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SUPPLYING APPARATUS**(30) **Foreign Application Priority Data**

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RATION**, Tokyo (JP)(21) Appl. No.: **11/137,508**(22) Filed: **May 26, 2005**(57) **ABSTRACT**

A ultracryostat is provided with a frigidity supplying member to supply frigidity to the ultracryostat which uses cryogen such as liquid helium, wherein the frigidity supplying member comprises a heat pipe and one end of the heat pipe is connected to a frigidity generating member of a cryocooler and the other end of the heat pipe is connected to a thermal anchor of a cryostat.

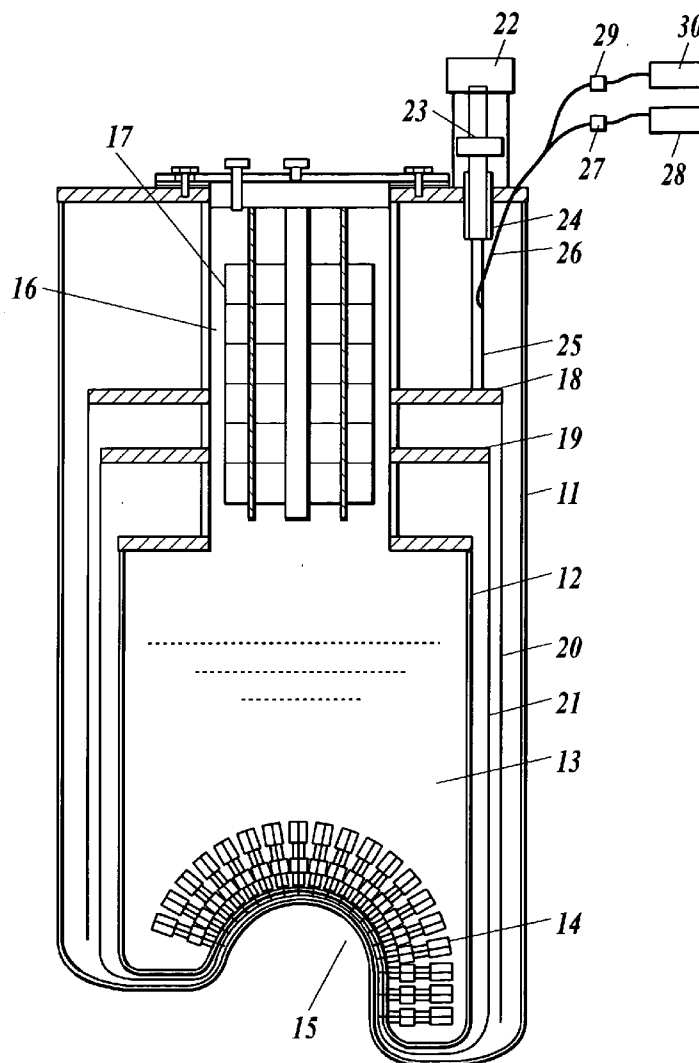


FIG 1

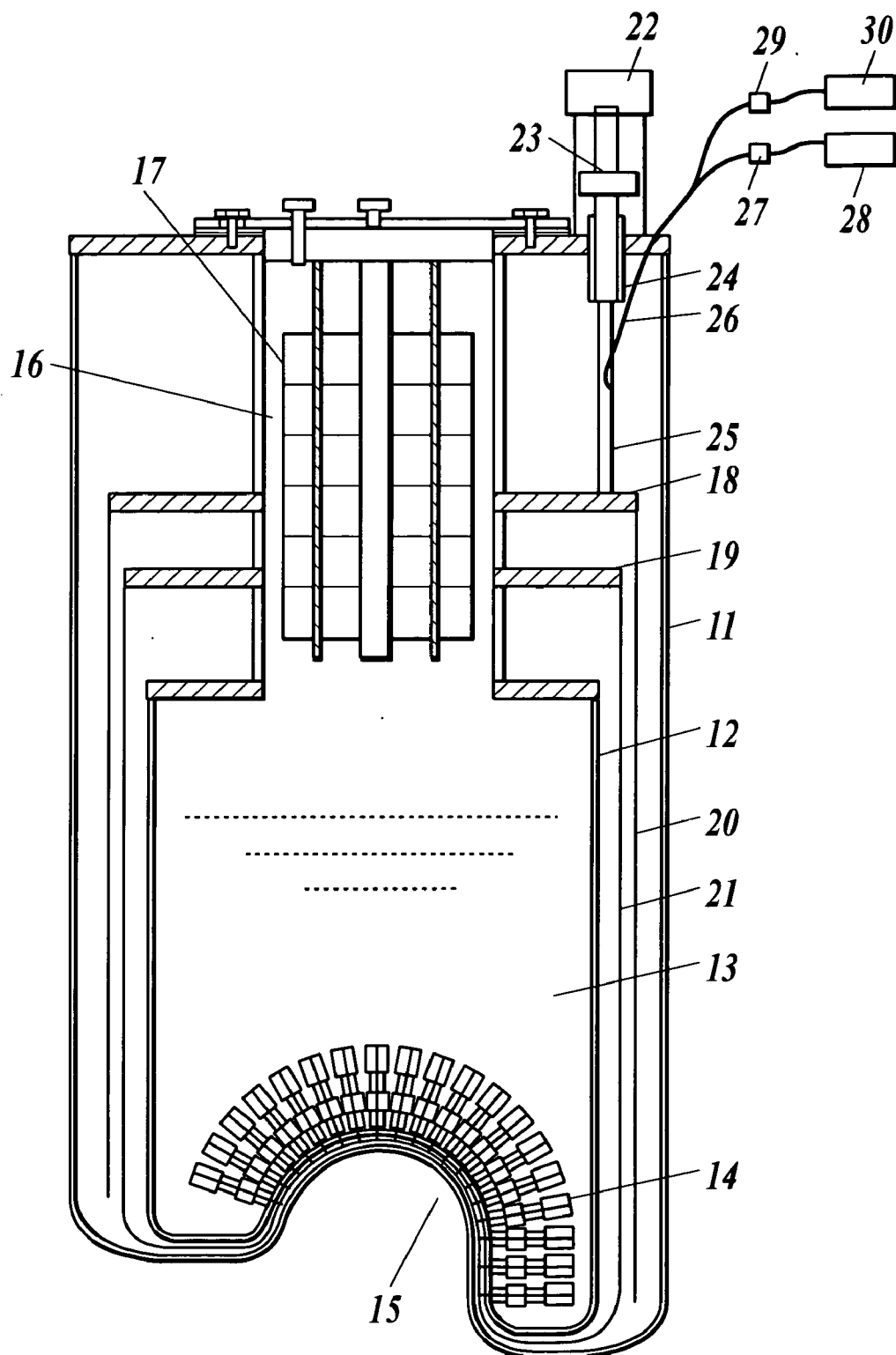
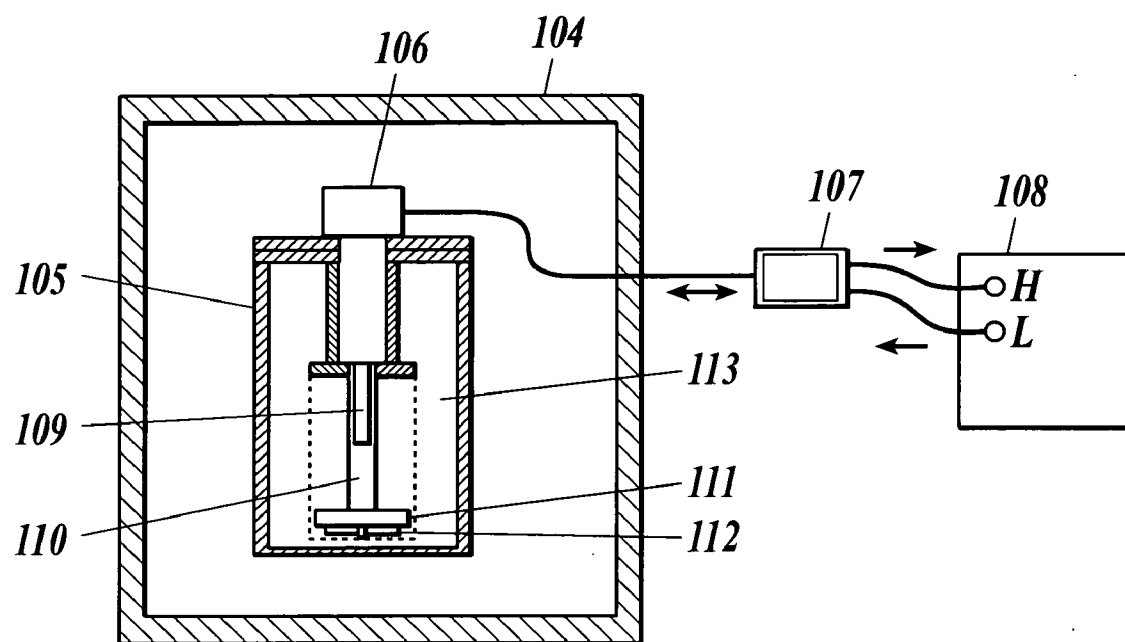


