Growth, morphological and structural characterization of silicon carbide epilayers for power electronic devices applications

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Silicon carbide (SiC) is a wide band gap semiconductor, interesting for its physical properties such as high breakdown field, high saturated drift velocity and high thermal conductivity, which has been intensively studied in the last years. Although the high potentiality of this material, the SiC technology shows at the moment some limitations, indeed, the reliability of SiC-based devices is strictly correlated to the defects present in the crystalline structure. 4H-SiC epilayers were grown by Hot Wall Chemical Vapor Deposition (at 1600°C) and by Sublimation techniques (at 2000°C). A surface investigation of the epilayers has been performed finding particular physical finger-prints correlated with several kind of defects aimed at giving an important feedback to the epitaxial growth processes.

1 Introduction

Although the high potentiality of SiC, the growth technologies need more know-how. Useful informations may be obtained by materials characterization, in particular by in-situ techniques which yield analysis of physical and chemical processes during the growth steps.

The aim of this work is to give a contribute to improve 4H-SiC epitaxial layers quality, because up to now it shows some limitations in order to obtain electronic devices with the same quality standards of the Si technology. Indeed, the reliability of SiC-based devices is strictly correlated to the defects present in the crystalline structure, thus their accurate classification is a key issue.

We have focused our investigation on 4H-SiC wafers and on 4H-SiC epitaxial layers A preliminary investigation has been performed by optical microscopy and Scanning Electron Microscopy with the aim to evidence the defect morphology on a large scale. A deeper insight on the defects typology has been obtained by Atomic Force Microscopy, Profilometer technique, and Micro-Raman spectroscopy. Different types of defects such as micropipes, comets, super dislocations, etch pits and so on, have been characterized finding particular physical finger-prints [1,2].

This acquired understanding can be used for further development of the growth equipment and for tuning of process parameters, aimed at growing a defect free material of excellent uniformity and homogeneity.

2 Experiment

The investigated 4H-SiC epilayers were grown on commercial 4H-SiC substrates. The characteristics of substrates are the following: n-type \(N_D = 2 \times 10^{19} \text{cm}^{-3}\), 2” diameter, 8° off-axis, selected micropipe density (16–30/cm²), silicon face.

The epilayers were grown by two different techniques: a) sublimation epitaxy, [4] b) hot wall chemical vapor deposition (HWCVD). Samples obtained by sublimation epitaxy and by HWCVD will be mentioned as samples Ax and By respectively. Growth parameters and epitaxial characteristics are reported in table 1. The epilayer thickness was determined by FTIR and the doping concentration by an electrical Hg-probe.

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Table 1 Summary of epilayers data.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Growth Temperature (°C)</th>
<th>Growth Rate (µm/h)</th>
<th>Epilayer Thickness (µm)</th>
<th>Doping Concentration (cm⁻³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>2000</td>
<td>19</td>
<td>19±10%</td>
<td>n-type 9×10¹⁵±50%</td>
</tr>
<tr>
<td>A2</td>
<td>2040</td>
<td>39</td>
<td>13±10%</td>
<td>n-type 2.3×10¹⁶±50%</td>
</tr>
<tr>
<td>A3</td>
<td>2040</td>
<td>40</td>
<td>10±10%</td>
<td>n-type 9×10¹⁵±50%</td>
</tr>
<tr>
<td>B1</td>
<td>1600</td>
<td>6.5</td>
<td>7.2±10%</td>
<td>n-type 3.7×10¹⁶±50%</td>
</tr>
<tr>
<td>B2</td>
<td>1600</td>
<td>6.5</td>
<td>5.5±10%</td>
<td>n-type 1.6×10¹⁶±50%</td>
</tr>
<tr>
<td>B3</td>
<td>1600</td>
<td>6.5</td>
<td>6.7±10%</td>
<td>n-type 2.4×10¹⁶±50%</td>
</tr>
</tbody>
</table>

The investigations of the samples have been performed by optical bright-field microscopy (NIKON microscope, with magnification up to 2000x) on whole 4H-SiC wafer in order to obtain the defects maps and their qualitative surface densities [3].

Optical Microscopy, Surface Profiler (TENCOR P-10), Scanning Electron Microscopy (JEOL 6400) and Atomic Force Microscopy (DME DS 95-200) were used on selected area with the aim to evidence the defect morphology. Structural characterization was performed by Raman spectroscopy just on the epilayers. The system used in this work is a Renishaw Micro Raman system equipped by an Argon laser with excitation line at 514.5nm and a cooled CCD camera as a detector. The microprobe technique was very useful because it collects informations from the epilayers getting rid of the substrate signal (depth field 2 µm in confocal configuration).

3 Results and discussion

A careful optical map of 4H-SiC wafers and epilayers was obtained by performing a matrix square elements of 1mm² [3]. Defects were classified in the following categories: micropipes, comets (or carrots), etch pits and down falls (category grouping other defects with different polytype inclusions and graphite incorporation). We focused the investigation on planar defects in order to check bulk defects propagation into epilayer and
polytype inclusions. A typical planar defect with polytype inclusion was carefully investigated as reported in figures 1–3.

![Micro Raman Spectra. 3C-SiC inclusion.](image)

In particular the cross section of a planar defect surface yielded by stylus profilometer, shows a depth of 1100Å (fig. 1) in agreement with the different lattice parameters between 3C and 4H polytypes. In fact, the density is the same for all SiC polytypes, so that the atom spacing is the same.

In the a-plane (parallel to the surface of our <0001> 4H-SiC samples) the lattice parameters are therefore the same, but along the c-axis (perpendicular with respect to the other axis) inter-atomic distances are strictly correlated to the different stacking order in the unit cell, so justifying the verified extended dip. Typical planar defect image by optical microscopy of polytype inclusion detected by MicroRaman spectroscopy is shown in Figg. 2-3. The figure 2 shows three different investigated areas by microprobe Raman analysis and a polytype (3C-SiC) inclusion was characterized. It is worth to underline that the maps obtained on 4H-SiC surface bulk wafer do not evidence the presence of 3C-SiC polytype. Nevertheless, structural characterization performed on epitaxial layer shows many areas with an evident 3C-SiC nucleation. [5] Since HWCVD is performed at a relatively low temperature (1600°C), where 3C can be thermodynamically stable polytype, which makes plausible the presence this phase. We checked the presence of 3C inclusion on all investigated epilayers grown by both the above mentioned techniques. Although HWCVD and sublimation epitaxy work at a different growth temperature (see table 1), no differences were pointed out for such kind of inclusion/defect. Typical size of 3C inclusion are of the order of tenth of micrometers, as reported in figures 1-2. On the other hand, sublimation epitaxy technique promotes the formation of graphite inclusions in the epilayer [6], scarcely observable in the samples grown by HWCVD.

4 Conclusion

A detailed mapping of 4H-SiC bulk wafers and epitaxial layers has been done by checking different defects typology. The comparison between bulk and epitaxial surface analysis does not show appreciable correlation. In particular, 3C-SiC inclusion detected by Raman spectroscopy on epilayers cannot be observed in the wafer bulk used as a substrate. On the other hand, it has to be taken into account that the low resolution of the grid lay-out (square elements with area of 1 mm²) does not allow a reliable spatial matching with other defects present in bulk substrates and epilayers.

References