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Temperature dependence of thermal conductivity in W and W–Re alloys from 300 to 1000 K

T. Tanabe[a,1], C. Eamchotchawalit[a], C. Busabok[a], S. Taweethavorn[a], M. Fujitsuka[b,*], T. Shikama[c]

[a] Thailand Institute of Scientific and Technological Research, 196 Phahonyothin Road, Chatuchak, Bangkok 10900, Thailand
[b] National Institute for Materials Science, Sengen 1-2, Tsukuba, Ibaraki 305-0047, Japan
[c] The Oarai Branch, Institute for Materials Research, Tohoku University, Narita-cho, Oarai-machi, Higashiibaraki, Ibaraki 311-13, Japan

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Abstract

The thermal conductivities of W and W–Re alloys with Re contents of up to 25% were obtained from their thermal diffusivity data. The W and W–Re alloys were fabricated by powder metallurgy process. The samples with 8-mm diameter and 1-mm thickness were prepared by wire cutting tool. The thermal diffusivities of W and W–Re alloys were measured from room temperature to 1000 K. The results show that the thermal conductivity of the W decreases while those of W–Re increase when temperature increases. Thermal conductivity due to electron estimated from Wiedeman–Franz–Lorenz law in W decreases with temperature while those in W–Re alloy increases. The contribution of phonon on the thermal conductivity of W with high percent Re proved to be less than the contribution of electron at high temperatures.

Keywords: Alloy; Temperature; Conductivity

1. Introduction

Though tungsten (W) and tungsten–rhenium (W–Re) alloys are very popular materials used at high temperatures, there is no systematic data on the thermal conductivity of the alloy system. Recently, some of the authors measured the thermal diffusivity of the alloy system (up to 25%Re), and found that the thermal diffusivity of the alloy increases with an increase in temperature, while that of W decreases [1].

The objective of this paper is to elucidate the reason of the temperature dependence difference between W and W–Re alloys. To clarify the problem, the thermal diffusivity is transformed into thermal conductivity so as to be able to treat the problem from the theoretical standpoint.

2. Experimental procedure

Tungsten (W) alloys with 0%, 5%, 10% and 25% rhenium (Re) were prepared by powder metallurgy.

* Corresponding author. Tel.: +81-298-59-2557; fax: +81-298-59-2501.
E-mail address: fujitsuka.masakazu@nims.go.jp (M. Fujitsuka).
[1] Present address: National Institute for Materials Science, 1-2 Sengen, Tsukuba, Ibaraki 305-0047, Japan.

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The powder of W with 99.9% purity and Re with 99.99% purity were mixed in ball mill using acetone as solvent for 24 h and dried at 535 K. The mixtures were pressed into rectangular shape with the dimension of $10 \times 30 \times 50$ mm using cold isostatic pressing (CIP) at 2000 kgf/cm^2. The samples were annealed in hot press at 2273 K (2000 °C) for 1 h in argon atmosphere before being placed in hot isostatic pressing (HIP) at 2173 K under 1500 kgf/cm^2 for 1 h. The chemical compositions of the samples were analyzed by inductively coupling plasma atomic emission spectroscopy (ICPS).

The samples were cut by wire cutting tool into a disk of 8-mm diameter and 1-mm thickness. Both sides of the sample were polished by Al_2O_3 powder (0.5 μm) before measuring thermal diffusivity. The thermal diffusivity data were obtained by the conventional half-time method using the advanced laser flash technique (Sinku Rikou). The thermal diffusivity measurements were carried out from room temperature up to 1000 K under vacuum ($< 3 \times 10^{-3}$ Pa). Then the samples were cooled to room temperature to obtain the room temperature diffusivity once again in order to check the occurrence of oxidation during measurement.

3. Results and discussion

The chemical analysis of the W and W–Re alloys with nominal Re contents of 5%, 10% and 25% show that Re contents are 0, 5.3, 9.8 and 25 wt.%, respectively. There are also impurities in the sample such as C, O and N in the range of ppm, which are too small to have an effect on the properties of the W–Re alloy.

The thermal diffusivities of the W–Re alloys were measured at various temperatures. The results are reproduced in Fig. 1. The thermal diffusivity of pure W decreases when temperature increases while those of W–Re alloys are almost stable or increase with test temperature. These data were transformed into thermal conductivities using the following relation.