FIG 2



ULTRACRYOSTAT AND FRIGIDITY SUPPLYING APPARATUS

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to an apparatus for extending low temperature retention time of a cryostat using a superconducting quantum interference device (SQUID) for biomagnetism measurement. In more detail, the present invention relates to an ultracryostat and a frigidity supplying apparatus to reduce evaporation of helium. Further, the present invention relates to an ultracryostat and a frigidity supplying apparatus applicable not only to an ultracryostat for biomagnetism measurement but also to the other cryostat, for example a helium cryostat for MRI (magnetic resonance imaging system) using superconductive magnet and one used in physicality study.

[0003] 2. Description of Related Art

[0004] As shown in FIG. 2, an ultracryostat in earlier development is such that a freezer 106 is connected to an upper part of a cryostat 105 installed in a magnetic shield room 104 (for example, JP Tokukai 2004-116914A (page 4, FIG. 14). A rotary bulb 107 for intaking and exhausting compression gas is connected to this freezer 106, and high and low pressure gas tubes are connected to a compressor 108. A frigidity generating member 109 of the freezer 106 is exposed to a helium gas tank 110 which forms a separate room inside the cryostat 105. The generated ultra low temperature refrigerates helium gas so as to refrigerate the whole helium gas tank 110. A SQUID sensor 112 is connected to a sensor mounting stage 111 attached to a lower part of the helium gas tank 110, and the SQUID sensor 112 is refrigerated by the action of heat conduction. A vacuum layer 113 for heat insulation is formed in space which surrounds the helium gas tank 110. A heat radiation shield foil, which is omitted in the figure, is installed in the vacuum layer 113, so that heat transmission by radiation is reduced.

[0005] However, a common problem in the ultracryostat described in description of related art, i.e. a cryostat for biomagnetism measurement is that sufficient heat shield cannot be obtained because vacuum heat insulation layer is structurally thin. This problem is caused by a purpose of measurement. That is, sufficient SN (a ratio of signal to noise) cannot be obtained unless a measurement is performed in a condition that a sensor under ultra low temperature is placed as close as possible to a feeble magnetic signal source. Thus, liquid helium used as cryogen evaporates rapidly and a refill cycle thereof is one week at longest. When volume of the cryostat is made larger, structural distortion becomes large and the thin vacuum heat insulation layer may brake to cause a thermal short. Therefore, it cannot be made larger blindly.

[0006] In order to solve such problems, a method of direct refrigerating by a freezer is suggested. However, it has not been into practical use due to the following problems regarding magnetic noise.

[0007] (1) Generation of magnetic noise by a magnetic coolant: A freezer includes an antiferromagnetic material or superconductive material inside an expansion device for generating frigidity. Vibration thereof caused by pressure pulsation of internal flowing gas generates feeble variations

of magnetism and magnetic gradient around the device. These vibrations are as high as several tens to several hundreds of pT (pico Tesla), and could be an extremely high disturbing signal in a measurement of feeble biomagnetism of several tens of fT (femto Tesla) to several tens of pT.

[0008] (2) The expansion device of a cold-head of the cryocooler is composed of stainless steel (SUS) having low heat conductivity, which is magnetized though it is feeble. Since a variation of expansion gas pressure generates a vibration thereof, magnetic noise occurs as described above.

[0009] In view of the foregoing, it is difficult to attach a cryocooler directly onto a cryostat in a field of biomagnetic measurement.

[0010] While gas layer is refrigerated in the above case in earlier development, there has been another attempt in which a frigidity generating member of a freezer is connected to a thermal anchor continued to a thermal shield member.

[0011] However, because of large magnetic noise derived from a freezer, it is difficult to use any of the above devices for measurement when the freezer is in operation.

[0012] Further, when the freezer is not in operation during a measurement, heat flows back immediately. Thus, noise increases in SQUID due to instability of the internal temperature as well as evaporation rate of helium extremely increases.

