Measurement of outgassing from multi-layered insulators for the Cryogenic Lase Interferometer Observatory

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Abstract

We measured the outgassing from the radiation shields of cryostats and evaluated the vacuum pressure in the cryostat of the Cryogenic Laser Interferometer Observatory (CLIO) project. The radiation shield is an aluminum plate covered by 40 layered insulator films. The insulator films are considered to be the dominant outgas source because of their large surface area in the cryostat. The outgassing from the radiation shield is 3.6×10^{-6} [Pa m^3/sec/m^2] after 100 hours of evacuation. From this result, the total outgassing in a cryostat of the CLIO project, which has a radiation shield covering 6 m^2 surface area is more than 2.2×10^{-5} [Pa m^3/sec] at 100 hour evacuation.

1. Introduction

A project involving a laser interferometric gravitational wave detector, that is the Cryogenic Laser Interferometer Observatory (CLIO) project is proceeding[2]. The key features of the CLIO project are a site in Kamioka mine which is in Gifu prefecture, Japan, and cryogenic cooled a sapphire mirror. The sapphire mirrors are cooled to under 20 K in order to reduce the thermal noise[6, 7, 8]. To cool the mirrors, they are suspended in cryostats by sapphire fibers[4, 5].

The cryostat for CLIO is a vacuum chamber with two (outer and inner) radiation shields. One purpose of the radiation shield is to reduce the radiation heat from 300 K. We planned for the equilibrium temperature of the outer radiation shield to be 100 K and that of the inner radiation shield to be 8 K. The suspended mirror is surrounded by an inner radiation shield. The radiation shield consists of two things. The first one is the base structure; the second one is multi-layered insulators. The materials of a base structure of the radiation shield is usually copper or aluminum. We chose aluminum because of its lower weight

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than copper.

The multi-layered insulators play a main role to reduce the radiation heat. The insulator is a thin polyester film coated by aluminum. FIlms composed of 40 to 60 layers are usually used for insulation in a cryostat. This means that the insulator has the largest surface area in the cryostat, and could be the largest outgas source in it. Because laser interferometric gravitational wave detectors require a high vacuum pressure, typically 10^{-6} [Pa], it is important to know the amount of outgassing from the insulator quantitatively.

To avoid thermal conduction between the layered films, two methods have been developed. One is to use a low thermal-conductivity meshed spacer between the films. The material of the spacer is usually fiberglass or nylon. Another one is use embossed films and not to use any spacer. Due to wrinkles on the embossed film, only point-to-point contacts are available between the films. We will use the embossed type in CLIO.

We measured the outgassing from the radiation shield, which has 40 layered films of an embossed-type insulator on an aluminum plate, and estimated vacuum pressure of CLIO.

2. Measurement

The relation among the outgas Q [Pa m^3/sec], the evacuation speed of a vacuum pump S [m^3/sec] and the pressure P [Pa] can be written,

$$P = \frac{Q}{S}. \tag{1}$$

We can evaluate the outgassing from a sample by comparing the vacuum pressure with the sample P [Pa] and without the sample P_0 [Pa],

$$Q = (P - P_0)S. \tag{2}$$

We prepared a sample composed of 40 layered insulator films, "CRYNSULATE" [3], of 100 mm × 100 mm on an aluminum plate of 100 mm × 100 mm × 5 mm. The films one of the embossed type, and one made of a polyester film of 6 μm thickness coated by aluminum of 500 Angstroms. This sample just simulates a radiation shield of CLIO of 100 mm × 100 mm. Before a measurement, we cleaned the sample with acetone.

We put the sample in a cylindrical vacuum chamber of ϕ250 mm × 290 mm and evacuated it by a turbo-molecular pump. Between the connection of the chamber and the pump, we attached an orifice of ϕ 10 mm; the evacuation speed was 9.2 L/sec. To measure the vacuum pressure, we used a spinning rotor gauge from 100 Pa to 10^5 Pa and a BA gauge at under 100 Pa. Because these pressure gauges have different sensitivity for different molecules, we checked the dominant molecule in the outgas from the sample by a mass analyzer, and confirmed that

H_2O the dominant. Also because these pressure gauges strongly depend on the temperature, we monitored the temperature on the chamber and used values measured at 25 degrees.

