

Parameters of cryogenic payload in LCGT

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1 Introduction

2 Outline

Here is figure.

3 Mirror

- Material : Sapphire
 - Density : $4.0 \times 10^3 \text{ kg/m}^3$
 - Young's modulus : $4 \times 10^{11} \text{ Pa}$
 - Poisson ratio : 0.29
- Shape : Cylinder ¹
 - Diameter : 22 cm
 - Thickness : 15 cm
 - Mass : 23 kg

Graphs for thermal expansion, specific heat, thermal conductivity, emissivity (Sakakibara's report).

3.1 Fiber between Mirror and Intermediate Mass

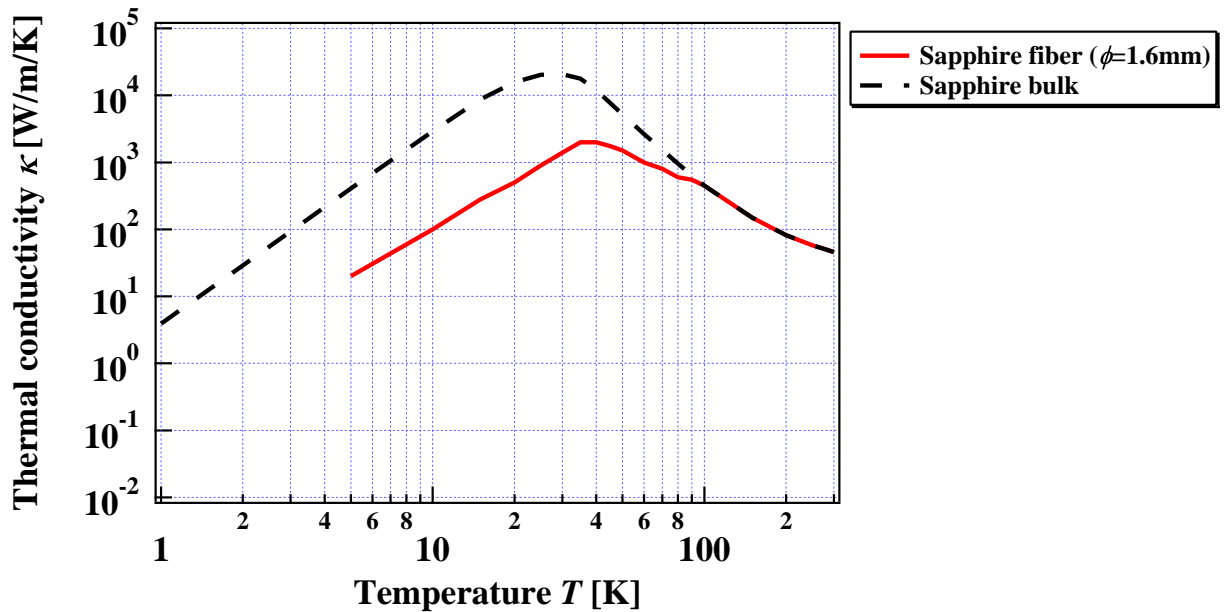
- Material : Sapphire

¹There are flat surfaces on barrel surface for sapphire fiber bonding.

- Density : $4.0 \times 10^3 \text{ kg/m}^3$
 - Young's modulus : $4 \times 10^{11} \text{ Pa}$
 - Poisson ratio : 0.29
- Number : 4
 - Cross section : circle
 - Diameter : 1.6 mm
 - Length : 30 cm

Graphs for thermal expansion, specific heat(Sakakibara's report).

When we use sapphire fiber, size effect (thermal conductivity depends on the radius of fiber) should be taken into account. The thermal conductivity of fiber (1.6 mm in diameter) is as Fig. 1. Tomaru *et al*[1] investigated fiber (0.16 mm in diameter). Below 35 K, it is supposed that sapphire fiber (1.6 mm diameter) is 10 times larger than Tomaru's result. It is assumed that the thermal conductivity of fiber above 35 K is the same as that of bulk. You can find data (sapphire_fiber_con_temp.txt,sapphire_fiber_con.txt).