SUMMARY OF THE INVENTION

[0013] In view of the foregoing, the object of the present invention is to provide a means to avoid heat flowback when a freezer is not in operation for a cryostat connected with a freezer for biomagnetic measurement, so as to solve the problem when a freezer is not in operation.

[0014] According to the first aspect of the invention, a ultracryostat is provided with a frigidity supplying member to supply frigidity to the ultracryostat which uses cryogen such as liquid helium, wherein the frigidity supplying member comprises a heat pipe, one end of the heat pipe is connected to a frigidity generating member of a cryocooler and the other end of the heat pipe is connected to a thermal anchor of a cryostat.

[0015] The heat pipe is preferably made of stainless steel.

[0016] The ultracryostat may further comprising a member to take in and out gas in the heat pipe from and to outside of the cryostat, wherein the member may comprise a narrow tube to take in and out gas from a part of the heat pipe.

[0017] The narrow tube is preferably made of stainless steel.

[0018] The member to take in and out gas in the heat pipe may comprise a gas supplying member to supply gas, connected to the narrow tube through a first bulb, and a vacuum pump to discharge gas, connected to the narrow tube through a second bulb.

[0019] The first and second bulbs may open or close in conjunction with switching of the cryocooler. That is, when the cryocooler is ON, the first bulb opens to supply gas from the gas supplying member to the heat pipe, the second bulb closes and the vacuum pump is OFF, and when the cryocooler is OFF, the first bulb closes to stop gas supply from

the gas supplying member to the heat pipe, the second bulb opens and the vacuum pump is ON to discharge gas in the heat pipe.

[0020] According to the second aspect of the invention, a frigidity supplying apparatus comprises: a cryocooler and a heat pipe having controllable thermal conductivity, wherein the cryocooler comprises a frigidity generating member, one end of the heat pipe is connected to the frigidity generating member, and the cryocooler supplies frigidity from the other end of the heat pipe.

[0021] Preferably, thermal conductivity of the heat pipe is controlled in conjunction with switching of the cryocooler, and the thermal conductivity when the cryocooler is OFF is lower than the thermal conductivity when the cryocooler is ON.

[0022] Preferably, the both ends of the heat pipe is made of copper and a wall of the heat pipe is made of stainless steel.

[0023] The frigidity supplying apparatus may further comprise a gas regulating member to take in and out gas in the heat pipe.

[0024] Preferably, the gas regulating member comprises a tube to take in and out gas in the heat pipe.

[0025] Preferably, the tube is made of stainless steel.

[0026] The gas regulating member may further comprises a gas supplying member to supply gas and a vacuum pump to discharge gas, the gas supplying member being connected to the tube through a first bulb, the vacuum pump being connected to the tube through a second bulb.

[0027] Preferably, the first and second bulbs open or close in conjunction with switching of the cryocooler, when the cryocooler is ON, the first bulb opens to supply gas from the gas supplying member to the heat pipe, the second bulb closes and the vacuum pump is OFF, and when the cryocooler is OFF, the first bulb closes to stop gas supply from the gas supplying member to the heat pipe, the second bulb opens and the vacuum pump is ON to discharge gas in the heat pipe.

[0028] According to the ultracryostat and frigidity supplying apparatus of the present invention, when the cryocooler is ON, gas is supplied into the heat pipe. Thus, frigidity is supplied by repeating condensation of gas in the heat pipe by the action of frigidity of the cryocooler and internal evaporation of the condensed gas by the action of heat supplied from the thermal anchor. On the contrary, when the cryocooler is OFF, the gas supply bulb closes and the bulb of the vacuum pump opens, so that the gas in the heat pipe is discharged. Thus, even if the temperature of the cryocooler rises, heat does not flow into the thermal anchor by heat conduction and convection. Further, penetration of heat caused by heat conduction at the heat pipe wall is low, since a material having low heat conductivity such as stainless steel (SUS) is used.

[0029] When the cryocooler is ON, although noise is large, evaporation rate of helium decreases since heat is discharged. On the contrary, when the cryocooler is OFF, although heat is not discharged, the device can be operated with small noise as same as an ordinal cryostat. Further,

evaporation does not increase needlessly since the cryocooler is not connected thereto.

BRIEF DESCRIPTION OF THE DRAWINGS

[0030] The present invention will become more fully understood from the detailed description given hereinbelow and the appended drawings which given by way of illustration only, and thus are not intended as a definition of the limits of the present invention, and wherein;

[0031] **FIG. 1** is a block diagram of the ultracryostat of the present invention, and

[0032] **FIG. 2** is a block diagram of the ultracryostat of earlier development.

