APPLICATION NOTE

In-situ curvature measurements in MBE

In-situ curvature measurements have become indispensable for monitoring and understanding the strain relaxation in group-III-nitride layers grown by MBE. Dr. Yvon Cordier of CRHEA (France, Valbonne) used LayTec's in-situ optical sensor EpiCurve® TT in a Riber Compact 21 system for stress engineering to obtain thick, high-quality GaN layers without cracks on Si substrates.

The heteroepitaxy of group-III-Nitrides often leads to problems related to stress due to the lattice mismatch between the substrate and the growing material as well as the difference in thermal expansion coefficient. The first leads to high densities of threading dislocations and is associated with residual stress. The second generates additional stress when cooling down to room temperature. In particular, for the MBE growth of Ga(Al)N films on SiC or Silicon substrate, the difference in thermal expansion coefficient is responsible for a tensile stress at room temperature, which can generate cracks in the films. Furthermore, the stressed epitaxial layers and the substrate experience a bending, which depends on the stress. Excessive bending and the presence of cracks hamper the development of devices especially for large substrates where the bow is even more significant.

Stress engineering helps to obtain thick, high-quality GaN layers without cracks even on Si substrates. AlN interlayers or AlGaN stress reducing layers allows the growth of thick GaN films on silicon. But the efficiency of such procedures depends to a large extent on growth conditions and layer quality. In-situ monitoring of stress is therefore a very useful tool for optimizing such layers.

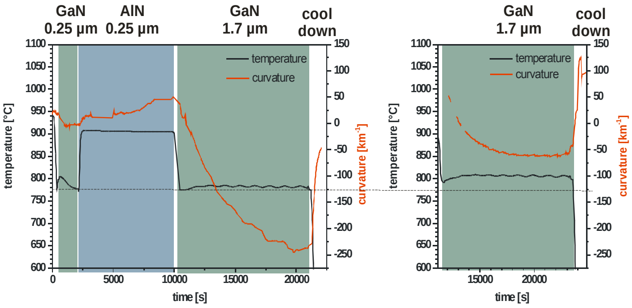

Fig. 1: Curvature (red) and temperature (black curve) data. Left: GaN-layer grown at 780˚C (run 240). Right: similar run with GaN-layer grown at 800˚C (run 246).

Experiments at CRHEA showed the strengths of the **EpiCurve® TT** sensor, combining curvature, temperature and reflectance measurements in a single optical head. The curvature measurement of the Silicon wafer bending during growth of AlN and GaN layers provided very useful information on strain relaxation for the design of structures based on thick GaN buffer layers, such as HEMTs.

Fig.1 (left graph) shows the wafer temperature and the curvature measured during the growth and cooling down to room temperature. This structure contained a GaN buffer layer capped with an AlN/AlGaN barrier and GaN as HEMT active layers. Like in many MBE systems, the substrate was not in contact with the heater and was heated by IR radiation. With a specially designed optical head, the wafer temperature was measured very accurately (with an offset

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due to radiation from the hot sources of only ≤ 3 K).

Once the growth of the first AlN layer was started, a concave curvature was observed. Then the growth of the GaN layer quickly changed the curvature to almost zero. The AlN layer re-established a curvature rise. Although the growth conditions were identical to those of the first 0.25 µm GaN interlayer, the 1.7 µm thick GaN layer rapidly developed a negative (convex) curvature that slowly saturated after the deposition of about 1.6 µm. The growth of the tensile strained AlGaN barrier layer also contributed to this saturation, before cooling down to room temperature reduced the curvature again.

The development of the curvature for the thick GaN layer depends on the growth conditions. Fig.1 (right graph) shows the curvature for GaN layer grown at 800°C (20°C higher substrate temperature than before). Despite similar RHEED patterns and initial curvature quickly developing towards negative values, the saturation of curvature was faster (after only half of the GaN growth). This is a clear indication of layer relaxation. This second type of growth structure was not able to compensate the thermal mismatch. The two times higher density of threading dislocation on the surface was observed, which illustrates how important influence of GaN-on-AlN nucleation conditions on defect density and relaxation rate is.

Since **EpiCurve® TT** measures not only curvature and wafer temperature, but also accurate reflectance at the same time, the thickness of the important GaN layers involved can be determined simultaneously as Fig. 2 shows.

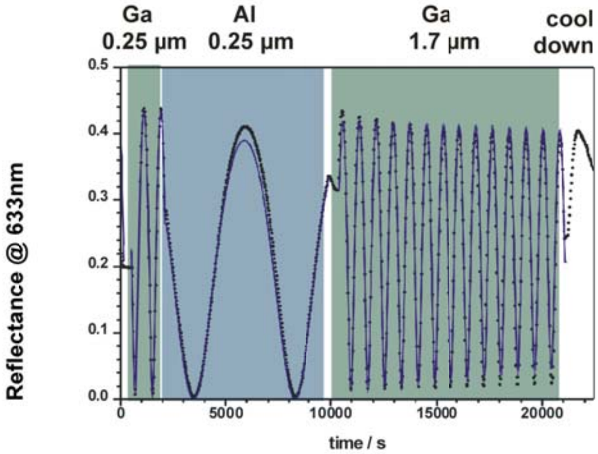

Fig. 2: In situ 633nm reflectance measurements of GaN/AlN/GaN growth on Silicon in a Riber Compact 21 performed by LayTec's **EpiTT** sensor. Black curve – as measured; blue curve – fitted by multi-layer simulation software.

Growth rates determined from reflectance measurements:

GaN 0.25 µm	0.1602 ± 0.0006 nm/s
AlN 0.25 µm	0.0310 ± 0.0002 nm/s
GaN 1.7 µm	0.1665 ± 0.0002 nm/s

In this study LayTec's EpiCurve TT sensor helped to understand the development of stress towards strain relaxation in multilayered structures and to optimize structures in order to deal with the thermal mismatch related stress during cool down. This provided the opportunity to obtain high-quality group III-Nitrides layers on silicon.

Further reading: Y.Cordier, N.Baron, F.Semond, J.Massies, M.Binetti, B.Henninger, M.Besendahl, T.Zettler: In-situ measurements of wafer bending curvature during growth of group-III-nitride layers on silicon by molecular beam epitaxy. In: Journal of Crystal Growth, Vo. 301-302 (2007), 71-74.