiments has been shown [2, 3].

The present note is intended to report on the construction, operation and calibration of a superconducting bolometer which, operated as a molecular beam detector, showed an order of magnitude improvement in signal to noise ratio compared with the previously used Ge bolometer.

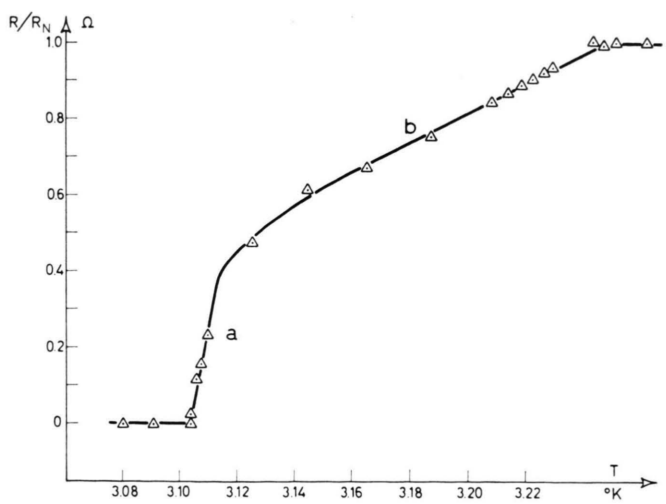
A superconducting bolometer has been reported, almost ten years ago, by MARTIN and BLOOR [4] which showed a noise equivalent power (N.E.P.) of about $3 \cdot 10^{-12}$ Watt $Hz^{-\frac{1}{2}}$ (reflection coefficient $\alpha = 0.1$) with a time constant of about $50 \cdot 10^{-3}$ sec. The sensitive element was an evaporated tin film maintained at a fixed temperature, to within 10^{-5} °K, in its superconducting transition (around 3.7 °K). In this condition the film has a very large temperature coefficient of resistance that can be used to transduce a chopped power imput to a voltage output which may then be integrated with standard techniques.

Up to the present time the superconducting bolometer has not been widely adopted in infrared spectroscopy for two main reasons. The first is the difficulty of thermo-regulating the sensitive element within 10^{-5} °K, and the second is the extreme delicacy of its construction.

Taking into account that the N.E.P. of Martin and Bloor's bolometer was reported to be limited by the electronics available at that time, we undertook the development of a superconducting bolometer with the aim of solving the mechanical ruggedness problem by relaxing the requirement that the film, when operating, should be homogeneous in temperature.

Indeed the possibility of a superconducting thin film acting as a non isothermal bolometer is qualitatively quite obvious and has also been quantitatively discussed theoretically in the literature by FRANZEN [5].

A superconducting bolometer of the non isothermal kind has also been reported by V. A. KONOVODCHENKO et al. at the 11th Low Temperature Conference (St. Andrews 1968). With respect to this point it should be noted, however, that it is not clear whether or not a non isothermal bolometer can be operated only in the way described by FRANZEN [5]. Indeed the transition curves obtained by us (see Fig. 1) were of the kind expected for a non isothermal element. Two types of operations are then possible: namely in the region a or in the region b. Region b corresponds to the type describec by Franzen. If sufficient thermal stability is available one can operate in region a which, in our opinion, corresponds to a different non isothermal kind of opera-



← Fig. 1. Transition curve of a typical bolometer.

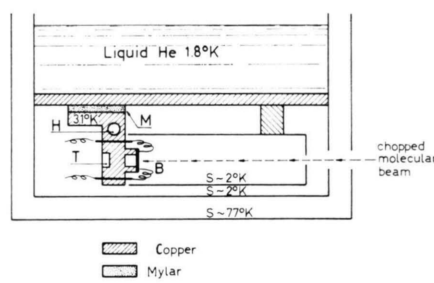


Fig. 2. Schematic experimental set-up.

