The Thermal Diffusivity of Quasicrystalline $Al_{72}Pd_{20}Mn_8$ Alloy

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A new cell has been developed for measuring the thermal diffusivity of small samples [about $(5 \times 2 \times 0.5)$ mm^3], using the laser flash method. The thermal diffusivities of small samples of titanium, SUS304 and Pyrex 7740 glass measured with this cell agree well with those obtained from samples of 10 mm in diameter and 0.4 mm in thickness. Then, the thermal diffusivity between 300 K and 950 K of quasicrystalline $Al_{72}Pd_{20}Mn_8$ with a single domain size of 5 mm, and that of crystalline $Al_{60}Pd_{25}Mn_{15}$ were measured. The thermal diffusivity of quasicrystalline $Al_{72}Pd_{20}Mn_8$ was found to be 4 to 7 times smaller than that of crystalline $Al_{60}Pd_{25}Mn_{15}$.

1. Introduction

A large number of quasicrystals become available since the discovery of an icosahedral phase in a rapidly solidified $Al_{86}Mn_{14}$ alloy in 1984 [1]. Many studies have been devoted to characterize the electronic and magnetic properties as well as the crystallographic features of such quasicrystals, however, knowledge of their transport properties is still very limited [2, 3].

Metastable quasicrystalline samples are usually prepared by rapid quenching, and almost all these samples contain a large number of defects. Recently, thermodynamically stable quasicrystals have been prepared [4, 5] and a quasicrystalline $Al_{72}Pd_{20}Mn_8$ ingot with large single domains was obtained by growing directly from the liquid phase [6].

The main purpose of this paper is to measure the thermal diffusivity between 300 K and 950 K of a single domain quasicrystalline $Al_{72}Pd_{20}Mn_8$ alloy by the laser flash method with a newly developed cell for small samples of about $(5 \times 2 \times 0.5)$ mm^3 in size.

2. Experimental Procedure

$Al_{72}Pd_{20}Mn_8$ was melted in an induction furnace and solidified in a copper mold in vacuum [6]. The single domains of this alloy are usually 2–3 mm in diameter and about 5 mm in length. The sample for measuring the thermal diffusivity was cut and polished by emery paper to become a piece of $(5 \times 2 \times 0.5)$ mm^3.

The apparatus for measuring the thermal diffusivity is shown in Figure 1. The sample is irradiated by a laser beam with a pulse duration of 1 ms and a diame-

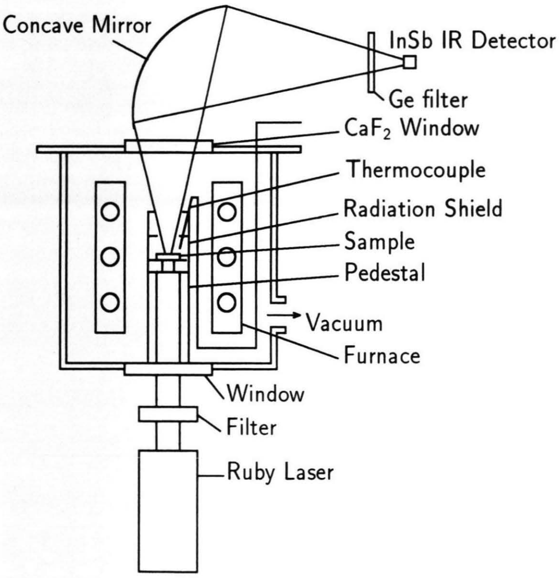

Fig. 1. Schematic diagram of the experimental arrangement for measuring the thermal diffusivity using the laser flash method.

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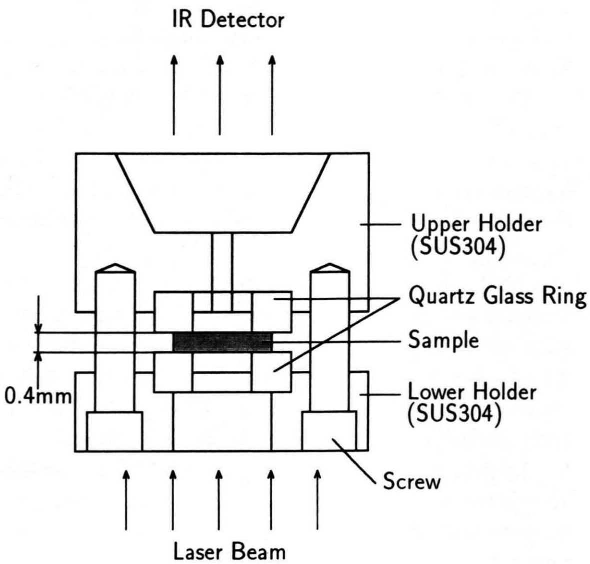

Fig. 2. Schematic diagram of a cell for measuring the thermal diffusivity of small samples.

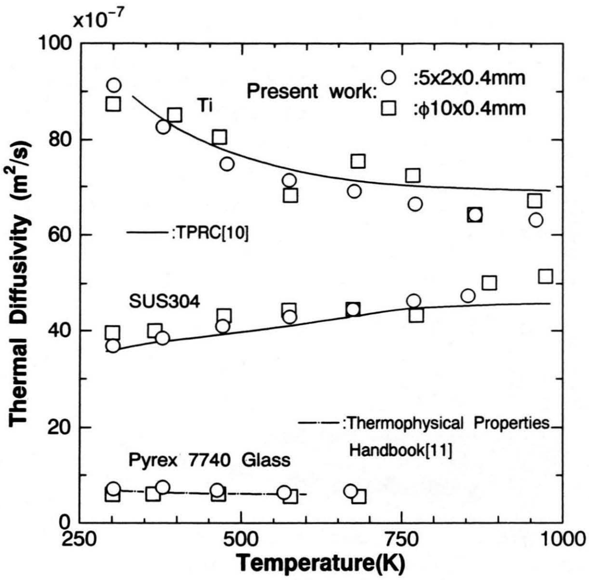

Fig. 3. Thermal diffusivities of titanium, SUS 304 and Pyrex 7740 glass.

