CB
FDHMT

Optimization of electrically cooled complex HPGe Detector

Contract No. 4500109716

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15. September 2012

CONTENTS

1. Heat losses due to the irradiative warming and temperature field analysis within the detector assembly: Ge-capsules and cryostat.

1.1 Material characteristics survey.

It is aimed in the proposed project a novel technique to be proven and optimized in order to assure the operational temperature range of the composite HPGe Detectors based on two or three EUROBALL Ge-capsules by means of electromechanical cooling engine.

For the detector cryostat manufacturing in order to reach the entire mechanical requirement Aluminium alloy AW-5083 has been foreseen. The data sheet of the material selected is given below.

Compounding	
Si	0.40
Fe	0.40
Cu	0.10
Mn	0.40-1.00
Mg	4.00-4.90
Cr	0.05-0.25
Zn	0.25
Other	0.15
Alu	Rest

Table 1. Aluminium alloy compounding.

Electrical Conductivity [m/Ω.mm²]	17
Thermal Conductivity [W/m.K]	110-120
Density [g/cm³]	2.66
E-Modul [kM/mm²]	71

Table 2. Physical properties.

The parts of the cryostat are to operate under a temperature interval range from cryogenic up to room temperature. That followed the temperature dependent behaviour of the thermal conductivity is to be taken into account. Reliable data are to be found in www.cryogenic.nist.org and here in Fig. 1. the thermal conductivity as a function of temperature is plotted. As it has been seen with temperatures increase from 70 up to 300 K the thermal conductivity rise more than twice.

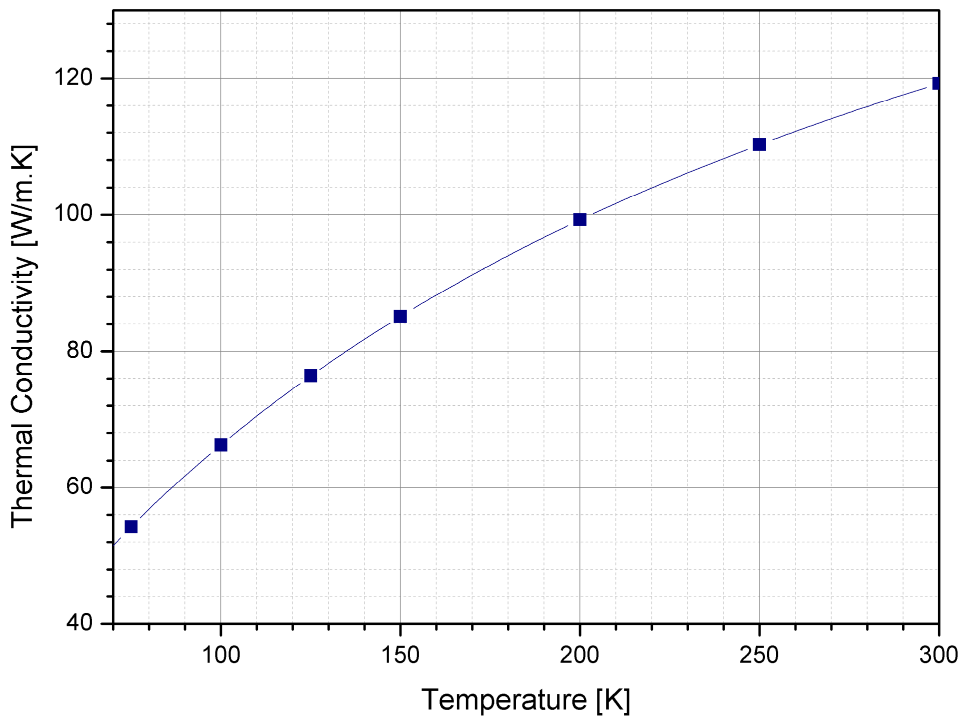


Fig. 1. Thermal conductivity of AW-5083 as a function of temperature.

Copper is known to be as one of the best thermoconductive materials and thus is supposed to be used for the cold finger manufacturing. It is to emphasize but that its thermal conductivity is a strong function of impurities and crystallographic defects. Since the residual-resistance ratio (RRR) can vary quite strongly for a single material depending on the amount of impurities and other crystallographic defects it serves as a rough index of the purity and overall quality of a sample. For instance RRR of copper wire is ~ 40-50 when used for telephone lines. Here the question to be answered is if the very high purity material is mandatory needed. Below the thermal conductivity as a function of temperature and residual resistivity ratio is exemplified in Fig. 2.

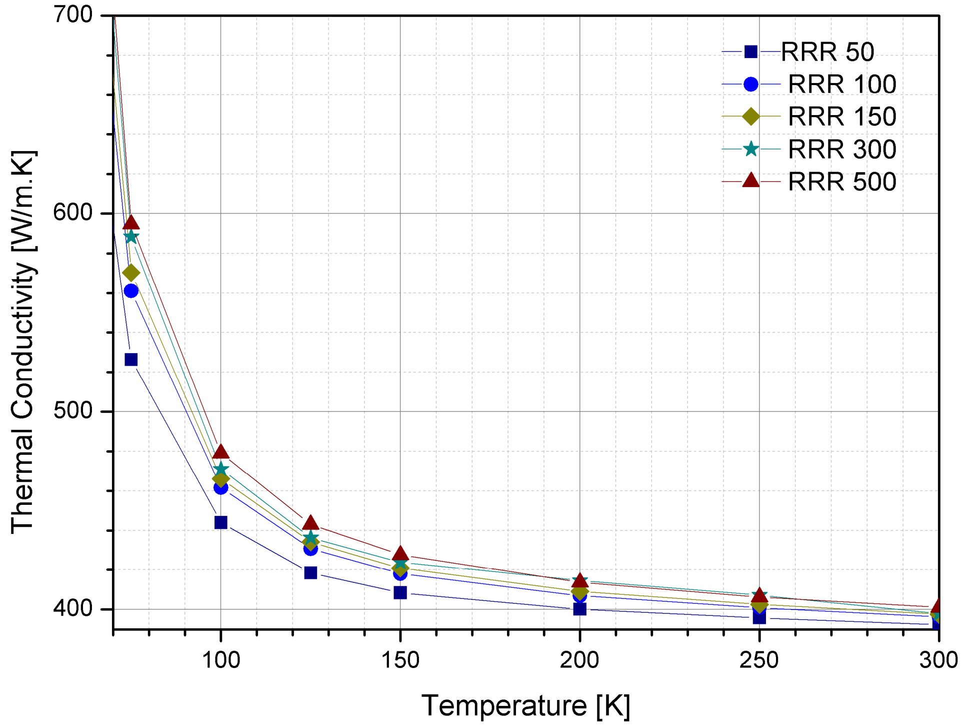


Fig. 2. Copper thermal conductivity as a function of temperature and residual-resistivity ratio (RRR).

