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Crystallographic Orientation of Fractured Plane about Fresh Snow Particles

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Abstract

It is necessary to understand sufficiently the structure of snowflakes fractured in the blizzard, in order to make a clear explanation for the electric charge on drifting snow. The author investigated the crystallographic orientations about the fractured planes of snowflakes and the cracks of single ice crystal created by the thermal shock, the impact and the scratch. As a result, these crystallographic orientations were parallel with $(1\bar{1}00)$, (0001), $(1\bar{2}11)$ and $(2\bar{4}21)$, with which the vacancies were arranged in parallel. Since the cracks and the vacancies disappeared with recrystallizing, it can be seen that the active energy of cracks and vacancies changed into grain boundary energy.

1. Introduction

Gold[1] found out that the creating process of cracks in ice can be well explained by the model for crack nucleation by the pile-up of dislocation suggested by Stroh[2] and Bullough[3]. Mae and Higashi[4] suggested that the dislocation may be separated into the dislocation-jog charged negatively and H_3O^+ on the basis of experiments about the dielectric relaxation of single ice crystals. On the other hand, the author[5] carried out measurements about the charging of particles by using a Faraday cage at Sugatami Station (Mt. Asahidake). As a result, in the case of the snow particles by fracturing the fresh snow it can be seen that the polarity of charging was clear against the shape rather than the size of particles, even if a sign of the charging was dependent on the height from a snow drift surface as pointed out by Magono and Sakurai[6]. Therefore, if the charging of the fractured snowflakes is closely related to characteristics of dislocation, in order to understand basically the charging of snowflakes it is necessary to investigate the crystallographic orientation about the fractured planes of snowflakes.

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2. Experimental procedure and results

2.1 Crystallographic orientation of snowflakes fractured in blizzard

The observation was carried out at Sugatami Station (Mt. Asahidake) at an altitude of 1970 m, through observation periods running from Dec. 23 to 28, 1977, and again from Jan. 21 to 27, 1978. In fractured snowflakes collected by using by a Reprica method were observed differentical interferences microscope. Figure 1 shows the examples of the particles made by fracturing snow crystals. It can be seen that the fractured planes are always in parallel with a-axis as shown in photograph-A, -B and -C. About the photograph -C, a new crystal began to grow up at the fractured plane in parallel with b-axis. On the other hand, as shown in photograph-D the fractured planes appear perpendicular to the a-axis direction (in parallel with b-axis). These few examples of the fractured planes were observed through these observation periods.

In order to clearly recognize the anisotropy about the fractured plane, three types of experiments were made according to the following methods.

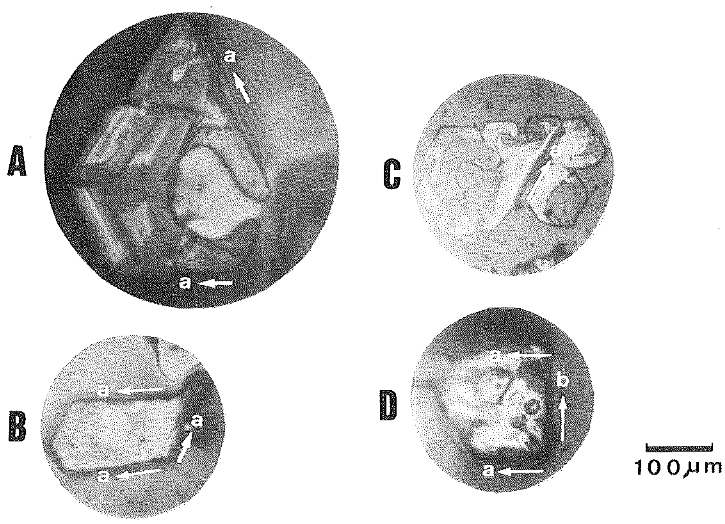

Fig. 1 Snow particles fractured in the brizzard.

