

# LOW-TEMPERATURE THERMAL CHARACTERIZATION OF SUPPORT MATERIAL FOR MASSIVE CRYOGENIC DETECTORS

M. BARUCCI, G. VENTURA  
*INFN-Florence, Italy*

T. DEL ROSSO, E. GOTTARDI, E. PASCA  
*Department of Physics, University of Florence, Italy*

G. BIANCHINI  
*CNR Iroec, Florence, Italy*

Materials used in the realization of supports for massive cryogenic detectors must have several properties which should be known down to the detector working temperature. This does not always happens, because of the difficulties in the measurement of material characteristics at very low temperatures. We studied the thermal properties of a Polypropylene copolymer (PP) at temperatures as close as possible to the working temperature (10 mK) of CUORE (Cryogenic Underground Observatory for Rare Events), in view of the possible use of PP in the realization of the supports for the TeO<sub>2</sub> crystal absorbers (750g). From the data obtained we conclude that, from a thermal point of view, PP is adequate for use as support material in cryogenic massive detectors.

## 1 Introduction

The choice of the materials to be employed as supports in cryogenic detectors is often crucial for the correct working of such devices. In the case of massive detectors, whether the thermal or the mechanical properties of all components should be known at temperatures as close as possible to the working temperature of the detector.

With regard to the thermal properties:

1. The thermal conductivity is usually known down to about 0.1 K. An extrapolation to lower temperatures often leads to values of conductivity higher than the real ones. Moreover, it must be recalled that, at very low temperatures, the thermal conductance toward the bath depends on the Kapitza resistance too.
2. The specific heat is also usually known down to about 0.1 K. In this case, the extrapolation of data of heat capacity to lower temperatures leads to underestimated values. In principle, the supports contribute with about

1/3 of their heat capacity to the total heat capacity of the detector<sup>1</sup>.

3. The data of thermal contraction usually extend down to 4 K, since below this temperature the contraction is negligible. The knowledge of the thermal contraction is of great importance because it warrants the mechanical stability of the detector at the working temperature and during the cooling down.

Data about the elastic moduli of the support material at the working temperature would also be precious; unfortunately very few measurements of mechanical properties at very low temperatures have been carried out up to now.

Among the large calorimeters with massive detectors, Edelweiss<sup>2</sup>, Mibeta<sup>3</sup> and CUORICINO<sup>4</sup> use Teflon supports. In CRESST<sup>5</sup> a type of insulation based on the Kapitza resistance of sapphire balls was at first used, but this method turned out to be very critical and Teflon was finally used<sup>6</sup>. Owing to the lower mass of the detectors, ROSEBUD<sup>7</sup> used stretched Kevlar fibres in the final configuration. Vespel<sup>8</sup> and Nylon<sup>9</sup> have also been employed.

In this work we present the thermal characteristics (thermal contraction, thermal conductivity and specific heat) of a Polypropylene copolymer (PP)<sup>a</sup> at temperatures close to the working temperature of the proposed experiment CUORE (Cryogenic Underground Observatory for Rare Events)<sup>11</sup>, in view of a possible use of PP in the realization of the supports for the TeO<sub>2</sub> crystal absorbers (750g).

## 2 Thermal expansion

Thermal expansion was measured by means of a laser interference-dilatometer<sup>10</sup>. Measurements were made by cooling a cylindrical sample (0.83 cm in diameter and 0.52 cm long), down to 4.2 K in a <sup>4</sup>He dewar, and recording the interference signal as a function of T during the heating up.

The relative thermal expansion between 4.2K and 300K is  $(1.2 \pm 0.06)\%$ . In the same range, the relative thermal expansion of Teflon is 2.1%<sup>12</sup>.

## 3 Thermal conductivity

The thermal conductivity was measured between 0.07 K and 0.3 K, using a longitudinal steady heat flow method. The sample was a cylinder with an

---

<sup>a</sup>supplied by Goodfellow Cambridge Limited - Cambridge Science Park-Cambridge England CB4 4DJ

area-to-length ratio  $g = \frac{A}{L} = 0.137 \text{ cm}$ .

