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COMPOSITE BOLOMETERS : PRELIMINARY RESULTS**

RUTHENIUM OXIDE RESISTORS AS SENSITIVE ELEMENTS OF COMPOSITE
BOLOMETERS : PRELIMINARY RESULTS

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ABSTRACT

Bolometers for particle detection made with Rutenium oxide thermistors could be produced by means of a simple technique on a variety of different materials as substrata. Preliminary results on alpha particle detection with devices realized using commercial RuO₂ thick film resistor (Tfr) are considered positive for devices operating between .3 and .1 K and determined us to pursue further the idea.

Rutenium oxide resistors on sapphire at the moment are being prepared. The behaviour of these devices at temperatures lower than .1 K has to be investigated in more detail.

In the last few years the use of rutenium oxide thick film resistors as low temperature thermometers was successfully introduced^(1,2,3).

The merits of these components and the expected relative easiness and simplicity of construction of rutenium oxide resistors on a variety of different materials as substratum suggest to develop devices of this kind as bolometers for particle detection.

Preliminary results on alpha particle detection with a test bolometer realized on a commercial RuO₂ thick film resistor (Tfr) is considered positive for devices operating between .3 and .1 K and determined us to pursue further the idea.

Rutenium oxide resistors on sapphire at the moment are being prepared.

The behaviour of these devices at temperatures lower than .1 K has to be investigated in more detail.

The static specific heat of RuO_2 is :

$$C(T) = .059 \frac{1}{T^2} + 5.77 \cdot T + .0225 T^3 \quad \text{mj/mole} \cdot \text{K}^4 \quad (1)$$

and, below .2 K , the first term, due to the nuclear quadrupole contribution becomes dominant.

It is expected that, due to the long relaxation time, the effective thermal capacity in pulse regime should be rather insensitive to the huge nuclear term. In Fig. 1 the computed thermal capacity of a commercial Tfr is reported. Dashed line represents only the Debye and electronic contribution.

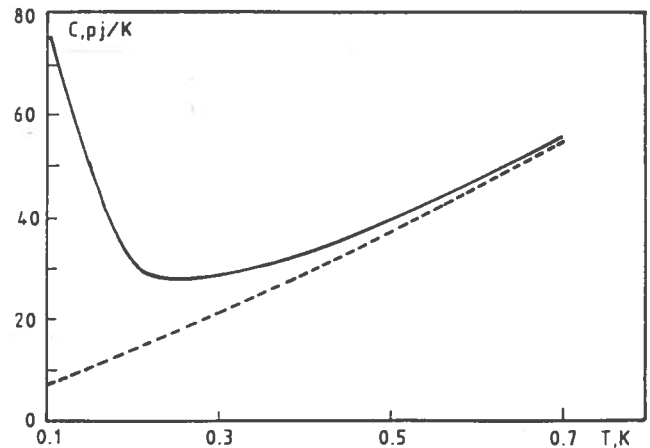


FIG. 1 - Thermal capacity of a commercial Tfr. Full line: total thermal capacitance. Dashed line: thermal capacitance with nuclear quadrupole term not included.

Experimental details:

Alpha particles hitting the top side of a commercial Tfr, with or without the protective layer, are easily detected at temperatures below 1 K.

We attribute the bad quality of the spectra observed to the non uniformity of the resistive film and to the poor thermal properties of the alumina substratum, as supported by the fact that alpha particles hitting the alumina on the side opposite to the resistive film do not produce any detectable pulse.

To verify this hypothesis and investigate further the feasibility of good RuO_2 detectors, a small composite bolometer was built with a small piece ($1.5 \cdot 1 \cdot 0.5 \text{ mm}^3$) of silicon glued with G.E. 7031 varnish to the central part of the resistor layer of a commercial Philips type RC-01 Tfr of 100 Kohm nominal value whose protective top layer was removed (Fig. 2).

