<table>
<thead>
<tr>
<th>Title</th>
<th>Formation of periodic steps with a unit-cell height on 6H-SiC (0001) surface by HCl etching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Author(s)</td>
<td>Nakamura, Shun-ichi; Kimoto, Tsunenobu; Matsunami, Hiroyuki; Tanaka, Satoru; Teraguchi, Nobuaki; Suzuki, Akira</td>
</tr>
<tr>
<td>Citation</td>
<td>Applied Physics Letters (2000), 76(23): 3412-3414</td>
</tr>
<tr>
<td>Issue Date</td>
<td>2000-06-05</td>
</tr>
<tr>
<td>URL</td>
<td><a href="http://hdl.handle.net/2433/24209">http://hdl.handle.net/2433/24209</a></td>
</tr>
<tr>
<td>Rights</td>
<td>Copyright 2000 American Institute of Physics. This article may be downloaded for personal use only. Any other use requires prior permission of the author and the American Institute of Physics.</td>
</tr>
<tr>
<td>Type</td>
<td>Journal Article</td>
</tr>
<tr>
<td>Textversion</td>
<td>publisher</td>
</tr>
</tbody>
</table>

Kyoto University
Formation of periodic steps with a unit-cell height on 6H–SiC (0001) surface by HCl etching

Shun-ichi Nakamura, Tsunenobu Kimoto, and Hiroyuki Matsumani
Department of Electronic Science and Engineering, Kyoto University, Yoshidahonmachi, Sakyo, Kyoto 606-8501, Japan

Satoru Tanaka
Research Institute for Electronic Science, Hokkaido University, Kita-12 Nishi-6, Kita-ku, Sapporo 060-0812, Japan

Nobuaki Teraguchi and Akira Suzuki
Advanced Technology Research Laboratories, Sharp Corporation, 2613-1, Ichinomoto, Tenri, Nara 632-8567, Japan

(Received 24 January 2000; accepted for publication 10 April 2000)

Step bunching on 6H–SiC (0001)-vicinal face etched by HCl at 1300–1500 °C is investigated by atomic force microscopy. When the substrate has the inclination toward near (0110) or even (1120), continuous parallel and periodic microsteps with six-bilayer height are laid perpendicular to the off direction, although those perpendicular to (1120) are apt to decompose into three bilayer or less. Formation mechanism of unit-cell-height steps is discussed based on consideration of bond configuration at step edges.

Surface pretreatment is an important technique to obtain superior epilayers. Especially for silicon carbide (SiC), the hardness and high chemical stability bring difficulty in removing surface polishing damage at a moderate temperature, resulting in many surface scratches observable even on commercially available wafers. On the other hand, the bunching of atomic steps on 6H– and 4H–SiC commercial available wafers. On the other hand, the bunching of atomic steps on 6H– and 4H–SiC (0001) vicinal faces has been reported to bunch atomic steps into six bilayers or more. Formation mechanism of microstep formation.

The etching was done at 1300 °C. The off angle was estimated to 0.3 °. Etching at 1300 °C showed similar results.

The samples used were 6H–SiC (0001)-vicinal faces specified as “on-axis” from three suppliers. The crystal orientation was determined from cleavage perpendicular to the (0110) direction and/or x-ray diffraction. The samples were etched by HCl (3 sccm) with H₂ carrier gas (1 slm) in a horizontal cold-wall CVD reactor, typically at 1300 °C for 10 min. Then, the step structure was observed by an atomic force microscope (AFM). The angle of off-axis was also estimated from the AFM observation. With the crystal orientation determined as described above, the direction of off-axis could be also estimated.

The microsteps showed different behaviors according to the off direction. In our experiment, three off directions were observed: (0110), (1120), and about 15° from both (0110) and (1120).

Figure 1 shows the AFM image of an etched surface with the off direction toward (0110). The etching was done at 1300 °C for 10 min. The microsteps are perpendicular to the (0110) direction (or, aligned along the (1120) direction and nearly parallel and periodic almost all over the sample. The height of these microsteps is about 1.5 nm, corresponding to the height of 6H–SiC unit cell (six bilayers). The terrace width is about 0.3 μm. From these results, the off angle is estimated to be 0.3° toward (0110). Etching at 1500 °C showed similar results.

