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# Geometrical control of 3C and 6H-SiC nucleation on low off-axis substrates

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**Abstract.** Growth of 3C or 6H-SiC epilayers on low off-axis 6H-SiC substrates can be mastered by changing the size of the on axis plane formed by long terraces in the epilayer using geometrical control. The desired polytype can be selected in thick (~200  $\mu\text{m}$ ) layers of both 6H-SiC and 3C-SiC polytypes on substrates with off-orientation as low as 1.4 and 2 degrees. The resultant crystal quality of the 3C and the 6H-SiC epilayers, grown under the same process parameters, deteriorates when lowering the off-orientation of the substrate.

## Introduction

The 3C-SiC polytype easily forms on 6H-SiC substrates having an on-axis orientation while homoepitaxial step-flow growth is achieved using larger off-axis (typically 3.5 degrees) substrate orientation. In case of the lower off-axis substrate orientation it is common that there is a mixture of both polytypes in the epilayer and it is desired to master single polytype growth. The control of 3C and 6H-SiC formation in sublimation epitaxy [1] is a challenging task at low substrate off-orientation due to the high probability of spontaneous 2D nucleation of 3C-SiC on the terraces of steps. In particular, a very long terrace is formed at the edge of the substrate (Fig. 1) while the length of terraces, originating from the substrate off-orientation, in step-flow growth is much shorter. The formation of 3C-SiC on the terraces, governed by the step-flow growth, can be controlled by lowering the Si/C ratio since more silicon rich growth conditions are commonly used to favor nucleation of 3C-SiC. A substantial decrease of Si/C ratio is needed in order to prevent the formation of 3C-SiC at the edge of the epilayer. However, such ratio can cause a significant reduction in growth rate due to graphitization of the source material since sublimation of the source determines the growth rate [1].

In this study we demonstrate a geometrical control which leads to selective growth of thick 3C and 6H-SiC epilayers on low off-axis substrates under the same growth conditions.

## Experimental procedure

Thick (~200  $\mu\text{m}$ ) layers of 6H-SiC as well as 3C-SiC were grown on research grade 6H-SiC (0001) substrates having 1.4 and 2 degree off-orientation in the  $\langle 11\bar{2}0 \rangle$  direction. The experiments were performed by the Fast Sublimation Growth Process (FSGP) [2] which is an industrially feasible modification of the original sublimation epitaxy technique [1]. The growth was carried out at 1775°C at a growth rate of 200  $\mu\text{m}/\text{h}$ . The driving force for the growth is the temperature difference between the source and the substrate. Due to the short distance between the source and the substrate

which is 1 mm, the vapor species are transported directly from the source to the substrate in a direction normal to the growth front. Polycrystalline SiC plates were used as source material. The Si/C ratio was controlled by introducing a Ta foil which absorbs carbon. The 3C-SiC at the edge of the epilayer was avoided by applying spacers with different opening shapes (rectangular and triangular), which at the same time acted as geometrical support to prepare the epilayer polytype. Thus, the spacer acted as a mask. The geometrical control does not need any photolithographic etching steps as in the growth of 3C-SiC on mesas [3].

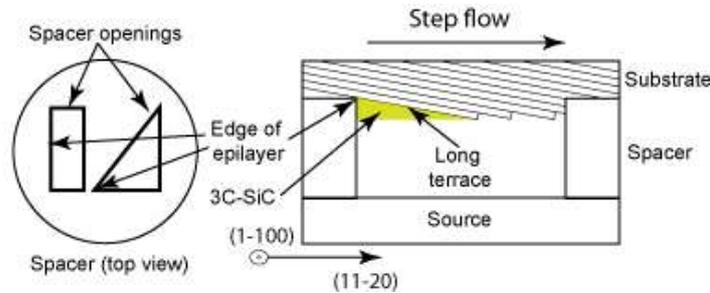


Fig. 1. Schematic view of geometry control using a spacer to separate source and substrate, growth arrangement and the long terrace which appears at the edge of the substrate

The samples were characterized using optical microscope with Nomarski interference contrast and high resolution X-ray diffraction (HRXRD). The polytype of the 3C and the 6H-SiC layers were distinguished by low-temperature photoluminescence using the position of the peak in donor-to-acceptor emission at 68K given by a background doping from the source material.

