LT 21 Proceedings of the 21st International Conference on Low Temperature Physics
Prague, August 8-14, 1996
Part S5 - Techniques and applications: Instrumentation

Proposal of Three Terminal Method for Low Temperature Thermal Diffusivity Measurement

Hiroyuki Fujishiro[a], Manabu Ikebe[a], Kiminari Nakasato[a] and Tomoyuki Naito[b]

[a] Faculty of Engineering, Iwate University, 4-3-5, Ueda, Morioka 020, Japan
[b] Institute for Materials Research, Tohoku University, Aoba-ku, Sendai 980, Japan

We propose a new technique, "three terminal arbitrary heating method" for the thermal diffusivity α measurement which at the same time enables one to determine the contact thermal resistance R_C between the sample and holder. By this method, the error in α due to R_C, which becomes progressively consequential at lower temperatures, can be eliminated. The method has been applied to $YBa_2Cu_3O_{7-\delta}$ oxide superconductors and the specific heat C has been accurately determined between 15 to 200K by use of the relation $C=\kappa/\alpha$, where κ is the thermal conductivity quasi-simultaneously measured with α.

1. INTRODUCTION

In low temperature physics and cryogenic engineering, the thermal conductivity κ and the thermal diffusivity α are important parameters of thermal transport. We have proposed an "arbitrary heating method" for the thermal diffusivity α measurement and have developed an automated simultaneous measuring system of α and κ with an identical experimental setup [1,2]. The measuring temperature range is from 10K to 200K using a GM cycle helium refrigerator as a cryostat. The specific heat C of various superconductors was determined from the relation $C=\kappa/\alpha$ and the Debye temperature Θ_D was estimated [3,4]. Since we determined the thermal diffusivity α assuming that the contact thermal resistance R_C at the clamped end was very small, the estimated $C=\kappa/\alpha$ was sometimes liable to errors due to non-negligible R_C especially at low temperatures. In this paper, we propose a new technique, "three terminal arbitrary heating method" for more precise thermal diffusivity α measurement which enables us to estimate R_C as well.

2. EXPERIMENTAL

Fig. 1 shows a schematic view of the sample setup on the cold stage in a vacuum chamber. One end of the sample was soldered to the cold stage by an In metal and a metal film resistance heater was attached to the isolated end of the sample using GE7031 varnish. AuFe(0.07at.%)-chromel thermocouples (73μm in diameter) were used differentially to monitor the three temperatures T_1, T_2 and T_3 at the positions of P_1, P_2 and P_3 which were attached using silver paint. The thermal conductivity κ was also measured under this setup by a steady-state heat flow method using P_1 and P_3 terminals. The determination of the contact thermal resistance R_C and the thermal diffusivity α was performed as follows: when a heat pulse was applied from a heater to a sample, time profile of temperature T(x,t) at a position x is determined by the following one-dimensional diffusion equation,

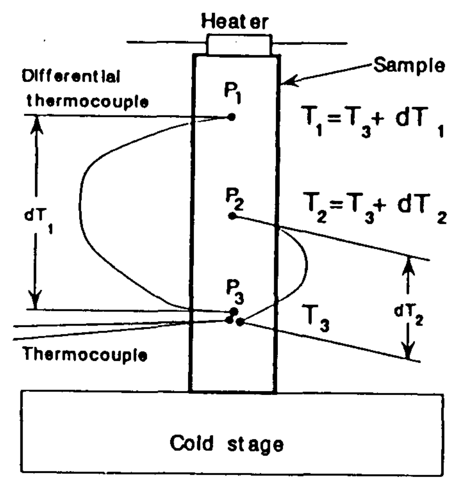

Fig. 1. Schematic diagram of the experimental setup on the cold stage of a GM refrigerator.

$$\frac{\partial T(x,t)}{\partial t} = \alpha \frac{\partial^2 T(x,t)}{\partial x^2}. \qquad (1)$$

For a certain temperature of the cold stage, the temperature changes $T_1(t)$, $T_2(t)$ and $T_3(t)$ at the three measuring points were recorded 7 times/sec after applying the heat pulse. R_C is at the clamped end defined by $R_C=\Delta T/Q$, where ΔT is the discontinuous temperature difference and Q is the power passing through the interface [5]. The measured temperature profile $T_1(t)$ and an arbitrary resistance R_C were used for boundary conditions of the diffusion equation. In order to determine the optimum α and R_C values systematically, the following calculation procedure was used. For a fixed R_C, the maximum values of the experimentally observed $T_2(t)$ and $T_3(t)$ curves and the calculated $T_2'(t)$ and $T_3'(t)$ ones were reduced to 1 and eighty points in the range from 0.1 to 0.9 of the rising part of the temperature changes were sampled to obtain the minimum squared time error $<\Delta t^2>$ between the observed and calculated curves. This procedure was continuously performed for different R_C values until the α values obtained from $T_2(t)$ and $T_3(t)$ agreed with each other and thus the optimum α and R_C were determined. This method has been applied to $YBa_2Cu_3O_{7-\delta}$ (YBCO) oxide superconductor and the specific heat C has been accurately determined between 15 to 200K.

