PART II
4.1 Introduction

Frank's theory of crystal growth (Frank 1949) suggests that the step height of a growth spiral will be equal to the Burgers vector of the screw dislocation causing the formation of the spiral. On SiC, spirals with step heights ranging from the crystallographic repeat distance c to values of a few hundred Ångströms have been reported (Verma 1951a, b, c; Amelinckx 1951a, b, c). But dislocations with a Burgers vector larger than the crystallographic repeat distance are not stable unless as Frank (1951a) has shown, they have an open core, a phenomenon always observed in SiC. The step heights of growth spirals are often too large to be understood in terms of screw dislocations and Buckley (1952, 1953) suggested that the formation of spirals is connected with macroscopic events occurring in the vapour adjacent to the surface at the moment of solidification. Forty (1952), Amelinckx (1952) and Steinberg (1952) have suggested that a spiral with a large step height might be formed not due to a single screw dislocation, but due to a group of dislocations having the same sign.
As SiC is a polytypic crystal, a large-step height may be due to its being equal to (i) the height of a large X-ray unit cell or (ii) a multiple of a small X-ray unit cell which may arise from a dislocation of a multiple of the X-ray unit cell. Verma (1952) observed the dissociation of spiral turns into visible components after few turns from the origin. This has been attributed to the different growth velocities of the layers as suggested by Frank (1951 b). Verma also observed that a group of dislocations arranged along a line generates a spiral system of few branches.

The questions now arise are: (i) If the spiral steps of large Burgers vector can dissociate into components, how do large steps which have not dissociated appear? (ii) Do these spirals originate as single screw dislocations or as a group of dislocations close together, which may not be resolved due to the limited resolution of optical microscope? Tolansky and Bhide (1956) and Bhide (1956) reported that the steps are (a) single and (b) frequently kinked. A number of spirals on (0001) planes of SiC were, therefore, examined under electronmicroscope. The step heights of the spirals were determined interferometrically.

4.2 Grain-like Structures of the Arms

Out of many SiC crystals from different sources
examined under the electronmicroscope, crystals from one source showed a grain-like (blob) structure on the arms of the spirals and growth fronts as shown in Fig. 15. These blobs are elevations and were aligned in rows on each spiral step thus revealing the large steps as if they are made of a number of steps of smaller step heights grouped together. Single rows of grains were also frequently observed.

4.3 Spirals of Different Strengths

Verma (loc. cit.) reported that in any one region of SiC crystals, the dislocations are not only predominantly of the same sign, but also have the same strength. Exceptions to this have been observed during the present investigations. Figure 16a shows the electron micrograph of a linear core from which three spirals of different strength but of the same sign originate. Only the spiral with the largest step height could be visible when examined in a phase contrast microscope as shown in Fig.16b. Thus in the case of spirals with smaller Burgers vector, there are only single rows of grains and the size of the grains varies with the step height.

4.4 Spirals with Large Step Heights

As stated earlier, the rows of grains constitute an arm of a spiral or growth front. The relationship
between the step height of such spirals and their components was evaluated.

Figure 17a is an optical photomicrograph of a hexagonal spiral originating from an elongated hollow core. The arms appear to be singular and do not show any dissociation. The multiple beam Fizeau fringes (Fig. 17b) gave a step height $h = 1122 \, \AA$ for this spiral. The electronmicrograph of the origin of this spiral shown in Fig. 17c reveals that the spiral is a combination of many component spirals originating separately from different sites of the core. Under higher magnification, it was observed that the spiral consists of eleven components (Fig. 17d). Thus the step height of each component, assuming them to be of same step height comes out to be $102 \, \AA$. A spiral with unusual step height (Fig. 18a) of $3192 \, \AA$ (Fig. 18b) was found to have about 28 components (Fig. 18c) giving an average height of $114 \, \AA$.

An interesting case is shown in Fig. 19a in which the spiral arm splits into two after the first turn. One of them proceeds to form the spiral while the other returns and joins the parent arm making a closed loop. This is repeated in every turn of the spiral. As a result, the step height varies in different parts as can be seen from Fig. 19b. The step height was measured to be $283 \, \AA$ at the centre and between $1260$ and $1649 \, \AA$ at
other places. Figure 19c shows the origin of this spiral where three spirals from the same source originate and unite together to form the initial turn. Later, two other small spirals, one of which is of opposite sign, from nearby regions of the centre join the larger one. The number of components in the outer region varied between 12 to 17.

