Growth of non-polar GaN on LiGaO$_2$ by plasma-assisted MBE

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Group III nitrides grown along the <0001> direction show a strong quantum confined Stark effect due to the electric fields resulting from the spontaneous and piezoelectric polarization. These fields cause a reduction of the oscillator strength due to a spatial separation of electrons and holes and a decrease in the energy of the radiative transition.

Epitaxial layers with non-polar surfaces such as the $M$-plane (1-100) and $A$-plane (11-20) are attractive due to the absence of built-in electrical fields in growth direction. It has been shown that multiple quantum well structures on the basis of $M$-plane GaN indeed exhibit higher quantum efficiency and a shift towards shorter wavelengths, compared to $C$-plane structures, as a consequence of the lacking internal electrostatic fields [1].

Since non-polar GaN substrates are not readily available for homoepitaxy, various alternative substrates have been examined for growth of high quality non-polar GaN crystals. In this sense $\beta$-LiGaO$_2$ (LGO) presents a very closely lattice matched substrate for GaN heteroepitaxy. While growth of $C$-plane GaN on (001) LGO has already been investigated in the past by a number of groups, e.g. [2], we now have examined the growth of non-polar $M$-plane GaN on (100) LGO and $A$-plane GaN on (010) LGO [3, 4]. Here we will show a comparison of both these non-polar GaN surfaces on LGO.

The LGO crystal can be grown by the Czochralski method and is thermally stable up to about 1600°C [5]. Further, it can be selectively etched with respect to nitrides. Although the bulk crystal quality is excelled as determined from x-ray rocking curves (FWHM of (200) LGO and (040) LGO are 23 and 18 arcsec, respectively), the polishing of epi-ready substrates needs improvement. AFM images show a large number of surface scratches with RMS roughness values on the order of 10-20 nm over 10 x 10 µm$^2$.

While a large body of experience exists for $M$-plane GaN growth on the chemically similar crystal, $\gamma$-LiAlO$_2$ (LAO), non-polar GaN growth on LGO lacks this benefit. However, a big advantage of LGO over LAO is the selective growth of the different GaN planes on different LGO planes, which should automatically lead to a high phase purity of the GaN film. While both $C$- and $M$-plane GaN are reasonably lattice matched to (100) LAO, the lattice mismatch and underlying crystal symmetry is only matched well for $M$-plane GaN on (100) LGO, $A$-plane GaN on (010) LGO and $C$-plane GaN on (001) LGO. However, there are also some challenges concerning GaN growth on LGO, e.g. the epitaxial films tend to peel off of the substrate, which has not been a major issue concerning growth on LAO.

Our results prove experimentally the expected epitaxial relationship of GaN on (100) LGO and (010) LGO. We consider substrate treatment prior to growth and a carefully applied growth procedure critical for the stability of the epitaxial film. We have investigated the effect of substrate cleaning via annealing and Ga desorption as well as nitridation of LGO. To characterize the samples we have performed reflective high energy electron diffraction (RHEED), x-ray diffraction (XRD), scanning electron microscopy (SEM), atomic force microscopy (AFM) and transmission electron microscopy (TEM).
From the data collected we find a high phase purity of the grown GaN films. The morphology of the GaN surface is, to a large extent, influenced from the underlying substrate morphology, therefore also showing a high abundance of surface scratches. Although the RMS roughness of the samples, excluding the deepest surface scratches, is already low, i.e. 2.9 nm for $M$-plane GaN and 10nm for $A$-plane GaN, we expect to obtain smoother surfaces and a higher crystal quality of the GaN films by optimizing growth conditions.

Figure 1: a) and d) show ball and stick models of the (100) and (010) LGO surface, respectively. The dotted rectangles signal the size of the LGO unit cell, while the shaded rectangles indicate possible nucleation sites for non-polar GaN. b) and e) show ω-2θ x-ray scans of $M$- and $A$-plane GaN grown on (100) and (010) LGO, respectively. AFM images of the $M$- and $A$-plane GaN surfaces are seen in c) and f), respectively.