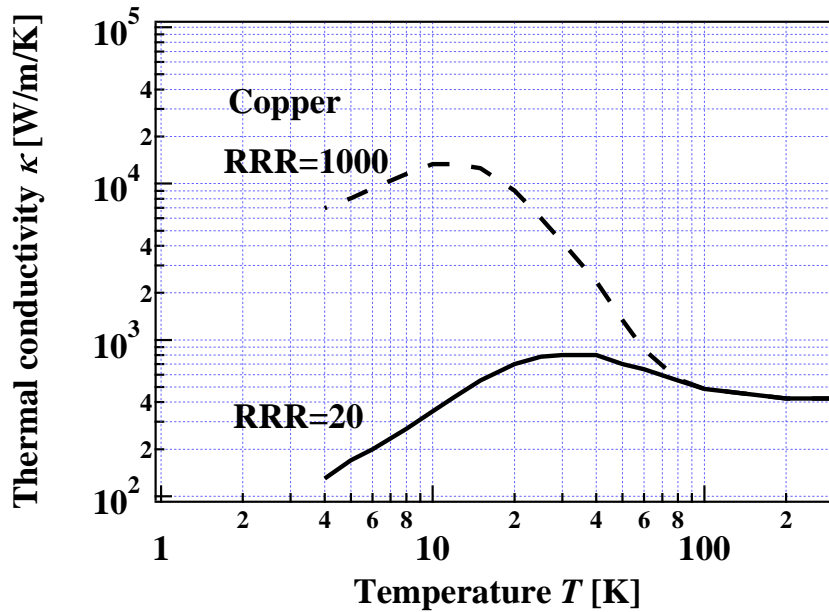
⊗ 1: Thermal conductivity of sapphire

4 Recoil mass

- Material : Copper(RRR=20)
 - Density : $8.93 \times 10^3 \text{ kg/m}^3$
 - Young's modulus : $1.298 \times 10^{11} \text{ Pa}$
 - Poisson ratio : 0.343
- Shape : Hollow cylinder (Tube)²
 - Outer diameter : 29 cm
 - Inner diameter : 26 cm
 - Thickness : 20 cm
 - Mass : 23 kg

Graphs for thermal expansion, specific heat, emissivity (Sakakibara's report)

Thermal conductivity of copper (RRR is 20) is as Fig. 2 [2]. You can find data (Cu_con_temp.txt,Cu_con.txt).



☒ 2: Thermal conductivity of copper

²The center of gravity of recoil mass is the same as that of the mirror.

4.1 Fiber between Recoil mass and Intermediate mass

These parameters are not necessary for thermal simulation.

- Material : ???
 - Density : $??? \times 10^3 \text{ kg/m}^3$
 - Young's modulus : $??? \times 10^{11} \text{ Pa}$
 - Poisson ratio : ???
- Number : 4
- Cross section : circle
 - Diameter : ??? mm
 - Length : 30 cm

Graphs for thermal expansion, specific heat, thermal conductivity

4.2 Heat links between Recoil mass and Intermediate mass

- Material : Aluminum (RRR=4000)
 - Density : $2.69 \times 10^3 \text{ kg/m}^3$
 - Young's modulus : $7.03 \times 10^{11} \text{ Pa}$
 - Poisson ratio : 0.345
- Number : 4
- : U shape
- Cross section : circle
 - Diameter of heat link : 1.6 mm
 - Diameter of U shape : 30 cm
 - Length of heat link : $\pi/2 \times 30 \text{ cm} \sim 47.1 \text{ cm}$

Graphs for thermal expansion, specific heat, thermal conductivity (Sakakibara's report). The size effect is observed if RRR is more than about 10000 [3]. Thus, here, it is not necessary to consider it.

5 Intermediate mass

- Material : Copper(RRR=20)
 - Density : $8.93 \times 10^3 \text{ kg/m}^3$
 - Young's modulus : $1.298 \times 10^{11} \text{ Pa}$
 - Poisson ratio : 0.343
- Shape : rectangular parallelepiped
 - Width : 31 cm
 - Thickness : 20 cm
 - Height : 11 cm
 - Mass : 60 kg

Thermal expansion, specific heat, thermal conductivity, emissivity are summarized in section about Recoil mass.

5.1 Fiber between Intermediate mass and Platform

These parameters are not necessary for thermal simulation.

- Material : ???
 - Density : $??? \times 10^3 \text{ kg/m}^3$
 - Young's modulus : $??? \times 10^{11} \text{ Pa}$
 - Poisson ratio : ???
- Number : 4
- Cross section : circle
 - Diameter : ??? mm
 - Length : 40 cm

Graphs for thermal expansion, specific heat, thermal conductivity

5.2 Heat links between Intermediate mass and Platform

- Material : Aluminum (RRR=4000)
 - Density : $2.69 \times 10^3 \text{ kg/m}^3$
 - Young's modulus : $7.03 \times 10^{11} \text{ Pa}$
 - Poisson ratio : 0.345
- Number : 5
- : U shape
- Cross section : circle
 - Diameter of heat link : 3 mm
 - Diameter of U shape : 40 cm
 - Length of heat link : $\pi/2 \times 40 \text{ cm} \sim 62.8 \text{ cm}$

Thermal expansion, specific heat, thermal conductivity are summarized in section about Heat links between Recoil mass and Intermediate mass.

