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Melting of alloys along the inter-phase boundaries in eutectic and peritectic systems

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Abstract

We discuss a simple model of the melting kinetics along the solid–solid interface in eutectic and peritectic systems. The process is controlled by the diffusion inside the liquid phase and the existence of a triple junction is crucial for the velocity selection problem. Using the lubrication approximation for the diffusion field in the liquid phase, we obtain scaling results for the steady-state velocity of the moving pattern depending on the overheating above the equilibrium temperature and on the material parameters of the system, including the dependences on the angles at the triple junction.

Keywords: Melting of alloys; Dendritic growth; Diffusion; Kinetics self-organization and patterning

1. Introduction

The systematic investigation of melting kinetics in alloys, and particularly in eutectic and peritectic systems, is much less developed than the investigation of solidification (for a recent review on solidification see [1] and references therein). Microstructures, being at the center of materials science and engineering, are formed during the solidification process and, in this sense, the melting process is less attractive for practical applications.

However, the interfacial pattern selection problem during the melting process might be very interesting. For example, in our previous publications [2,3] we discussed a free boundary problem for two moving interfaces that strongly interact via the diffusion field in the liquid layer between them. This problem arises in the context of liquid film migration during the partial melting of solid alloys [4] and could also be relevant to the sintering process in the presence of the liquid phase [5]. For the melting of one-phase alloys to proceed in this way, the local equilibrium concentrations have to be different for the two interfaces providing the driving force for the process. It is now well accepted (see e.g. [6,7]) that the difference of the equilibrium states at the melting and solidification fronts is due to the coherency strain energy which is important only at the melting front because of the sharp concentration profile ahead of the moving melting front.

The other source of elastic deformations during the melting process, even in pure materials, is the density difference between the solid and the liquid phase. If the melt inclusion is entirely inside the solid matrix, inhomogeneous elastic deformations inevitably arise. The peculiar behavior of the melting kinetics in such systems was discussed in Refs. [8,9].

The main purpose of this paper is to describe the problem of contact melting in eutectic and peritectic systems along the boundary between two solid phases (see Figs. 1 and 2). The local concentrations at the L/α and L/β interfaces in such systems are different because of the chemical difference between the α and β phases, and weak coherency strain effects are not so important here. If we also assume that the liquid phase extends up to the sample surfaces, the mentioned elastic deformations due the

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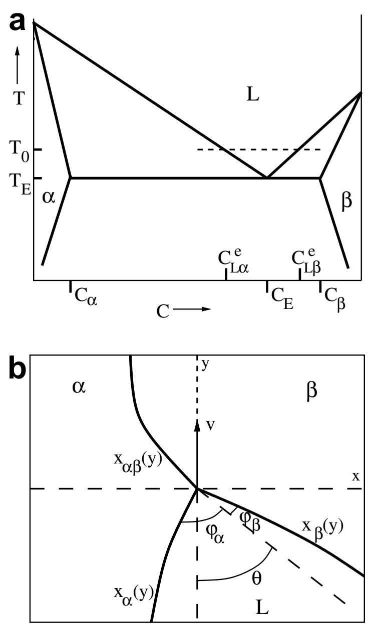

Fig. 1. Schematic presentation of the phase diagram (a) and configuration of different interfaces near the triple junction (b) in eutectic systems. $x_{\alpha\beta}(y)$ is the interface between two solid phases, α and β; the interfaces between the liquid phase L and the solid phases are denoted by $x_\alpha(y)$ and $x_\beta(y)$. In the steady state regime this configuration moves along the y-axis with a constant velocity v. The origin of the coordinate system is located at the triple junction.

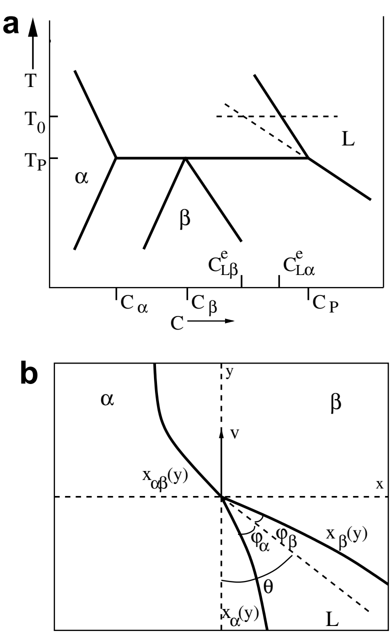

Fig. 2. Schematic presentation of the phase diagram (a) and configuration of different interfaces near the triple junction (b) in peritectic systems. $x_{\alpha\beta}(y)$ is the interface between two solid phases α and β; the interfaces between the liquid phase L and the solid phases are denoted by $x_\alpha(y)$ and $x_\beta(y)$. In the steady-state regime this configuration moves along the y-axis with a constant velocity v. The origin of the coordinate system is located at the triple junction.

density difference are not important either, because a weak hydrodynamic flow inside the liquid phase compensates the density difference.

We concentrate here on the velocity selection problem during the melting along the solid–solid interface. The presence of the triple junction (see Figs. 1b and Fig. 2b) plays a crucial role in this process. In the classical problem of dendritic growth, where the triple junction is not present, the velocity selection is controlled by tiny singular effects of the anisotropy of the surface energy (for review see [10,11]). The triple junction produces a very strong perturbation of the liquid–solid interfaces and controls the velocity selection. The other important difference compared to the classical dendritic problem is that the kinetics of the contact melting in eutectic and peritectic systems is controlled by the diffusion inside the needle-like liquid phase and not in the outer phase.

All features of the contact melting process mentioned so far are common for both systems. There is, however, important difference between eutectic and peritectic systems. In the eutectic system (Fig. 1) both interfaces L/α and L/β are melting fronts while in the peritectic system (Fig. 2) the L/α interface is a solidification front if the temperature T_0 is above the peritectic temperature T_P. In other words, during the melting of peritectic systems the low-temperature β-phase melts while the high-temperature α-phase solidifies. It means that, additionally to the formation of the liquid phase, the polymorphic transition $\beta \rightarrow \alpha$ occurs. In this context the contact melting in the peritectic system is similar to the process of liquid film migration, mentioned above, where the liquid film is also located between melting and solidification fronts.

Finally, we discuss in this paper the evolution of the solid–solid interface due to surface diffusion. This process inevitably arises due to the deviation of the interface from a flat configuration in the vicinity of a triple junction. We show, however, that surface diffusion does not play a controlling role in the melting kinetics, and only allows for the necessary adjustment of the solid–solid interface. We note that the curvature of the liquid–solid interfaces is very important in the melting kinetics.

The rotation of the structure in the vicinity of the triple junction has been discussed in the literature for many different processes: growth from the melt [12,13], eutectic crystallization [14], discontinuous precipitation [15], diffusion induced grain boundary migration [16], reactive wetting [17]. In all these papers (except [17]) the surface diffusion along the free surfaces of the solid or along the inter-phase and grain boundaries has been discussed. In [17] the equilibration of the liquid droplet and the motion of the triple junction in reactive wetting is investigated under the assumption that the triple junction remains in the plane of the substrate.

In this paper we describe the problem of isothermal contact melting of two semi-infinite solid phases with concentrations C_α and C_β in eutectic and peritectic systems along the boundary between the phases (see Figs. 1 and 2). We are interested in the steady-state velocity of the triple junction which depends in this case on the overheating above the eutectic or peritectic temperature.