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A Cryostat Suitable for Thermal Conductivity Measurements under High Pressure

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Abstract. A cryostat especially designed to be used for the measurements of thermal conductivity under high pressure has been constructed. Using this cryostat, the thermal conductivity measurements of laminated superconductors have been sufficiently performed under the pressure up to 10 Kbar at liquid helium temperatures.

1. Introduction
It is well known that the thermal conductance between two bodies increases as a high pressure applied [2]. This is explained as follows. When two solids are pressed together, they touch only at a small number of high spots. The actual contact area is very tiny. Therefore, the applied pressure is enormously magnified at the high spots which undergo plastic deformation. Consequently, the actual contact area and thus the thermal conductance increase as the force with which the pieces are pressed together is added.

Every part of superconducting magnet is under high stress (approximately 1 Kbar), when it works. Furthermore, the temperature of the superconducting wires must be kept below the transition temperature. Therefore, enough data on the thermal conductivity under high pressure are necessary to design and construct a superconducting magnet. However, these data are few. The purpose of our cryostat is to extend the pressure region of the thermal conductivity measurement to 1 Kbar and the temperature region to 1.2 K.

2. Apparatus and Experimental Methods
A cryostat especially designed to be used for measurement of thermal conductivity under high pressure has been constructed. The apparatus is schematically drawn in Fig. 1. The thermal shields of multilayer insulations (double-alminized Mylar with a nylon netting spacer) shown with the dashed lines are attached to liquid nitrogen bath (I) and liquid helium bath (H), respectively. Copper blocks (A) and (C) are thermally anchored to (H) through flexible copper wires (F). A manganin heater of about 100 Ω is attached to a copper block (B). Three 51 Ω - 1/8 W Allen Bradley carbon resistors (D) are used as thermometers. They are attached to
Figure 1. Schematic drawing of the apparatus: A, B, C: cooper blocks, D: thermometers, E: manganin heater, F: flexible cooper wires, G: thermal insulator blocks (G-10), H: liquid helium bath, I: liquid nitrogen bath, J: press head.

(A), (B), and (C) by copper plates and GE7031 varnish. The measuring current is 1 µA for the thermometry.

Two specimens have the same shape. One is placed between (A) and (B), the other is placed between (B) and (C) symmetrically. A 5-ton oil press (J) equipped with a pressure control system is used to apply a constant load on the thermal conductivity measurement system (Copper block (A) - Specimen - Copper block (B) - Specimen - Copper block (C)) through thermal insulator block (G) (made of G-10) and stainless steel rod. Thermal conductivity \( \kappa \) is given as follows:

\[
\kappa = \frac{Q}{\Delta T}
\]

in which \( Q \) is the heat flow through a unit area of the specimen during a unit time and \( \Delta T \) is the temperature gradient. In this experiment, the heat applied to (B) is distributed between (A) and (C) in proportion to each temperature gradient.

3. Result and Discussion

Using this cryostat, the thermal conductivity measurements of laminated superconductors have been performed under the pressure up to 1 Kbar at liquid helium temperature. The specimen to be measured is a part of the superconducting magnet used to accelerate the protons. Approximately 1 Kbar of pressure is applied to the specimen as a result of high magnetic stress when the superconducting magnet works.

The specimen (a rectanguler of 17.5mm long 9.5mm wide 16.5mm high) is consist of 10 layers of superconductor strips wrapped by Kapton tape as shown in Fig. 2. The pressure is applied vertically and the mean thermal conductivity in this direction is measured. Fig. 3 shows the temperature difference \( \Delta T \) vs. heat flow \( Q \) of this laminated superconductors under the pressure of 1 Kbar and 0.07 Kbar at 4.5K. As shown with the dashed line, the temperature difference \( \Delta T \) depends on the heat flow \( Q \) almost linearly. Thus the mean thermal conductivity is derived from the gradient of the dashed line. The mean thermal conductivity \( \kappa \) is 0.14 W/K.m under the pressure of 1 Kbar at 4.5 K. Fig. 4 shows the mean thermal conductivity \( \kappa \) vs applied pressure.
4. Conclusion
The thermal conductivity measurements have been satisfactorily performed under the pressure up to 1 Kbar using cryostat designed and constructed for high pressure experiment at low temperatures.
5. References

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