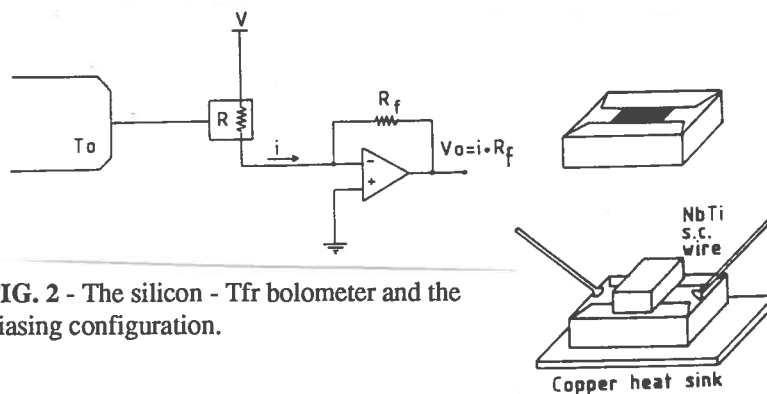


FIG. 2 - The silicon - Tfr bolometer and the biasing configuration.

The electrical terminals, that resulted to be made of nickel, where reduced to minimum; NbTi superconducting wires provide the electrical connection to the external world.

The bottom side of the Al_2O_3 substratum of the Tfr was fixed with G.E.7031 varnish to a bulky copper wire acting as heat-sink in an adiabatic demagnetization cryostat described elsewhere⁵⁾ and operating at temperatures ranging from 70 mK to 300 mK.

The thermal link between the device and the thermostat is mainly determined by alumina conductance.

A constant bias voltage was applied to one lead of the RuO_2 resistor; the second lead was D.C. connected to the virtual ground of a current to voltage converter realized with an OPA111 operational amplifier and a 10 Mohm feedback resistor R_f .

This solution, eliminating the integrating effect of the parasitic capacitance of the input connections, allowed us to examine the fast time structure of the signals with ambient temperature electronics.

In these experimental conditions, in order to check the thermometer responsivities, the V-I load curves where registered using:

- 1) Tfr resistor in the original condition.
- 2) Tfr with the protective layer removed.
- 3) The compound device described.

We have made two sets of measurements on R vs T dependence for 100 Kohm RC-01 Tfr, one at constant voltage and power level of less than 10^{-11} watt, the second with pulses of variable height at very low duty cycle.

Comparison of the two sets of measures indicates that deviations from the ohm law due to field effects, if present, are under 5%.

Typical results, as shown in Figs. 3, 4, are in agreement with previously reported data^(1,2,3).

Under .31 K an almost constant value of -3.4 is obtained for the thermal responsivity $A = -d \log R / d \log T$. (A and the parameter $\alpha = \frac{1}{R} \frac{dR}{dT}$, are connected by the relation $\alpha = \frac{A}{T}$).

A reasonable good fit is obtained with the law:

$$R = R_o \exp \left(\frac{T_o}{T} \right)^{\frac{1}{2}} \quad \text{with } T_o = 9.7 \text{ K} \quad (2)$$

According to the model of Sheng and others⁶⁾, that assumes hopping conduction between metallic grains we find a grain diameter $d=1.8\mu\text{m}$ and a "charging energy" $E_c=.8 \text{ mV}$.

Apart from a slight increase of resistance, no change is observed removing the protective layer of the resistor.

For alpha particles testing, a mixed nuclides source with three main alpha lines at 5.15, 5.48, 5.81 MeV or americium sources where used.

The shapes of the pulses at the output of the current to voltage transducer, produced by the alpha particles where registered with a 2430 Tektronix digital scope and are reported in Fig. 5.