The experimental set-up is shown in fig. 1: one end of the sample was in thermal contact with the mixing chamber of a dilution refrigerator. A copper block with a Ni-Cr resistance heater and a RuO<sub>2</sub> calibrated thermometer, was screwed onto the other end of the sample. The electrical connections were made of 25 $\mu\text{m}$  in diameter Nb-Ti wires. The power flowing through the Nb-Ti wires was thus negligible in comparison with the power flowing through the sample. Power was supplied to the heater (raising the temperature  $T_1$  of

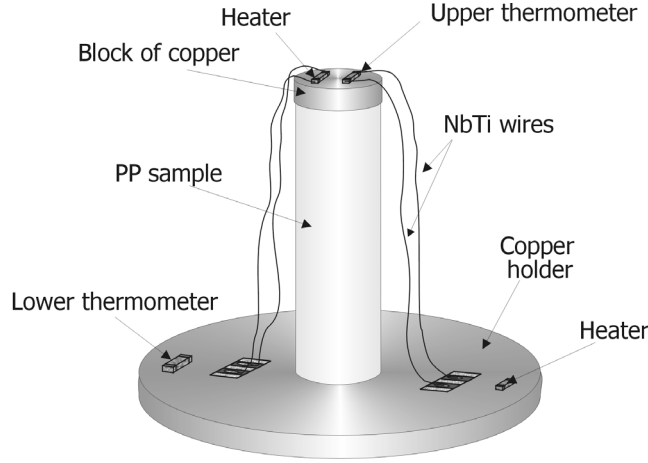


Figure 1. Experimental set-up for the measurement of the thermal conductivity.

the upper end of the sample) in order to determine the integrated thermal conductance:

$$P = \int_{T_0}^{T_1} G(T) dT = \int_{T_0}^{T_1} g \cdot k(T) dT$$

During our measurements, the mixing chamber was kept at a constant temperature  $T_0$ . The values of  $k$  were calculated as the derivative of  $\frac{P}{g}(T)$  and then fitted with the law  $k = \alpha \cdot T^n$ . We obtained:

$$\alpha = (2.74 \pm 0.13) \cdot 10^{-5} \text{ W/cmK}^{n+1}$$

$$n = 1.28 \pm 0.03$$

Measurements were carried out on samples with different geometrical factors  $g$ , to verify that our results did not depend, within the experimental error, on the thermal contact resistances.

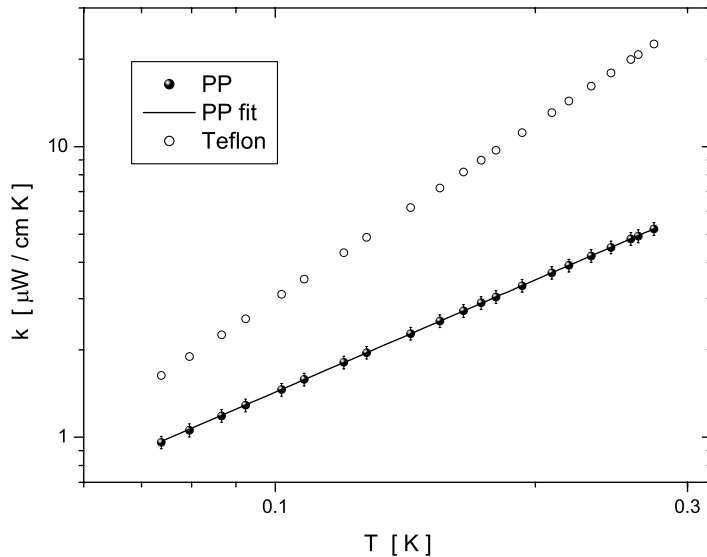


Figure 2. Thermal conductivity of PP and Teflon. The solid line represents the fitting curve for PP.

For sake of comparison, in fig. 2 we report the thermal conductivity data of PP together with those of Teflon<sup>12</sup>.

It should be noted that the fit curve appreciably disagrees from the  $T^2$  behavior, typical of all amorphous solids below 1 K as explained by the tunneling state theory<sup>13,14</sup>.

A nearly linear temperature dependence of thermal conductivity has been found also for semicrystalline polymers such as polyethyleneterephthalate PET<sup>15,16</sup> and polyimides<sup>17</sup>.

This “anomalous” behavior is to be ascribed to a mechanism of scattering by tunneling states together with a structure scattering process<sup>19</sup>, which is associated with a correlation length  $a_c$  that causes fluctuations in the elastic properties of the material<sup>20</sup>.

