Orbital Processing of High-Quality Zn-Alloyed CdTe Compound Semiconductors

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Task Objective

The objective of this research is to investigate the influences of gravitationally-dependent phenomena (hydrostatic and buoyant) on the growth and quality of doped and alloyed Cadmium-Zinc-Telluride (CdZnTe) crystals grown by the modified seeded Bridgman-Stockbarger technique. It is hypothesized that the damping of the gravitationally-dependent buoyancy convection will substantially enhance chemical homogeneity and the near-elimination of hydrostatic pressure will enable significant reduction in defect (dislocations and twins) density.

Microgravity Rationale

The rationale for this experiment was to exploit the near-absence of hydrostatic pressure to allow the crystal to grow without forced wall contact. It was hypothesized that a crystal grown under conditions without wall contact might have substantially reduced defects due to the absence of hoop stresses during the growth and post-solidification cooling. Two geometries were employed, both of which used the balance of forces at the solid/liquid/vapor interface to minimize the likelihood of wall contact.

Significant Results

Zn:CdTe crystals were grown in unit gravity and in microgravity for comparative analysis. Two crystals were grown on the First United States Microgravity Laboratory (USML-1/STS-50) mission in 1992, and two additional crystals were grown on the Second United States Microgravity Laboratory (USML-2/STS-73) mission in 1995. The Crystal Growth Furnace (CGF) in the seeded Bridgman-Stockbarger crystal growth geometry was utilized on both missions. Crystals grown on USML-1 were found to have solidified with partial wall contact due to the near-absence of the hydrostatic pressure in microgravity, a residual g-vector that was not axial, and the non-wetting sample/ampoule wetting conditions. Crystals grown on USML-2 included: a sample/ampoule identical to the USML-1 sample/ampoule (with the addition of a restraining spring to simulate hydrostatic pressure internally) and a tapered ampoule which accomplished 2.2 cm of crystal growth without wall contact.

Infrared transmission of all ground and flight samples was found to be 63-66%, very close to the theoretical 66%, suggesting good stoichiometric control. Infrared microscopy confirmed that the primary precipitates were Te and their size (1-10 μm) and density suggested that the flight and ground-based samples experienced similar thermal histories.

Longitudinal macrosegregation, calculated using scaling analysis, was predicted to be low. Nearly diffusion controlled growth was achieved even in unit gravity and macrosegregation data could be fit with a diffusion controlled model. Radial segregation was monitored and was found to vary with fraction solidified, particularly through the shoulder region, where the sample cross-section was varying significantly. It was also disturbed in the flight samples in regions where asymmetric wall contact was noted. In regions where a steady-state was established, the radial segregation was invariant, within our experimental measurement error. Local segregation near free surfaces was investigated for evidence of thermocapillary convection using low temperature photoluminescence techniques. No evidence of compositional segregation was detected.

Flight samples were found to be much higher in structural perfection than samples processed in unit gravity under identical growth conditions. In regions where solidification had occurred without wall contact, the free surfaces evidenced virtually no twinning, although twins appeared in the flight samples in regions of wall contact and were pervasive in the ground samples. These results were confirmed using optical microscopy and synchrotron x-ray white beam topography. Full-width half-maximum (FWHM) rocking curve widths, recorded in arc-seconds, were significantly reduced from 20 a-s (1-g) to 9 a-s (μg) for the best regions of the crystals. The 9 a-s (FWHM) rocking curve value in the unconfined flight samples equals the best value reported terrestrially for this material.

Further evidence of high structural perfection was determined using low temperature photoluminescence (PL). The PL spectra exhibited well defined bound- and free-exciton peaks and donor-acceptor pair recombinations with phonon replicas of both types of features. Noticeably absent was the deep broad-band often reported at ~1.4 eV in lesser quality material.

The ground samples exhibited a fully developed (111)[110] dislocation mosaic structure, whereas dislocations within the flight samples were discrete and no mosaic structure was evident. The defect density was quantitatively reduced from 75,000 (1-g) to 800 (μg) ± 50%. Dislocation etch pit density results were confirmed using transmission synchrotron white beam and monochromated beam topography. The low defect density is thought to have resulted from the near absence of hydrostatic pressure, which allowed the molten boule to solidify with little or no wall contact. This minimized the transfer of hoop stresses during solidification and post-solidification processing.