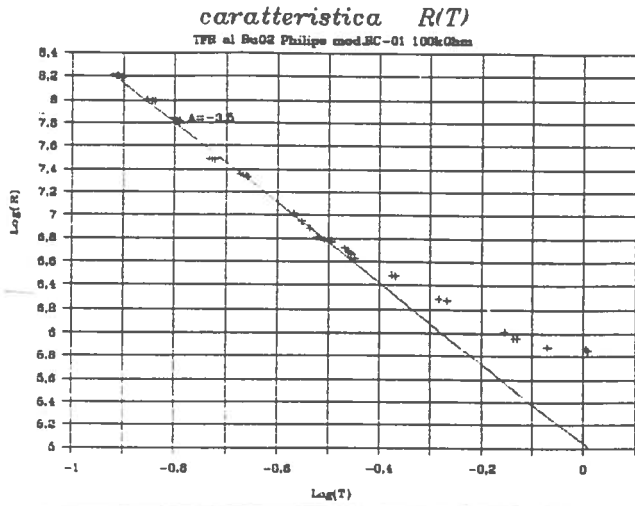
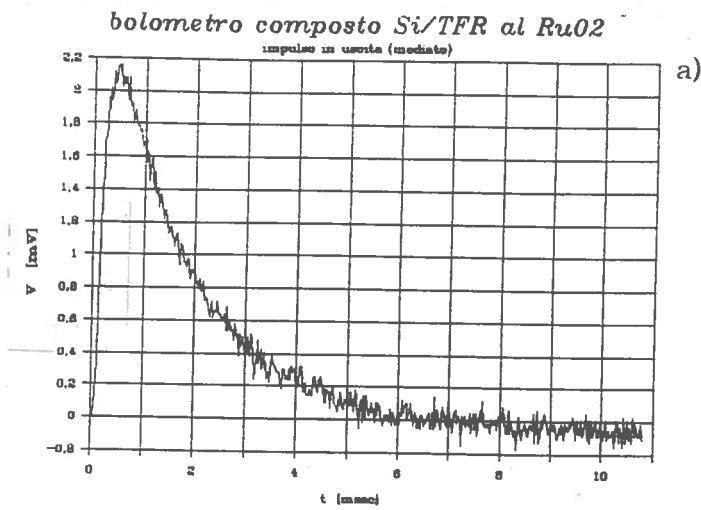
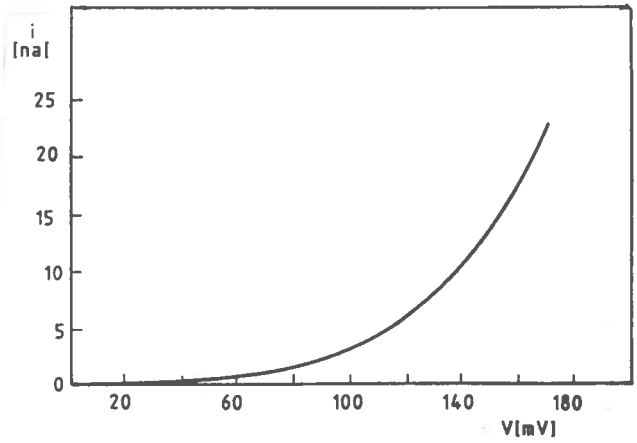
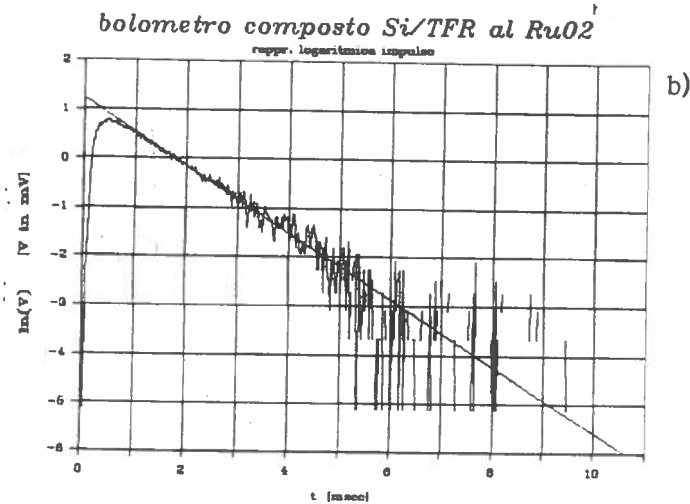


FIG. 4 - Load curve of a 100 Kohm RC-01 Tfr. Heat sink temperature $T_0 = 120$ mK.