2.2 Crystallographic orientation of a crack created by falling of a steel ball.

The crack was created by the falling of a steel ball of 3 mm in diameter onto an ice plate from a station, 5 cm high. Using the magnetic plate, the steel ball fell vertically on the surface of the ice plate. The specimens were cut out from one single ice crystal of Mendenhall Glacier by using a saw. The shape of specimens is a circular plate of 15 cm in diameter and 1 cm thick. In order to annual the strain due to the mechanical device, these specimens were washed in distilled water of 1°C, and had been left at an ambient temperature of -2°C for at least 24 hours. It can be seen that there is no effect of the mechanical history on the characteristics of specimens by using the treatment as above (Magono and Shio[7]). The results are shown in Figures 2, 3 and 4. The cracks created at the surface with a basal plane are shown in Figure 2. The crystallographic orientation of cracks was checked by using a Reprica method as shown in the lower photograph. As shown in the upper photograph three sheets of cracks are parallel with a-axis, the other six sheets of cracks are parallel with b-axis. However, we can see that, probably, the cracks parallel with b-axis are tilted more or less to the basal plane. In order to determine their inclination with accuracy, the cracks were created by the falling of a steel ball onto the surface with a prism plane. An example of such results is shown in Figure 3. In that figure the upper and the lower

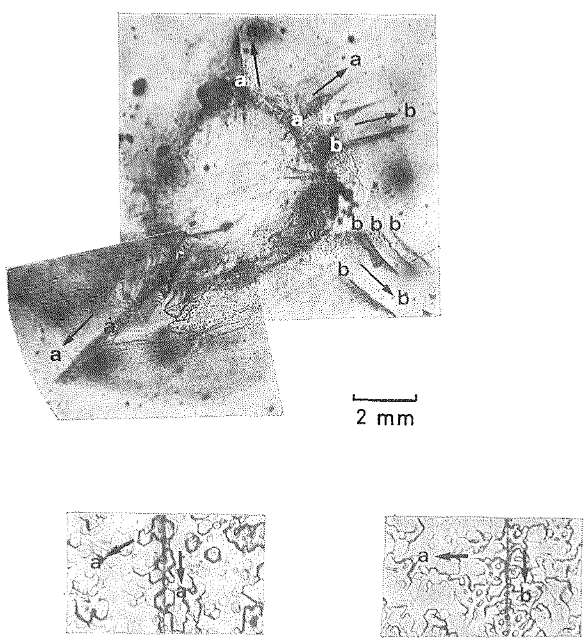

Fig. 2 Cracks created at basal plane by falling of a steel ball. Upper: a – Parallel with a-axis. b-Parallel with b-axis. Lower: Etching by using Reprica method.

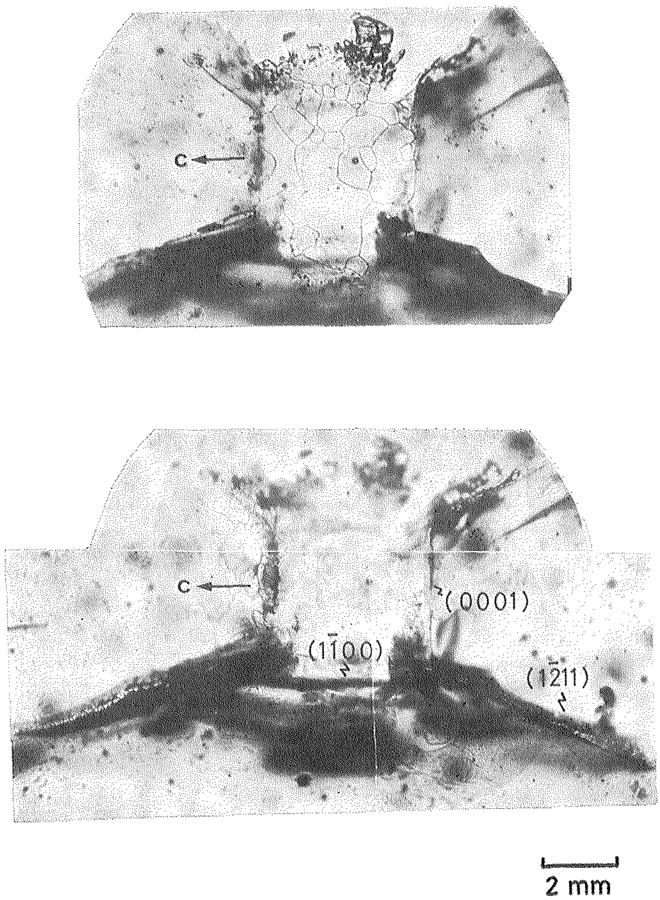

Fig. 3 Cracks created at prism plane by falling of a steel ball. Upper: Surface of specimen. Lower: Layer at a depth of 10 μm from its surface.