In order to increase the hardness of the cold finger some copper alloys with better mechanical characteristics but still with good thermal conductivity have been also searched.

Today, most commonly used copper alloys display low thermal conductivity. The new family of copper-silver alloy displays thermal conductivity much higher than any of the commercially available alloys.

Copper Alloy Designation	Composition%	Softening Temperature	Hardness HV	Thermal Conductivity	USA UNS
Chromium Zirconium	Cu min 99+ Cr.65 Zr.08	500°C	170	335	CrZr
Phosphorous Deoxidized	Cu min 99.9 P 0.015-.040	300°C	115	335	DHP C12200
Silver Alloy	Cu 99 Ag 0.8-1.2	400°C	125	395	CuAg

Table 3. Comparative properties of available contact tip alloy (http://www.superiorconsumables.com/copper-alloy-tips.asp)

The Chromium Zirconium Alloy is characterized with a good hardness and is available for instance through the Fa. Walter Looser AG, Zürich, Switzerland, MKM Mansfelder Kupfer und Messing GmbH, Hettstedt, Germany, fib Sachs OHG, Radevormwald, Germany and etc. The data sheet of CuCrZr DIN 17666/17672 (Fa. Walter Looser) is given below

Compounding (DIN EN 12163)					
Element	Cu	Cr	Zr	Si*	Fe*
Min. [%]	-	0,5	0,03	-	-
Max. [%]	Rest	1,2	0,3	0,1	0,08

Table 4. CuCrZr Compounding.

Thermal expansion					
Wärmeausdehnungskoeffizient	[10^{-6}/K]	17	Electrical Conductivity	[m/Ωmm^2]	47
Thermalconductivity	[W/mK]	322	Density	[kg/dm^3]	8,9

Table 5. CuCrZr physical characteristics.

The temperature dependent thermal conductivity behaviour of Germanium is calculated after www.efunda.com and presented in Fig. 3.

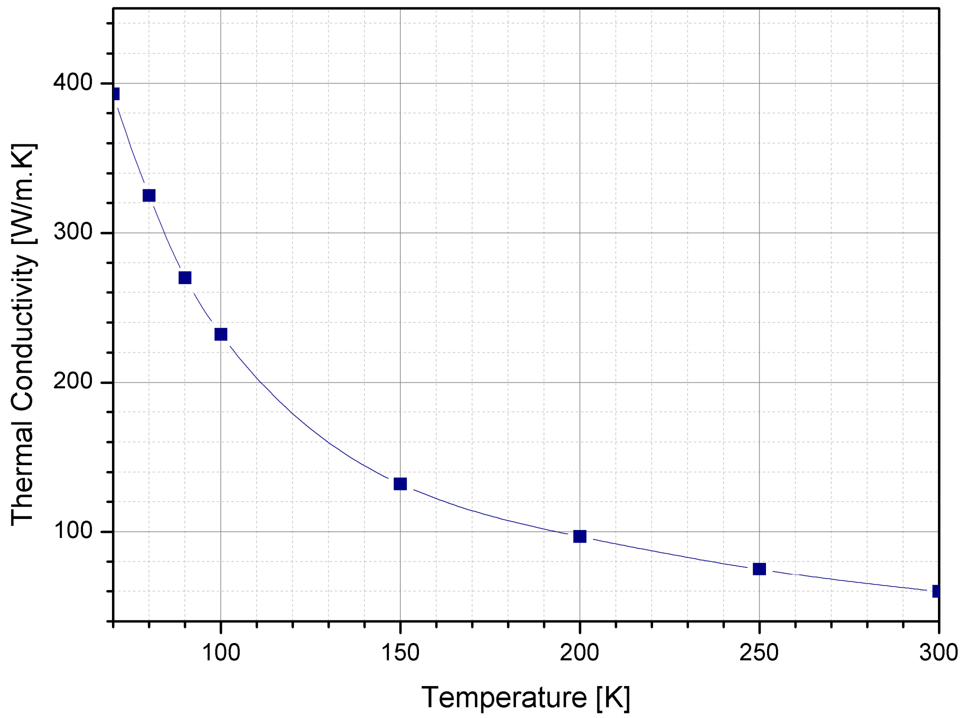


Fig.3. Germanium thermal conductivity as a function of temperature.

The data presented above are in agreement with one provided by P. D. Maycock [1] (s. Fig. 4).