FIG. 3 - Log(R) vs log(T) dependence of a 100 Kohm RC-01 Tfr.



a)



b)

FIG. 5 - a) Averaged pulse shape due to α particles. Linear plot. b) Averaged pulse shape due to α particles. Semilog plot.

Digital averaging was applied to reduce the effects of electronic noise, that is mostly due to the feedback resistor R_f and to environmental conditions.

The current pulse shape is well reproduced by a step with a single exponential decay.

After shaping the signals through a simple RC integrator-RC differentiator with equal time constants, the pulse height distribution, shown in Fig. 6, was obtained. In Figs. 7 and 8, for comparison, the distributions due to alpha particles hitting the resistive top layer of a simple Tfr resistor with and without the protective layer removed are reported.

Conclusions

In Table I the relevant parameters detected during the recording of the spectra are reported.

TABLE I

		I (Fig. 7)	II (Fig. 8)	III (Fig. 6)
T^a	mK	300	210	120
T^{aa}	mK	410	410	230
R	Mohm	2.9	4.46	15
Vb	mV	200	125	130
w	nW	14	3.75	1.0
G	nW / K	164	43	23.6
τ	msec	.48	.50	1.5
Geq	nW / K	96	24	11
S	MV / W	35	64	100
$Geq \cdot \sqrt{\tau}$	pJ / K	46	14	16.4

^{a)} Heat sink temperature.

^{aa)} Resistor temperature.

A comparison of the three spectra shown in Figs. 6, 7, 8 indicates that the silicon crystal glued to the resistive film of the Tfr gives a rather uniform detector with respect to the other two cases. It should be noted that data in Fig 6 are taken with an uncollimated source.

It is clear from table I data that differences in gain are essentially due to the different values of R for the three spectra.

The energy resolution of 4% is actually limited by electronic noise, mostly due to the environment and to the feedback resistor R_f .

The analysis in terms of the simple "concentrated constants model" ^{7,8,9)}, is expected to be quite inadequate in the present case.

Anyway, the decaying exponential voltage pulse

$$D \quad V(t) = \frac{E}{C} V_B \frac{R_f}{R_B} \frac{A}{T} e^{-\frac{t}{\tau}} \quad (3)$$

is much smaller than expected from an energy release E at time $t = 0$, but reproduces the observed pulse shape and satisfactory accounts for the pulse height ratios observed in the three cases.

FIG. 6 - Silicon-Tfr bolometer: spectrum of an uncollimated mixed nuclides α source.

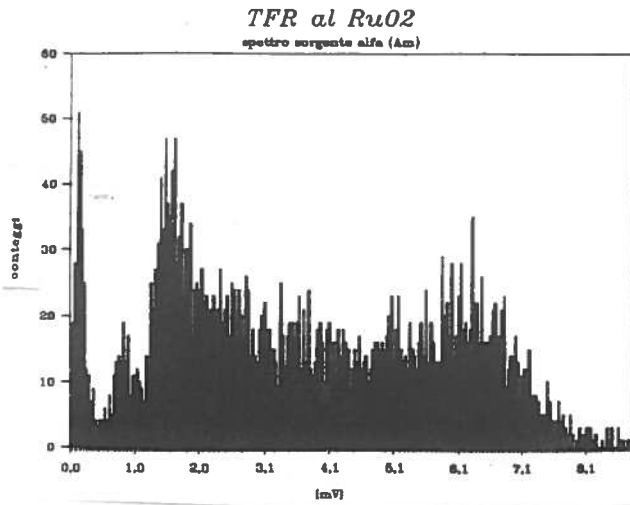
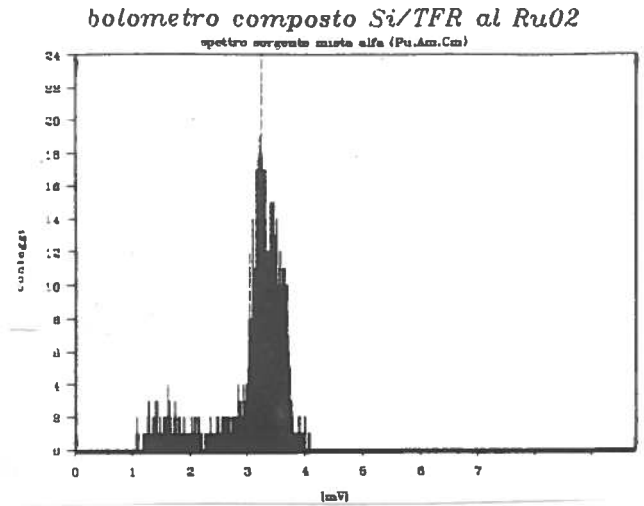


