The Study of Dopant Segregation Behavior during the Growth of GaAs in Microgravity

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Description of Experiment

The original proposal for the study of dopant segregation behavior during the growth of gallium arsenide (GaAs) in microgravity was a program to investigate techniques for obtaining complete axial and radial dopant uniformity during crystal growth of selenium doped gallium arsenide (Se/GaAs). The primary goal of the reflight opportunity on the Second United States Microgravity Laboratory (USML-2) was to characterize and, if possible, controllably modify the melt-solid interface shape during the growth of Se/GaAs to achieve uniform radial segregation of the dopant. The reduced effective gravitational accelerations in a microgravity environment can reduce or eliminate the driving force for buoyancy driven convection. As the level of convection is reduced, axial segregation approaches that of diffusion controlled growth. An axial segregation profile due to diffusion controlled growth will have a uniform steady state region after an initial transient. Radial segregation during diffusion controlled growth, however, is controlled by the shape of the melt-solid interface. In these experiments, the booster heater and gradient zone configuration of NASA's Crystal Growth Furnace (CGF) were utilized in an attempt to achieve a near planar interface shape in order to minimize radial dopant variation.

Each of the experiments used a Se/GaAs crystal grown using the Liquid Encapsulated Czochralski (LEC) technique. Each crystal was machined to a diameter of 1.5 cm and inserted into a pyrolytic boron nitride (PBN) sleeve. A graphite cup supports the cold end of the crystal. At the hot end of the crystal was a spring composed of a stack of PBN leaf springs inside a graphite spring chamber. This spring expands when the GaAs melts and maintains electrical contact with the melt surface. The expansion of the spring also kept the melt in contact with the wall of the container and prevented the formation of a free surface on the melt. This entire assembly was hermetically sealed inside a quartz ampoule. Electrical current was passed through the quartz ampoule using the molybdenum feedthroughs. The CGF was modified to include a Current Pulse Interface Demarcation (CPID) system. This allowed a current pulse to be sent through the solidifying crystal. Peltier cooling resulted in the incorporation of a portion of the solute boundary layer. This change in the composition of the solute was seen as a demarcation line when a slice of the final crystal was viewed in infrared transmission. The demarcation lines show the interface shape and position at known points in time.

Justification for Microgravity Research

During ground-based experimentation, buoyancy driven convection mixes the melt and results in a dopant distribution profile that may be described by the complete mixing theory. During experimentation in microgravity, buoyancy driven convection may be reduced such that diffusion is the dominant driving force for movement of the Se within the liquid GaAs. Diffusion controlled growth results in a concentration profile with initial and final transients and a long steady state

region of constant composition in between the transients. The duration of these experiments is on the order of days. Thus, the microgravity environments available in drop towers and aircraft flying parabolic arcs are insufficient and it is necessary to do these experiments in a space environment.

Flight Experiment Results

Two Se/GaAs samples (primary and secondary) were processed during the USML-2 mission. One piece single crystals were partially melted and regrown in microgravity. The primary sample was processed for 67 hours, 45 minutes and included 19 hours of growth at 0.5 mm/s to grow 3.42 cm and 5 hours of growth at 1.5 mm/s to grow 2.7 cm. During the second experiment, the furnace temperature was adjusted to move the melt-solid interface position towards the hot end of the furnace in order to flatten the interface shape. The second sample was processed for 50 hours, 10 minutes and included 11 hours of growth at 0.5 mm/s to grow 1.98 cm and 1 hour, 25 minutes of growth at 5.0 mm/s to grow 2.6 cm. The cartridges containing the samples were x-rayed at the NASA Marshall Space Flight Center. The x-rays show that the crystals are in contact with the container along the length of the crystals and no voids were formed in the crystals.

Ground-based experimentation demonstrated that the Current Pulse Interface Demarcation (CPID) system could be used to successfully demark the interface position in the crystal at a known point in time. This position and time could later be used to calculate the actual growth rate of the crystal. The growth rate of the crystals was equal to the translation rate of the furnace for translation velocities of less than 1.5 mm/s. The melt-solid interface position could be moved relative to the gradient zone of the furnace, but the interface remained concave into the solid at all positions in the furnace. Numerical modeling also predicted this behavior.