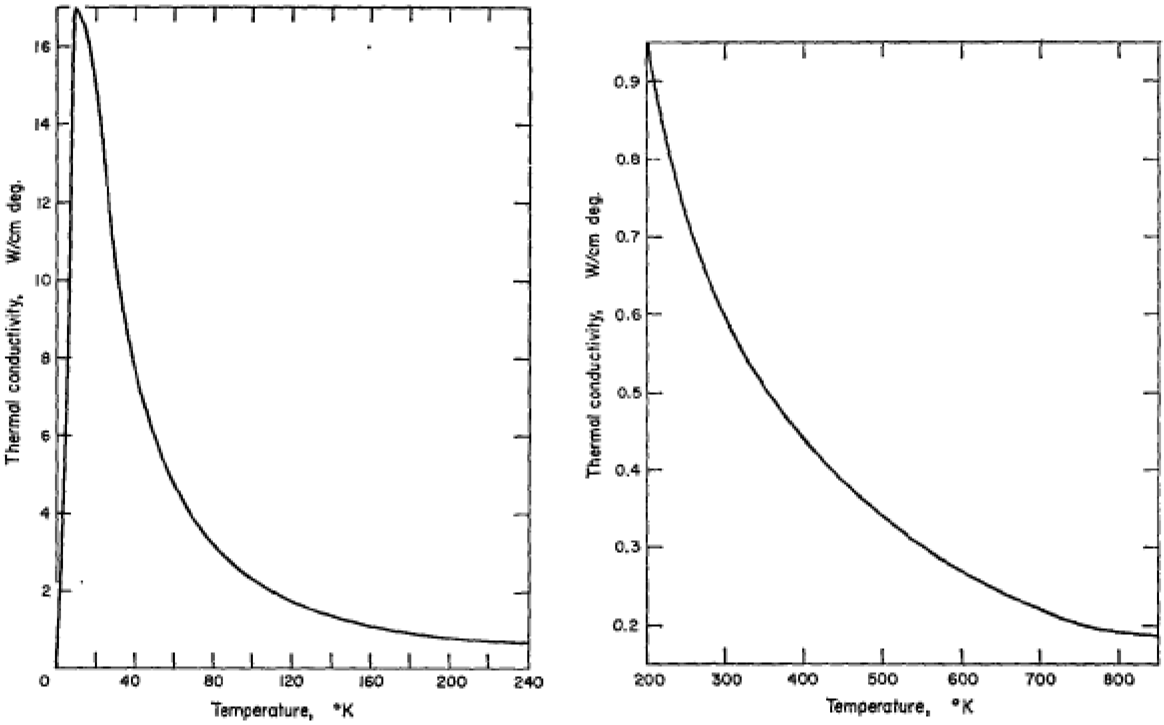


Fig. 4. Thermal conductivity of germanium: (a) low- and (b) high-temperature after Maycock.

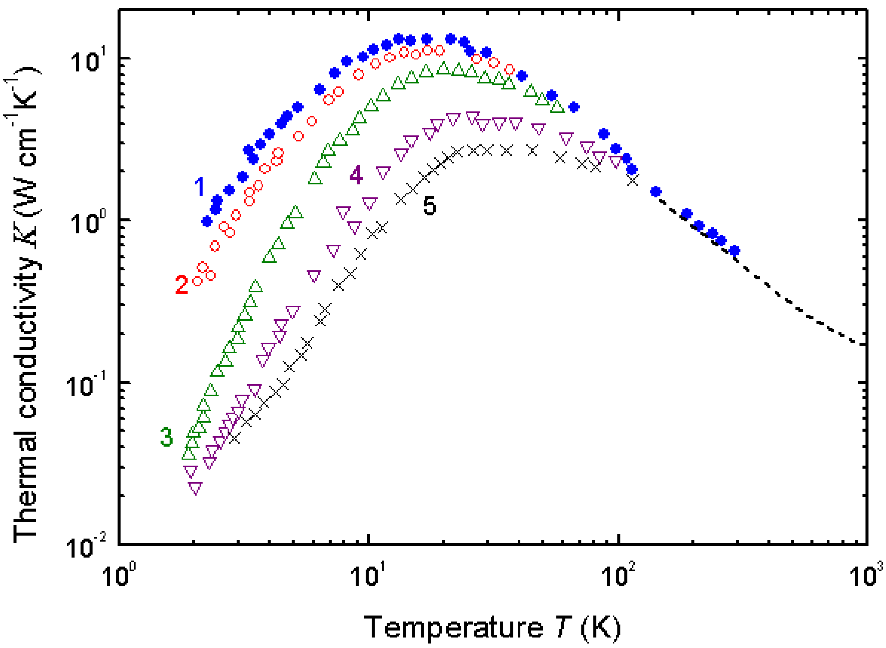


Fig. 5. Temperature dependence of thermal conductivity at different doping level. p-Ge. N_a (cm^{-3}): **1.** 10^3; **2.** 10^{15}; **3.** $2.3 \cdot 10^{16}$; 4. $2 \cdot 10^{18}$; **5.** 10^{19} (Carruthers et al. [1957]). Dashed line - (Glassbrenner and Slack [1964]).

The correlation between the doped level and the thermodynamical characteristics of the semiconducting material has been extensively studied in the second half of the last century [2, 3, and 4] and is shown in Fig. 5. for p-doped and in Fig. 6 for n-doped material. Within the temperature range above 100 K the effect is negligible and is not to be accounted in the present study.

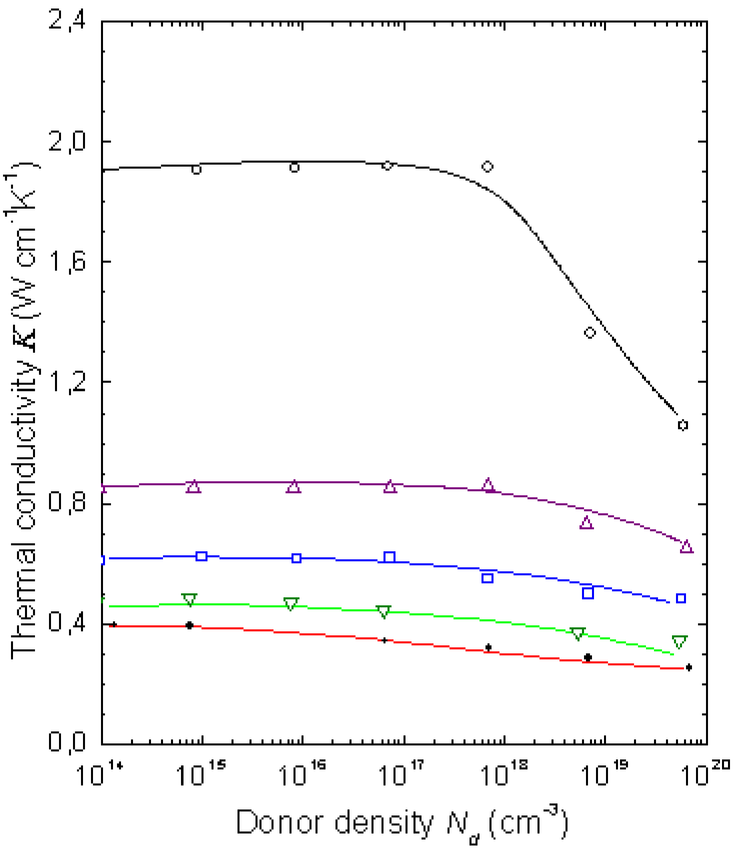


Fig. 6. The dependence of thermal conductivity versus doping level. n-Ge. T^o(K): **1.** 100; **2.** 200; **3.** 300; **4.** 400; **5.** 500. (Okhotin et al. [1972]).

