Growth kinetics of elementary spiral steps on prism faces of ice crystals grown in vapor and their temperature dependence

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The growth kinetics of ice crystals is crucially important for understanding a wide variety of natural phenomena on the earth surface. To understand the growth kinetics of ice crystals at the molecular level, the observation of individual elementary steps is indispensable. We have so far developed laser confocal microscopy combined with differential interference contrast microscopy (LCM-DIM), which can visualize elementary steps (0.4 nm in thickness) on ice crystal surfaces [1]. Using ice basal faces heteroepitaxially grown on a cleaved AgI crystal, we studied the growth kinetics of elementary spiral steps systematically by LCM-DIM [2,3]. In contrast, studies on a prism face, which is another important facet of an ice crystal, are still very preliminary because of the lack of such heteroepitaxial substrate. Therefore, in this study [4], we first tried to find a heteroepitaxial substrate crystal for prism faces of ice crystals. Then, we observed elementary spiral steps on prism faces by LCM-DIM.

We found that a prism face of a CdSe crystal, which has the Wurtzite structure, and the lattice constants close to those of ice crystals, can work as a heteroepitaxial substrate crystal for prism faces of ice crystals. Then we grew prism faces of ice crystals heteroepitaxially on a CdSe crystal and observed the lateral growth of elementary spiral steps on prism faces in vapor by LCM-DIM. On prism faces, we found that outcrops of screw dislocations are mostly located in the interiors of prism faces and that distance L between adjacent spiral steps is uniform, whereas these two features are not observed on basal faces. We measured the lateral velocity V_{step} of elementary spiral steps on ice prism faces using LCM−DIM. From the dependence of V_{step} on supersaturation σ, we determined the step kinetic coefficient β on prism faces. We performed similar experiments in a temperature (T) range from −25.0 to −2.6 °C and found that β on prism faces decreases monotonically with decreasing T, indicating ordinary Arrhenius-type T dependence. In contrast, from the relation between L and the driving force for the crystallization $\Delta\mu$, we found that the step ledge free energy κ on prism faces presents an extraordinary peak at T~-15°C, implying the change in surface structure at this temperature. The T dependences of β and κ measured on prism faces [4] are significantly different from those on basal faces [3]. To elucidate the reasons for these differences, T dependence of surface structures of prism faces needs to be studied by surface-sensitive methods, such as grazing-incident diffractometry and sum frequency generation spectroscopy in the future.

References

[1] Sazaki G et al. Elementary steps at the surface of ice crystals visualized by advanced optical microscopy. Proc Nat Acad Sci USA. 2010;107,19702-19707.
[2] Asakawa H et al. Roles of surface/volume diffusion in the growth kinetics of elementary spiral steps on ice basal faces grown from water vapor. Cryst Growth Des. 2014;14; 3210-3220.
[3] Inomata M et al. Temperature dependence of the growth kinetics of elementary spiral steps on ice basal faces grown from water vapor. Cryst Growth Des. 2018;18;786-793.
[4] Miyamoto G et al. Growth kinetics of elementary spiral steps on ice prism faces grown in vapor and their temperature dependence. Cryst Growth Des. 2022;22;6639-6646.