Final Report on DOE Grant DE-FG02-84ER45132
*Non-Linear Dynamics and Pattern Selection
at the Crystal-Melt Interface (09/01/84-02/28/98)*

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Abstract

Pattern formation at the solidifying crystal-melt interface was investigated with a model binary alloy system of the molecular crystal succinonitrile doped with the laser dye Coumarin 152. Videomicroscopy and computerized digital image analysis provided detailed data for quantitative comparison with theoretical predictions. Application of a single localized laser pulse or a row of UV spots to the interface during solidification allowed for direct measurements of pattern stability. These thermal perturbations also resulted in dramatic modifications of the observed solidification patterns, suggesting that the controlled thermal perturbation approach may allow the microstructure of metallic alloys to be controlled during solidification.

In this research program we investigated several dynamical phenomena taking place at the interface of a crystal solidifying into its melt. The initial focus was on the origin of an intense anomalous interfacial light scattering phenomenon discovered by J. Bilgram and his coworkers. Our work on this problem was reported in publications #1, 2, 3, 4, 7, 10, and 11 of the attached list of publications, and has been described in detail in previous progress reports.

In the second phase of the program we investigated the initial instability that occurs when an initially planar crystal-melt interface undergoes the Mullins-Sekerka instability (Refs. 5, 6, and 8). In carrying out these experiments we developed our videomicroscopy apparatus with computerized digital image analysis which was used in our subsequent work. We also investigated the applicability of microscopic solvability theory to pattern selection (Ref. 12) and the subcritical vs supercritical aspect of planar-cellular bifurcation (Ref. 14).

The third and most important part of the project began in 1990 when we demonstrated that a brief laser pulse directed onto the tip of a solidifying dendrite can generate a single sidebranch (Ref. 9). We then showed that a periodic sequence of laser pulses could completely alter the dendritic sidebranching pattern, converting the usually noisy array into a completely regular array with the spacing controlled by the period of the applied perturbation (Ref. 13). In this experiment we were also able to quantitatively test a theory of dendritic sidebranching due to Pieters and Langer.

We then modified one videomicroscope by adding a UV light source and installing a metal slide in the focal plane. This device allowed us to project a row of spots (with selected spacing) onto the crystal-melt interface in order to explore the onset of instability and to test theoretical predictions of Warren and Langer (Refs. 16 and 17). We also showed that this type of perturbation, applied before the interface became unstable, could induce novel interface morphologies which do not occur spontaneously. This work is being prepared for publication together with closely related phase field computer simulations carried out by Prof. Alain Karma and his coworkers at Northeastern University (Ref. 18).

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Finally, we investigated the problem of how the primary dendrite spacing is selected in steady state dendritic arrays. We found that a given spacing is stable over a large range of growth speeds bounded from below by a period-doubling bifurcation as Warren and Langer had predicted (Ref. 15). We then carried out an experiment with O. Mesquita and J. Figueiredo of the University of Minas Gerais in Brazil to directly study the stability of a dendritic array as this lower bound is approached from above (Ref. 19).

This last series of experiments, reported in Refs. 13-19, is potentially of major technical importance since it demonstrates the possibility of controlling the microstructure of solidifying alloys by applying spatially periodic thermal perturbations. Unfortunately, since continued funding was denied, the project has been terminated without further exploration of possible technical applications of this thermal perturbation technique.

Two copies each of References 16-19 are included with this report. Copies of previous publications have been submitted previously with technical reports and renewal proposals.

Publications Reporting Research Supported by
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