1.2. Triplet detector: thermal field simulation

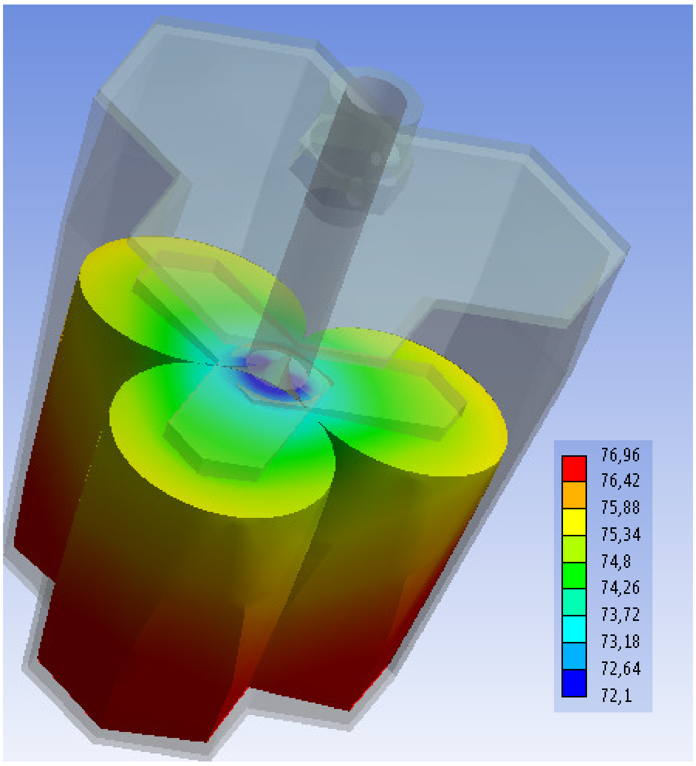
Thermal field simulations have been performed for 3-capsules (triplet) and 2-capsules (doublet) detector assembly respectively. First the results concerning the triple detector are to be discussed.

The calculations have been performed for two different temperature of the cooling part (70 K and 100 K) while the environment temperature varies from 295.15 K up to 303.15 K. The emissivity of the Ge-capsules is supposed to vary between 0.2 und 0.1 while the emissivity of the other parts of the assembly is taken to be 0.1.

Here the simulation under the following conditions has been exemplified: temperature of the cooling part is supposed to be 70 K and the ambient temperature is 295.15 K. The emissivity of the Ge-capsules is supposed to be 0.2, when the emissivity of the processed inner surface of the cryostat is 0.1. The temperature distribution is presented in Fig. 7. It is seen that the temperature variation along the Ge-capsules is within 5 grad, which may be attributed to the good germanium and aluminium thermal conductivity especially at cryogenic temperatures.

The data regarding to the total heat losses and only those accumulated by the Ge-capsules are summarized in Table 6.

Deviations of the temperature of the cooling parts within tens of degrees weakly influenced the total heat losses and the uniformity of the temperature distribution along the Ge-capsules (s. Fig. 7 and 8 as well as Table 6.).



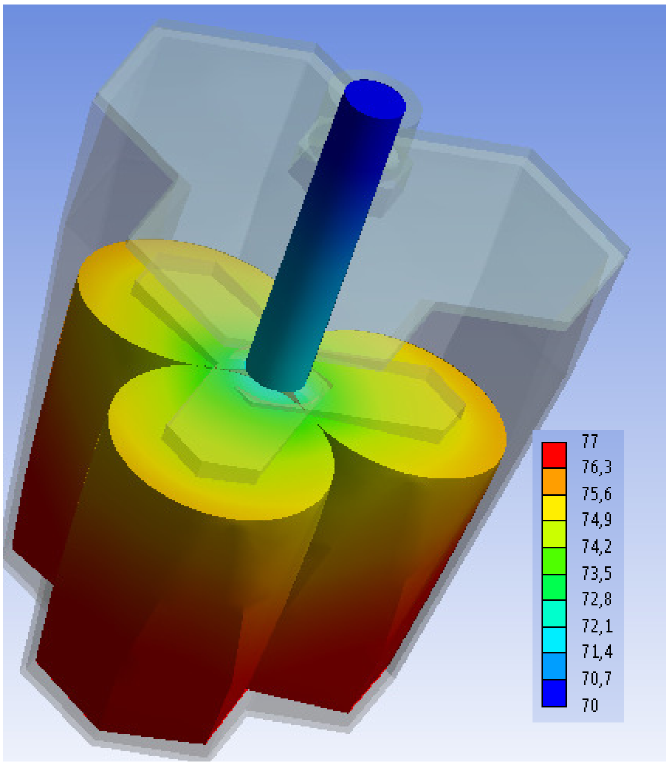
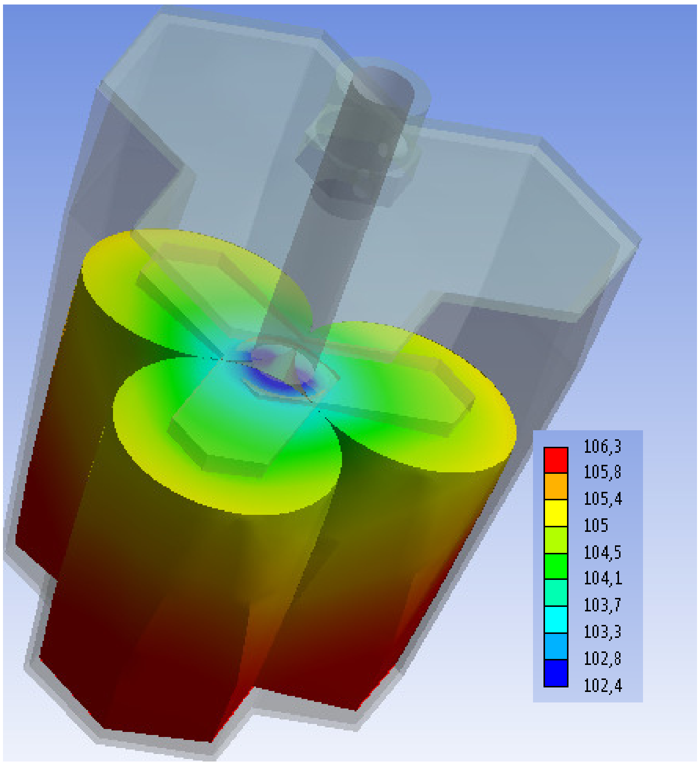


Fig. 7. Temperature distribution along the Ge-capsules and the cold finger when the temperature of the cooling part is 70 K and the ambient temperature is 295.15 K. The emissivity of the Ge-capsules is 0.2, when the emissivity of the processed inner surface of the cryostat is 0.1.



