Parameters of cryogenic payload in LCGT

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1 Introduction

2 Outline

Here is figure.

3 Mirror

- Material : Sapphire
  - Density : 4.0×10^3 kg/m^3
  - Young's modulus : 4×10^{11} 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
  - Density : 4.0×10^3 kg/m^3
  - Young's modulus : 4×10^{11} Pa
  - Poisson ratio : 0.29

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

- 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).

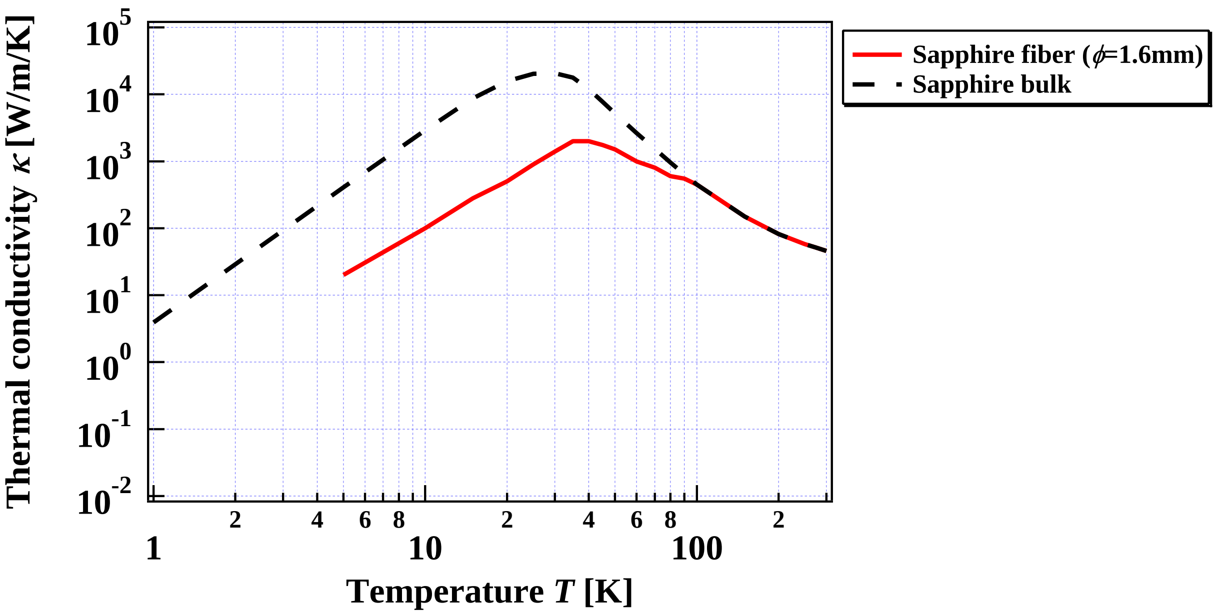

Figure 1: Thermal condcutivity of sapphire

4 Recoil mass

- Material : Copper(RRR=20)
  - Density : 8.93×10^3 kg/m^3
  - Young's modulus : 1.298×10^{11} 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).

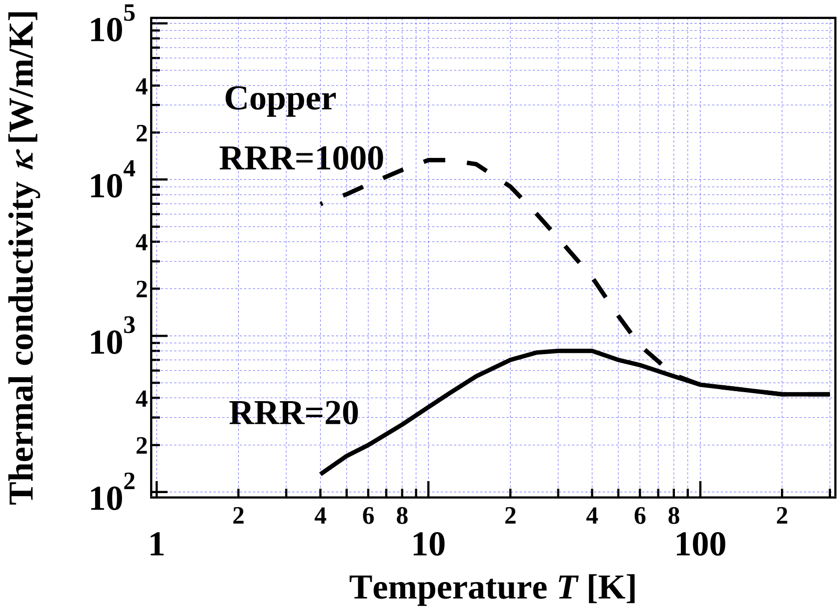

Figure 2: Thermal condcutivity of copper

4.1 Fiber between Recoil mass and Intermediate mass

These parameters are not necessary for thermal simulation.