Hence, the temperature dependence that we found for our samples may be explained by the presence of crystalline regions inside the polymer.

## 4 Specific heat

The specific heat was measured on a 0.05 cm-thick Polypropylene sheet, using the thermal relaxation technique. The temperature range investigated was  $0.06 < T < 0.3$  K.

In order to take into account the heat capacity of the *addendum*, we carried out measurements in two experimental set-ups, with a different mass of the sample.

We first used a 59.7 cm-long, 3.6 cm-high PP sample with a mass of 9.365 gr. A  $7\mu\text{m}$ -thick copper foil, with a mass of 1.360 gr, was used to thermalize the sample. The Cu and PP sheets were superposed one upon the other, obtaining a double layer that was rolled up to form a hollow cylinder, as shown in fig. 3(a). This peculiar set-up allowed to reduce the thermalization time of the sample<sup>21</sup>. The sample was blocked between two tin-coated copper

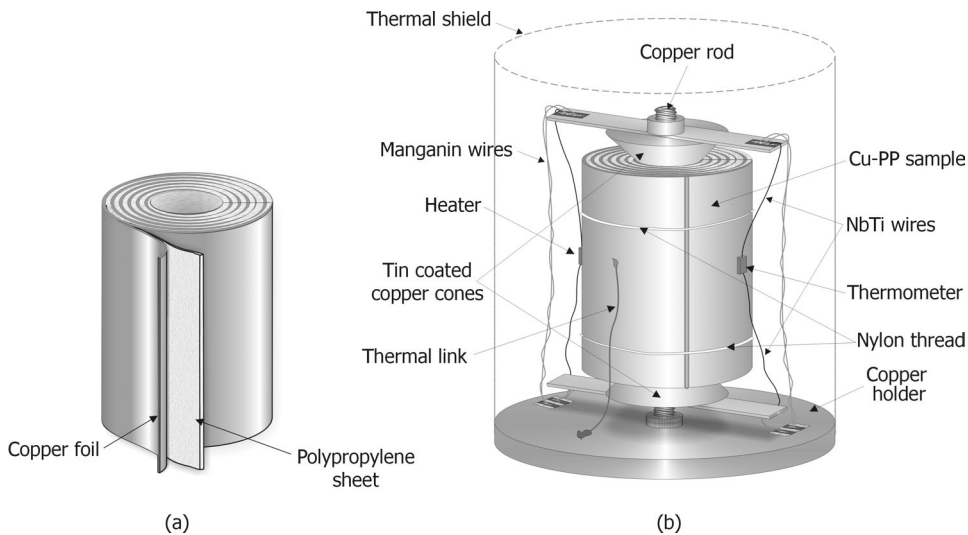


Figure 3. Experimental set-up for the measurement of the specific heat.

cones, screwed to a Cu rod that was fixed to a sample holder in thermal contact with the mixing chamber of a dilution refrigerator.

A Ni-Cr heater and a  $\text{RuO}_2$  calibrated thermometer were glued onto the copper foil in contact with the sample. The electrical connections for these resistances were made by  $25\mu\text{m}$  in diameter Nb-Ti wires. In order to control the temperature of the thermal bath, another Ni-Cr heater and a  $\text{RuO}_2$  sensor

were glued on the mixing chamber. The experimental set-up is shown in fig. 3(b).

In order to obtain the heat capacity of the sample, we measured its temperature relaxation toward the thermal bath: a small power supplied to the heater rose the temperature  $T$  of the sample above  $T_0$  ( $T - T_0$  typically between 7 and 15 mK); when the thermal equilibrium was reached, the heating power was switched off and the exponential decay of the sample temperature was recorded by means of a resistance bridge<sup>b</sup>, with a sampling rate of 5 samples/s. We repeated the same procedure at different values of  $T_0$  between 60 mK and 300 mK.

The values of the heat capacity were obtained as  $\tau \cdot G$ , where  $\tau$  is the relaxation time constant and  $G$  is the thermal conductance of the sample toward the thermal bath. The thermal conductance,  $G$ , was measured with the same technique described in section 3.