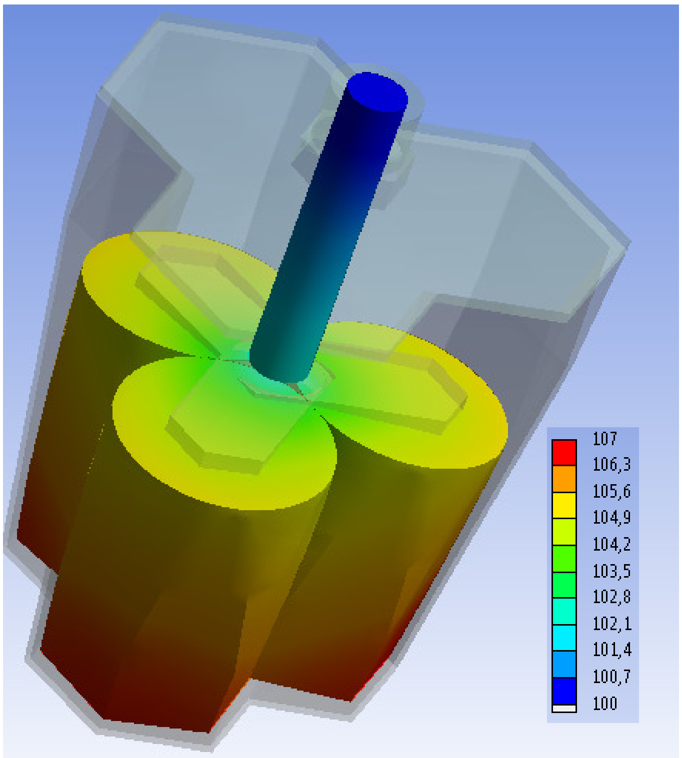


Fig. 8. Temperature distribution along the Ge-crystals and the cold finger when the temperature of the cooling part is 100 K and the ambient temperature is 295.15 K. The emissivity of the Ge-capsules is 0.2, when the emissivity of the processed inner surface of the cryostat is 0.1.

Temp. of the cooling part [T]	Amb. Temp. [T]	Ge capsules emissivity	Assembly emissivity	Crystal warming power [W]	Cold plate warming power [W]	Total Heat [W]	Temp. deviation [K]
70	295.15	0.2	0.1	2.83	0.23	3.06	5
100	295.15	0.2	0.1	2.80	0.23	3.05	4
70	295.15	0.1	0.1	1.91	0.26	2.17	3.5
100	295.15	0.1	0.1	1.89	0.26	2.15	3
70	293.15	0.2	0.1	2.77	0.22	3.00	4.5
100	293.15	0.2	0.1	2.73	0.22	2.95	4
70	298.15	0.2	0.1	2.95	0.24	3.19	5
100	298.15	0.2	0.1	2.91	0.24	3.15	4
70	303.15	0.2	0.1	3.11	0.25	3.36	4.3
100	303.15	0.2	0.1	3.11	0.25	3.36	4.3

Table 6. Crystals warming and total heat losses

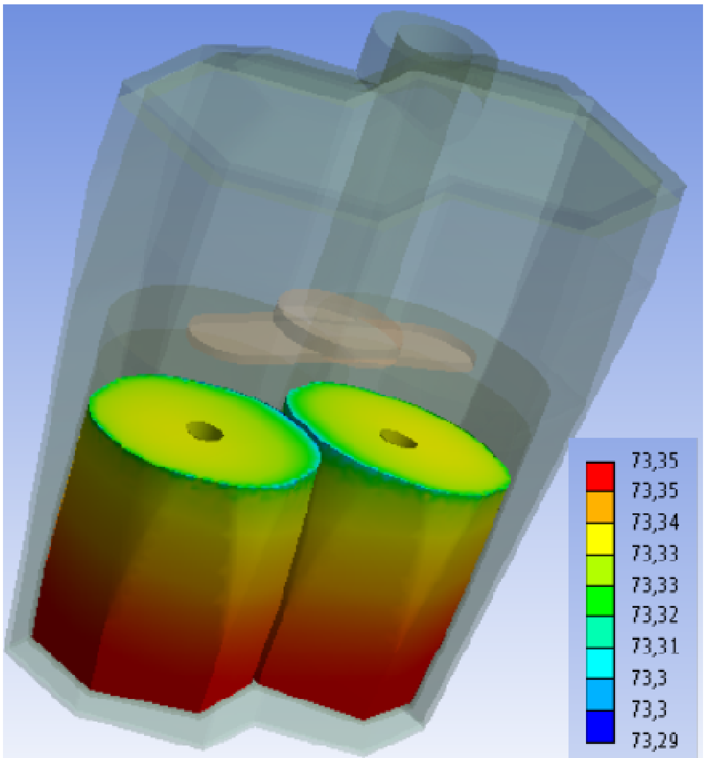
The influence of the ambient temperature on the total heat losses and on the temperature distribution along the Ge-capsules also has been investigated and the data are given in Table 6. Only increase of the temperature in three degree causes increase of the total heat losses with 3.3 %. If the ambient temperature increases once again with five degree more, the heat losses increase with 10.2 %.

1.3 Double detector: thermal field simulation

The temperature distribution along the Ge-capsules and crystals as well as the total heat losses have been investigated for the double detector configurations in dependence on the environment temperature and the temperature of the cooling parts. The emissivity variations along the Ge-capsules and the other parts of the assembly have been also taken into account.

The temperature field distribution is exemplified in Fig. 9 when the temperature of the cooling part is considered to be 70 K and the environment temperature is 295.15 K. Here the Ge-capsule emissivity is 0.2 while the emissivity of the other parts of the assembly is supposed to be 0.1.

All the date obtained are summarised in Table 9. As it is seen the temperature deviation along the Ge-capsules deviates within 4 K and is not critical for the detector performance.



