The effect of carbon precursor on the evolution of surface morphology of 4H-SiC epitaxial layers during the growth

M. Ghezellou¹, Robin Karhu¹, J. Ul Hassan¹

¹ Department of Physics, Chemistry and Biology, Linköping University, SE-58183 Linköping, Sweden
E-mail: Misagh.Ghezellou@liu.se (corresponding author)

The effect of using different carbon precursors on the evolution of surface morphological defects in as-grown 4H-SiC homoepitaxial layers is presented. The samples were grown on 4° off-cut substrates. Methane (CH₄) and propane (C₃H₈) were used as two different sources of carbon. The surface morphology of the samples was investigated by optical microscopy and AFM (Atomic Force Microscopy). The growth of epilayers was performed in a horizontal hot-wall MOCVD reactor equipped with a TaC coated susceptor. The substrates were under a heavy flow of H₂ as the carrier gas during the temperature ramp-up and etched for 5 min at the growth temperature before the introduction of precursors. Optical images from the substrates after the etching step revealed the formation of Short Step Bunching (SSB) on the surface. Introducing CH₄ as the carbon source resulted in more pronounced SSBs elongated perpendicular to the steps direction. On the other hand, C₃H₈ as the carbon source leads to the formation of inclined line-like surface morphological defects. It is shown that surface morphological defects have a negative impact on the gate oxide reliability of SiC devices [1,2]. Hence, decreasing the density and eventually eliminating the surface morphological defects is critical for further improvement in SiC-based devices.

Several studies have been made on the influence of different Si precursors on the quality of 4H-SiC epilayers however, very few studies have been reported for different C precursors [3].

In this study we have used chloride-based chemistry to study the effect of different carbon precursors, C₃H₈ and CH₄ on the surface morphology and evolution of surface defects in as-grown epilayers. The samples were grown at a temperature of 1640 °C with a growth rate of 25 μm/h and a C/Si ratio of 1.1 to a thickness of 25 μm. Same growth parameters were used for both hydrocarbons and substrates were also obtained from the same wafer. The surface of the substrates was prepared before the growth with 5 min in-situ etching in H₂ atmosphere at the growth temperature. A summary of the samples used in this study is given in Table. 1.

Fig. 1 shows a comparison of the optical images from two samples grown using C₃H₈ and CH₄. Epilayer grown with C₃H₈ shows inclined line like features (Fig. 1a) whereas the epilayer grown with CH₄ shows SSB (Fig. 1b), indicating that different carbon precursors may lead to different surface morphological defects even if both substrates are taken from the same wafer, gone through same in-situ surface preparation and grown under the same growth conditions. To see whether these features are related to the defects in the substrate, some of the epilayers were etched in KOH. Analysis of the surface revealed the presence of threading screw dislocation (TSD) related etch pit next to each incline line (Fig. 2a). No relationship was found between the SSB and any kind of etch pits (Fig. 2b).

Substrates from the same wafer were also etched in H₂ for 5 minutes at the same temperature used for the growth. The optical analysis of the surface did not reveal any feature on the surface however, dark-field imaging revealed the presence of SSB on the surface while no inclined line features were observed. This indicates that the SSB and inclined line-like features have different origins. The inclined line-like features are formed during growth while SSB related features already start to form during in-situ surface preparation. Epitaxial growth with CH₄ enhances the SSB but suppresses the formation of inclined line-like features. C₃H₈, on the other hand, suppresses the further propagation of SSB already formed on the substrate surface during in-situ etching but leads to the formation and further enhancement of inclined line like feature during growth. A detailed analysis of inclined line-like features using a combination of KOH etching, polishing, and x-ray topography revealed that the defect is originated from TSD in the substrate and formed through the interaction of local spiral growth around TSD and the step-flow growth.
More detailed investigation of the evolution of surface morphology, the origin and formation mechanism of SSB and inclined line-like features, their relation to defects in the substrates, and the influence of growth parameters using different hydrocarbons will be presented. Furthermore, the suppuration and complete elimination of these surface morphological defects will also be presented through optimization of the growth process.

Table I. A Summary of the studied samples

<table>
<thead>
<tr>
<th>Etching Temp.</th>
<th>Etching time</th>
<th>Etchant</th>
<th>Growth temp.</th>
<th>Carbon source</th>
<th>C/Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-Methane</td>
<td>1640 °C</td>
<td>5 min</td>
<td>H$_2$</td>
<td>1640 °C</td>
<td>CH$_4$</td>
</tr>
<tr>
<td>S-Propane</td>
<td>1640 °C</td>
<td>5 min</td>
<td>H$_2$</td>
<td>1640 °C</td>
<td>C$_3$H$_8$</td>
</tr>
</tbody>
</table>

Fig. 1 Optical and AFM images of epilayer grown using a) C$_3$H$_8$ and b) CH$_4$ as the carbon source. The epilayer grown with C$_3$H$_8$ shows inclined line-like features whereas epilayer growth with CH$_4$ shows SSB.

Fig. 2 Optical image of epilayer after etching in KOH grown using a) C$_3$H$_8$ and b) CH$_4$.

Fig. 3 Optical image of the substrate after etching in a) H$_2$ b) in a mixture of H$_2$ + SiH$_4$ and c) in a mixture of H$_2$ + CH$_4$. Only SSB like features are observed on etched surfaces. SSB is more pronounced on the substrate surface that is etched in a mixture of H$_2$ + CH$_4$. Such features are very faint on the substrates that are etched in a mixture of H$_2$ + SiH$_4$.