In order to obtain a  $\tau \sim 10^2$  sec, a thermal link between the sample and the holder was made by gluing the ends of a copper wire (3 cm in length and 20  $\mu m$  in diameter) to the copper sheet and to the sample holder. A single relaxation time constant was always observed. An example of  $T(t)$  is reported in fig. 4. We repeated all the measurements on a second sample, made of a 7.9 cm-long, 3.6 cm-high PP sheet (1.240 gr in mass) and the same copper foil used in the first sample.

The specific heat of polypropilene, obtained by comparing the measurements made on the two samples, is reported in figure 5. Data of the specific heat of Teflon<sup>18</sup> are also shown. Our results have been interpreted on the basis of the tunneling model<sup>13,14</sup>. In this model a wide distribution of thermal relaxation times for the energy transfer between Debye phonons and two level systems is assumed; hence a quasi-linear temperature dependence of the specific heat is expected:  $c(T) \propto T^{1+\delta}$ , where  $0.2 < \delta < 0.5$ <sup>22</sup>. For vitreous silica, for instance, the experiments show, below 0.3 K, a  $T^{1.3}$  dependence<sup>23</sup>.

Our data were fitted using the law:

$$c(T) = P_1 T^{1+\delta} + P_2 T^3$$

where the  $T^3$  term is the Debye contribution to the specific heat. We obtained the following results:

$$\delta = 0.33 \pm 0.04$$

$$P_1 = (6.15 \pm 0.7) \times 10^{-6} [J/gK^{2+\delta}]$$

$$P_2 = (2 \pm 0.3) \times 10^{-5} [J/gK^4]$$

---

<sup>b</sup>Linear Research, model LR700

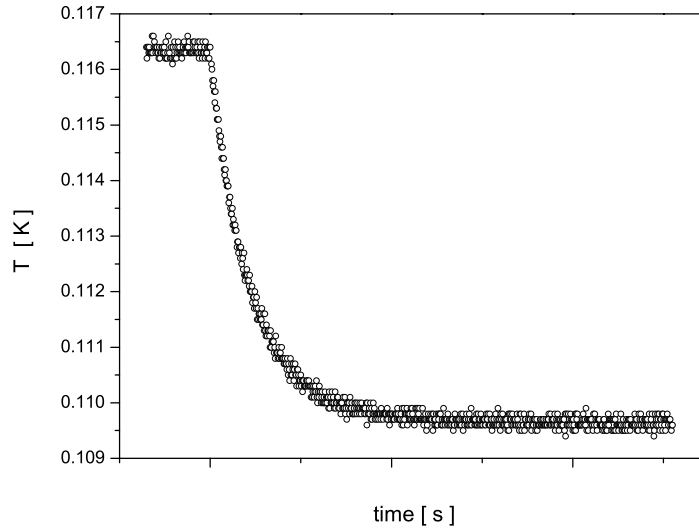


Figure 4. Example of discharge of the sample temperature vs time.

## 5 Conclusions

We studied the characteristics of a Polypropylene copolymer (PP) at temperature as close as possible to the working temperature (10 mK) of CUORE, in view of the possible use of PP, instead of Teflon, in the realization of the supports for the  $\text{TeO}_2$  crystal absorbers (750g).

Below 0.3 K, our thermal conductivity data can be represented as  $k = (2.7 \pm 0.13) \times 10^{-5} T^{1.28 \pm 0.03} \text{ W/cm K}$ , giving a thermal conductivity  $< 7 \cdot 10^{-8} \text{ W/cmK}$  at 10 mK, to be compared with  $3 \cdot 10^{-9} \text{ W/cmK}$  of Teflon. In most cases the thermal conductance to the bath is not realized through the support; hence a very low thermal conductivity means that the contribution of the PP to the overall conductance is negligible.

The specific heat below 0.3 K can be represented as  $c = (6.15 \pm 0.7) \times 10^{-6} T^{1.33 \pm 0.04} + (2 \pm 0.3) \times 10^{-5} T^3 \text{ J/gK}$ , which means a specific heat of  $1.5 \cdot 10^{-8} \text{ J/g K}$  at 10 mK, to be compared with Teflon specific heat of about  $2 \cdot 10^{-8} \text{ J/g K}$ , at the same temperature.

We found a total contraction  $\Delta l/l = (1.2 \pm 0.06)\%$  between 300 and 4 K.