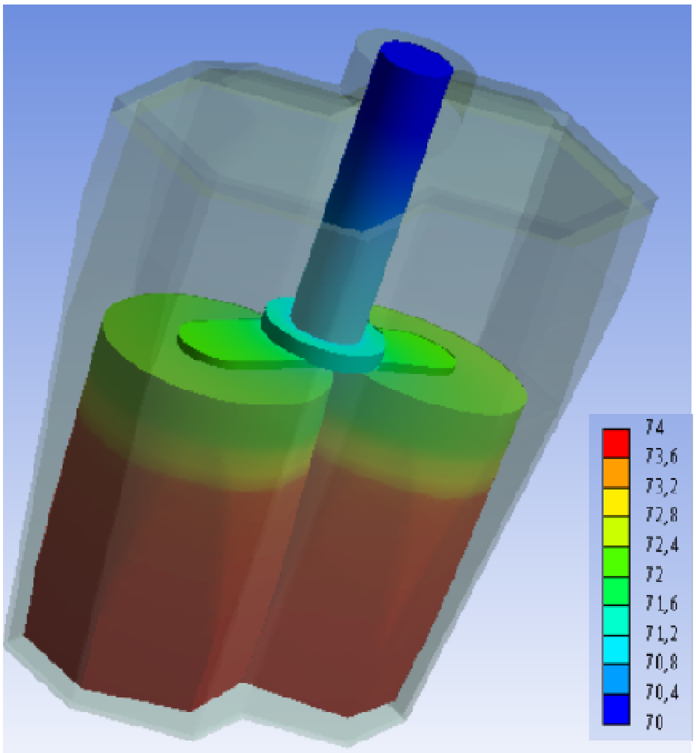


Fig. 9. Temperature distribution along the Ge-capsules and the cold finger when the temperature of the cooling part is 70 K and the ambient temperature is 295.15 K. The emissivity of the Ge-capsules is 0.2, when the emissivity of the processed inner surface of the cryostat is 0.1.

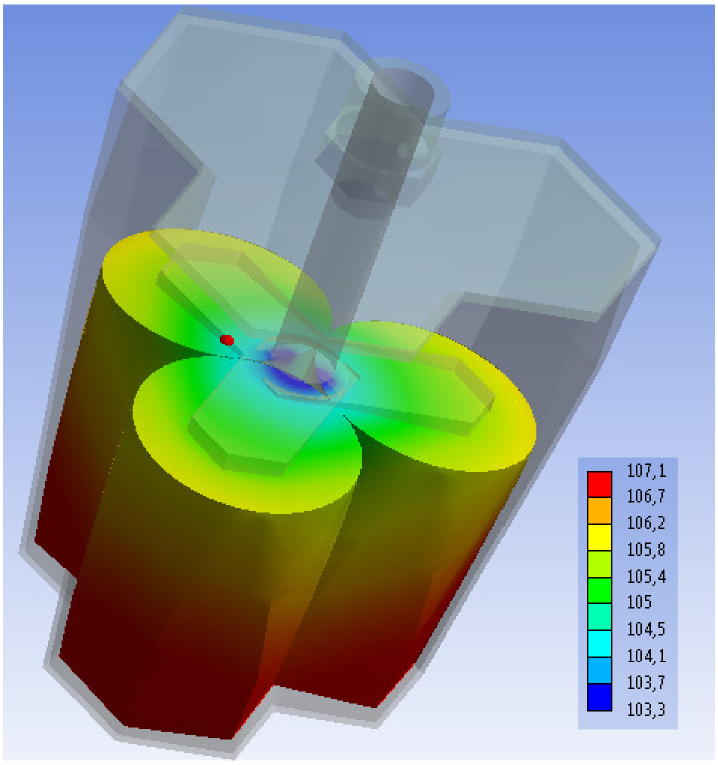
Temp. of the cooling part [T]	Amb. Temp. [T]	Ge capsules emissivity	Assembly emissivity	Crystal warming power [W]	Cold plate warming power [W]	Total Heat [W]	Temp. deviation [K]
70	295.15	0.2	0.1	2.38	0,12	2.49	3.5
100	295.15	0.2	0.1	2.34	0.12	2.46	3.2
70	295.15	0.1	0.1	1.6	0.14	1.73	2.4
100	295.15	0.1	0.1	1.78	0.14	1.71	2.2
70	293.15	0.2	0.1	2.30	0.12	2.42	3.3
100	293.15	0.2	0.1	2.29	0.12	2.41	3.1
70	298.15	0.2	0.1	2.46	0.13	2.58	3.5
100	298.15	0.2	0.1	2.42	0.13	2.57	3.5
70	303.15	0.2	0.1	2.62	0.14	2.76	3.8
100	303.15	0.2	0.1	2.60	0.13	2.73	3.5

Table 9. Crystals warming and total heat losses

2. Estimation the heat losses in the case of Copper Chromium Zirconium Alloy cold finger.

As it was already discussed copper is characterized with high thermal conductivity but it hardness is not to meet the mechanical requirement for cold finger manufacturing, especially in the case of triple detector. In view of that the thermal characteristics of the assembly when cold finger is supposed to be made from Copper Chromium Zirconium Alloy has also been studied.

The temperature field distribution is presented in Fig. 10 and it has been seen the application of the CuCrZr leeds to minor temperature increase along the Ge-capsules which is but acceptable.



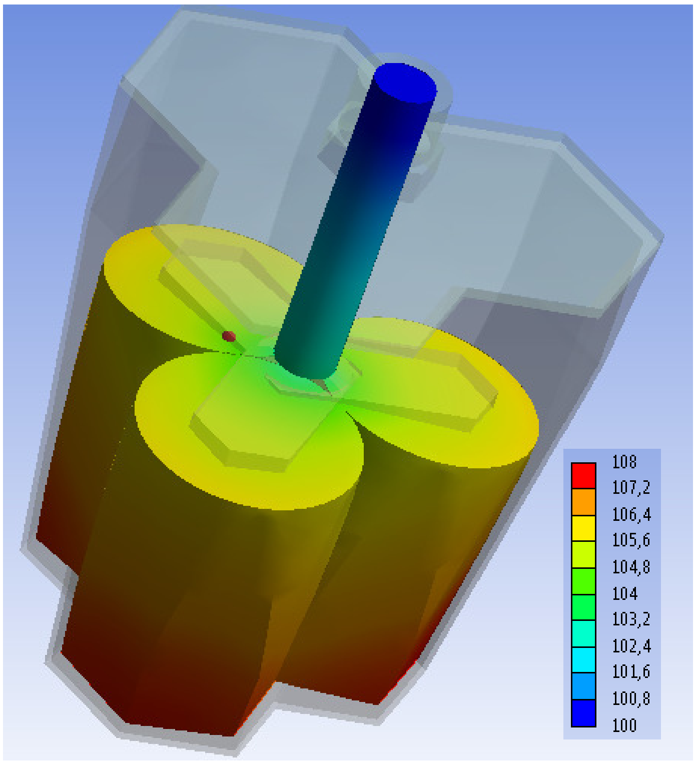


Fig. 10. Temperature distribution along the Ge-crystals and the CuCrZr cold finger when the temperature of the cooling part is 100 K and the ambient temperature is 295.15 K. The emissivity of the Ge-capsules is 0.2, when the emissivity of the processed inner surface of the cryostat is 0.1.

