

THERMAL CONDUCTIVITY OF Al-Li ALLOY AT CRYOGENIC TEMPERATURES^①

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ABSTRACT By using steady-thermal flow method, the thermal conductivity of round material bars 3 mm in diameter and 6 mm in length after solid solution treatment (830 K, 1 h) were measured between 4~90 K range in continuous flow helium isothermal temperature apparatus. Some experimental results were reported and profitable discussion about mechanism of thermal conductivity at different temperatures was made.

Key words thermal conductivity Al-Li alloy cryogenic temperatures

1 INTRODUCTION

With the advance of the applying study on superconducting material, the exploitation of structural material used in cryogenic temperatures has acquired extensive attention. Al-Li alloy is regarded as a cryogenic temperature structural material with highly applied value for its excellent properties such as low density, high rigidity, non-magnetic property and structure stability and etc^[1-3]. As far as cryogenic temperature structural material is concerned, its thermal conductivity is surely an important physical parameter. In this paper, some experimental results are reported about thermal conductivity of binary Al-Li alloy containing different components used at cryogenic temperatures and profitable discussion about mechanism of thermal conductivity at different temperatures was made.

2 MATERIAL AND METHOD

The experimental material was Al- (10.7% - 3.0%) Li alloy and pure Al (99.99%). It was made into a round bar 3 mm in diameter and 60 mm in length. After solid solution treatment (830 K, 1 h), thermal conductivity of the bars were measured between 4~90 K range in continuous-flow helium isothermal temperature apparatus

by using steady-thermal flow method.

3 RESULTS AND DISCUSSION

Fig. 1 shows the relation curve between temperature and thermal conductivity of pure Al. When temperature is changed, the thermal conductivity first increases, at 30 K it comes up

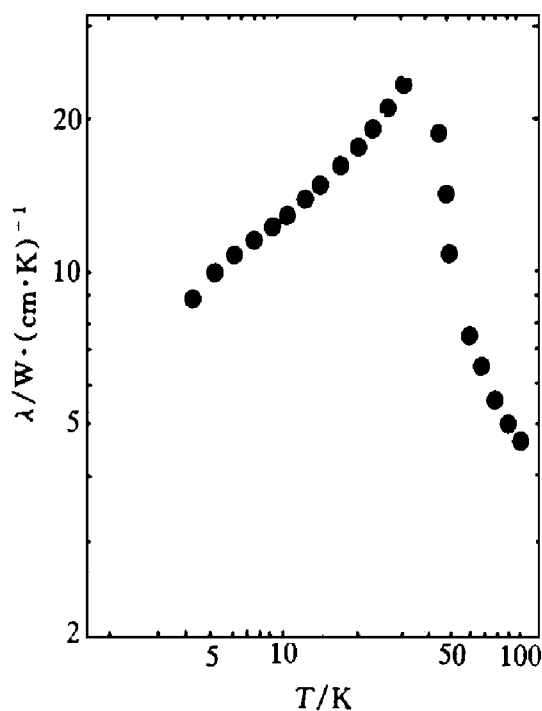


Fig. 1 Temperature(T) dependence of thermal conductivity(λ) of pure Al

to a maximum value, then decreases with increasing temperature and the decreasing rate is faster than increasing rate at low temperature.

Fig. 2 shows the relationship between temperature and thermal conductivity of Al-Li alloy containing four kinds of components, which shows the same variation tendency as that of pure Al, but the temperature with the appearance of maximum thermal conductivity of Al-Li alloy increases and can arrive at 50 K. Thermal conductivity varies with different Li contents. The value of thermal conductivity becomes less with increasing of Li content, but temperature with maximum thermal conductivity almost unchanged.

