
Research Term
FY 2000 ~ FY 2002

Research Fields
Microgravity Science

Research Categories
Phase IA Research

Research Themes
Study on solidification and crystal growth from the undercooled melt and the measurement of their physical properties

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Summary of Research
The research contained three different topics related to the containerless processing of semiconductor material. They were (1) Crystal growth kinetic from the undercooled melt of semiconducting materials, (2) Thermo-physical properties and surface reaction of the undercooled melt of semiconducting materials and (3) Structural evaluation of containerlessly solidified materials. Based on the results, the research theme "Containerless Crystallization of Silicon in Microgravity" was proposed to "Microgravity Science Research International Announcement of Opportunity 2000" and successfully accepted. The summaries of the topics are described below.

The dendrite growth of silicon from its undercooled melt was investigated by using a phase-field model for a faceted crystal with anisotropic interfacial energy. The phase-field mobility at the thin interface limit was derived and used in the simulation. The accuracy of the model was estimated from the calculated equilibrium interface shapes. The errors in anisotropy and Gibbs-Thomson coefficient were within 1% and 10%, respectively. The dendrite growth from the undercooled melt of silicon was analyzed and the relationship between growth rate and undercooling was obtained. The results were in good agreement with the experimental.

The undercooled drop of silicon was grown to crystals in containerless states by electromagnetic and electrostatic levitators. A high-speed video camera was used to observe the crystal-melt interface and to estimate the growth rate as a function of undercooling. The
morphology of the growing crystal was changed from a mono-plate crystal to multi-plate crystals, and then to a faceted dendrite with increasing undercooling. The mono- and multi-plate crystals were observed at undercooling less than 100K, and they were shaped by faceted plane and wavy edge plane. The critical undercooling for the transition from mono-plate to multi-plate crystals were 50 K for the sample of 5 mm in diameter and 80 K for 1.7 mm in diameter, respectively. A novel criterion for the transition from mono-plate to multi-plate crystals was proposed, based on the instability of a wavy edge plane.

The surface tension and density of molten silicon were precisely measured using an improved sessile drop method. The measured surface tension of silicon, $\gamma$ (mN/m) is expressed as $\gamma = 733 - 0.062(T-1687)$, where $T$ is temperature (K). In addition, a new method was developed based on the principle of the oscillating drop method. The oscillation of a falling droplet was precisely recorded using the combination of a line sensor, a cylindrical lens and a laser backlight. The measured physical properties of pure water agree quite well with the reported values.

The evaporation rates of silicon and boron from Si-200ppmB melt were measured under pure Ag atmosphere. The evaporation of silicon was estimated as $1.2 \times 10^{-3} \text{ g/cm}^2\text{min}$, though it contain the evaporation of silica caused by the oxidation. On the contrary the evaporation of boron was negligible.

Containerless solidification experiment for Nd$_{70}$Fe$_{20}$Al$_{10}$ ternary alloy was carried out using an electromagnetic levitator with gas-jet cooling. The relationship between the formation of the ferromagnetic metastable phase with high $H_c$ and the undercooling at crystallization was observed. It was shown that the metastable phase formation was dominated by both undercooling and heterogeneous nucleation substance.

The structure and electrical properties of Si solidified from the undercooled melt was investigated. The recrystallization property of Si crystal was also studied in detail. The Si ball solidified under levitation condition was polycrystalline. Since the solidification starts from the surface of the specimen, the volume expansion at solidification introduces strain in the ingot. The condition rate under levitation condition was restricted so that it was difficult to compare the structure and electrical properties of levitation specimen with those of normal grown Si crystals.

9. Publication Lists