3. Evaluation of the thermal contacts between the cold finger and the cold frame

Contact between the cold finger and the cold frame is of paramount importance for the thermal management of the whole detector assembly. That is why here different scenarios have been evaluated.

Most of the literature presented in the thermal contact conductance is associated with two solid surfaces together under applied load. But recently an experimental study of thermal conductance was conducted with pairs of aluminium alloy speciments jointed by bolts [5].

The calculations have been performed for a typical configuration when the cooling part is under temperature of 70 K when the environment temperature is 295.15 K. Ge-capsules emissivity is taken to be 0.2 and the emissivity of the other parts of the assembly is 0.1. The thermal conductance serves as a figure of merit of the thermal contact quality. The temperature distribution along the Ge-capsules is presented in Fig. 11-13 for thermal conductance considered to be 6000 $W/m^2.K$; 2000 $W/m^2.K$ and 1000 $W/m^2.K$ respectively.

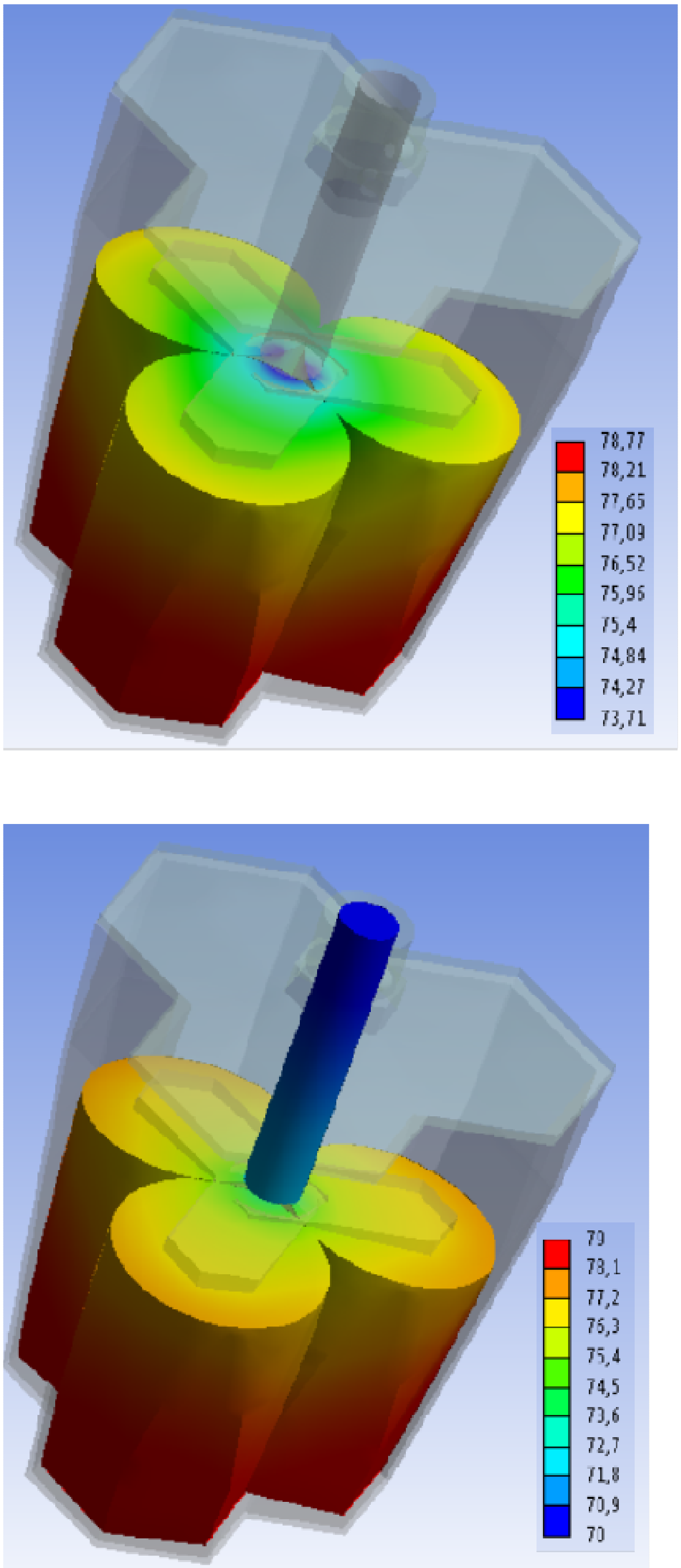


Fig. 11. Temperature distribution along the Ge-crystals and the CuCrZr cold finger when the temperature of the cooling part is 100 K and the ambient temperature is 295.15 K. The emissivity of the Ge-capsules is 0.2, when the emissivity of the processed inner surface of the cryostat is 0.1. Thermal conductance is 6000 W/m².K.

