Space- and Ground-Based Crystal Growth Using a Magnetically Coupled Baffle

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Background

The Submerged Heater Method (SHM) for directional solidification (developed under NAG8-95) significantly reduces the level of buoyancy-driven convection. The main feature of this method is a disk-shaped baffle which acts as a partition, creating a small zone melt at the interface. The zone melt is relatively insensitive to axial and lateral acceleration. Other advantages include reduction of the initial transient due to zone-solidification effects. This is essential for systems having $k<<1$.

Objectives

We propose to use the baffle in space to reduce the level of natural convection driven by residual acceleration. The combined effect of microgravity and small zone melt (small L and ΔT) will generate the effective conditions of "nano-gravity" (the Rayleigh number, Ra is reduced by a factor of 10^9). Based on the Segregation number criterion and numerical simulations, we expect that "nano-gravity" will reduce the level of natural convection in the melt to the point that it has no effect on crystal composition in the following systems, which we propose to study in space:

(a) a binary, GaSb doped with Te (k=0.35), InSb (k=0.1) and Sn (k=0.06);

(b) a tetra-atomic quasi-binary $(GaSb)_{1-x}$ $(InAs)_x$ doped with Te (k=0.35); and,

(c) ternary pseudo-binary $(GaSb)_{1-x}$ $(InSb)_x$, x=0.03 doped with Te (k=0.35).

Single crystals will be grown with the baffle and, for comparison, without the baffle. Based on scaling and numerical modeling, we expect to have a precisely known flow velocity field in the zone melt between the interface and the baffle (the residual acceleration will produce a negligible flow). The concentration field is uncoupled from the velocity field-driven residual acceleration. Furthermore, the baffle can produce a low level of well-defined forced convection resulting in controlled radial solute transfer/segregation. This can be used to prepare specimens having specified radial compositional gradient throughout the crystal boule, needed for studies or specific applications.

If the experiments yield the expected results, directional solidification with the baffle may become a preferred technique for crystal growth in space. It will help to ensure that in space experiments crystals are grown under known conditions of negligible natural convection, or known forced

convection in the melt. The experiments will demonstrate that the baffle, without additional expense and drawbacks, will reduce the natural (i.e., free buoyancy-driven) convection in the melt to the point that it will not affect segregation. The concentration profiles will provide the scientific information needed to:

1. Determine the value of the diffusion coefficients of dopants in GaSb and $(GaSb)_{1-x}$ $(InAs)_x$. The diffusion coefficients is needed for modeling, which has increasing importance for optimization of industrial crystal production.
2. Test the theory (Se and Pe number), which is important for planing of the future space experiments. Establish one-to-one correlation between Se number and gravity level for diffusion-controlled growth. Determine material systems that will yield diffusion-controlled growth at the levels of residual acceleration achievable at the Space Station.
3. Determine if our ground-based experiments with the baffle are nearly diffusion-controlled.

Significant Results

Using the baffle in vertical Bridgman configuration, we studied extensively ground-based growth of binary and ternary (pseudo-binary) semiconductor crystals, under conditions of low convection. In several experiments with Te-doped GaSb, steady state segregation was achieved. The studies were assisted by detailed numerical modeling. Based on the data obtained in previous space experiments, our experiments with the submerged heater, scaling, numerical modeling and integral analysis, it is evident that the influence of the convection on crystal composition depends on the value of the segregation coefficient k and the growth rate R, which do not appear in the Peclet number. For example, if $k \rightarrow 1$, or $R \rightarrow 0$, the composition of the crystal is not affected by any level of convection. Therefore, the Pe number, when used alone, can lead to erroneous conclusions on the effect of convection on segregation. To account for the effect of all relevant parameters, k, R D, V and d, we derived a new non-dimensional parameter, named the Segregation number:[6,7]

$$Se \equiv \left(\frac{V}{R^2}\frac{D}{d}\right)\left(\frac{1-k}{k}\right)$$

It is a key goal of our present research to prove that the composition of the crystal is not influenced by convection if Se <<1.

The tetra-atomic quasi-binary systems were recently invented in our laboratory and studied in some detail.[3] The quasi-binary $(GaSb)_{1-x}$ $(InAs)_x$ has numerous advantages over the ternary pseudo-binary alloys, the most important being: small lattice mismatch and $k \sim 1$. We were able to grow crack-free single crystals at relatively high growth rates. The crystals revealed significant band gap narrowing. Based on the results obtained so far, we expect that $(GaSb)_{1-x}$ $(InAs)_x$ and related quasi-binary will replace the ternary pseudo-binaries which are hard to grow (because of lattice mismatch).

For the use in sealed ampoules in microgravity, two designs of the submerged baffle are being developed and tested. In one, the baffle is being driven by a commercial linear motion feedthrough mechanism, model BLM-133-6, designed to provide 10^{-11} torr.[4] In the other design, the baffle is driven by volumetric expansion of the melt during solidification.[5] It has a simple design and does not require active control. The location of the growth interface and the actual growth rate is ascertained by measuring the position of the baffle during growth. Current pulses are sent through the baffle, making interface demarcation simple.

References

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