



Determination of thermal conductivity and interfacial energy of solid Zn solution in the Zn–Al–Bi eutectic system

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ABSTRACT

The equilibrated grain boundary groove shapes for solid Zn solution (Zn–3.0 at.% Al–0.3 at.% Bi) in equilibrium with the Zn–Al–Bi eutectic liquid (Zn–12.7 at.% Al–1.6 at.% Bi) have been observed from quenched sample with a radial heat flow apparatus. Gibbs–Thomson coefficient, solid–liquid interfacial energy and grain boundary energy for solid Zn solution in equilibrium with Al–Bi–Zn eutectic liquid have been determined to be $(5.1 \pm 0.4) \times 10^{-8}$ K m, $(80.1 \pm 9.6) \times 10^{-3}$ and $(158.6 \pm 20.6) \times 10^{-3}$ J m⁻² from the observed grain boundary groove shapes, respectively. The thermal conductivity variation with temperature for solid Zn solution has been measured with radial heat flow apparatus and the value of thermal conductivity for solid Zn solution has been determined to be 135.68 W/km at the eutectic melting temperature. The thermal conductivity ratio of equilibrated eutectic liquid to solid Zn solution, $R = K_{L(\text{Zn})}/K_{S(\text{Zn})}$ has also been measured to be 0.85 with Bridgman type solidification apparatus.

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1. Introduction

The solid–liquid interfacial energy, σ_{SL} , is recognized to play a key role in a wide range of metallurgical and materials phenomena from wetting [1] and sintering through to phase transformations and coarsening [2]. Thus, a quantitative knowledge of σ_{SL} values is necessary. However, the determination of σ_{SL} is difficult. Since 1985, a technique for the quantification of solid–liquid interfacial free energy from the grain boundary groove shape has been established and measurements have been reported for several systems [3–21]. The grain boundary groove shape formed at the solid–liquid interface in a thermal gradient can be used to determine the interfacial energy and the interface near the groove must everywhere satisfy

$$\Delta T_r = \left[\frac{1}{\Delta S_f} \right] \left[\left(\sigma_{SL} + \frac{d^2 \sigma_{SL}}{dn_1^2} \right) \kappa_1 + \left(\sigma_{SL} + \frac{d^2 \sigma_{SL}}{dn_2^2} \right) \kappa_2 \right] \quad (1)$$

where ΔT_r is the curvature undercooling, ΔS_f is the entropy of fusion per unit volume, $n(n_x, n_y, n_z)$ is the interface normal, κ_1 and κ_2 are the principal curvatures, and the derivatives are taken along the directions of principal curvature. Eq. (1) is valid only if the interfacial free energy per unit area is equal to surface tension per unit length, $\sigma_{SL} = \gamma$. When interfacial free energy differs from surface tension, the problem is more complicated and the precise

modification of the Gibbs–Thomson equation is not yet established [21]. When the solid–liquid interfacial free energy is isotropic, Eq. (1) becomes

$$\Delta T_r = \frac{\sigma_{SL}}{\Delta S_f} \left(\frac{1}{r_1} + \frac{1}{r_2} \right) \quad (2)$$

where r_1 and r_2 are the principal radii of the curvature. For the case of a planar grain boundary intersecting a planar solid–liquid interface, $r_2 = \infty$ and the Eq. (2) becomes

$$\Gamma = r \Delta T_r = \frac{\sigma_{SL}}{\Delta S_f} \quad (3)$$

where Γ is the Gibbs–Thomson coefficient. This equation is called the Gibbs–Thomson relation [13].

Gündüz and Hunt [13] also developed a finite difference model to calculate the Gibbs–Thomson coefficient. This numerical method calculates the temperature along the interface of a measured grain boundary groove shape rather than attempting to predict the equilibrium grain boundary groove shape. If the grain boundary groove shape, the temperature gradient in the solid (G_S) and the ratio of thermal conductivity of the equilibrated liquid phase to solid phase ($R = K_L/K_S$) are known or measured the value of the Gibbs–Thomson coefficient (Γ) is then obtained with the Gündüz and Hunt's numerical method.

One of the common techniques for measuring solid–liquid interfacial free energy is the method of grain boundary grooving in a temperature gradient. In this technique, the solid–liquid interface is equilibrated with a grain boundary in a temperature gradi-

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