Solidification of II-VI Compounds in a Rotating Magnetic Field

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Background

This work is targeted at using the concept of using a rotating magnetic field (RMF) to control fluid transport during directional solidification of elemental and compound melts. Microgravity solidification experiments have shown that even small residual accelerations are sufficient to destroy or prevent the formation of a true diffusion layer during solidification. The RMF will superimpose a controlled stirring effect on a liquid column so that rather than aiming at diffusion controlled transport through a boundary layer, one can control the transport through a stirring motion introduced by the field, providing the melt is electrically conducting. By changing the strength and frequency of the field it is possible to affect the characteristics of the stirring and hence obtain controlled convection in the form of secondary flow which enhances mass transport in both axial and radial directions. Thus the technique enables one to achieve a great deal of control of the solidification process; the crystals obtained, especially those grown in previous low gravity flights have demonstrated exceptional properties. The principal geometries to be studied are zones in which constant dimensions and aspect ratios are maintained during processing. Thus during crystal growth the thermal field and the composition field will remain essentially constant. Modeling studies of flow in a cell specifically emulating a traveling heater method (THM) zone geometry are being used to test the effect of field strength and frequency on the flow induced by the RMF, at various accelerations between terrestrial and microgravity levels.

Concurrent with this modeling, crystal growth of CdZnTe and HgCdTe from a tellurium traveling solvent zone (THM) is ongoing. It is in the II-VI compounds, and particularly those solid solution compounds where interface control is most difficult to achieve, that RMF will be most valuable. An element, namely germanium, is also under investigation as a model material rather that a solid solution. Growth from a lead solution has been attempted and growth from a silver-germanium eutectic composition is in preparation.

Microgravity Relevance

The THM technique involves temperature and solutal profiles which are unstable in a gravitational field; the result is buoyancy driven convection. In microgravity, the transport through the zone is predominantly by diffusion and becomes prohibitively slow for crystal growth. In 1-g, the RMF can significantly influence the nature of the flow, but such resultant flow patterns are complex due to the competing natural convection. Although it is possible that significant benefits might result

from using RMF in a 1-g environment and these are being investigated, the full and unmitigated potential can only be fully realized by conducting experiments using this technique in microgravity. A strong data base derived from microgravity-grown crystals where the RMF effect can be more easily understood and more directly related to crystal quality will enable better optimization of the technique for future ground based processing. Ground-based data acquired from liquid cells operating with a RMF have demonstrated the stirring predicted by models, but the influence from buoyancy driven flow makes the unambiguous influence of the magnetic field difficult to interpret.

Accomplishments

The work has proceeded along two natural fronts, namely numerical modeling and accompanied crystal growth. The modeling incorporates the momentum balance as formulated by the incompressible Navier-Stokes and continuity equations, but with three velocity components to account for the azimuthal flow. The force term includes thermal and solutal buoyancy forces and also an electromagnetic stirring force. Thermal boundary conditions are imposed on the THM system, and it is also assumed that the dissolution and growth rates are equal. Finally, for the CdTe case, it is assumed that the average concentration of CdTe in the tellurium zone is 12%. This imposes a growth temperature and a zone thickness. In conventional THM, the mass transport Peclet number is less than unity at $10^{-6}g_0$, and becomes 6000 at $10^{-1}g_0$. Solute transport is convection dominated above $10^{-4}g_0$. The effect of the magnetic field is to set up body forces which oppose the buoyancy-induced convection at the growth interface and to reinforce it at the dissolution interface. At low gravity, application of the RMF will result in two Ekman recirculating cells which will completely overcome the buoyancy convection. At high gravity ($>^{-3}g_0$), however, the interaction of the buoyancy forces with the Ekman cells results in a strong cell structure with a single cell at the dissolution interface and two weaker cells at the growth interface. Increase of the field strength to 14 mT is sufficient to overcome convection and form very thin Ekman cells, but thermally induced convection caused by the heat input persists. Thus, low gravity is essential to obtain the full control of flow desired. A movie demonstrating these effects will be shown.

A series of THM growth runs based on a 2 cm diameter sample with a 4 cm inner diameter furnace has been completed. The furnace system consisted of four heaters mounted together on one translation device. Two of these had magnetic field capability and two were conventional THM. The samples were split to grow two CdZnTe alloys and two HgCdTe alloys, each with and without magnetic field. Characterization of the samples is incomplete as yet, but the HgCdTe samples both show exceptional radial homogeneity, are single crystal (mimicking the <111> CdTe seed), and have low defect density. Heater control problems were present in the first series of runs and affected the CdZnTe samples. A second system was set up to grow germanium by a THM method. The first solvent zone attempted was from lead, as this has been used for growing LPE Ge. For THM, however, the solubility is very low below 820 °C, and so the low temperature benefits of THM are lost. In our experiment, lead inclusions persisted. The possibility of growing Ge from a Ge-Ag eutectic at low temperature is now being tried.