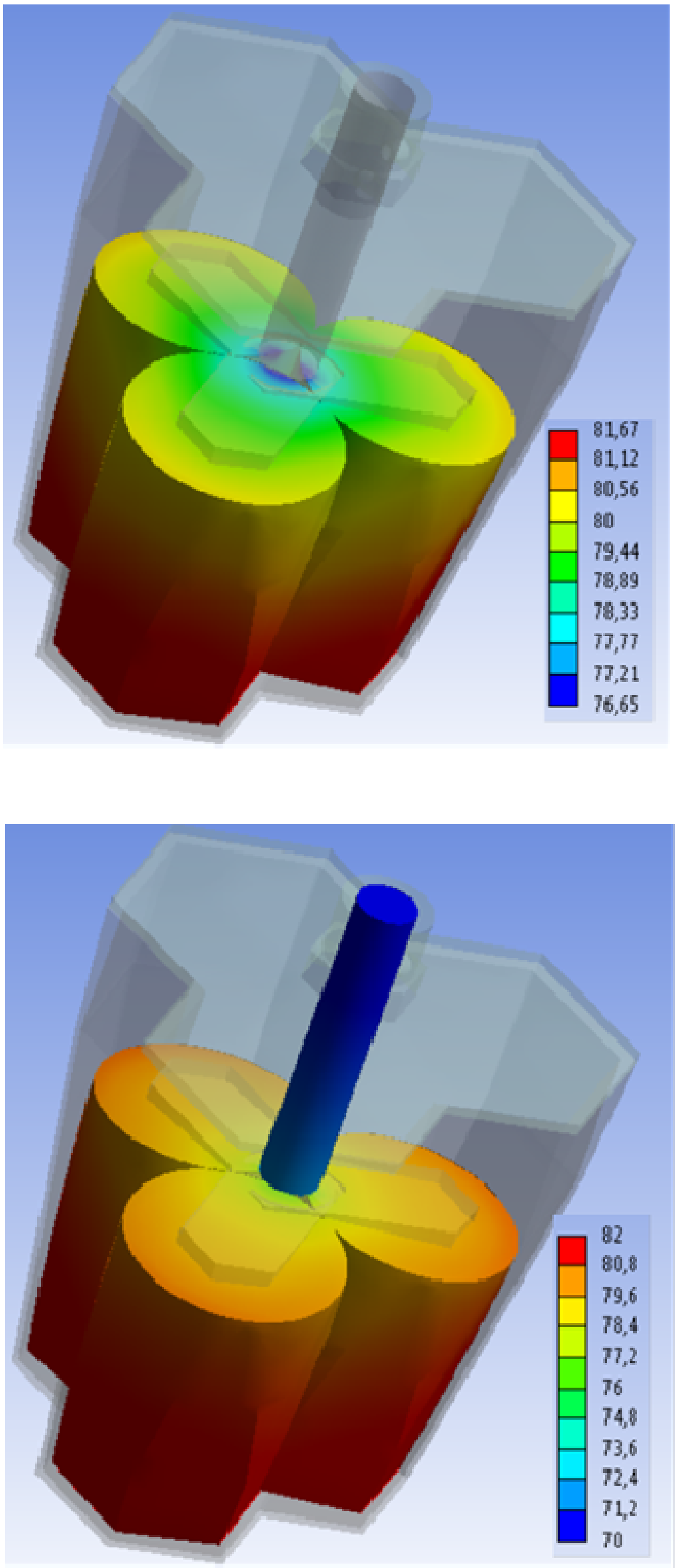
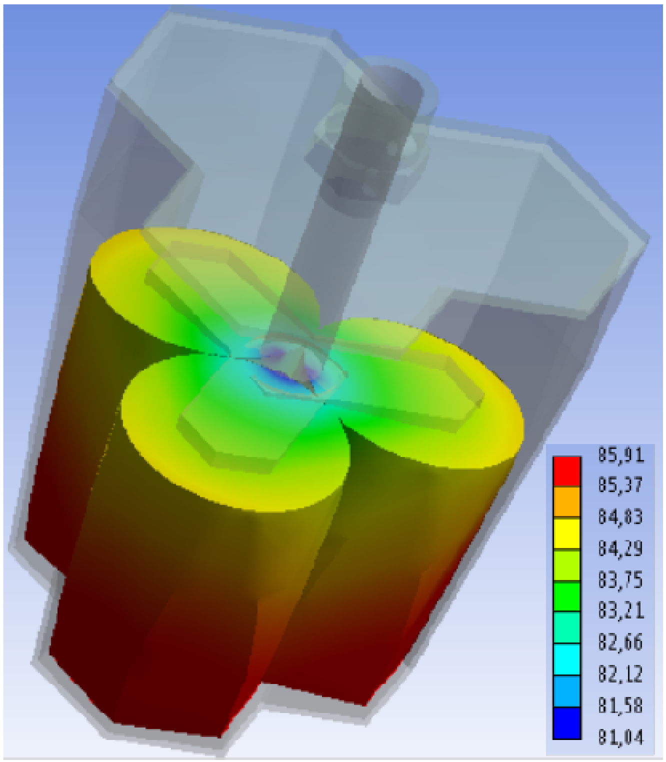


Fig. 12. Temperature distribution along the Ge-crystals and the CuCrZr cold finger when the temperature of the cooling part is 100 K and the ambient temperature is 295.15 K. The emissivity of the Ge-capsules is 0.2, when the emissivity of the processed inner surface of the cryostat is 0.1. Thermal conductance is 2000 W/m².K.



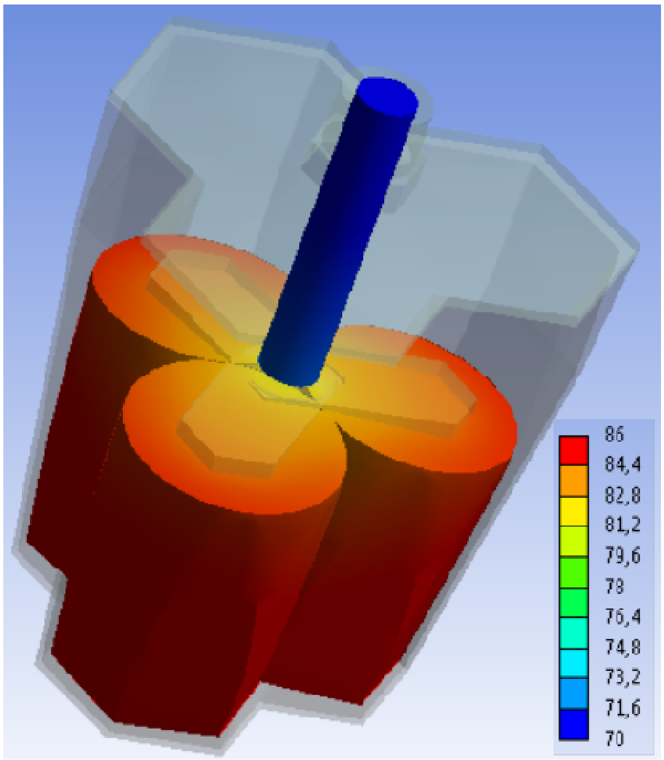


Fig. 13. Temperature distribution along the Ge-crystals and the CuCrZr cold finger when the temperature of the cooling part is 100 K and the ambient temperature is 295.15 K. The emissivity of the Ge-capsules is 0.2, when the emissivity of the processed inner surface of the cryostat is 0.1. Thermal conductance is 1000 W/m².K.

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