Morphological Stability and Pattern Formation under Dynamic Conditions

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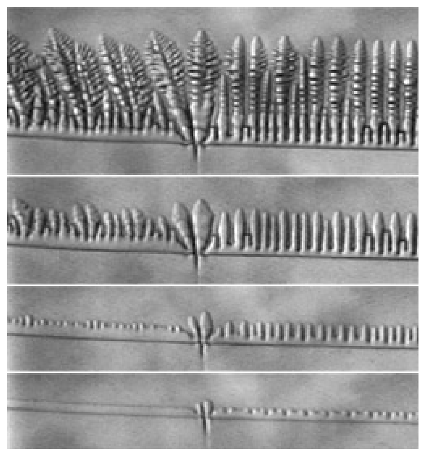
Abstract:

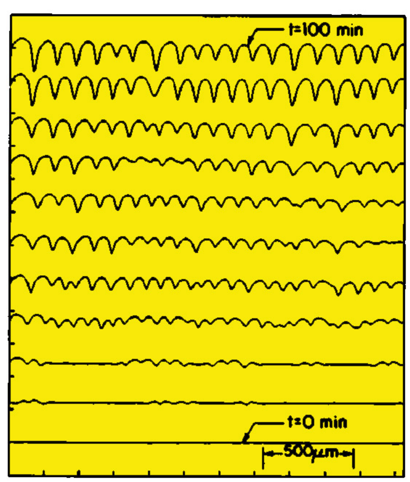
The effect of crystallographic anisotropy on the dynamics of interface pattern formation is examined in binary alloys of transparent systems. Specific emphasis is placed on the role of anisotropy in the selection of wavelength during the process of dynamical evolution of cellular structures. It is shown that the dynamics in an anisotropic system are significantly different from those in a nearly isotropic system, and that a dominant mode is selected at some critical nonlinear effect. The physics of this critical nonlinear effect on wavelength selection are investigated.

Background



During the evolution of microstructure, the anisotropic interfacial properties have been found to play a crucial role. For example, it has now been well established that dendritic structures will be unstable if the anisotropic effect is neglected. The selection of preferred growth direction and length scale in dendritic growth is strongly coupled with the magnitude of the interface energy anisotropy. In contrast, the effect of anisotropy on cellular pattern formation is not quantitatively understood. It is generally assumed that the role of anisotropy is negligible, and that cells grow in the direction of heat flow. In order to examine the role of anisotropy, we have carried out experiments in the binary pivalic acid-ethanol system, in which the anisotropy in interface energy is about 5.0%. The figure to the right shows the formation of cells and dendrites in two adjoining crystals with different orientations. Here, the different breakup dynamics, including the selection of the initial instability exhibited by the two grains, illustrate the importance of anisotropic interfacial properties in natural pattern formation. A quantitative knowledge is thus required regarding the fundamental processes through which the interface anisotropy effect influences pattern formation.

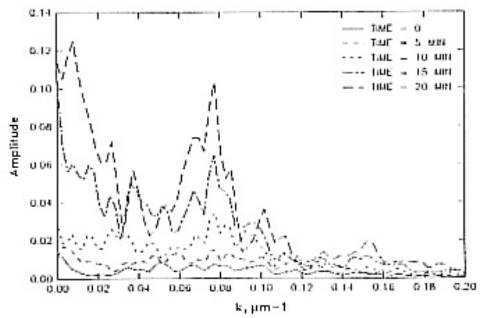
Recent Results

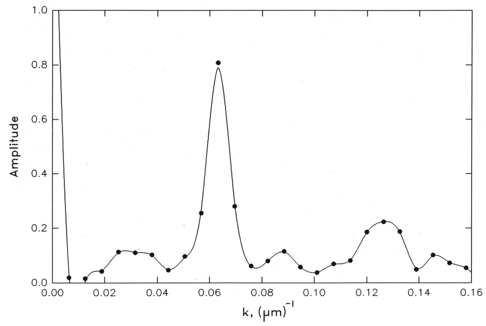


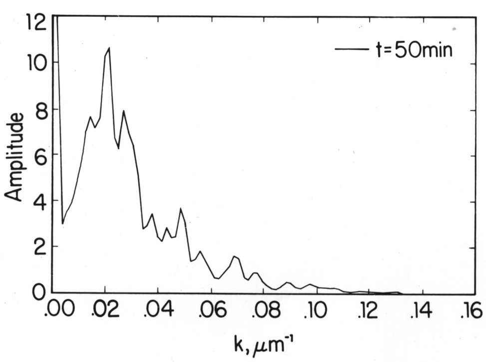
Multiple specimens are placed in the directional solidification unit so that crystals with different crystallographic orientations can be grown simultaneously and viewed within the same thermal field. The thermal profile was measured in selected experiments by placing a thermocouple inside the specimen ampoule. Test materials are carefully purified and alloyed using standard distillation and zone refining practices. Investigations to date include constant imposed (pulling) velocities, however we have begun analytical and numerical investigation of more complex velocity profiles. Experimental studies in this area are planned.

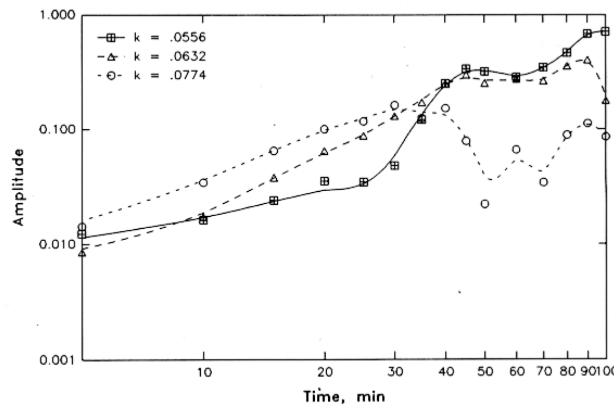
The figure to the right shows an experimentally observed interface shape sequence in an alloy of pivalic acid–ethanol for 100 minutes at

10-minute intervals. Fourier analysis (upper left) of this profile reveals the dominance of a few selected modes, with the *k=0.0556 μm⁻¹* mode being dominant initially. However, with time, a rapid amplification of the *k=0.0556 μm⁻¹* mode is observed, and the entire pattern forms with this mode at steady state (middle left). This strong selection of final model is quite different from the wavelength selection in the weakly anisotropic system of succinonitrile-acetone (lower-left), which shows significant disorder. These results suggest that the anisotropy of interfacial properties plays a crucial role in time evolution of the pattern. In order to examine the selection of the final wave number in the nonlinear regime, the time evolution of different modes in the pivalic acid system was investigated. This revealed that the finally selected mode becomes dominant between 20 and 30 minutes, as shown below.









Significance

The interface anisotropy effects have been shown to play an important role in the time evolution of cellular patterns, where anisotropy promotes ordering in the cellular array. The selection of the final pattern is shown to initiate as the nonlinear effects become important and the amplification rate of the dominant mode increases rapidly.

Future Work

One of the key aspects that will be emphasized is the fundamental understanding of the physics that lead to the dynamical selection of interface patterns in anisotropic materials. There are many subtle features of the initial transient that will also be investigated very carefully. For example, we will examine the role of anisotropy on the initial instability of planar interface and employ complex pulling velocity profiles and examine its influence on the dynamics of pattern evolution. These critical experiments will give insight into the changes in the selection modes as the velocity is altered, and would provide quantitative understanding of the pattern selection dynamics.

Interactions

This effort includes collaboration with Professor Alain Karma (Northeastern University), who is investigating these dynamics through phase-field modeling.