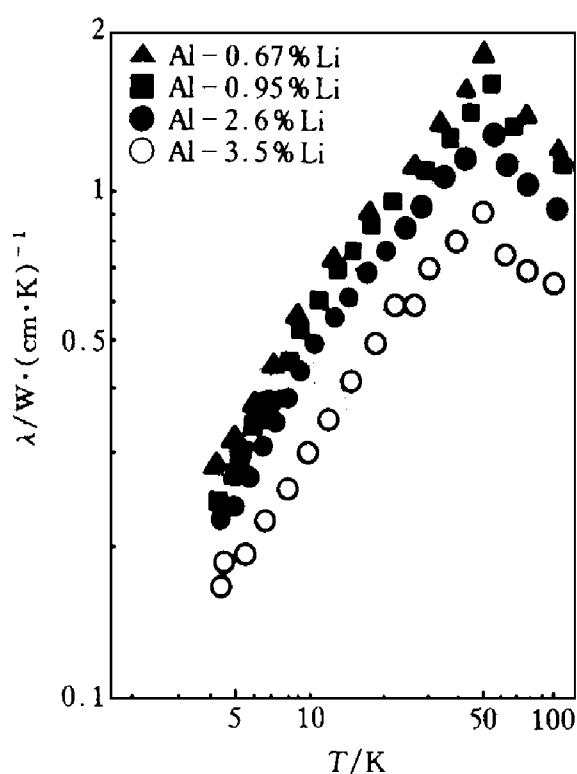


Fig. 2 Temperature(T) dependence of thermal conductivity(λ) of Al-Li alloys

Generally speaking, the main carriers of thermal flow in solids are electron and phonon. It can be expressed in mathematical form^[4]:

$$K = K_e + K_{ph}$$

where K is thermal conductivity of the material. K_e is thermal conductivity of free electrons which is caused by movement of free electrons; K_{ph} is thermal conductivity of phonon which is caused by heat vibration of ion in lattice, i. e. contribution of lattice vibration. For pure metal,

thermal conductivity mainly depends on the movement of free electrons and for alloy the contribution of thermal conductance of phonon should also be considered. However, in the case of cryogenic temperature, thermal conductivity of alloy mainly depends on the thermal conductivity of free electrons because of the weak lattice vibration.

In terms of electron energy band theory, free electrons in metal are hindered in potential field caused by ion in lattice and crystal defect rather than moving freely as ideal gas molecule does. Thus, resistance W_e of electronic thermal conduct can be divided into thermal resistance W_e^s by scattering of main solute atoms, impurity and various crystal defects and W_e^{ph} by lattice vibration scattering. According to the results of this experiment, the relationship between W_e and temperature is given by:

$$\begin{aligned} K_e^{-1} &= W_e = W_e^s + W_e^{ph} \\ &= \alpha T^{-1} + \beta T^{-2} \end{aligned}$$

where α and β are constant; T is temperature.

In the case of cryogenic temperature, thermal resistance is mainly W_e^s and the value of K_e increases in proportion to T , but at higher temperature, K_e decreases in proportion to T because thermal resistance transforms into W_e^{ph} . As for even higher temperature (> 100 K), thermal conductivity K tends to be stable because of the increasing phonon thermal conductivity K_{ph} .

The experimental results show that Al-Li alloy differs from pure Al on temperature with maximum thermal conductivity. This is because that the scattering process of phonon is postponed by Li element soluted in Al lattice. Thermal conductivity of pure Al and Al-Li alloy shows the same variation trend with temperature, which proves in the other way that thermal conduct at cryogenic temperatures is mainly caused by free electrons.

Comparing the results of Fig. 1 and Fig. 2, we can conclude that thermal conductivity of Al-Li alloy is much less than that of pure Al, and the value of K decreases with increasing Li content. According to the metallic electron theory, a large number of free electrons in metal can be

regarded as free electronic gas, so we can describe the thermal conductivity of free electrons by using thermal conductivity formula of ideal gas^[5]:

$$K_e = 1/3 C_v^e \cdot V \cdot L$$

where C_v^e is electron thermal capacitance per unit volume; V is average speed of free electrons; L is mean free path. As far as alloy is concerned, the existence of solute elements will diminish the mean free path of free electron and then cut down the average speed, so we can learn from formula (3) that thermal conductivity of alloy is less than that of pure metal. This difference will be obvious in the case of cryogenic temperature at which the thermal conductivity is mainly caused by free electrons.

4 CONCLUSIONS

(1) Thermal conductivity of pure Al and Al-Li alloy changes with temperature. Thermal conductivity of experimental sample first increases with temperature from low degree (4 K) to the

maximum at (30 ~ 50 K) and then decreases with increasing temperature.

(2) Temperature with maximum value of K keeps stable roughly with increasing Li content, but the value of K decreases.

(3) Thermal conductivity of Al and Al-Li alloy is mainly caused by electron thermal conductivity and also affected by solute atoms and lattice defects.

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4 SUMMARY

The internal circulation within bubbles results in a series of special electrophoretic phenomena, such as the dependence of electrophoretic mobility on the bubble size and the electrical field direction. These can not be explained by the classical electrophoresis theories. In the previous work, authors have advanced a new formula to describe the bubble electrophoretic mobility. The aim of this paper is at the verification of the formula experimentally. We are satisfactory to point out that the experimental results are all predictable according to the new-derived theoretical formula (Eqn. 6).

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