Reduction of Defects in Germanium-Silicon

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Objectives of the Investigation

It is well established that crystals grown without contact with a container have far superior quality to otherwise similar crystals grown in direct contact with a container. In addition to float-zone processing, detached-Bridgman growth is often cited as a promising tool to improve crystal quality, without the limitations of float zoning. Detached growth has been found to occur quite often during µg experiments and considerable improvements of crystal quality have been reported for those cases. However, no thorough understanding of the process or quantitative assessment of the quality improvements exists so far. This project will determine the means to reproducibly grow Ge-Si alloys in the detached mode.

Specific objectives include:

- measurement of the relevant material parameters such as contact angle, growth angle, surface tension, and wetting behavior of the GeSi-melt on potential crucible materials;
- determination of the mechanism of detached growth including the role of convection;
- quantitative determination of the differences of defects and impurities among normal Bridgman, detached Bridgman, and floating zone (FZ) growth;
- investigation of the influence of defined azimuthal or meridional flow due to rotating magnetic fields on the characteristics of detached growth;
- control time-dependent Marangoni convection in the case of FZ-growth by the use of a rotating magnetic field to examine the influence on the curvature of the solid-liquid interface and the heat and mass transport; and,
- grow high quality GeSi-single crystals with Si-concentration up to 10 at% and diameters up to 20 mm.

Microgravity Relevance

At this time, the most reliable environment for obtaining and studying detached growth is reduced gravity. The proposed work seeks to compare processing-induced defects in Bridgman, detached Bridgman, and floating-zone growth configurations in Ge-Si crystals (Si ≤ 10 at%) 20 mm in diameter. The occurrence of detachment during growth is widely thought to be related to gas pressures in the crucible and the evolution of gases at the growth interface. Gas evolution will be strongly effected by convection in the melt, which is dominated in the Bridgman configuration by buoyancy-driven flows. Thus, terrestrial detached growth (even when reproducible) will differ significantly from microgravity detached growth and the comparison of the two will provide vastly more insight than either alone. There is also a high potential for gaining new understanding of the role of convection in defect generation. Finally, the comparison of samples grown by detached growth with float-zone samples of the same diameter is fundamental to this study because the float-zone technique is truly and completely containerless in contrast to detached Bridgman growth. Terrestrial floating zones of this material are limited to diameters of about 8 mm. Therefore, these floating-zone experiments can only be conducted in a reduced gravity environment.

Results

Detached Bridgman growth itself as well as the transition from detached to attached growth was observed *in-situ* for the first time, using a quartz-glass ampoule in a mirror furnace. The crystal diameter was 9 mm, the growth length 40 mm, and the growth velocity 1 mm/min. Undoped <111>-oriented germanium served as seed material; the melt was doped with gallium ($C_0 = 1 \cdot 10^{18}$ at/cm^3). Detachment took place after a growth length of 6 mm and continued for 27 mm; the remaining 7 mm grew with wall contact again. The detached growth could be observed over the whole circumference except for some small ridges (width: few tens of micrometers; length: some hundreds of micrometers), where the crystal grew in contact with the wall. In the detached-grown part of the crystal, the {111}-related growth lines are clearly visible. The transition from attached to detached growth and vice versa did not take place along a straight line but was irregular within about 1 mm. The gap between the growing crystal and the container wall was measured at one point to be 31 µm. The etch-pit density is greatly reduced in the part of the crystal that grew detached. An increase in the EPD is seen in the area where the crystal had contact with the ampoule wall by the ridges described above.