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[1] M. CAVALLINI, G. GALLINARO, and G. SCOLES, Z. Naturforsch. **22 a**, 413 [1967].

[2] P. CANTINI, M. CAVALLINI, M. G. DONDI, and G. SCOLES, Phys. Letters **27 A**, 284 [1968].

[3] M. G. DONDI, G. SCOLES, F. TORELLO, and H. PAULY, J. Chem. Phys. **51**, 392 [1969].

[4] D. H. MARTIN and D. BLOOR, Cryogenics **1**, 159 [1961].

[5] W. FRANZEN, J. Opt. Soc. Am. **53**, 596 [1963].

a) b) c) d)

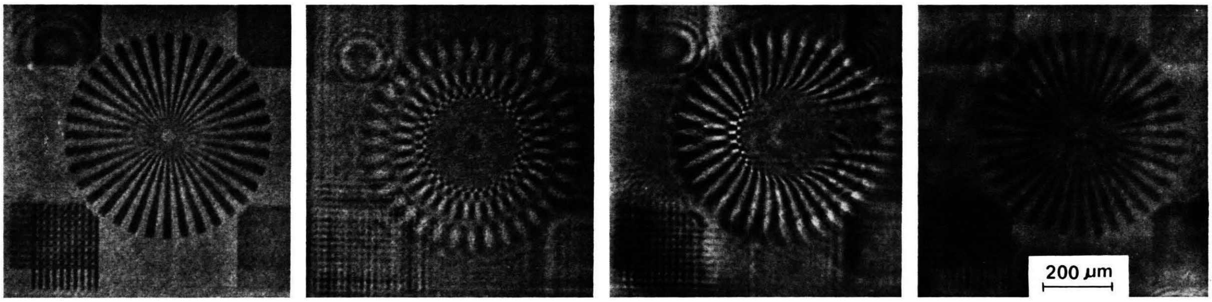

Abb. 1. a) Lichtmikroskopisches Bild eines kohärent beleuchteten schwachen Phasenobjekts, aufgenommen unter Verwendung einer Zernike-Platte; das Objekt steht im Fokus; b) wie Teilbild a), jedoch ohne Zernike-Platte und 2,5 mm defokussiert; c) wie Teilbild b), aber mit Einseitenband-Ausblendung (Einseitenband-Hologramm); d) Rekonstruktion von Teilbild c). Ebenso wie hier für die Defokussierung gezeigt, kann auch der Einfluß des Öffnungsfehlers durch Rekonstruktion aufgehoben werden.

tion. In both cases the limiting noise will be that generated by thermal fluctuations of the bath; but in mode of operation b, where, in general, the intrinsic gain factor is lower, a more refined electronics is needed, in order for the electronic noise not to be the dominating one.

In the following we will describe our bolometer system, schematically shown in Fig. 2, by describing a) the sensitive element cnstruction, b) the thermo-regulating unit, c) the electrical read-out amplification integration chain, d) the calibration.

a) Sensitive element construction. The copper support shaped as shown in Fig. 2 has been coated on top of the two protruding columns with a thin layer of an insulating paint (Formvex, obtained by Invex S.p.A. Quattordio Italy). A mylar strip B $(0.03 \times 0.3 \text{ cm})$ $6 \cdot 10^{-4}$ cm thick has been attached between the two columns in the same way.

At each side of the strip two lead-tin coated 47 copper wires were attached by a silver conducting paint. Finally a single tin evaporation covering the mylar and the silver contacts connects the sensing element (i. e. the central part of the film) thermally to the copper columns and electrically to the copper wires. The two wires are thermally anchored to the copper block, thus preventing any extra thermal impút to the sensing element.