$$\delta t = \alpha C_p D$$

where δt is a thermal conductivity, α is thermal diffusivity, C_p is specific heat capacity and D is density. In this equation, C_p of an alloy at a given temperature above room temperature is calculated from the data [2,3] by interpolation method for temperature and also for Re content; those of W are 0.132 J/(g K) at 298 K and 0.15 J/(g K) at 1000 K, and those of W–26%Re are 0.138 J/(g K) at 300 K and 0.16 J/(g K) at 1000 K. The change of density with temperature is neglected because of the very small amount of thermal expansion coefficient (volume change at 1000 K due to thermal expansion is estimated to be less than 1%). The calculated thermal conductivities of W–Re alloys are shown in Fig. 2 (here, the porosities of the samples were all very small, so we did not use Maxwell–Eucken equation). The conductivity of W decreases with an increase of temperature while those of alloys increase and the tendency is clearer as the Re content increases. To clarify the cause, thermal conductivities due to electron (δ_e) and phonon (δ_p) were taken into consideration. To evaluate the contributions of electron and phonon to the thermal conductivity of W–Re alloys, the δ_e was calculated based on the Wiedemann–Franz–Lorenz law using the electrical resistivity data shown in the literature [4] (the Debye temperature of W is about 300–330 K). Fig. 3 shows the temperature dependence of electrical resistivity in the W–Re alloys as a function of temperature. Here, the data

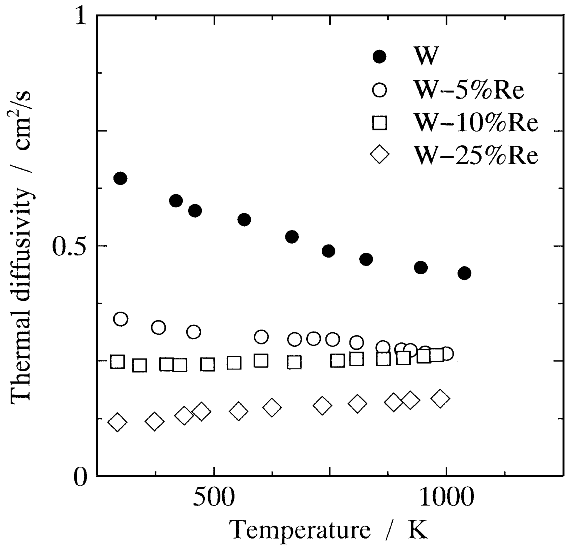

Fig. 1. Temperature dependence of the thermal diffusivities of W–Re alloys.

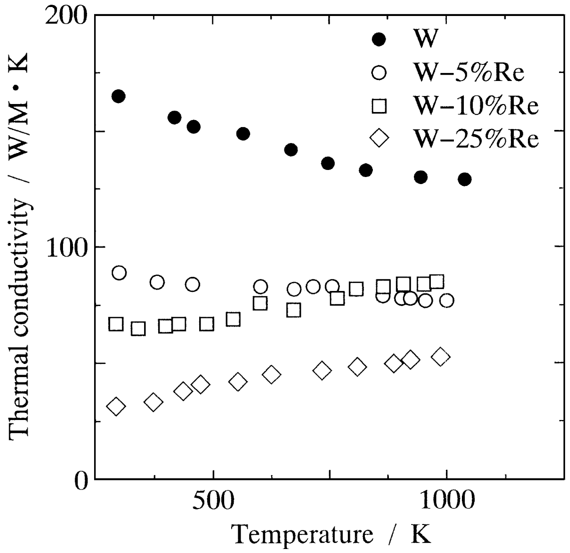

Fig. 2. Temperature dependence of the thermal conductivities of W–Re alloys.

shown in the literature are presented as solid lines and the calculated resistivities corresponding to the Re contents are also presented. The electrical resistivity of pure W and W–Re alloys shows the same tendency; that is, the resistivity increases when the

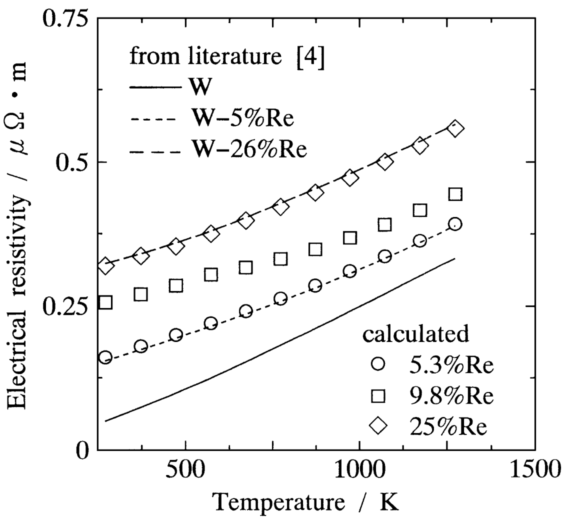

Fig. 3. Temperature dependence of electrical resistivities of W–Re alloys. Solid lines from the literature [4], the rests were calculated.