- Material : ???
  - Density : ???$\times 10^3$ kg/m^3
  - Young's modulus : ???$\times 10^{11}$ Pa

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

- 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 : 2.69×10^3 kg/m^3
  - Young's modulus : 7.03×10^{11} 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 : $\pi/2\times30$ cm $\sim$ 47.1 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 : 8.93×10^3 kg/m^3
  - Young's modulus : 1.298×10^{11} 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 summarzied in section about Recoil mass.

5.1 Fiber between Intermediate mass and Platform

These parameters are not necessary for thermal simulation.

- Material : ???
  - Density : ???$\times 10^3$ kg/m^3
  - Young's modulus : ???$\times 10^{11}$ 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 Intermeadite mass and Platform

- Material : Aluminum (RRR=4000)
  - Density : 2.69×10^3 kg/m^3
  - Young's modulus : 7.03×10^{11} 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 : $\pi/2 \times 40$ cm ~ 62.8 cm

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

6 Recoil mass for Intermediate mass

- Material : Copper(RRR=20)
  - Density : 8.93×10^3 kg/m^3
  - Young's modulus : 1.298×10^{11} 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 summarzied 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 : ???$\times 10^3$ kg/m^3
  - Young's modulus : ???$\times 10^{11}$ 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 Intermeadite mass and Platform

- Material : Aluminum (RRR=4000)
  - Density : 2.69×10^3 kg/m^3
  - Young's modulus : 7.03×10^{11} 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 : $\pi/2\times40$ cm $\sim$ 62.8 cm

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

7 Platform

- Material : Copper(RRR=20)
  - Density : 8.93×10^3 kg/m^3
  - Young's modulus : 1.298×10^{11} 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 summarzied in section about Recoil mass.

7.1 Fiber between Platform and SAS

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

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 steinless steel as Fig. 3 [2]. The thermal condcutivity of G10 is 10 times smaller [2]. You can find data (Bolfur_con_temp.txt,Bolfur_con.txt).

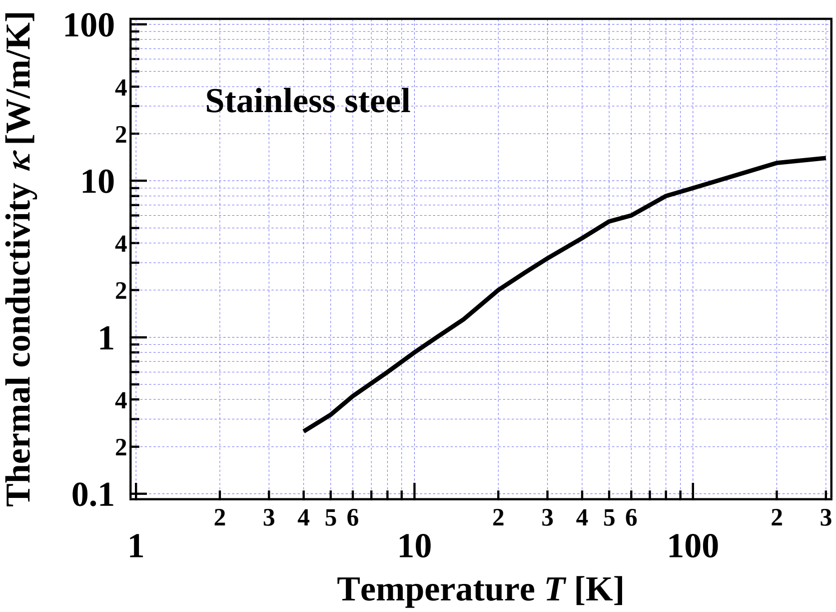

Figure 3: Thermal condcutivity of Bolfur (It is assumed that it is the same as that of steinless steel).

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

7.2 Heat links between Platform and Inner shield

- Material : Aluminum (RRR=4000)
  - Density : 2.69×10^3 kg/m^3
  - 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 : $\pi/2\times40$ cm $\sim$ 78.5 cm

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

8 Cryocooler power

The power of the 2nd stage of a cryocooler has already been measured [4]. This result is adopted and summarized in Fig. 4.

