Planar semipolar (10\(\overline{1}\)1) GaN on (11\(\overline{2}\)3) sapphire

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We report on the growth of planar semipolar (10\(\overline{1}\)1) GaN on (11\(\overline{2}\)3) prepatterned sapphire. This is a method that allows the growth of semipolar oriented (10\(\overline{1}\)1) GaN on large scale. Using x-ray diffraction only the peaks of the desired (10\(\overline{1}\)1) plane could be observed. Scanning electron, transmission electron, and atomic force microscopy measurements show an atomically flat surface. Further investigations using photoluminescence spectroscopy show spectra that are dominated by the near band edge emission. The high crystal quality is furthermore confirmed by the small full width at half maximum values of x-ray rocking curve measurements of less than 400 arcsec.

Devices like light emitting diodes (LEDs) based on GaN are usually grown in c-direction. Due to induced biaxial strain and the lattice geometry of group-III nitrides, huge piezoelectric fields are present within heterostructures along this particular direction. As result of this band bending there are some undesirable effects on the quantum wells (QWs) grown in that direction, like spatial separation of the wave functions of electrons and holes. As consequence there is a reduced recombination probability, which can be advantageous for longer wavelength light emitters.

The growth was carried out in a commercial horizontal flow Aixtron-200/4 RF-S reactor with the standard precursors trimethylgallium (TMGa), trimethylaluminum (TMAI), and high purity ammonia (\(\text{NH}_3\)). For the carrier gas we used Pd diffused hydrogen. The process temperature was controlled by a pyrometer at the backside of the rotation tray. As starting substrate lithographically structured (11\(\overline{2}\)3) oriented sapphire was used with grooves along the in-plane m-direction. Therefore we deposited a 200 nm silicon dioxide (\(\text{SiO}_2\)) mask via plasma-enhanced chemical vapor deposition which also acts as a mask for the selective area growth. A 550 nm thick mask of nickel and gold, structured with a (3 \(\mu\)m opening) \(\times\) (3 \(\mu\)m mask) stripe pattern was used for dry etching of the sapphire via reactive ion etching. To start growth we used an oxygen doped low temperature AlN nucleation layer, followed by approximately 1 \(\mu\)m GaN with a V/III ratio of 650 at a temperature of 1130 °C and a pressure of 150 hPa.

To characterize the samples and their crystal quality we used x-ray diffraction (XRD) rocking curve measurements (XRC) and \(\omega-2\theta\) scans as well as low temperature (14 K) photoluminescence (PL) measurements. Particularly, the latter enables us to judge about typical defects in semipolar and nonpolar GaN layers, like basal plane stacking faults (BSFs). The surface quality could be accessed via scanning electron microscopy (SEM), transmission electron microscopy (TEM), optical phase contrast microscopy (OM), and atomic force microscopy (AFM).

Figure 1 shows the growth principle. The GaN growth starts from the groove facets of the sapphire wafer in the usual c-direction, which has a certain inclination to the surface [Fig. 1(a)] resulting in a flat and planar semipolar substrate [Fig. 1(b)]. The crystal orientation was measured via a symmetrical XRD \(\omega-2\theta\)-scan (Fig. 2). The sapphire substrate

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grow more in lateral direction. The wing tilt of the overgrown area is about 0.2°, as visible in XRD measurements. Additionally, the excellent surface quality was confirmed by AFM and TEM measurements (Fig. 4). The root mean square roughness determined by AFM was as small as 0.1 nm for a 1×1 μm²-scan and below 0.3 nm for a 3×3 μm²-scan, respectively. An atomically flat surface was found by high resolution (HR)-TEM investigations.

The high crystal quality was verified by narrow XRC peaks. The full width at half maximum of both, the symmetrical (101) reflection and the asymmetrical (0002) and (1012) reflections were smaller than 400 arcsec, respectively. Furthermore, the low-temperature PL-spectra (Fig. 5) revealed a comparably strong and dominating near band edge emission (NBE) at 3.46 eV. Typically in semi- and nonpolar GaN grown on sapphire this luminescence is quite weak and the defect correlated luminescence is dominating. Nevertheless some of the typical defect related peaks are also visible in our sample. The transition around 3.43 eV, which can be attributed to BSFs, could not be suppressed completely. Also, the lower energy peaks (around 3.30 eV), usually assigned to (pyramidal) stacking faults (and partial dislocations) are still visible. Performing TEM investigations the local distribution of stacking faults could be investigated (not shown). The highest density of stacking faults can be found in the −c-wing, the +c-wing of the laterally overgrown area provides the lowest density. This area might be further increased and the defect density decreased by adequate growth conditions.

In summary planar semipolar (1011) GaN on (1123) prepatterned sapphire was grown. This method allows large area growth of semipolar oriented (1011) GaN on sapphire. Compared to other growth techniques and the resulting qualities

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ity of nonpolar GaN on sapphire this approach is quite promising, in particular if further optimization steps are included.

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