ter of 10 mm. The temperature response at the center of the back surface of the sample is focused through a CaF_2 window by an aluminum concave mirror on a liquid-N_2-cooled InSb infrared detector. The thermal diffusivity α can be estimated from the temperature response using the equation [7]

$$\alpha = 1.38\, l^2/\pi^2\, t_{1/2}\,,$$

where l is the thickness of the sample and $t_{1/2}$ the time required for the temperature response to reach 1/2 of its maximum value. Correction for the heat loss by radiation was made by using the theoretical values [8] estimated from the idea proposed by Takahashi et al. [9].

Both surfaces of the sample were coated with carbon power (Type dgf 123, Miracle Powder Products Corp.) by spraying to increase the signal top noise ratio. The sample was heated by a nicrome wire heater, and its temperature was controlled to ± 1 K of the required temperature.

Disk shaped samples of about 10 mm diameter are usually used for the laser flash method, the single domains of quasicrystals, however, are smaller. Therefore the cell shown in Fig. 2 was designed for samples with dimensions of $(5 \times 2 \times 0.5)$ mm^3. The sample is sandwiched by two quartz glass rings of 2 mm thickness and 5 mm inner diameter. The low thermal conductivity of quartz glass is convenient for minimizing heat leaking. A hole of 1 mm diameter in the center of the upper holder, set close to the back surface of the sample prevents mixing of the laser beam and the infrared radiation emitted by the sample. The cell is kept in a vacuum chamber.

3. Results and Discussion

The feasibility of the new cell was checked using titanium (purity: 99.5%), SUS 304 and Pyrex 7740 glass (Corning Ltd.) whose thermal diffusivities are known [10, 11]. Both small samples $(5 \times 2 \times 0.4)$ mm^3 and disk shaped samples (10 mm in diameter and 0.4 mm in thickness) were prepared from the same block of these standard materials.

Figure 3 gives the results of these measurements with the laser flash method and the correspondingly literature values [10, 11]. These results clearly confirm that the new cell works well in the thermal diffusivity range between 5×10^{-7} m^2/s and 1×10^{-5} m^2/s and the temperature range between 300 K and 950 K.

Based on these encouraging results, the thermal diffusivity of quasicrystalline $Al_{72}Pd_{20}Mn_8$ was measured. The results are shown in Fig. 4 together with those of crystalline $Al_{60}Pd_{25}Mn_{15}$ for comparison. Empty pentagonal plots show the thermal diffusivity values determined on heating by steps from room

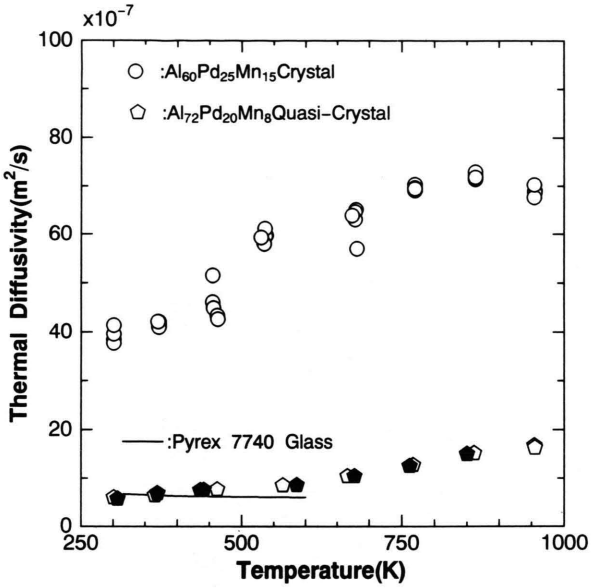

Fig. 4. Thermal diffusivity of quasicrystalline $Al_{72}Pd_{20}Mn_8$ and crystalline $Al_{60}Pd_{25}Mn_{15}$ alloys.

temperature, and solid pentagonal plots correspond to the values obtained on cooling by steps from 950 K. Any significant difference is not detected in the thermal diffusivity values of quasicrystalline $Al_{72}Pd_{20}Mn_8$ alloy on heating and cooling.

At room temperature the thermal diffusivity of quasicrystalline $Al_{72}Pd_{20}Mn_8$ ($6.0 \pm 0.2 \times 10^{-7}$ m^2/s) is very low and similar to that of Pyrex glass. A slight increase is found with increasing temperature. On the other hand, the thermal diffusivity of crystalline $Al_{60}Pd_{25}Mn_{15}$ is $40 \pm 2 \times 10^{-7}$ m^2/s at room temperature, which roughly equals that of stainless steel. It increases up to 70×10^{-7} m^2/s with increasing temperature. At easily seen in Fig. 4, the thermal diffusivity of quasicrystalline $Al_{72}Pd_{20}Mn_8$ is 4 to 7 times smaller than that of crystalline $Al_{60}Pd_{25}Mn_{15}$ in the temperature region between 300 K and 950 K.

The present study represents the first effort at measuring the thermal diffusivity of a singe domain quasicrystalline alloy by using a new type of cell for samples whose size is about $(5 \times 2 \times 0.5)$ mm^3, coupled with the laser flash method. The results are still limited to $Al_{72}Pd_{20}Mn_8$. Nevertheless, the present authors take the view that these results provide the essential features of the thermal transport property of quasicrystals in contrast to that of related crystalline alloys.

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