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)

$$0.23\ [\mathrm{W}] \left(\frac{P}{75\ [\mathrm{W}]}\right) \left(\frac{G_{\mathrm{PR}}}{10}\right) \left(\frac{a}{20\ \mathrm{ppm/cm}}\right) \left(\frac{t}{15\ \mathrm{cm}}\right), \tag{1}$$

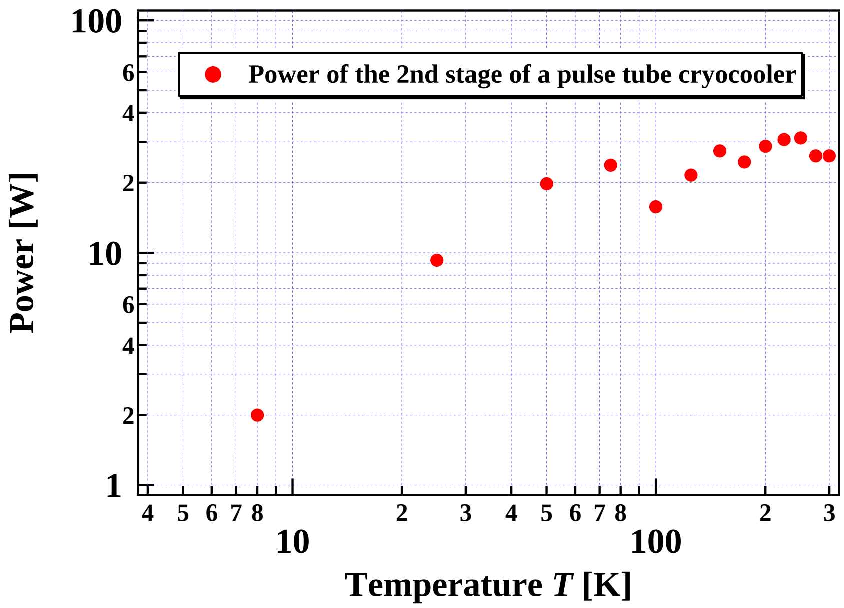

Figure 4: Power of the 2nd stage of a pulse tube cryocooler

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

$$0.19\ [\mathrm{W}] \left(\frac{P}{75\ [\mathrm{W}]}\right)\left(\frac{G_{\mathrm{PR}}}{10}\right)\left(\frac{\mathcal{F}}{1550}\right)\left(\frac{b}{0.5\ \mathrm{ppm}}\right), \qquad (2)$$

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

10.2 Heat from duct

According to Sakakibara's calculation [6], the 300 K radiation transmitted by a duct is about 0.1 W. Since buffles 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 emissitivity must be consider, here, it is supposed that the mirror absorps all power of radiation [4].

10.3 Heat from SAS

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

[4] In general, emissitivity at lower temperature is smaller. The emissitivity of sapphire at 20 K is 0.08[7]. However, as long as I know, the emissivity of coating is unknown.

The top end of (Bolfur) wire is at 300 K. If the thermal conductivity of Bolfur is comparable with that of steinless 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:

$$\sigma_{\mathrm{Stefan-Boltzmann}} A_{\mathrm{platform}} \epsilon_{\mathrm{platform}} \frac{1}{4\pi} \left({T_2}^4 - {T_1}^4\right) \frac{\pi r_{\mathrm{hole}}^2}{d_{\mathrm{hole}}} \quad (3)$$

$$= 85\ [\mathrm{mW}] \left(\frac{A_{\mathrm{platform}}}{0.44 \times 0.33\ [\mathrm{m}^2]}\right) \left(\frac{\epsilon_{\mathrm{platform}}}{1}\right) \left(\frac{2r_{\mathrm{hole}}}{10\ [\mathrm{cm}]}\right)^2 \left(\frac{0.7\ [\mathrm{m}]}{d_{\mathrm{hole}}}\right) \quad (4)$$

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

References

[1] T. Tomaru et al., Phys. Lett. A 301 (2002) 215.

[2] Lakeshore, Cryogenic Reference Tables (http://www.lakeshore.com/pdf_files/Appendices/LSTC_appendixI_l.pdf)

[3] K. Kasahara, Master thesis (The university of Tokyo, 2003, in Japanese)

[4] N. Kimura et al.'s measurement.

[5] Y. Sakakibara, 14 June 2011.

[6] Y. Sakakibara, 28 June 2011.

[7] Y. Sakakibara, 8 June 2011.