The shields S indicated in Fig. 2 are necessary in order to: a) provide beam collimation, b) reduce the background radiation input to about 10^{-8} Watt.

b) Thermo-regulating unit. The thermal stability of the bolometer copper support is achieved by its thermal insulation (by means of the 0.03 cm mylar strip M) and temperature control by means of the sensing Allen Bradley carbon resistor thermometer T which controls the power dissipated in the heater H. The control is performed by an A.C. compensated resistance bridge with lock-in phase sensitive zero detection. The time constant of the feed-back system is around 300 sec. The temperature stability reached in this way is about 10^{-4} °K.

c) Electronics. In Fig. 3 the block diagram of the electrical read-out amplification-integration chain is shown. The electronic noise is given by the intrinsic noise of the RA5 Texas Instruments parametric amplifier and is about $50 \cdot 10^{-9}$ V r.m.s. from 0.1 to 13 Hz. Our limiting noise was not caused by the electronics but was probably due to thermal fluctuations.

d) Calibration. The bolometer has been calibrated with molecular beams of Ar, air, CO_2 and He. The molecular beam effuses from a $1.1 \cdot 10^{-3}$ cm diameter circular hole at a distance of 33 cm from the bolometer. A motor driven chopper chops the beam at 13 c.p.s. The pressure in the source is measured with an Atlas Micro Membrane Manometer used as a differential pressure detector between the source and a chamber pumped to 10^{-6} Torr by a liquid N_2 trapped oil diffusion pump. Figure 4 shows the linearity of the bolometer. The lower response of the bolometer to Helium with respect to Argon is due to the low accomodation coefficient of He on the evaporated tin surface. The minimum detectable signal, $S/N=1$, in molecules per second on the bolometer surface is 7, 30, 6 and $4 \cdot 10^6$ for Ar, He, air and CO_2, respectively, with an equivalent band width of $4 \cdot 10^{-2}$ Hz. For Argon, where the accomodation coefficient can be thought to be approximately unity the minimum detectable signal corresponds to a N.E.P. of $3 \cdot 10^{-13}$ Watt $\text{Hz}^{-\frac{1}{2}}$. By treating the surface both the accomodation coefficient for He and the reflection coefficient for infrared radiation can eventually be improved. In Table 1 the characteristics of a typical bolometer are reported.

Size:	$0.3 \times 3 \times 6 \cdot 10^{-3}$ mm
Time constant:	10^{-2} sec
Responsivity:	$4 \cdot 10^3$ V_{eff} watt^{-1} (at 13 Hz chopping frequency)
N.E.P.:	$3 \cdot 10^{-13}$ Watt $\text{Hz}^{-\frac{1}{2}}$
$R(4{,}2\ °K)$	$=0.5\ \Omega$

Table 1.

Acknowledgements

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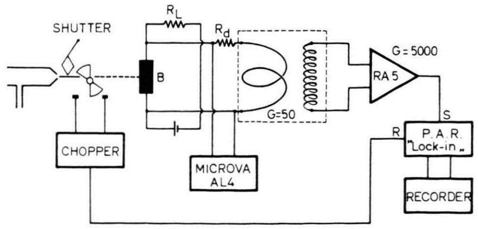

Fig. 3. Block diagram of the electronics.

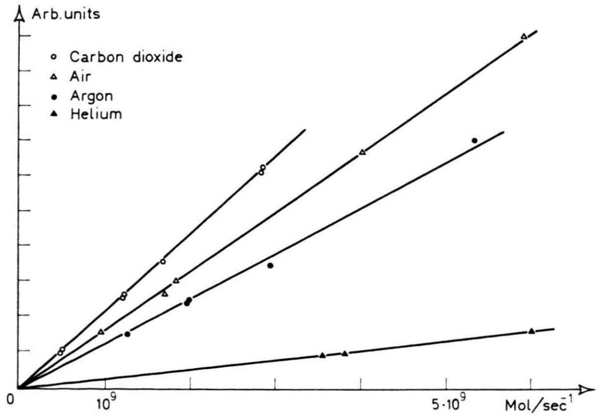

Fig. 4. Calibration curves of the bolometer for four different gases. →