6 Recoil mass for Intermediate mass

- Material : Copper(RRR=20)
 - Density : $8.93 \times 10^3 \text{ kg/m}^3$
 - Young's modulus : $1.298 \times 10^{11} \text{ Pa}$
 - Poisson ratio : 0.343
- Shape : Hollow rectangular parallelepiped
 - Outer width : 44 cm
 - Inner width : 35 cm
 - Outer thickness : 33 cm
 - Inner thickness : 24 cm
 - Height : 11 cm
 - Mass : 60 kg

Thermal expansion, specific heat, thermal conductivity, emissivity are summarized in section about Recoil mass.

6.1 Fiber between Recoil mass for Intermediate mass and Platform

These parameters are not necessary for thermal simulation.

- Material : ???
 - Density : $??? \times 10^3 \text{ kg/m}^3$
 - Young's modulus : $??? \times 10^{11} \text{ Pa}$
 - Poisson ratio : ???
- Number : 4
- Cross section : circle
 - Diameter : ??? mm
 - Length : 40 cm

Graphs for thermal expansion, specific heat, thermal conductivity

6.2 Heat links between Recoil mass for Intermediate mass and Platform

- Material : Aluminum (RRR=4000)
 - Density : $2.69 \times 10^3 \text{ kg/m}^3$
 - Young's modulus : $7.03 \times 10^{11} \text{ Pa}$
 - Poisson ratio : 0.345
- Number : 5
- : U shape
- Cross section : circle
 - Diameter of heat link : 3 mm
 - Diameter of U shape : 40 cm
 - Length of heat link : $\pi/2 \times 40 \text{ cm} \sim 62.8 \text{ cm}$

Thermal expansion, specific heat, thermal conductivity are summarized in section about Heat links between Recoil mass and Intermediate mass.

7 Platform

- Material : Copper(RRR=20)
 - Density : $8.93 \times 10^3 \text{ kg/m}^3$
 - Young's modulus : $1.298 \times 10^{11} \text{ Pa}$
 - Poisson ratio : 0.343
- Shape : Rectangular parallelepiped
 - Width : 44 cm
 - Outer thickness : 33 cm
 - Height : 5.7 cm
 - Mass : 74 kg

Thermal expansion, specific heat, thermal conductivity, emissivity are summarized in section about Recoil mass.

7.1 Fiber between Platform and SAS

- Material : Bolfur (Unitika)
 - Density : $7.6 \times 10^3 \text{ kg/m}^3$
 - Young's modulus : $1.568 \times 10^{11} \text{ Pa}$
 - Poisson ratio : ???
- Number : 1
- Cross section : circle
 - Diameter³ : 1.5 mm
 - Length : 3.47 m

³Tensile strength is 3.528 Gpa if the diameter is 100 μm .

Graphs for thermal expansion, specific heat, thermal conductivity

The thermal conductivity will be measured in KEK. Here, it is assumed that it is the same as that of stainless steel as Fig. 3 [2]. The thermal conductivity of G10 is 10 times smaller [2]. You can find data (Bolfur_con_temp.txt,Bolfur_con.txt).

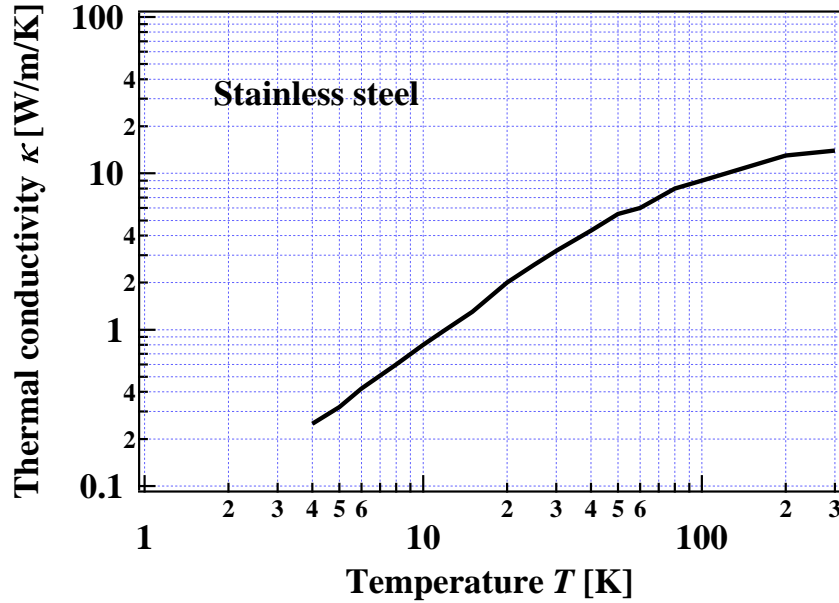


Fig. 3: Thermal conductivity of Bolfur (It is assumed that it is the same as that of stainless steel).

