CHAPTER VII

FRACTURE AND CLEAVAGES OF SiC

7.1 Introduction

Cleavage faces were preferred to the habit faces for the studies on etching of silicon carbide (Part III) as they often are free of usual growth patterns and other structures. Besides, no detailed work has been reported on the fracture and cleavages of SiC.

Wolff and Brodder (1959, 1960) during their studies on the microcleavages and bonding of different materials found that SiC has a cleavage along (0001) and a microcleavage along (1010), both being conchoidal in appearance; though Venkateswaran (1949) has referred to the basal plane as the cleavage plane. Keyes (1960) reported (1010) planes as cleavages with a secondary cleavage along (11̅20) planes for hexagonal silicon carbide platelets; but they were not as flat as the grown faces. So the present work was undertaken to know more about the fractures of thicker crystals and the micro-structural aspects of it using the conventional 'razor-blade' technique.

7.2 Cleavage along \{0001\} Planes

Figure 43 shows a (0001) fracture surface. The fracture lines appear to start from a point which is
generally located near the specimen corner or near to one edge. This type of fracture is characteristic of extremely brittle materials among which SiC is one. Such nucleus areas are considered as the tension regions initiating cracks. A secondary fracture origin marked A in Fig. 43 is occasionally found but is not very common. In certain other crystals the patterns are similar to perfectly cleavable hard crystals (Fig. 44). A typical matching pair of fracture surfaces is shown in Figs. 45a and 45b. The perfect correspondence of fracture lines is easily visible. The smooth and linear nature of the multiple beam interference fringes in Figs. 46a and 46b on these faces suggests that the fracture is not conchoidal or rough but plane and smooth. The regions on the two sides of a cleavage line belong to the same crystallographic plane but are with a slight level difference. The shift of the interferogram fringes reveals that the cleavage steps are sharp. The shining of the fracture surfaces is found as good as, and sometimes better than, that of a perfectly as grown face. These characteristics and results obtained by etching (Chapters VIII and IX) indicate that they are real cleavages along \( \{0001\} \) planes. The lamellar structure of SiC can also be deduced from the interacting-growth-front-like cleavage lines (Zapffe and Worden 1949) shown in Fig. 47.
The circular and hexagonal black features seen in Fig. 45 are cavities which are common in SiC. It can be seen that new fracture lines originate from these cavities. They may act as stress concentrators and initiate and propagate the fracture across the crystal. Figure 48 shows a cavity from which the fracture of the crystal has initiated.

The cavities seen on the \{0001\} cleavages of SiC are sometimes quite big with very flat as grown faces having many growth features including spirals on them, an example of which is shown in Fig. 49. It is well known that during the growth of SiC the reaction gases form voids in the mass. During cooling of the mass, the SiC vapour caught inside might become supersaturated and may deposit on the flat bottom and if there is a screw dislocation spiral growth will arise. Another possibility is that a cavity has been formed over a grown surface when additional growth has taken place. However, the possibility of this is less because the flat bottoms of the counterpart parts of the cavities also often show growth features, suggesting that this is an after-growth phenomenon. Further, the small cavities are generally terraced with growth fronts originating from the bottom.

7.3 Cleavage along \{10\overline{1}0\} Planes

The fracturing along \{10\overline{1}0\} planes was easier
as reported by Keyes (loc. cit.). Figure 50 shows a fracture along this plane. Here again, it can be noticed that the fracture originates from a nucleus near the external surface. This was generally true for the fracture along (1010) planes. It propagates across the sample in steps radiating out from the origin and the steps are of different heights and widths. The dark region in such a fracture recurred almost persistently. It is not crystallographic and the area of such regions varies systematically. The cleavage lines from this area on entering the \{1010\} plane turn almost immediately parallel to the c-axis. The other cleavage lines do so only gradually but ultimately they too become parallel to the c-axis. This means that the tendency for cracks to propagate on \{1010\} planes is in the \{0001\} direction rather than in any other direction. In no case evidence was obtained that the cleavage propagated in a \{11\overline{2}0\} direction. Two factors appear to affect the turning of cleavage lines parallel to the c-axis: (i) sudden emergence of the (1010) plane from the nucleus, and (ii) straight bands (marked BB') running perpendicular to the c-axis in the \{11\overline{2}0\} direction. These are identified as resistivity bands by Ellis and Moss (1967). The predominant influence of resistivity bands in the fracture of SiC would be discussed shortly.

The small cavities also almost invariably give
rise to fresh cleavage lines. The interferometric studies with an interference microscope revealed that planar areas exist (Fig. 51a and 51b). Fractures, similar to those described by Keyes (loc. cit.) were also frequent. A fracture is shown in Fig. 52a under normal illumination. The matched face in oblique illumination (Fig. 52b) shows that the faces are not very plane.

