Title: Microgravity effects for the pattern formation and interface phenomena during one-directional growth of ice


Summary of Research: Morphological instability and pattern development at the ice/water interface are one of the typical cases of pattern formation under the non-linear and non-equilibrium conditions. The main controlling factors for the melt growth of crystal are the diffusion process of latent heat at the interface, the interfacial free energy (interfacial tension) and the interfacial kinetics. In order to understand the crystal growth and pattern formation mechanisms, we have to elucidate the interactions among these factors. New models for the melt growth and the pattern formation will be confirmed by the precise microgravity experiments.

In this research, ice crystal growth experiment from the supercooled water which include several types of impurities, namely, KCl, surfactant or anti-freeze glycoprotein (AFGP) were carried out using a one-directional growth apparatus. In case of the melt growth, it is very difficult to observe directly the interfacial microstructures and the diffusion field near the interface. Consequently, the impurity effect for the melt growth has not been made clear so far. In this research project, the several optical measurement systems such as the interferometer, the ellipsometer and the dynamic light scattering were used to measure the dynamic behaviors of impurities at the vicinity of interfaces. The purpose of this project is to clarify the scientific and engineering significances of the ice crystal growth experiments under the long-term microgravity conditions in space.

The main growth method of ice crystals used in this project was the one-directional growth methods. The position of ice/water interfaces always remained at the stationary position during the growth so that this growth method is convenient for the in-situ measurements of interfacial phenomena. The following results were obtained.

(1) A new model for the circular-disk growth and morphological instability of ice crystals was newly developed on the basis of the interaction of different growth modes between the basal and prismatic planes, controlled by the slow molecular arrangement and the thermal diffusion process, respectively. This model will cause the clear theoretical background for the space shuttle STS-R2 experiment that is in the planning stage.
Air bubbles in the concentration field of surfactant are accelerated in the direction along the concentration gradient. It has been expected that the origin of this force should be the surface tension gradient caused on the air bubble surface. The ice crystals were grown from the water containing the surfactant of \( C_{17}H_{35}SO_3Na \), and the diffusion field of surfactant and the behavior of air babbles were observed at the same time under the \( \mu \)G condition created by the parabolic flight of airplane. As a result, we first confirmed that only the air bubbles inside the diffusion field are forced to move.

The AFGP molecules are expected to modify the growth kinetics at the ice/water interfaces in the more direct manner. Zigzag patterns were observed at the ice/water interfaces. Analyzing the patterns, the interfacial kinetic supercooling, \( \delta T \), was first determined as a function of growth rate, and \( \delta T \) shows a peak at an intermediate growth rate. Furthermore, the self-oscillatory growth was also observed when the prismatic plane faces the growth front. The oscillation was connected with the diffusion process of AFGP in front of interface. A new model for the self-oscillatory growth was also developed.

New methods for the analysis of interference fringes (namely, Window Fourier Transformation analysis and Phase-Shift analyses) were developed. These made it possible to analyze the thermal diffusion field around a growing ice dendrite and the in-situ measurement of protein diffusion field and will be applicable for the analysis of STS-R2 experiments.