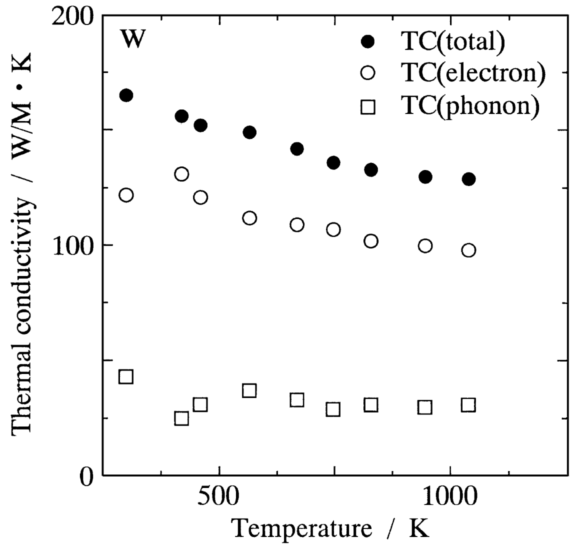

Fig. 4. Temperature dependence of the thermal conductivity of W. TC: total thermal conductivity, TC(e): thermal conductivity due to electron, TC(p): thermal conductivity due to phonon.

temperature increases, and it is obvious that increase of the amount of Re brings about the increase of resistivity.

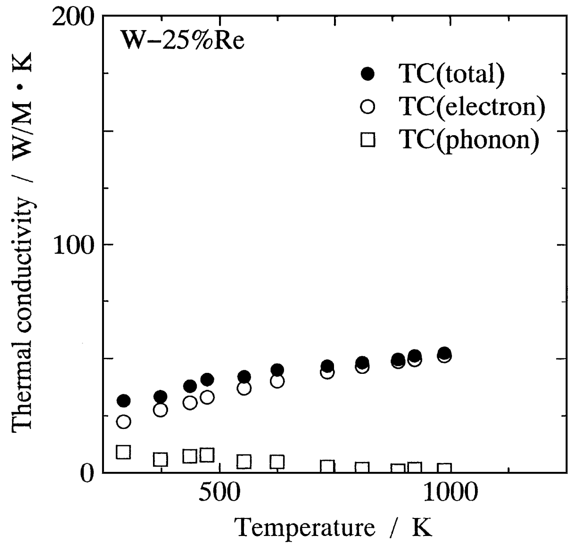

Fig. 5. Temperature dependence of the thermal conductivity of W–25%Re. TC: total thermal conductivity, TC(e): thermal conductivity due to electron, TC(p): thermal conductivity due to phonon.

The thermal conductivity of the electron was calculated using the equation below:

$$\delta_e \times \rho / T = 2.443 \times 10^{-8} \ (\mathrm{V}^2 \ \mathrm{K}^{-2})$$

where δ_e is the thermal conductivity of electron, ρ is electrical resistivity of material and T is temperature (K).

Thermal conductivity of phonon was obtained by subtracting the thermal conductivity of electron, δ_e, from the total thermal conductivity. Here, the temperature dependence of electrical resistivity, specific heat and density of the alloys were referred from the literature [2,4]. Inadequate data forced the authors to estimate the resistivity using the interpolation method not only on the temperature but also on Re content.

Figs. 4 and 5 show the temperature dependence of thermal conductivity in W and that in W–25%Re selected as a typical example of the alloy. It is clear that thermal conductivity of W and W–25%Re are contributed by electron and phonon. In W, both thermal conductivities due to electron and phonon decrease with the increase of temperature. In W with 25%Re, the δ_e increase considerably with an increase of temperature, while δ_p decreases. As the δ_e always increases with temperature in W–Re alloys with more than 5%Re, if δ_p does not drop severely with temperature, increase of thermal conductivity of the alloy would be observed as test temperature rose, and the phenomenon is really observed in W–25%Re as shown in Fig. 5.

In brief, in the W–Re alloys at high temperature, the thermal conductivities due to electrons have more contribution to the total thermal conductivity of the alloy than those due to phonons.

4. Conclusions

The thermal conductivities of W decrease with an increase of temperature, while those of W–25%Re increase. The thermal conductivities due to the electron in W decrease with an increase of temperature; however, those in W–25%Re increase. At high temperature, the thermal conductivities due to electrons have more pronounced effect to the thermal conductivity of the materials than those due to phonons.

References

[1] M. Fujitsuka, et al., J. Nucl. Mater. 283–287 (2000) 1148.
[2] High Purity Metals and Chemicals for R&D, Nilaco, Tokyo, 1994, pp. 240–244.
[3] El Be Khaterinikof, et al. (Eds.), Handbook for Ultrahigh Melting Point Materials, Metallurgy Publisher, Moscow, 1969, p. 18, Japanese edition.
[4] T. Grobstein, et al. (Eds.), Metals Handbook, ASM International, Refractory Metal, Fiber Reinforced Composites, vol. 2, NASA Lewis Research Center, USA, 1990, p. 583.