Modeling Semiconductor Crystal Growth with Magnetic Fields

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Abstract

1. Magnetic damping of the buoyant convections driven by the residual accelerations in microgravity.

   Models have been developed for the buoyant convections driven by residual accelerations for a Bridgman process with a uniform axial magnetic field. A magnetic flux density of 0.2 Tesla is sufficient to reduce the melt velocities to such small levels that convective heat transfer and nonlinear inertial effects are negligible. As a result, one can obtain accurate predictions of the melt motion for any residual acceleration history by the superposition of the independent solutions for (1) the steady or mean component of the residual acceleration, (2) the random fluctuations or g-jitters, and (3) isolated spikes of much larger acceleration, and one can obtain the solution for an acceleration whose direction is a random function of time by the superposition of the independent solutions for an axial acceleration and a transverse acceleration.

2. Magnetic stabilization of the thermocapillary convections in crystal growth processes with free surfaces.

   In the floating zone process or other crystal growth processes with free surfaces, the deleterious unsteadiness in the thermocapillary convection can be eliminated by applying a magnetic field, while an axial magnetic field does not disturb the axisymmetry of the process. The only previous model for the magnetic stabilization contained a fundamental error, so that we have developed the first accurate model to predict the minimum magnetic flux density required to eliminate unsteadiness.

3. Mass transport with magnetically damped melt motions.

   Most previous treatments of dopant or species transport have involved the simultaneous numerical solution of the full equations governing the conservation of linear momentum, internal energy and species. Since the intrinsic time scales for these equations are radically different, such an approach is limited to the simulation of only a few minutes of actual crystal growth. By recognizing that magnetic damping generally reduces the melt velocities so much that convective heat transfer and nonlinear inertial effects are negligible, we developed models to accurately predict the transport of a dopant during the entire time period to grow a crystal. Our initial efforts have been focused on dopant concentrations which are so small that the variations of the melt density with concentration are negligible. Our current efforts are focused on non-dilute models in which the compositionally driven buoyant convection is at least as large as the other components of the melt motion. These new non-dilute models are needed to predict species distributions in solid solution or alloyed crystals such as GeSi and HgCdTe.

4. Stability of thermoelectric magnetohydrodynamic flows.

   A facet or a compositional dependence of the solidification temperature can lead to a temperature difference along the crystal-melt interface which in turn produces a circulation of thermoelectric current through the melt and crystal. If a magnetic field is used to control the buoyant or thermocapillary convections, it will interact with the thermoelectric current to drive a melt motion. Recent experiments have indicated that this melt motion may be unstable, leading to unexpected striations in crystals grown in very strong magnetic fields. We have developed models for the steady melt motion driven by the thermoelectric current and an externally applied magnetic field. We are now beginning to study the stability of this motion.

5. Melt motions driven by rotating magnetic fields.

   A periodic transverse magnetic field, often called a rotating magnetic field (RMF), can be used to stir the melt in order to obtain a more homogeneous crystal and may also stabilize certain melt motions. In our first study, we focused on a strong RMF and showed that the non-rotating crystal acts as a generator which is short-circuited by the melt. The electric current from the crystal interact with the RMF to accelerate the melt near the crystal-melt interface, so that it rotates faster than the magnetic field. Our current studies are focused on a weak RMF. The effects of a RMF are intrinsically nonaxisymmetric, but all previous studies have ignored the deviations from axisymmetry in the melt motion driven by a weak RMF. We have developed the first model of the deviation of the melt motion from axisymmetry. This deviation is proportional to the square root of the interaction parameter based on the frequency of the RMF. We are currently developing computationally efficient methods to compute a RMF with a moderate and high frequency, for which the magnetic field does not instantly penetrate throughout the electrically conducting melt.

6. Melt motions due to Peltier marking.

   A model is being developed for the stirring associated with a Peltier current pulse and an axial magnetic field.