MORPHOLOGICAL INSTABILITY OF POLYHEDRAL ICE CRYSTALS GROWING IN AIR AT LOW TEMPERATURE

by

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EXPERIMENTAL PROCEDURES

Details of a growth chamber have been described in a previous paper (Kuroda and Gonda 1984). The chamber is designed to cool independently an ice plate for supplying water vapor and a substrate for the growth of ice crystals, inserting a thermal insulator between the upper and the lower plates. To keep the ice plate and the growth substrate at constant temperatures, electric current flowing to the thermoelectric cooling panels attached at the upper and lower plates is automatically turned on and off, using two temperature regulators. By these operations, the accuracy in the temperatures on the ice plate and the growth substrate is kept within ± 0.05°C.

Water vapor is supplied by keeping the ice plate at slightly higher temperature than that on the growth substrate. Ice crystals are nucleated in air by inserting about 3 cm³ of diluted silver iodide smoke into the growth chamber. Minute ice crystals nucleated in air fall in a short time on the growth substrate. Ice crystals were grown in air at 4.0 x 10⁵ Pa at -30°C and 1.0 x 10⁴ Pa at -18°C and various constant supersaturations, and we observed the growing ice crystals in situ using a differential interference microscope.

EXPERIMENTAL RESULTS

Figure 1 shows an ice crystal grown in air at 4.0 x 10⁵ Pa at -30°C and a supersaturation of 5.8%. As shown in Figure 1, the columnar ice crystal with small skeletal structures grows in air at 4.0 x 10⁵ Pa, while Gonda and Koike (1983) produced a polyhedral plate-like ice crystal in air at 4.0 x 10⁴ Pa at the same temperature and supersaturation. The upper (0001) face of the columnar ice crystal grows stably in early stages (a) but becomes unstable with time (b). The (0001) face becomes stable again later (c) and the skeletal structure on the (0001) face is contained inside the crystal as air bubbles (d, e and f). Afterward, the same phenomenon takes place on the lower (0001) face of the crystal. Why the surface instability does not come out symmetrically on both the (0001) faces may be due to a slight difference of the forward velocity of steps towards a center of the crystal on both the (0001) faces for some reason or another.

Figure 2 shows an ice crystal grown in air at 1.0 x 10⁵ Pa at -30°C and a supersaturation of 5.8%. The ice crystal grown in air at 1.0 x 10⁵ Pa grows along the c-axis longer than that at 4.0 x 10⁵ Pa, and a long prism is formed. At the same time, skeletal structures (d, e and f) larger than those at 4.0 x 10⁵ Pa are formed on the upper and lower (0001) faces of the crystal. The (0001) face of the crystal grows in air at 1.0 x 10⁵ Pa is kept at unstable growth even when the crystal size has grown considerably.

Figure 3 shows the instability limits of the (0001) face of columnar ice crystals grown in air at 4.0 x 10⁵ Pa, 3.3 x 10⁴ Pa and 1.0 x 10⁴ Pa. The crystal size is the length along c-axis of ice crystals. As shown in the figure, the instability limits of ice crystals depend not only...
Fig. 2. Columnar ice crystal grown in air at 1.0 x 10^5 Pa at -30°C and a supersaturation of 5.8%. (a) 3.3, (b) 8.8, (c) 18.4, (d) 47.0, (e) 98.2, (f) 141.4 min.

Fig. 3. Instability limits of the (0001) face of columnar ice crystals grown in air at 4.0 x 10^4, 3.3 x 10^4, and 1.0 x 10^5 Pa at -30°C.

Fig. 4. The relations between the ratio of growth rates \( R_b/R_p \) and the ratio of axial lengths \( c/a \) of ice crystals of 80 \( \mu \)m grown in air at (a) 3.3 x 10^4 and (b) 1.0 x 10^5 Pa at -30°C when the instability occurs first on either the (0001) or the (1010) faces. \( R_b \) and \( R_p \) show the growth rates of the (0001) and (1010) faces respectively. \( a \) and \( c \) show the lengths along \( a \)- and \( c \)-axes of ice crystals respectively.

**DISCUSSION**

To clarify factors controlling the morphological instability of snow crystals growing at a low temperature, and to infer the formation mechanism of snow crystals forming in polar regions, especially long prisms with skeletal structures, ice crystals have been grown in air at 4.0 x 10^4, 3.3 x 10^4, and 1.0 x 10^5 Pa at -30°C and various constant supersaturations. As a result, it has been found that the air pressure plays a very important role in both the habit change and the morphological instability of ice crystals. That is, polyhedral plate-like ice crystals grow in air at 4.0 x 10^4 Pa at -30°C, while column-like ice crystals with skeletal structures grow in air above 4.0 x 10^5 Pa at -30°C. The higher the air pressure, the longer prismatic columns with large skeletal structures grow.

Morphological instability of ice crystals depends not only on air pressure but also on supersaturation, crystal size, the ratio of growth rates of the (0001) and the (1010) faces and the ratio of axial lengths. Instability depends on the factors described above because the shape of diffusion field of water molecules around the crystals and the thickness of the diffusion layer depend on these factors. Consequently, morphological instability of the crystals is explained in terms of inhomogeneity in supersaturation at the crystal surface.

Many long prisms with skeletal structures precipitating in polar regions are explained by the rise and fall in supersaturation. However (Figure 3), the lowest supersaturation at which the morphology of ice crystals growing in air at 4.0 x 10^5 Pa at -30°C becomes unstable is about 10.1%, in air at 3.3 x 10^4 Pa at -30°C, it is about 4.1%, while in air at 1.0 x 10^5 Pa at -30°C, it is about 1.7%. That is to say, the lowest supersaturation at which the morphology of ice crystals becomes unstable decreases with increasing air pressure. On the basis of in situ observations of ice crystal surfaces growing in air at 1.0 x 10^5 Pa at -30°C, using a Video tape recorder, it has been found that at a supersaturation below a few %, long prisms with skeletal structures are formed when screw dislocations emerge near the corners of the (0001) faces of the crystals. It has also been found that long solid prisms grown when screw dislocations emerge near a center of the (0001) faces of columnar crystals under the same growth condition. That is, the formation of long prisms with or without skeletal structures depends on whether screw dislocations emerge near the corners or near a center of the (0001) faces. The reason why long prisms with and without skeletal structures are both observed in polar regions at relatively low supersaturation will be explained by our experimental results. Details of this experiment will be published in the near future.

**CONCLUSIONS**

The morphological instability of ice crystals grown in various constant air pressures at -30°C and various constant supersaturations has been studied. The results obtained are as follows.

1) Air pressure plays a very important role in both the
habit change and the morphological instability of ice crystals.

2) Morphological instability depends not only on air pressure but also on supersaturation, crystal size, the ratio of growth rates and the ratio of axial lengths. The experimental results are finally explained in terms of inhomogeneity in supersaturation at the crystal surface.

3) It is supposed from the experimental results that long prisms with small skeletal structures forming at low supersaturation are precipitating in polar regions.

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