PREFERRED EMBODIMENT OF THE INVENTION

[0033] Hereinafter, the ultracryostat of the present embodiment is explained in more detail with reference to the drawings.

Embodiment 1

[0034] The feature of the invention is that the heat pipe having thermally variable conductance, i.e. having variable thermal conductivity, connects the cryocooler as the frigidity generating member with the thermal anchor continued to the radiation shield of the cryostat which requires the frigidity.

[0035] That is, by using the heat pipe which can switch frigidity transporting effect, frigidity conducts from the cryocooler to the thermal anchor when the cryocooler is ON, and heat does not conduct from the cryocooler to the thermal anchor when the cryocooler is OFF.

[0036] Here, for the following explanation, the frigidity designates an absorption of heat and has opposite meaning of heat diffusion or heat flow. Further, a high pressure supplying pipe and gas compressor and the like included in the cryocooler are omitted.

[0037] **FIG. 1** is a whole constitution of the ultracryostat of the invention, and shows an embodiment in which the cryocooler is connected to the cryostat through the heat pipe, where reference numeral **11** denotes an outer container of the cryostat, reference numeral **12** denotes an inner container and space between inner and outer container, **11** and **12** is kept vacuum. Reference numeral **13** denotes a helium reservoir in which a SQUID sensor **14** is immersed and refrigerated. Reference numeral **15** denotes a measuring section to insert a human head, and a constitution of magnetoencephalogram meter is shown here. Reference numeral **16** denotes a neck portion of the cryostat, in which heat is exchanged with sensible heat of helium gas evaporation. Reference numeral **17** denotes a heat insulation material which prevents penetration of heat from upward. Reference numerals **18** and **19** denote metal-made thermal anchors connected to the neck portion **16**, which block heat radiation toward the outer container **11** by frigidity being supplied from evaporating helium gas and the frigidity being transmitted to heat shields **20** and **21**. Reference numeral **22** denotes the cryocooler and reference numeral **23** denotes the frigidity generating member. Reference numeral **24** denotes a connecting member to retain heat insulation and vacuum, and reference numeral **25** denotes a heat pipe to transmit

frigidity. The cryocooler 22, frigidity generating member 23, thermal anchors 18 and 19, and heat pipe 25 constitute a frigidity supplying device. In the frigidity supplying device, one end of the heat pipe 25 is connected to the frigidity generating member 23 of the cryocooler 22, and the other end thereof is connected to the thermal anchor 18 of the cryostat.

[0038] A narrow tube 26 made of a material having low heat conduction such as stainless steel is connected to the heat pipe 25. A vacuum pump 28 for discharging internal gas of the heat pipe 25 is connected to the narrow tube 26 through a second bulb 27, and a gas container 30 (gas supplying member) for supplying gas to the heat pipe 25 is also connected to the narrow tube 26 through a first bulb 29.

[0039] The both ends of the heat pipe 25 is composed of a material having high heat conduction such as copper, and the intermediate portion thereof is composed of a material having low heat conduction such as stainless steel (SUS).

[0040] As described above, the heat pipe 25 connects the cryocooler 22 with the thermal anchor 18 continued to the radiation shield of the cryostat which requires the frigidity, and the ultracryostat is provided with the vacuum pump 28 for discharging internal gas of the heat pipe 25 and the gas container 30 for supplying gas to the heat pipe 25. By doing so, when the cryocooler 22 is ON, the first bulb 29 opens and gas is supplied from the gas container 30 into the heat pipe 25. Thus, frigidity is provided by repeating condensation of the gas in the heat pipe 25 by frigidity of the cryocooler 22 and internal evaporation of the condensed gas by heat supplied from the thermal anchor 18.

[0041] On the contrary, when the cryocooler 22 is OFF, the first bulb 29 for supplying gas closes and the second bulb 27 of the vacuum pump 28 opens, so that the gas inside the heat pipe 25 is discharged. Thus, even if the temperature of the cryocooler 22 rises, heat does not flow into the thermal anchor 18 by heat conduction and convection. Further, penetration of heat caused by heat conduction at the wall of the heat pipe 25 is low, since a material having low heat conductivity such as stainless steel (SUS) is used.

[0042] When the cryocooler 22 is ON, although noise is large, evaporation rate of helium decreases since heat is discharged.