FIG. 7 - Normal Tfr: uncollimated ^{241}Am α source.

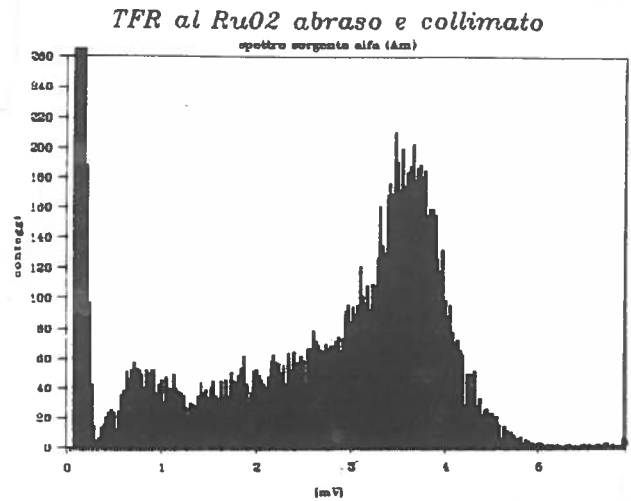


FIG. 8 - Tfr with protective top layer removed: collimated ^{241}Am α source.

Evaluations of the thermal capacity C of the absorber + thermometer system at temperatures ranging from .7 to .1 K have the expected order of magnitude and do not show a rise with decreasing temperature.

These values are computed as $C = G_{eq} \cdot \tau$, where τ is the thermal time constant and the equivalent thermal conductivity, G_{eq} is determined from the static load curves.

In our constant voltage configuration, we have:

$$(G_{eq})_v = G + \alpha P = 2I^2 \frac{Z}{Z-R} \frac{dR}{dT} \quad (4)$$

where $Z=dV/dI$ is the slope of the load curve.

The pulse height is less than 10% of what expected for complete thermalization of alpha energy from the zero frequency responsivity S_v that in our case, at the output of the I/V converter is:

$$(S)v = I_\alpha \frac{R_f}{G_{eq}} = \frac{1}{2I} \frac{R_f}{R} \left(1 - \frac{R}{Z}\right) \quad (5)$$

The size of the pulse height reduction can hardly be completely attributed to microscopic energy trapping in the thermalization process.

Different hypothesis, as the possible existence of some kind of parasitic thermal capacity, a thermal short circuit, or the not uniform heating of the resistive film could contribute to signal reduction, but the point requires a deeper investigation with a more appropriate device.

We conclude that it is worthwhile to test ruthenium oxide resistors deposited on a substrate with much better thermal properties than alumina and to study carefully their effective thermal capacity below .1 K.

At the moment we have produced resistors with silver palladium terminals on sapphire that will be tested at low temperatures soon.

In the Table II are reported the expected performances at .1 K and .3 K of RuO_2 -Sapphire composite bolometers of 1 mm^3 and 1 cm^3 , whose sensitive element is assumed to be 1/10 in volume of that of commercial Tfrs.

TABLE II

		.1 K		.3 K	
Thermal capacitance pJ/K					
Resistor		26	2.5*	10	7.5*
Sapphire					
a	1 mm^3	.35		10	
b	1 cc	350		10000	
Total	a	26	3*	20	17*
	b	376	353*	10000	
Thermal noise	a	76	25*	67	62*
(ev)	b	290	281*	4500	

(*) nuclear contribution not included.

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