Dimensional Stability of Supermatrix Semiconductors

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Abstract

Supematrix Semiconductors (SMS) are *in-situ* composite semiconductor materials produced by directional solidification of eutectics in which the phases form in oriented, periodic, and crystallographically oriented arrays in 3 dimensions. SMS technology makes possible the 3-dimensional superlattice, the Quantum Cable, and materials with new or enhanced electronic, optoelectronic, electro-optic, and photorefractive properties. Objectives of the program are two-fold: (1) to demonstrate microgravity as an enabling environment for producing SMS materials with a high degree of microstructural control required for device applications; and, (2) to establish a broader scientific understanding of growth-property relationships of multi-phase solidification.

Our approach to simulating microgravity conditions has been to apply magnetic damping to crystal growth from a small, low-Rayleigh-number melt. Three tasks have been addressed. First, a low-pressure Czochralski crystal growth system with an integrated 7 kgauss electromagnet has been designed and constructed, and a liquid encapsulated growth process has been established for Ge/GeAs, the SMS chosen for study. Emphasis in the design of the system was placed on achieving high thermal symmetry to minimize temperature gradients across the melt. The diameter and height of the starting melt are both 2.6 cm, and the weight is 100 grams. Crystals (i.e., two-phase ingots containing Ge rods aligned along the axis of solidification in a GeAs matrix) of between 50 and 100 grams are typically grown.

Establishment of sample preparation and characterization procedures has also been addressed as a part of this task. Crystals are sliced by using an annular I.D. saw, lapped, and polished with colloidal silica. The microstructure of as-polished samples is revealed by using Normarski microscopy without preferential etching due to differential polishing of the two components. Automated image analysis has been used to assist in detailed microstructural characterization. SEM, EDAX, TEM, HREM, X-ray diffraction, Hall effect measurements, and photoluminescence are also being applied.

Characterization of thermohydrodynamic properties of the encapsulated melt is the second program task. Temperature fields and temperature spectra (i.e., temperature versus time at constant probe position) have been determined with and without magnetic damping by using a movable, multi-channel temperature probe. Results show (1) that the condition of the undamped melt is laminar, and (2) that the application of a magnetic field has a major impact on the temperature field further enhancing the hydrodynamic stability.

For example, in the absence of a magnetic field, the temperature within the melt is uniform to within ± 3 ° C, and the temperature distribution (bottom hotter than top) is consistent with an axis non-centrosymmetric flow pattern. Vertical gradients increase from 0.9 ° C per cm to 5.2 °C per cm with the application of a 6 kgauss field apparently as a result of the suppression of convective heat transfer. Measurements of the vertical and horizontal gradients as a function of field strength indicate a threshold possibly related to the re-orientation and alignment of the undamped flow pattern to the magnetic field. Saturation of the temperature gradient with field strength is also observed at about 5 kgauss. Temperature spectra with and without an applied field show no significant and identifiable fluctuations associated with turbulent conditions. In addition, empirical

Rayleigh numbers on the order of 4000 are close to published values for the laminar-to-conductive transition.

The third program task is to establish cause-effect relationships between microstructural features and conditions of solidification, including the solidification rate, crystal rotation, and magnetic field strength. A matrix of growth experiments is being conducted, and available data will be presented and discussed.

Three important results have been obtained to date:

(1) Dimensional stability depends on both seed rotation and magnet field strength. Continuity of the microstructure along the axis of solidification exhibits a dramatic dependence on magnetic field strength as the length of Ge rods increases by about 300% under super-threshold fields. Furthermore, cross-sectional uniformity is enhanced by employing slow seed rotation, and a figure of merit of non-uniformity decreases from 25% to 10% as super-threshold fields are applied.

(2) The application of a magnetic field refines the microstructure, and the average inter- rod spacing decreases by about 30% under magnetic damping.

(3) A natural tendency of the microstructure in undamped growth to coarsen as solidification proceeds has been established.

A picture is emerging supported by the data that dimensional stability is promoted by hydrodynamic stability and magnetic damping. However, cause-effect relationships are not clear, and the results have not been reconciled with available models despite the fact that some parallel behavior has been reported for space growth experiments. Although additional analysis remains, a more refined technique of materials characterization, such as interface demarcation, may be required to elucidate the physical mechanisms.