3. RESULTS AND DISCUSSION

Fig. 2 shows the temperature dependence of the thermal diffusivity α_2 and α_3 of the YBCO sample which were calculated at the positions of P_2 and P_3, respectively (in case of R_C=0). The temperature dependence of the thermal conductivity κ was also shown in the inset. At higher temperatures, the thermal diffusivities calculated at both positions are almost the same which indicates R_C is really very small at these temperatures. α_2 becomes larger than α_3 with decreasing temperature. This indicates that α_3 at a nearer position from the clamped end was more influenced than α_2 by R_C. We performed the iterative process to decide the optimum α and R_C. Fig. 3 shows an example of the measured and calculated temperature changes $T_3(t)$, $T_3'(t)$ (R_C=0) and $T_3''(t)$ (R_C =optimum value). The fitting curve which takes account of the contact resistance R_C reproduced the experimental data quite satisfactorily. The revised thermal diffusivity α_{cal} was also shown in Fig. 2. Fig. 4 shows the specific heat $C_2(\kappa/\alpha_2)$, $C_3(\kappa/\alpha_3)$ and revised $C_{cal}(\kappa/\alpha_{cal})$, together with t he Debye's specific heat C_{Debye}. The revised C_{cal} taking account of the contact resistance R_C satisfactorily reproduced the Debye's specific heat C_{Debye} with Θ_D=430K down to low temperatures.

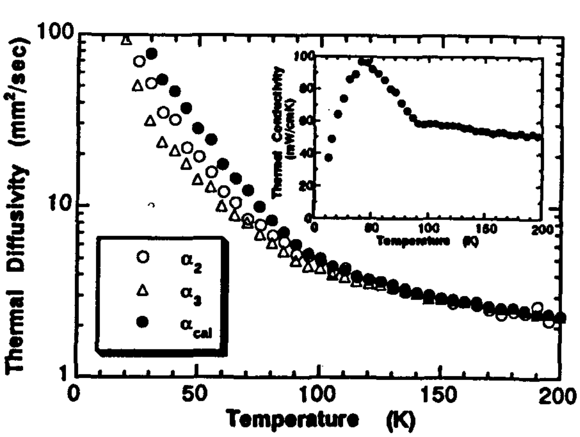

Fig. 2. Temperature dependence of the thermal diffusivity α_2 and α_3 (R_C=0) and α_{cal} (R_C=optimum).

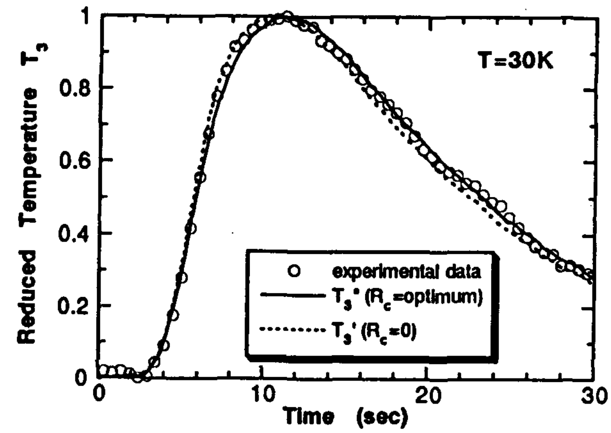

Fig. 3 An Example of measured and calculated time variations of temperature at P_3.

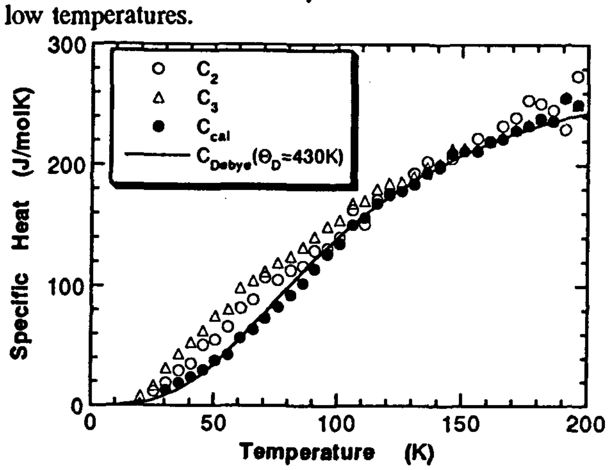

Fig.4. The specific heat C vs. temperature T.

4. SUMMARY

We propose a "three terminal arbitrary heating method" for the thermal diffusivity α measurement. By this method, the error in α due to the contact thermal resistance R_C, which becomes progressively impotant at lower temperatures, can be eliminated.

REFERENCES

[1] H. Fujishiro et al.: Cryo. Eng. 28 (1993) 533.
[2] M. Ikebe et al.: J. Phys. Soc. Jpn. 63 (1994) 3107.
[3] H. Fujishiro et al.: Jpn. J. Appl. Phys. 33(1994) 4971.
[4] H. Fujishiro et al.: Physica C235-240 (1994) 825.
[5] C. McMenamin et al.: Cryogenics 33 (1993) 941.