FIG. 1. AFM image of the etched surface with off direction toward (0110). The etching was done at 1300 °C. The off angle was estimated to 0.3°.
Figures 2 and 3 show some results for the off direction toward (1120). The microsteps on the surface in Fig. 2 are perpendicular to the (1120) direction (or, aligned along the (0110) direction) with six-bilayer height, and nearly parallel and periodic. The terrace width is about 0.2 \(\mu\)m, and the off angle is estimated to be 0.5° toward (1120). The microsteps on some samples were apt to decompose into steps with three-bilayer height or less, which was enhanced when etched at 1500 °C. On some samples, microsteps with “triangular depressions” at step edges were observed as shown in Fig. 3(a). The “depressions” are three bilayer in height and surrounded by steps perpendicular to (0110). When the microsteps completely decomposed by the etching at 1500 °C, two kinds of steps emerged alternately as shown in Fig. 3(b): straight steps perpendicular to [1120] with two bilayer height and zigzag steps perpendicular to [0110] or to [1010] with one bilayer height. To the authors’ knowledge, this alternation has not been reported for H$_2$ etching. Thus, with the off direction toward (1120), inhomogeneity of step structure was observed in different samples or even in one sample. The cause of this inhomogeneity is not clear yet, although maybe attributed to the variation of surface quality such as polishing damage.

On the sample with the off direction of about 15° from both (0110) and (1120) in the (0001) basal plane, microsteps were not continuous: in some narrow band regions the microsteps seemed not to bunch. These results suggest that the step-bunching behavior should strongly depend on the off direction.

It is of scientific interest that parallel and periodic microsteps with a unit-cell height were obtained for the samples inclined toward (0110). In contrast, with the off-axis toward (1120), steps alternately emerged apparently perpendicular to (1120) and to (0110) family. In epitaxial growth, it is reported that when tilted by a small angle toward (0110), the surface shows many stripe-like undulations after growth, while relatively smooth when tilted toward (1120). This may be because of instability of steps perpendicular to the (1120) direction. With a larger off-angle, however, a group reported that such undulations were not observed. Now we assume that the etching process be inverse step-flow growth. Atomic bonds near the (0110)-off surface should be as shown in Fig. 4: each of the three adjacent Si–C bilayers has two dangling bonds at the step edge, and each of the next three bilayers has only one dangling bond. Although it is not clear which three bilayers are etched faster, either three bilayers should be etched faster as shown in Fig. 5. As a result, “fast-etched” steps catch up to the adjacent “slow-etched” steps, forming microsteps with six-bilayer height. The formation of the six-bilayer-height microsteps may be realized easily when the off direction is (0110) as shown in Fig. 5(a). If the off direction is except for (0110), and in usual circumstances such as H$_2$ etching, the steps perpendicular to (0110) family should have the lowest surface energy among all the directions in the (0001) basal plane, i.e., be etched at the lowest rate, leaving steps perpendicular to (0110) family. Thus, except for the off direction toward (0110), zigzag steps perpendicular to (0110) family should be formed as shown in Fig. 5(b). In the case of 6H–SiC, there are two
kinds of steps with different etch rate mentioned above, and the etch rate changes every third bilayer. As a result, zigzag microsteps are formed, but the terraces between the steps perpendicular to \( \langle 01\bar{1}0 \rangle \) and the terraces between the steps perpendicular to \( \langle 1\bar{1}20 \rangle \) have three-bilayer offset in height: that is, interlacing. In the case of HCl etching, however, straight steps were observed even on \( \langle 11\bar{2}0 \rangle \)-off substrates as shown in Fig. 2. Hence, the etch rate toward \( \langle 11\bar{2}0 \rangle \) should be as slow as, or even slower than, toward \( \langle 01\bar{1}0 \rangle \) under some circumstances. The reason of this difference in the etch rate is not clear yet, but probably due to the presence of Cl adatoms. As another feature, alternation of two- and one-bilayer-height steps were observed on some \( \langle 11\bar{2}0 \rangle \)-off substrates as shown in Fig. 3(b). The cause may be attributed to the difference of bond configuration, i.e., hexagonal and cubic site.

In summary, step bunching on 6H–SiC (0001)-vicinal face etched by HCl was investigated by AFM. When the substrate had the inclination toward near \( \langle 01\bar{1}0 \rangle \) or even \( \langle 1\bar{1}20 \rangle \), continuous parallel and periodic microsteps with six-bilayer height were laid perpendicular to the off direction, although with the inclination toward \( \langle 1\bar{1}20 \rangle \), the microsteps were apt to decompose into three-bilayer or less and inhomogeneity of step structure was observed in different samples or even in one sample.

FIG. 5. Shapes of the steps on (a) \( \langle 01\bar{1}0 \rangle \)-off substrate and (b) \( \langle 11\bar{2}0 \rangle \)-off substrate. The letters F and S indicate fast- and slow-etched steps, respectively.

\[^{1}\text{A. R. Verma, Philos. Mag. 42, 1005 (1951).}\]
\[^{7}\text{H. S. Kong, J. T. Glass, and R. F. Davis, J. Appl. Phys. 64, 2672 (1988).}\]
\[^{10}\text{B. E. Landini and G. R. Brandes, Appl. Phys. Lett. 74, 2632 (1999).}\]