## Results and discussion

As a starting base for the study on geometrical control, we determined growth conditions at which we prevented the spontaneous nucleation of 3C-SiC on step terraces originating from the substrate. These conditions were achieved by introducing Ta foil, which was partly converted to TaC before the growth in order to create more carbon rich growth environment in comparison to an untreated foil. However, the 3C-SiC still appeared at the epilayer edge. Our proposed way to substantially reduce or enhance the 3C-SiC formation at the edge of epilayer is to reduce or increase the on-axis area by introducing spacers with different opening shapes. In order to demonstrate the proof of concept of our method we have used two different spacer opening shapes produced on the same spacer (Fig. 2).

The rectangular spacer opening leads to the formation of a long terrace at the edge of the epilayer (Fig. 2a). In contrast, the use of the triangular shaped spacer results in significant smaller terrace (Fig. 2b). The step propagation was substantially reduced at an angle of 50 degree towards the step flow direction compared to the rectangular shape. At such geometry, the step flow continues along the spacer opening edge, except at the corner of the triangle, where a small area of the edge formation cannot be avoided during spacer fabrication.

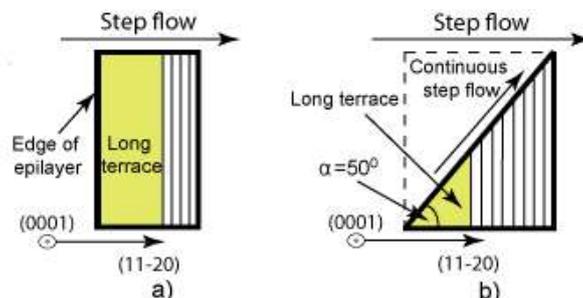


Fig. 2. Top view of the spacer with: a) rectangular, b) triangular opening shapes

The growth on differently oriented substrates was performed using the same growth conditions. In both, 1.4 and 2 degree samples, the formation of 3C-SiC at the hypotenuse of the triangular shaped opening was suppressed since no large edge terrace area was created during the growth (Fig. 3). In such a way, 6H-SiC polytype can be favored in triangle and 3C-SiC in rectangular shape at the same time during the growth.

It becomes more difficult to control the 3C-SiC nucleation by decreasing the off-axis of the substrate, because with the lower off axis the length of the step terraces increases and there is a higher probability for spontaneous nucleation of 3C-SiC.

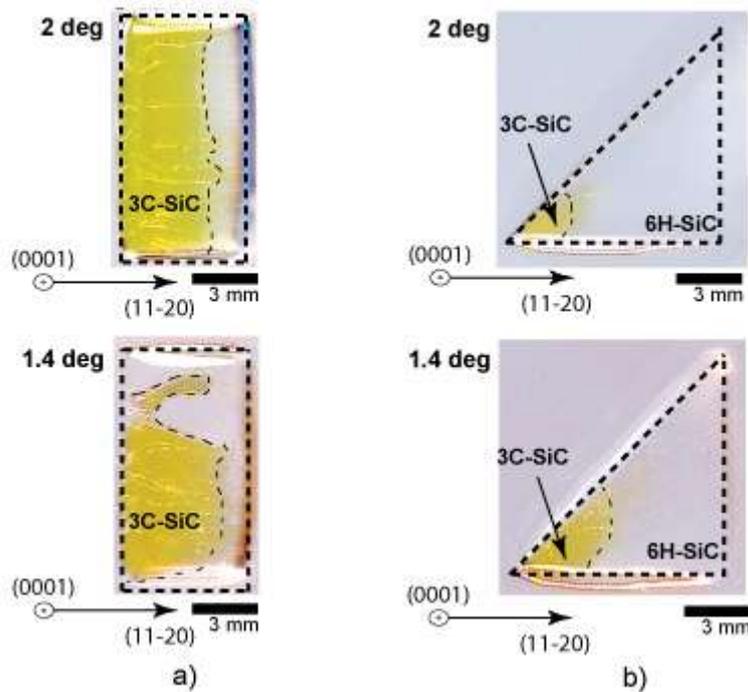


Fig. 3. Transmission light mode optical micrographs of epilayers grown using a) rectangular and b) triangular spacer opening