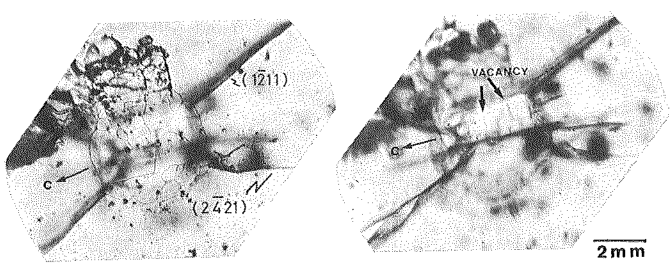

Fig. 4 Cracks created at prism plane by falling of a steel ball. Left: Surface of specimen. Right: Layer at a depth of 10 μm from its surface. Cracks parallel to (2$\bar{4}$21) and vacancies created at crack shown by arrows.

photographs show the surface of the specimens and the layer at a depth of 10 μm from the surface. We can see three types of cracks, namely, one is parallel with the pyramid plane, the others the prism plane and the basal plane respectively. In comparison with the photograph about the basal plane, as shown in Figure 2, we may considered that the crystallographic orientations of cracks are parallel with $(1\bar{1}00)$, (0001) and $(1\bar{2}11)$. Moreover, on the basis of the result shown in Figure 4, we may see a crack with $(2\bar{4}21)$ in addition to the crystallographic orientation as described above. It can be recognized that the disappearance of the cracks and the vacancies on the recrystallization are observed in the upper photograph of Figure 3 and in the left photograph of Figure 4. Its result suggested that a part of energy of the cracks and vacancices changed into grain boundary energy (grain growth, secondary recrystallization).

2.3 Crystallographic orientation of cracks created by thermal shock

The shock was thermally applied to the ice plate by the following method: Namely, the plate surface cooled to below –40°C was put in contact with distilled water of about 1°C which removed air bubbles by boiling, for a few seconds at the ambient temperature of –40°C. Then, a little liquid was absorbed very quickly into the crack formed in the plated, and freezed easily in the crack. The surface of the plated treated with the above method is the same single crystal as that of the plate before the treatment. An example of these results is shown in Figure 5. The left and the right photographs show the crack of the basal plane and the prism plane respectively. The crack pattern was always dependent on the crystallographic orientation of the surface. About the basal plane, the crack pattern forms a system of equilateral triangles, and a trace of the crack is almost entirely parallel with a-axis. About the prism plane, the rectangular crack developed on its surface, one trace is parallel with c-axis, the other track is perpendicular with its axis. However, there are deviations from regularity due to unknown reasons. These results are the same as those suggested by Gold[8]. Since no flaws are at these cracks made by the thermal shock method, these names may rather be termed boundaries instead of cracks. Moreover, with paying special attention, not being noted by Gold,[8] a new interesting crack parallel with b-axis may be observed in the left photograph, even if it is unclear since the crack in not perpendicular to the surface. A peculair crack as above may be equivalent to the cracks shown with the arrow in the right photograph. As a result, the author may consider that a crack is parallel with $(1\bar{2}11)$ or $(2\bar{4}21)$ as suggested in the previous results.

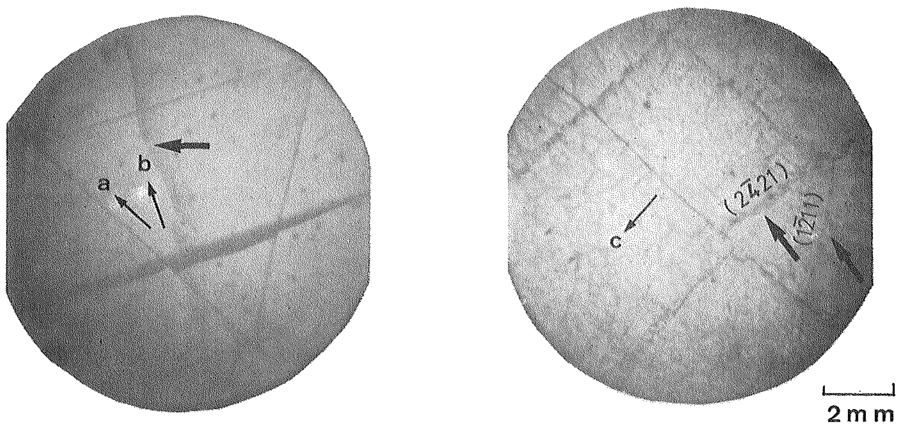

Fig. 5 Crack created by thermal shock. Left: Basal plane. Right: Prism plane.