3. Results and discussions

We evaluated the outgassing from radiation shields from the measured value. Fig. 1 shows the outgassing from a radiation shield of $1\,\mathrm{m} \times 1\,\mathrm{m}$ square with 40 films of the embossed type insulator. Also, we plot the outgassing from an embossed-type insulator film having $1\,\mathrm{m}^2$ surface area. To evaluate this value, we assumed that the outgassing from the aluminum plate is much smaller than that from the insulators. A measurement of the outgassing from the spacer-type insulator has been done by Kubo[1] in 2001. To compare with the embossed type, we plot the outgas from the 80 sheets of the spacer type insulator (40 insulator films + 40 spacers) of $1\,\mathrm{m} \times 1\,\mathrm{m}$ square. Ideally, this configuration can be expected to produce the same heat reduction as 40 films of the embossed-type insulator. Table 1. shows the outgas values from these three items after 100 hours of evacuation.

The outgassing from the spacer-type insulator is much larger than that from the embossed-type until 20 hours of evacuation. The difference in the amount of the outgassing from both insulators, however, becomes smaller after 50 hours of evacuation. This means that the outgassing from the spacer-type insulator is dominated by that of the spacer in the first 20 hours of evacuation, and that outgassing from the spacer rapidly decreases with time. As a result, the same polyester films coated by aluminum dominate the outgassing from both insulators after a long-term evacuation. The outgassing from a radiation shield with the embossed-type insulator is proportional to $T^{-1.2}$. T is the evacuation time. This means that the outgas is emitted from the surface of the insulator.

In the case of CLIO, the cryostat has radiation shields covering $6\,\mathrm{m}^2$ of the surface area. According to our result, more than 2.2×10^{-5} [$\mathrm{Pa\,m^3/sec}$] is the estimated outgassing in the cryostat after 100 hours of evacuation. Typically, the evacuation speed of a turbo-molecular pomp is less than 1000 L/sec. According to Eq. (1), the vacuum pressure in the cryostat after 100 hours of evacuation is estimated to be more than 2.2×10^{-5} [Pa]. On the other hand, if the radiation shield is to about 8 K, it becomes a cryo-pump which has more than 10^5 [L/sec] evacuation speed. We will obtain 2.2×10^{-7} [Pa]. This value satisfies the requirement of CLIO.

Table 1. Outgassing after 100 hours of evacuation.

Item	outgas [$Pa\,m^3/sec/m^2$]
Spacer type 80 sheets	6.8×10^{-6}
Embossed type 40 films	3.6×10^{-6}
Embossed type 1 film	4.5×10^{-8}

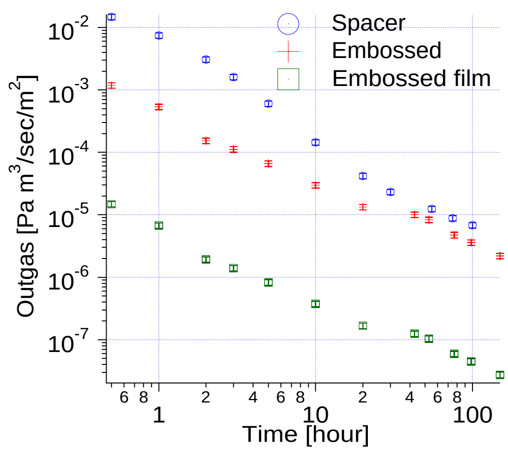

Fig. 1. Outgassing as a function of time. "Spacer" shows the outgas from a radiation shield of $1\,m \times 1\,m$ square with 80 layered sheets of the spacer-type insulator (40 insulator films + 40 spacers) measured by Kubo. "Embossed" shows the outgassing from a radiation shield of $1\,m \times 1\,m$ square with 40 layered films of the embossed-type insulator. "Embossed film" shows the outgassing from a sheet of the embossed-type insulator of a $1\,m^2$ surface area.

4. References

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