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Initial dynamics of a solid–liquid interface within a thermal gradient

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In directional solidification experiments an alloy is placed in the thermal gradient assembly and kept stationary to achieve a steady-state thermal profile. During this time an interface motion occurs that is experimentally characterized and shown to generate a solute boundary layer at the interface whose thickness depends on the time the sample is kept stationary before the external velocity is imposed. This boundary layer must be included in the theoretical description of the initial transient during a planar front growth.

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The dynamics of solid–liquid interfaces plays a crucial role in the evolution of microstructures during directional solidification of alloys. The most basic process is the motion of a planar interface in a binary alloy system that is controlled by the development of a solute boundary layer with time until a steady-state condition is reached. Theoretical models have been proposed by using approximate analytical treatments or numerical simulations [1–6]. In all the models proposed so far, the sample is considered to solidify from one end so that the initial composition in the liquid is uniform. In contrast, in directional solidification experiments, a solid alloy of uniform composition is placed in a thermal gradient stage. The sample is generally held stationary until a steady-state thermal profile is established and a planar interface forms [7]. The sample is then moved at a fixed rate to achieve directional solidification.

When the sample is placed in the thermal gradient stage (Fig. 1a) the liquid and solid are at the initial alloy composition far from the interface, but the liquid and solid compositions at the interface must be different for local equilibrium to be present. Therefore, solute boundary layers develop, as schematized in Figure 1b, which in turn influence the concentration field when the sample is directionally solidified, and must be taken into account in the description of the initial transient during the planar front growth.

Nguyen Thi et al. [8] first characterized the presence of an initial solute boundary layer in an Al–1.5 wt.% Ni alloy. They discussed the homogenization process by temperature gradient zone melting process in the mushy zone, and concluded that when liquid diffusion is the mode of transport, the limiting condition of a homogeneous liquid may not be fulfilled due to the very long time required.

The present study examines the dynamics of the planar interface that forms quickly in a dilute alloy of a transparent system in the presence of a thermal gradient but no externally imposed velocity. We seek to determine the position or temperature of the interface when the interface stabilizes and remains stationary within the temperature gradient. For a pure material the interface will be at the melting point isotherm. However, in a binary system the interface temperature can have any value between

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