Investigation of Vibrational Control of the Bridgman Crystal Growth Technique

Alexandre Fedoseyev
Center for Microgravity and Materials Research
University of Alabama in Huntsville
Huntsville, AL 35899

E-mail: alex@cmmr.uah.edu

Research Project Objectives

- Conduct a parametric theoretical and numerical investigation of vibro-convective buoyancy-driven flow in differentially heated cylindrical containers.
- Investigate buoyant vibro-convective transport regimes in Bridgman-type systems with a focus on the use of vibration to suppress, or control, convection in order to achieve *transport* control during crystal growth.
- Assess the feasibility of vibro-convective control as a means of offsetting "g-jitter" effects under microgravity conditions.
- Exchange information with the experimental group at the General Physics Institute (GPI) of the Russian Academy of Science and Stanford University (Prof. R. Feigelson) who are undertaking a complementary experimental program.

Significance and Justification for Microgravity Research

The character of natural buoyant convection in rigidly contained inhomogeneous fluids can be drastically altered by vibration of the container boundaries or through the introduction of vibration sources into the interior of the fluid.

Control of convective transport continues to be an important aspect of crystal growth research. Control of convection through static and rotating magnetic fields is being actively pursued by several groups. However, there are many instances, whether due to materials properties or other practical considerations, where the use of magnetic fields to induce stirring or suppress flow may not be an option. In such cases, vibrational control could become an attractive alternative.

While active vibration isolation can be a partial solution, it will not solve the problems that might arise due to the quasi-steady and very low-frequency acceleration components related to the gravity gradient and other orbital factors. Thus, as an alternative to vibration isolation, one might envisage using vibration to either suppress flow or to provide flow regimes tailored to particular crystal growth experiments. These flows would not be accessible under terrestrial conditions due to strong natural convection effects.

Significant Results of the Investigation

It has been recognized for some time that oscillatory or pulsatile flow can significantly alter the transfer of mass, heat, and momentum in fluid systems. Our research involves a numerical investigation of vibro-convective transport regimes with application to the control of convection and transport during growth of crystal by the Bridgman technique. We implemented a 3D model

of convective buoyancy-driven melt flow in differentially heated cylindrical containers in FEMINA/3D code. That was carefully tested on a published experimental and numerical data for a variety of 2D/3D viscous flow problems.

We take into account the influence of the Coriolis force caused by rotation. It is characterized by the Ekman number, which can be of the order 10^{-4} to 10^{-5} for frequencies ~1 Hz. This results in large coefficients, *Pr/E,* for Coriolis terms in the governing equation and causes difficulties in the numerical solution. To resolve this, we implemented a high accuracy solution method with preconditioning by high order incomplete decomposition. This allows a high precision solution with the accuracy up to 10^{-9} and results in up to 2 orders faster computation of the 3D flow than currently available commercial codes.

A question of the validity of the Boussinesq model for binary alloys and for thermal convection under microgravity conditions has been discussed recently by P.S. Perera and R.F. Sekerka, V. Pukhnachev and G. Gershuni, and D. Lyubimov. Investigation of the validity of the Boussinesq model has been performed. The estimates show that the Boussinesq model is quite adequate for our case of a closed ampoule and range of parameters under investigation.

A parametric study of the general buoyant-vibrational flow in a Bridgman growth system is being performed. This includes the cases of angular and rotational translational vibrations under typical microgravity conditions for typical semiconductor melts. The first phase of a thermo-vibrational study has been completed.

We have considered the influence of both translational (polarized) vibrations and rotational (angular) vibrations on a melt flow. Comparison with the results obtained experimentally and using the average equations for small amplitude vibrational displacements has been performed. The consideration of rotational vibrations necessitates the use of the full 3D equations governing the transport of heat, mass, and momentum.

The influence of angle between a direction of vibration and ampoule axis (temperature gradient) has been studied for translational vibrations. When the angle is zero, there is no influence of the vibration on a flow even if vibrational Raleigh number is very high. The maximum observed effect corresponds to an angle of 90 degrees. Here transport is significantly enhanced.

We found that both translational and angular vibrations can cause average melt flow for a range of parameters typical of practical semiconductor growth. For a given vibration amplitude and frequency, rotational (angular) vibrations result in more intensive melt flow than translational ones. In the light of these results, we discuss the use of vibration as a practical means of flow control and also discuss the relative importance of Coriolis force for flows generated by rotational vibrations. Typical flow patterns for different flow regimes have been identified.