Measurement of thermal properties for modeling and optimization of large mass bolometers

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Abstract

We present measurements about the thermal parameters of our TeO_2 bolometric detectors, operated in the Gran Sasso Laboratory to search for rare events. These measurements allow us to model the detectors. We have introduced a parameter (Detector Figure of Merit) that allows to compare the device performance.

Key words: thermal conductance; specific heat; bolometers

CUORE (Cryogenics Underground Observatory for Rare Events) is a new generation experiment for rare events search consisting of an array of 1000 bolometric particle detectors to be operated in the underground Gran Sasso laboratories. [1].

Bolometric technique is based on the record of the temperature increase due to the conversion of the energy released by the particles in phonons. This energy release occurs in a component of the detector called absorber that in our case is also the active part of the device, i.e. it is also the source of the rare decay we are searching for (Double Beta Decay of ^{130}Te).

The two main components of each array element are the absorber ($\sim$ 790 g TeO_2 crystal) and the thermometer (Neutron Transmutation Doped Ge thermistor) that measures the temperature increase as a variation of the resistance. The thermometer is glued on the absorber using some spots of epoxy (Araldit) while the thermal and electric contacts are made using gold wires of 50 μm diameter. The thermal and mechanical contacts with the heat sink (copper frame supports) are made using PTFE elements.

In order to explain the detector response, we can see the bolometer as the combination of three different decoupled systems. The thermistor consists of two separate systems (phonons and conduction electrons) characterized by their own heat capacities (C_{ph} and C_{el}), and by the thermal conductance, G_{ph-el}, between them (Hot Electron Model). The thermal conductance of the phonon system to the heat sink (G_{ph-hs}) is provided by the read-out gold wires (or more likely by the contact pad area). The third system composing the detector is the absorber, characterized by its heat capacity C_{abs} and decoupled from the lattice thermistor by a thermal conductance G_{abs-ph} (provided by a set of epoxy spots) and from the heat sink by a thermal conductance G_{abs-hs} (provided by PTFE elements).

To explain the signal shape we have before to understand the static behavior of the detectors. So we have to know the heat sink temperature, the four thermal conductances and the parameters of the thermistor R(T) curve, which is described by the following law

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(Variable Range Hopping theory):

$$R = R_0 \cdot exp(T_0/T)^{\frac{1}{2}} \quad (1)$$

where we have measured $R_0 = 1.76\Omega$ and $T_0 = 3.04K$ for our thermistor.

The thermal conductances have been measured independently down to 20 mK [2] and the results are summarized as follows:

$$G_{glue\ spot}[W/(K \cdot spot)] = 0.26 \cdot 10^{-3} \cdot T[K]^3 \quad (2)$$

$$G_{el-ph}[W/(K \cdot mm^3)] = 0.67 \cdot 10^{-1} \cdot T[K]^{4.37} \quad (3)$$

$$G_{gold\ wires}[W/(K \cdot mm^2)] = 7.91 \cdot 10^{-6} \cdot T[K]^{2.4} \quad (4)$$

$$G_{PTFE}[W/K] = 8 \cdot 10^{-5} \cdot T[K]^2 \quad (5)$$

For the dynamical behavior, we need to know the heat capacities, whose independent measurements have provided the following results:

$$C_{electron}[J/(K \cdot g)] = 0.22 \cdot 10^{-6} \cdot T[K] \quad (6)$$

$$C_{TeO_2}[J/K] = 2.2 \cdot 10^{-3} \cdot T[K]^3 \quad (7)$$

corresponding to $\Theta_{D_{TeO_2}}[K] = 232 \pm 7$ [3].

At every heat-sink temperature we can determine the temperatures of the three systems, and the resistance of the thermistor, at different conditions of power supplied on the electron system. In this way we are able to build the Resistance-Power curves (load curves) and to compare them with experimental data.

For every load curve we define "optimum operation point" the point for which the highest pulse is obtained. For every detector we can collect the optimum points at different temperatures of the heat sink and build a new curve characterized by the optimum amplitudes of the signals, in μV/MeV, versus the resistance of the thermistor at these points (A-R curves).

This curve is very important for the comparison of different detectors. Since both the intrinsic and spurious noise increases as the resistance increases, pulse amplitudes for different detectors must be compared at the *same* resistance value. Detector performance can be classified by means of their A-R curve. Unfortunately we don't have the complete A-R curve for all the 790 g detectors we have developed. Anyway we observed that the slopes of the A-R curves are approximately the same in a log-log scale. So, with the complete A-R curves, we have first determined the best-fitting common slope, which results to be 0.624. We have introduced then a new parameter, the Detector Figure of Merit (DFM), defined as the signal amplitude (in μV/MeV) at a fixed resistance (100 $M\Omega$). For the detectors that do not have a complete A-R curve but only one point, we can determine the DFM by extrapolation using the common slope introduced above. The results show that we have a not negligible spread in the DFM. (Fig. 1).

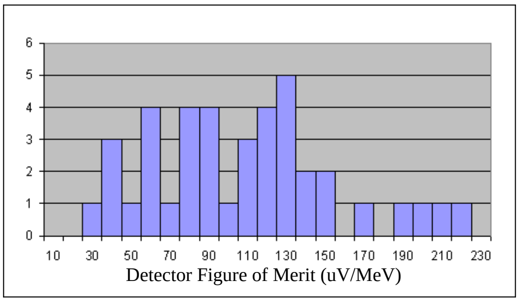

Fig. 1. Distribution of the DFM

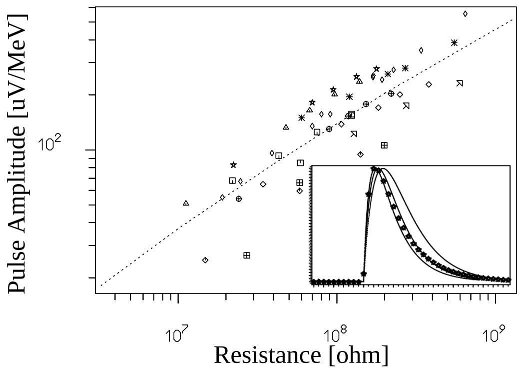

Fig. 2. Comparison between a simulated A-R curve (line) and the experimental A-R curves (symbols). In the inset, normalized simulated pulses at different operation points (lines) are compared with an experimental pulse (symbols). The full time scale is 2 s.

In order to see if we are understanding our detectors and to optimize them, we have tried to simulate their dynamical behavior using the thermal model and the measured thermal parameters presented before. In particular, we have simulated the A-R curves and the pulse shapes in order to compare with experimental data not only the signal amplitude but also other pulse parameters (rise-time, decay-time). The simulation results (Fig. 2) prove that our simulated detector is a good sample of our various real devices. Furthermore, the simulations show that the large spread is probably due to the irreproducibility of the thermal coupling between thermistor and absorber.

References

[1] Letter of intent of Cuore experiment. See web site http://crio.mib.infn.it/wig/

[2] A. Alessandrello et al., Czechoslovak J. Phys. **46-S5** (1996) 2893.

[3] M.Barucci et al., J. Low Temp. Phys. **123** (2001) 303.