Spirals of comparatively smaller step heights were also examined. Thus a spiral of 238 Å height had only two components. But on the other hand a triangular spiral (Fig. 20a) with a step height of 786 Å (Fig. 20b) had only one component (Fig. 20c), though it showed five components at the outermost step. Similarly another spiral was made of two components only, each being 543 Å high.

The observations made on some spirals are summarised in table 1.

4.5 The Core of the Dislocations and Secondary Growth

Often the open cores of the dislocations gave the appearance of vortices as shown in Fig. 21 or they appeared very orderly as in Fig. 22. An interesting feature, sometimes observed, is the hexagonal secondary growth on the arms (Fig. 21). These features are rotated through an angle of 30° with respect to the arms and have sides parallel to $\langle 1010 \rangle$ direction.
Table 1

<table>
<thead>
<tr>
<th>No.</th>
<th>Step height $h$ in $\AA$</th>
<th>No. of components</th>
<th>Average step height of components in $\AA$</th>
<th>Probable type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>1122</td>
<td>11</td>
<td>102</td>
<td>6H</td>
</tr>
<tr>
<td>2.</td>
<td>3192</td>
<td>28</td>
<td>114</td>
<td>6H</td>
</tr>
<tr>
<td>3. a centre</td>
<td>283</td>
<td>3</td>
<td>94</td>
<td>6H</td>
</tr>
<tr>
<td>3. b 1st region</td>
<td>1260</td>
<td>12</td>
<td>105</td>
<td>6H</td>
</tr>
<tr>
<td>3. c 2nd region</td>
<td>1649</td>
<td>17</td>
<td>95</td>
<td>6H</td>
</tr>
<tr>
<td>4.</td>
<td>238</td>
<td>2</td>
<td>119</td>
<td>6H</td>
</tr>
<tr>
<td>5.</td>
<td>786</td>
<td>1</td>
<td>786</td>
<td>?</td>
</tr>
<tr>
<td>6.</td>
<td>1086</td>
<td>2</td>
<td>543</td>
<td>?</td>
</tr>
</tbody>
</table>

4.6 Conclusions and Discussions

The observations reveal that spirals with large step heights, hitherto considered as the result of single screw dislocations of large Burgers vector are actually due to many subunits originating independently from the same source; rather they can be regarded as a group of many co-operating spirals. This aspect might have an important bearing on the screw dislocation theory of polytypism which demands two or more co-operating spirals for the formation of certain types for which, however, experimental evidences are lacking (Verma and
The formation of a large single step, consisting of components from independently originating spirals may be due to the cohesive force at the core created by the fast and large angular growth velocity at the centre.

Though single spirals with only one row of grains have different strengths, it is found that in the case of majority of spirals with large Burgers vectors, the heights of the components lie in a range of $105 \pm 15 \text{Å}$ as revealed by the table 1. This value is an integral multiple of $15 \text{Å}$, the c parameter of 6H type. The spirals with subunit step heights of $786 \text{Å}$ and $543 \text{Å}$ may be of different types. From these observations it is evident that the large step height is not due to the 'giant' screw dislocations but is due to the combination of number of turns from individual dislocations of smaller step heights.

The spirals of different strengths in Fig. 16 should not be considered as the components of a big spiral since the arms of all of them are parallel in the beginning; on the other hand, they may be considered as three co-operating spirals originating from three screw dislocations of unequal Burgers vectors. This might have occurred due to the dissociation of big screw dislocations into components of unequal strength. If it is so and if growth continues, the system (wholly or individually) may generate
a polytype different from the parent crystal causing syntactic coalescence. This may be the reason for the recent observations of Wallace (1968). He has shown that the same platelet of SiC is a sandwich of 6H, 15R and 15R types. He also reported the epitaxial growth of 15R and 15R on a basic structure of 6H.

The hexagonal features of secondary growth shown in Fig. 21 might have occurred after the main growth and may probably be the traces of SiO\textsubscript{2} which will grow epitaxially on SiC with an orientation of 30° as shown by Amelinckx (1960) by etching.

The blobs on the arms are thought to originate due to VLS mechanism of growth. The obvious way to follow up this suggestion would be to employ electron-probe microanalysis to see whether foreign elements can be detected in these decorations on the growth steps (Frank 1968).