To study the quality of the dominating polytypes by the geometrical control, HRXRD measurements were performed on 6H-SiC (triangular shape epilayers) and 3C-SiC (rectangular shape epilayers) grown on 1.4 and 2 degree substrates under the same growth conditions. The spot size of  $1 \times 1 \text{ mm}^2$  was used. The omega angle was measured using (0006) and (111) Bragg reflections for 6H and 3C-SiC, respectively. The crystal quality of 6H-SiC (Fig. 4a) was evaluated by the full width at half maximum (FWHM), which were 28 and 64 arcsec on 2 and 1.4 degree substrates respectively. For 3C-SiC (Fig. 4b), the FWHM were 35 and 200 arcsec on 2 and 1.4 degree substrates, respectively. In both cases the quality was better with the larger off-axis of the substrate. Since the growth conditions were the same in all growth runs, the crystal quality was very likely affected by the off-orientation of the substrate. In the case of 6H-SiC (Fig. 4a), the decrease in crystal quality could be due to higher competition with two-dimensional growth mechanism at the 3C/6H border in the corner of the triangle, which could cause stress. Also, there could be an influence of misoriented 6H-SiC domains originating from the research grade substrates. In the case of 3C-SiC (Fig. 4b), the deterioration of the crystal quality could be related to: i) at the same growth conditions, the 2D spontaneous nucleation has higher probability to appear on lower off-axis substrates, which yields more nucleus that are rotated by  $60^\circ$  relative to each other and form double positioning boundaries, ii) with increasing off-orientation there could also be an effect of domains which are overgrowing each other [4]. Highly misoriented domain in the substrate could cause the off-center peaks in the curves.

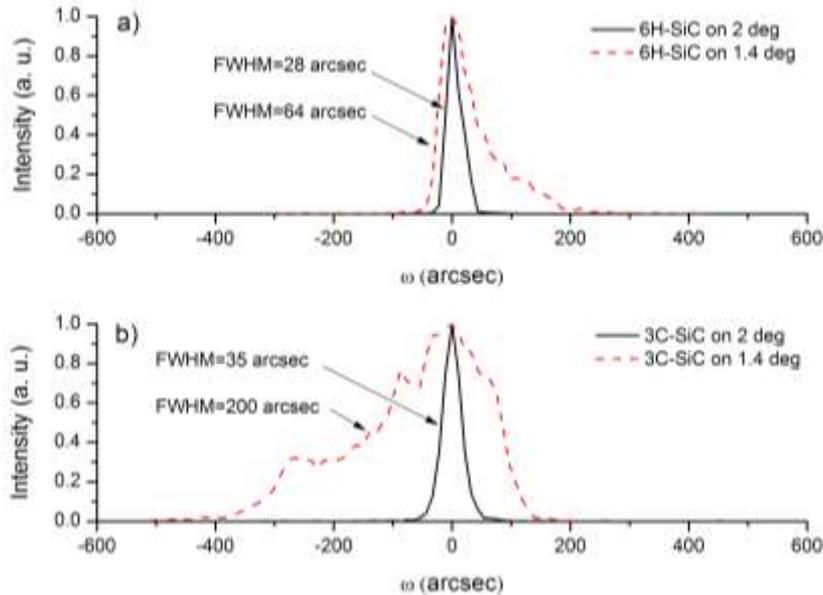


Fig. 4. Rocking curves of 3C and 6H-SiC grown on 1.4 and 2 deg 6H-SiC substrates under the same growth conditions

## Summary

A new concept of geometrical control of 3C and 6H-SiC nucleation on low off-axis 6H-SiC substrates using sublimation technique has been presented. It was demonstrated that high quality 3C-SiC and 6H-SiC material at a growth rate of 200  $\mu\text{m}/\text{h}$  can be fabricated. It is reasonable to believe that adjustment of each growth condition according to the specific off-axis of the substrate can allow even higher crystal quality of the 3C and 6H-SiC.

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