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The effect of a static magnetic field on buoyancy-aided silicon dissolution into germanium melt

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Abstract

The effect of a static magnetic field on silicon dissolution into the germanium melt has been experimentally investigated. The experiments in this study show a trend to higher dissolution in the presence of an applied magnetic field. This can be attributed to the flow structure of the melt. The dissolution interface showed improved stability compared with experiments conducted without an applied field. The homogeneity of the dissolved silicon in the melt was reduced. Areas of low silicon concentration were present in the melt. Despite this, more silicon was dissolved into the melt with a static magnetic field applied than in experiments without an applied magnetic field.

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1. Introduction

Silicon germanium, Si_xGe_{1-x}, as a semiconductor material has important applications as bulk material and device layers. Full miscibility across its composition range allows for adjustment of the band gap and lattice parameter for tailoring to specific applications [1]. Bulk SiGe has applications in photodetection, photovoltaics and as a substrate for SiGe epitaxial layers [2]. SiGe substrates can be lattice matched to the device layer being grown, leading to a much higher quality layer. Device structures of interest include heterobipolar transistors, modulation-doped field effect transistors and 1.3 μm optoelectronics [3].

The growth velocity in liquid-phase diffusion (LPD), a solution growth technique, is determined by silicon transport through the germanium melt to the growth interface [4–6]. The crucible is not translated and the temperature profile is fixed. LPD has been proposed as a method for producing SiGe seeds for Czochralski (Cz) growth. The growth rate in LPD is slow as it is a diffusion-limited process due to silicon's buoyancy in the melt. The silicon is dissolved from the top of the melt. A geometry using silicon's buoyancy to aid transport would improve growth rates. However, previous work has shown that the buoyancy-aided process is very fast and unstable [7].

In the Czochralski growth of SiGe, Ge is rejected at the solidification interface requiring that Si be replenished in the melt to ensure the composition of the grown material remains constant [8]. Top feeding silicon rods into the melt as the crystal is pulled or using a double-crucible-type arrangement are possible replenishment techniques [9]. Utilizing silicon's buoyancy in the germanium melt to aid transport would seem like a method to aid transport. Once again, silicon dissolution in this arrangement has proved unstable [7]. Application of a static magnetic field may be an option for stabilizing silicon transport to the solidification interface.

To examine the possibility of using silicon source at the bottom, we have previously investigated the behavior of

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silicon dissolution in a germanium melt with a silicon source at the bottom [7]. The buoyancy of the silicon in the melt was found to have profound consequences on the dissolution rate and mixing of silicon into the germanium. The questions then were: (a) whether the convection in the melt was enhancing or reducing the dissolution of silicon in this system and (b) whether stable growth can be achieved under an applied static magnetic field (under altered convection conditions in the melt). In order to address these questions, a vertical static magnetic field was applied during the experiments in this study to observe the dissolution and mixing processes of silicon in the germanium melt.

2. Experimental procedure

The experiments were conducted in a three zone vertical DC resistance tube furnace. An isotherm was maintained over the crucible length at 1100 °C to the K-type thermocouple accuracy of ±1 °C. The materials were contained in a quartz crucible. The silicon used was single-crystal optical grade, 5 N, material. The germanium used was 6 N material. The silicon and germanium were both cleaned and etched prior to loading into the crucible. The cleaning, etching and loading took place in a clean room. Once the materials were loaded, the crucible was evacuated to approximately 1×10^{-3} Pa. The crucible was then sealed with a hydrogen torch.

The furnace is inside the bore of 1.25 T superconducting magnet. The vertical field chosen for these experiments was 0.8 T. This field strength was chosen based upon previous experience using the magnetic field to suppress convection, and was considered sufficient to provide the required suppression in the Ge melt. The crucible, when in the 1100 °C section of the furnace, is located in the most uniform section of the field. The magnetic field was kept on during the entire experimental process.

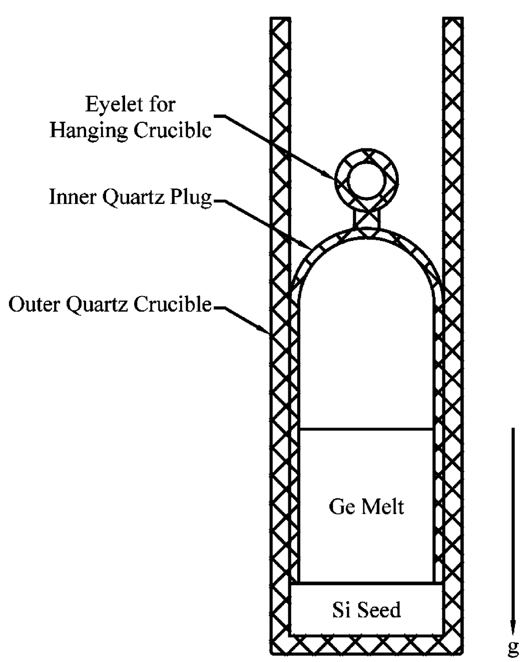

Fig. 1. A schematic view of the crucible used for experiments.

The crucible was hung in the furnace on a stainless-steel rod. The crucible is illustrated in Fig. 1. The material was first preheated for approximately 1 h above the hot zone in a region at approximately 800 °C. To start the experiment, the crucible was dropped into the isothermal area of the furnace from the preheating position. It was allowed to remain there for the given experiment time, 10, 20 or 30 min. At the conclusion of this time, the crucible was pulled from the furnace and quickly quenched in ice-water.

The samples were then sectioned into two bulk halves and a 2-mm-thick center slice. All pieces were polished for analysis. One bulk section was differentially etched to reveal structure. The center slice was used for EDS compositional analysis.

Two different material arrangements were used. The arrangements are illustrated in Fig. 2. The basic setup is a silicon seed secured at the bottom of the crucible with the germanium located above. The germanium quickly melts on introduction to the 1100 °C section of the furnace and begins to dissolve the silicon. The first arrangement features a free surface at the top of the germanium melt, exposed to vacuum. The second arrangement covers the free surface of the melt by means of a graphite cap floating on top of the melt, to eliminate the effect of free surface on the flow structure of the melt.

These experiments are follow-up work on similar experiments conducted without a magnetic field [7]. The experimental setup was kept identical in order to properly compare results.

The quenching in ice water was performed to maintain the concentration profile developed during the experiment. The fast transition to solid should capture the concentration profile and not allow further evolution. An EDAX EDS instrument on an FEI SEM was used for determining the concentration profile in the material. The quenching process was very hard on the material resulting in many fractures. To maintain the relative spatial location of all points in the melt, the fractured pieces were joined back into position with epoxy.

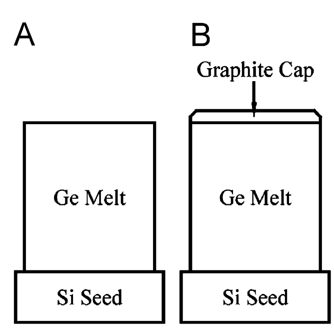

Fig. 2. Schematic views of the two material configurations used in experiments.