7.2 Heat links between Platform and Inner shield

- Material : Aluminum (RRR=4000)
 - Density : 2.69×10^3 kg/m³
 - Young's modulus : 7.03×10^{11} Pa
 - Poisson ratio : 0.345
- Number : 7
- : U shape
- Cross section : circle

- Diameter of heat link : 1 mm
- Diameter of U shape : 50 cm
- Length of heat link : $\pi/2 \times 40$ cm \sim 78.5 cm

Thermal expansion, specific heat, thermal conductivity are summarized in section about Heat links between Recoil mass and Intermediate mass.

8 Cryocooler power

It is assumed that the power of a cryocooler is described as [4]

$$20 \text{ [W]} \frac{T - 4 \text{ [K]}}{296 \text{ [K]}}, \quad (1)$$

where T is temperature.

9 Radiation

When we consider initial cooling time, radiation can not be neglected. The radiation between mirror (or intermediate mass) and recoil masses should be taken into account. Some kinds of coating make emissivity larger.

10 Heat load

10.1 Laser light

The absorption of laser light in the mirror is the heat source. The absorption in substrate is written as (in the case of end mirror, it is not necessary to consider it)

$$0.23 \text{ [W]} \left(\frac{P}{75 \text{ [W]}} \right) \left(\frac{G_{\text{PR}}}{10} \right) \left(\frac{a}{20 \text{ ppm/cm}} \right) \left(\frac{t}{15 \text{ cm}} \right), \quad (2)$$

where P , G_{PR} , a and t are the incident power at beam splitter, power recycling gain, absorption per unit length, and thickness of the mirror. The absorption in coating is represented as

$$0.19 \text{ [W]} \left(\frac{P}{75 \text{ [W]}} \right) \left(\frac{G_{\text{PR}}}{10} \right) \left(\frac{\mathcal{F}}{1550} \right) \left(\frac{b}{0.5 \text{ ppm}} \right), \quad (3)$$

where \mathcal{F} and b are finesse of cavity and absorption in coating.

10.2 Heat from duct

According to Sakakibara's calculation [5], the 300 K radiation transmitted by a duct is about 0.1 W. Since baffles on duct work well, almost all of 300 K radiation attack the mirror directly. Thus, in total, 0.2 W radiation arrives at the mirror. Although the emissivity must be considered, here, it is supposed that the mirror absorbs all power of radiation⁴.

10.3 Heat from SAS

There are two heat paths from SAS, wire and radiation. In both cases, heat reaches the platform.

The top end of (Bolfur) wire is at 300 K. If the thermal conductivity of Bolfur is comparable with that of stainless steel, the heat which passes through wire is on the order of 1 mW (you must check it).

The power of 300 K radiation is as follows:

$$\sigma_{\text{Stefan-Boltzmann}} A_{\text{platform}} \epsilon_{\text{platform}} \frac{1}{4\pi} (T_2^4 - T_1^4) \frac{\pi r_{\text{hole}}^2}{d_{\text{hole}}} \quad (4)$$

$$= 85 \text{ [mW]} \left(\frac{A_{\text{platform}}}{0.44 \times 0.33 \text{ [m}^2\text{]}} \right) \left(\frac{\epsilon_{\text{platform}}}{1} \right) \left(\frac{2r_{\text{hole}}}{10 \text{ [cm]}} \right)^2 \left(\frac{0.7 \text{ [m]}}{d_{\text{hole}}} \right) \quad (5)$$

where $\sigma_{\text{Stefan-Boltzmann}}$, A_{platform} , $\epsilon_{\text{platform}}$, $T_2 (= 300 \text{ [K]})$, $T_1 (= 8 \text{ [K]})$, r_{hole} , d_{hole} are Stefan-Boltzmann constant ($5.67 \times 10^{-8} \text{ [W/m}^2\text{/K}^4\text{]}$), surface area and emissivity of platform, temperature of outside and platform, radius of hole for wire and the distance between platform and hole.

参考文献

- [1] T. Tomaru et al., Phys. Lett. A 301 (2002) 215.
- [2] Lakeshore, Cryogenic Reference Tables
(http://www.lakeshore.com/pdf_files/Appendices/LSTC_appendixL1.pdf)
- [3] K. Kasahara, Master thesis (The university of Tokyo, 2003, in Japanese)
- [4] Y. Sakakibara, 14 June 2011.

⁴In general, emissivity at lower temperature is smaller. The emissivity of sapphire at 20 K is 0.08[6]. However, as long as I know, the emissivity of coating is unknown.

[5] Y. Sakakibara, 28 June 2011.

[6] Y. Sakakibara, 8 June 2011.