7.4  **Transgranular Cleavage on \(\{10\overline{1}0\}\) Faces**

The resistivity bands play an important role in the case of \(\{10\overline{1}0\}\) fracture of SiC as the grain boundaries do in certain other crystals (Low 1959). Figure 53a shows a fractured face on which two resistivity bands are present and Fig. 53b shows its counterpart in oblique illumination. The area between the bands is completely dark denoting that it is a different plane; and the two areas on both the sides of this region belong to another plane. All the regions are quite planar. The angle \(\alpha\) between these two sets of planes was measured to be \(\sim 5^\circ\). This type of cleavage is called transgranular cleavage and is found to occur whenever passed through two close bands. A remarkable feature of transgranular cleavage in SiC is that the step pattern does not change intersecting the resistivity bands unlike grain boundaries. (Low loc. cit.). This is because, apart from
an anisotropic bond at the bands from other regions, there is no increase in the reinitiation stress for transgranular cleavage because $\alpha$ is very small.

7.5 Wallner Lines

Examination of specimens fractured revealed many examples of fracture faces marked with 'Wallner' lines. These are periodic 'wave-like' undulations caused by the interaction of a crack with shear waves (Wallner 1939). In a few cases, a single set of Wallner lines are observed (Fig. 54). They are observed along with hackle markings on (0001) cleavages as shown in Fig. 55. They give an appearance of imperfect cleavage surfaces which, on a macroscopic scale, may be misunderstood to be shaped by conchoidal fracture. This phenomenon is due to the interaction of sonic and ultrasonic waves with a moving crack.

7.6 $\{10\bar{1}5\}$ and $\{11\bar{2}0\}$ Fractures

The fractures along $\{10\bar{1}5\}$ pyramidal and $\{11\bar{2}0\}$ 2nd order prism planes were always imperfect and conchoidal in agreement with Keyes (loc. cit.). Their occurrence was more that of a chance and the identification was often difficult due to absence of known habit faces on the pieces which had their fracture. Therefore resort had to be made to etching. Figure 56a and 56b represent two matched fractures of $\{11\bar{2}0\}$ planes. Even in this case the
perfect correspondence of the cleavage pattern is striking.

7.7 Discussion

SiC is a strongly homopolar crystal and such a crystal as a manifestation of its covalent binding should reveal a cleavage along \{0001\} plane as in the case of diamond type crystals. The Figs. 43 through 49 suggest that SiC is having a perfect cleavage along \{0001\} plane. Other evidences to show that they are true and perfect \{0001\} cleavages obtain from etching.

The facility for and frequency of splitting along an absolute true plane having an orientation within the crystal show that the cleavages along \{0001\} are not exceptions but the rule.

Differences are to be expected in the cleavage behaviours observed when the fracture is affected by different methods, as Tertsch (1949) has pointed out. Most methods of test strain the structure prior to fracture; consequently the fractures obtained indicate the direction of weakness of distorted structures. This difference may sometimes reverse the relative appearance of cleavages. That perfect \{10\overline{1}0\} cleavages are obtained in many cases in the present work compared to the poor ones obtained by Keyes substantiates this point. Keyes (loc.cit.)
used a blunt hammer to cause fracture while the author employed the 'razor-blade' technique. The result is that in the latter, in most cases the crystals are strained only at the initiation of the crack; otherwise the propagation of fracture is controlled by the crystal structure.

Though a few of the \{0001\} cleavages and a majority of the other cleavages reveal a point of initiation and a corresponding strained region, it does not appear that the material undergo any plastic deformation. Upon etching the fractured surfaces, no evidence of plastic deformation was observed. It follows that the fracture was caused by elastic deformation as in certain cases of quartz (Schlossin 1965 and Baêta and Ashbee 1967), silicon (Sylwestrowicz 1962) and MgO (Tattersall and Clarke 1962).

Grown-in dislocations have no relation to fracture. The etching studies on different cleavages exclude grown-in dislocations as a factor responsible for the initiation and propagation of cleavages. Neither impurities do have any effect on these cleavages. Specimens with different impurities show the same general features of fractured surfaces. It is postulated that cracks introduced or present on the surfaces initiated cleavages in silicon carbide as in no case it was found that cleavage tracks propagated around from an internal nucleus, except from cavities in few cases.
The resistivity bands act only as a reflector of cleavage propagation and not as a barrier. Whether the apparent surface energy increases, as in the case of grain boundaries, once the crack front crosses these bands is a fruitful line of research. If it does so, the strain energy release rate of the crack should be very high to allow it to continue propagating.

7.8 Conclusions

1. Silicon carbide has perfect \{0001\} and \{10\bar{1}0\} cleavages.

2. The \{10\bar{1}5\} and \{11\bar{2}0\} cleavages are anyway conchoidal and imperfect as reported by Keyes.

3. The perfection of cleavage particularly the first order prism cleavage depends on the method of cleaving and the occurrence of resistivity bands.

4. The fracture is by elastic deformation.

5. The fractures are sometimes decorated with Wallner lines, which indicates the generation of supersonic waves at the time of fracture.