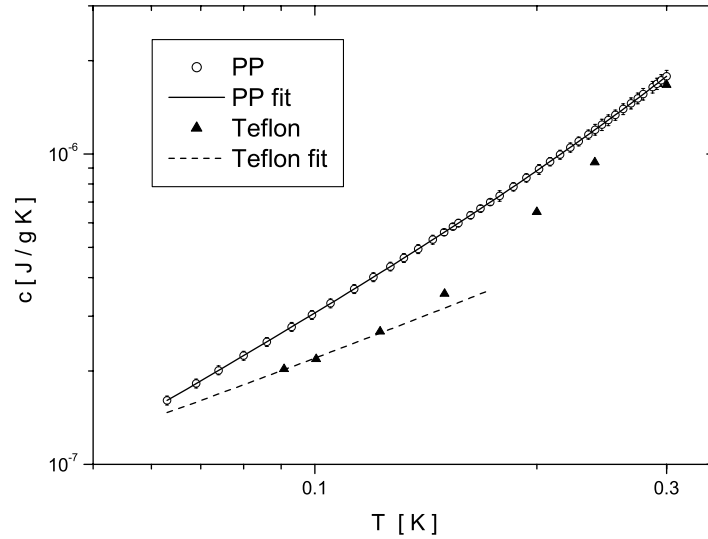


Figure 5. Specific heat of PP and Teflon. The solid line is the fit curve for PP data. The dashed line instead, represents the fitting curve for Teflon data below 130 mK ( $\propto T$ ). It should be noted that the specific heat of Teflon tends to be higher than that of PP at very low temperatures.

In the same range, the overall thermal contraction of Teflon is 2.1 %.

From the data obtained for the three thermal parameters, we conclude that, from a thermal point of view, PP is adequate for use as support material in cryogenic massive detectors.

## References

1. P.F.Sullivan, G.Seidel Phys Rev. 173 (1968) p. 679,
2. X.Navick, M.Chapellier, F.Deliot, S.Herv, L.Miramonti: Nucl. Instrum. and Methods in Phys. Res. A 444 (2000) p.361
3. S.Pirro et al: Nucl. Instrum. and Methods in Phys. Res. A 444 (2000) p.71
4. E.Fiorini: Nucl. Instrum. and Methods in Phys. Res. A 444 (2000) p.65
5. M. Frank: Nucl. Instrum. and Methods in Phys. Res. A 345 (1994) p.

6. M.Sisti et al. Nucl. Instrum. and Methods in Phys. Res. A 444 (2000) pag 312
7. Cebrian et al. Astop. Phys. 10 (1998) 1-8
8. Spooner et al. Phys. Lett. 273B (1991) 333
9. C. Bobin et al. Nuclear Instrum. and Methods in Phys. Res. A 386 (1997) p. 453
10. G. Ventura, G. Bianchini, E. Gottardi, I. Peroni, A. Peruzzi: Cryogenics 39 (1999) p. 481
11. A. Alessandrello et al. Nucl. Phys. B (proc. Suppl. 87,(2000), p.78.
12. F. Pobell, *Matter and Methods at Low Temperatures*, Springer-Verlag (1992)
13. P.W. Anderson, B.I. Halperin, C.M. Varma: Phil. Mag. 25 (1972) p.1
14. W. A. Phillips: J. Low Temp. Phys. 7 (1972) p.351.
15. D. Greig, M.S. Sahota : J. Phys. C: Solid State Phys. 16 (1983) L1051.
16. D.M. Finlayson, P.J. Mason: J. Phys. C Solid State Phys. 18 (1985) p.1777.
17. M. Barucci, E. Gottardi, I. Peroni and G. Ventura: Cryogenics 40 (2000) p.145.
18. A. Nittke et al. Eur. Phys. J. B 8 (1999) p.19
19. G. J. Morgan, D. Smith: J. Phys. C Solid State Phys. 7 (1974) p. 649.
20. D. M. Finlayson, P. J. Mason: J. Phys. C: Solid State Phys 18 (1985) p. 1791.
21. R.C. Richardson, E.N. Smith, *Experimetnal Techniques in Condensed Matter Physics at Low Temperatures*, Addison-Wesley (1988)
22. J. Zimmermann, G. Weber: Phys. Lett. 86A (1981) p.32
23. J. Lasjaunias et al. Solid State Commun. 17 (1975) 1045