[0043] On the contrary, when the cryocooler 22 is OFF, although heat is not discharged, the device can be operated with small noise as same as an ordinal cryostat. Further, evaporation does not increase needlessly since the cryocooler 22 is not connected thereto.

[0044] As a result, it becomes possible to provide the ultracryostat in which the heat pipe connects the cryocooler with the thermal anchor continued to the radiation shield of the cryostat which requires the frigidity, and the ultracryostat is provided with the vacuum pump for discharging internal gas of the heat pipe and the gas container for supplying gas to the heat pipe. When the cryocooler is ON, gas is supplied from the gas container into the heat pipe. Thus, frigidity is provided by repeating condensation of the gas in the heat pipe by the action of frigidity of the cryocooler and internal evaporation of the condensed gas by the action of heat supplied from the thermal anchor. On the contrary, when the cryocooler is OFF, the bulb for supplying gas closes and the bulb of the vacuum pump opens, so that the gas in the heat

pipe is discharged. Thus, even if the temperature of the cryocooler rises, heat does not flow into the thermal anchor by heat conduction and convection.

[0045] The entire disclosure of Japanese Patent Application No. 2004-164266 filed on Jun. 2, 2004, including specification, claims, drawings and summary are incorporated herein by reference in its entirety.

What is claimed is:

1. An ultracryostat with a frigidity supplying member to supply frigidity to the ultracryostat which uses cryogen,

wherein one end of a heat pipe is connected to a frigidity generating member of a cryocooler and the other end of the heat pipe is connected to a thermal anchor of a cryostat.

2. The ultracryostat as claimed in claim 1, wherein the heat pipe is made of stainless steel.

3. The ultracryostat as claimed in claim 1, further comprising a member to take in and out gas in the heat pipe from and to outside of the cryostat, wherein the member comprises a tube to take in and out gas from a part of the heat pipe.

4. The ultracryostat as claimed in claim 3, wherein the narrow tube is made of stainless steel.

5. The ultracryostat as claimed in claim 3, wherein the member to take in and out gas in the heat pipe comprises a gas supplying member to supply gas, connected to the narrow tube through a first bulb, and a vacuum pump to discharge gas, connected to the narrow tube through a second bulb.

6. The ultracryostat as claimed in claim 5, wherein the first and second bulbs open or close in conjunction with switching of the cryocooler, when the cryocooler is ON, the first bulb opens to supply gas from the gas supplying member to the heat pipe, the second bulb closes and the vacuum pump is OFF, and when the cryocooler is OFF, the first bulb closes to stop gas supply from the gas supplying member to the heat pipe, the second bulb opens and the vacuum pump is ON to discharge gas in the heat pipe.

7. A frigidity supplying apparatus comprising:

a cryocooler and a heat pipe having controllable thermal conductivity,

wherein the cryocooler comprises a frigidity generating member, one end of the heat pipe is connected to the frigidity generating member, and the cryocooler supplies frigidity from the other end of the heat pipe.

8. The frigidity supplying apparatus as claimed in claim 7, wherein thermal conductivity of the heat pipe is controlled in conjunction with switching of the cryocooler, and the thermal conductivity when the cryocooler is OFF is lower than the thermal conductivity when the cryocooler is ON.

9. The frigidity supplying apparatus as claimed in claim 7, wherein the both ends of the heat pipe are made of copper and a wall of the heat pipe is made of stainless steel.

10. The frigidity supplying apparatus as claimed in claim 7, further comprising a gas regulating member to take in and out gas in the heat pipe.

11. The frigidity supplying apparatus as claimed in claim 10, wherein the gas regulating member comprises a tube to take in and out gas in the heat pipe.

12. The frigidity supplying apparatus as claimed in claim 11, wherein the tube is made of stainless steel.

13. The frigidity supplying apparatus as claimed in claim 11, wherein the gas regulating member further comprises a gas supplying member to supply gas and a vacuum pump to discharge gas, the gas supplying member being connected to the tube through a first bulb, the vacuum pump being connected to the tube through a second bulb.

14. The frigidity supplying apparatus as claimed in claim 13, wherein the first and second bulbs open or close in conjunction with switching of the cryocooler, when the

cryocooler is ON, the first bulb opens to supply gas from the gas supplying member to the heat pipe, the second bulb closes and the vacuum pump is OFF, and when the cryocooler is OFF, the first bulb closes to stop gas supply from the gas supplying member to the heat pipe, the second bulb opens and the vacuum pump is ON to discharge gas in the heat pipe.

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