2.4 Crystallographic orientation of cracks created by scratch

The ice plate was scratched by a conical sider of diamond with a cone angle of 105°. A diamond slider which was fixed at the center of a base mounted by a pole was supported by a counterbalanced pivotted bar. Normal loads were applied on the ice plate by the addition of weights directly on the top of the base. The ice plate which was stuck on the aluminum plate fixed at the centre of the stage was moved horizontally to an axis of the pole at a speed of approximately 1 mm/s. The ice plate 15 cm long by 15 cm wide by 1.5 cm thick. The mechanical history of the ice plate was removed by the same method as described previously. The results are shown in Figure 6. The cracks are observed only on the surface with a prism plane under the conditions with weights larger than 50～100 gr and ambient temperatures from −12～−15°C. The left photograph shows the cracks created by scratching in parallel to c-axis on the surface with a prism plane under a weight of 50 gr. Perhaps, the cracks shown by signs a, b and c are equivalent to (0001), $(1\bar{1}00)$ and $(1\bar{2}11)$. However, a crack corresponding to $(2\bar{4}21)$ can not be observed in these experiments. The right photograph shows the surface with a prism plane transformed by scratching vertically to c-axis. The cracks may correspond to the slip bands (glide plane) vertical to c-axis.

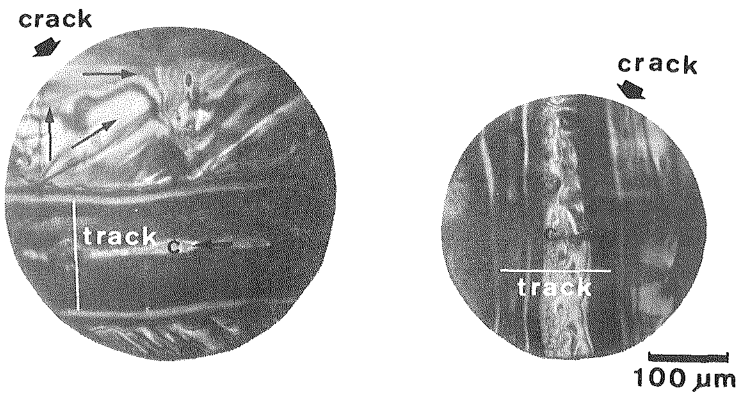

Fig. 6 Crack created on the prism plane by scratching. Left: Scratching in parallel to c-axis. Right: Scratching vertically to c-axis.

3. Consideration and conclusions

In these experiments it can be recognized that the fractured planes of snowflakes and single ice crystals were orientated in parallel with $(1\bar{1}00)$, (0001), $(1\bar{2}11)$ and $(2\bar{4}21)$, a part of vacancies were observed near the cracks. Kuroiwa[9] found out that etch channels on a fresh crystal surface were mainly oriented along $<11\bar{2}0>$ directions, sometimes etch channels oriented along $<10\bar{1}0>$ directions were found predominant on a sublimed crystal surface. As compared with the results of the author's experiments, the anisotropy of crack planes has very similar characteristics to the orientation of etch channels with the exception of cracks parallel to $(2\bar{4}21)$. Namely, a crack parallel with $(1\bar{1}00)$, $(1\bar{2}11)$ correspond to etch channels oriented along $<11\bar{2}0>$, $<10\bar{1}0>$ respectively. In the author's results, too, a great part of the orientation of cracks was in parallel $(1\bar{1}00)$. These are qualitatively similar to Kuroiwa's results. Muguruma and Higashi[10] found out that only when an external force corresponding to the stress greater than 3% was vertically applied to the surface with a non-basal plane, etch channels orient-ed along $<10\bar{1}0>$ directions were observed together with $<11\bar{2}0>$ directions. Therefore, the author's results are obviously supported on the basis of the suggestion furnised by Muguruma and Higashi's results.

On the other hand, Gold[1] found out that the creating processes of the cracks of ice are consistent with the models for crack nucleation by a pile-up of dislocations about the metal suggested by Stroh[2] and Bullough[3]. Since the vacancies were created by a pile-up of dislocations, coas ncerns the cracks created by the falling of a steel ball, the author's experimental results where a part of vacancies was observed near the crack can be explained easily according to Gold's suggestion.

It is said that the fundamental fracture types consist of a brittle fracture, a ductile fracture and a transcrystalline fracture. As far as a single ice crystal is concerned, since the orientation of the fractured plane is dependent not on the direction of the stress but on the crystallographic orientation, the fracture of a single ice crystal may be based on the brittle fracture.

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