ESRF	**Experiment title:** Strain relaxation in GaAIN alloys grown in-situ on bulk GaN substrates by Molecular Beam Epitaxy	**Experiment number:** HS-239
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Report:

Gallium nitride, aluminium nitride and other III-V nitrides are currently the subject of intense research. Their physical properties make III-V nitrides extremely attractive for high wavelength optoelectronics (blue light emitting diodes, ultraviolet and blue light emitting lasers), white light emitters and high temperature electronics. The aim of our experiment was to provide the detailed description of relaxation phenomena in $Ga_{1-x}Al_xN$ ternary alloys (up to x = 1) grown on hexagonal GaN (0001) substrates (the lattice parameter mismatch between GaN and AlN is 2.4%). As GaN substrates, the bulk single crystals have been used and compared with pseudosubstrates obtained by a thick (2μm) GaN epilayer deposition by MOCVD (metalorganic chemical vapour deposition) on sapphire.

The single crystal bulk GaN substrates had been grown by UNIPRESS (Poland) under high pressure - high temperature conditions (15 kbar, 1500 K). The MOCVD pseudosubstrates had been grown at Montpellier University. The SUV station on the CRG IF - D32 beamline has been used to perform the epitaxial growth and in-situ X-ray surface diffraction. The most important results obtained are the following:

1. The extremely high crystallographic quality of bulk GaN substrates has been confirmed by in-plane and out-of-planediffraction. The half-width of (300) Bragg peak is as low as 25 arcsec.
2. The crystallographic quality of $Ga_{1-x}Al_xN$ epilayers grown in-situ on MOCVD pseudo-substrates is comparable to the best reported results.

3. In **the case** of the AlN epitaxy on bulk GaN substrates, the AlN epilayer is not fully relaxed even for 1500 Å thickness. This is illustrated in figure 1 where the reciprocal lattice map of (224) Bragg peak is plotted for 200 Å thick and 1500 Å thick epilayers. We tentatively attribute the observed high resistance of AlN epilayer to relaxation to the high quality of the GaN bulk single crystal surface.
4. For the 200 Å thick epilayer, the detailed analysis of (224) Bragg peak reveals two states of AlN with different degrees of relaxation. Our result shows that there is a coexistence of the underlying highly strained layer and the upper layer which is more relaxed. This could be tentatively explained by the formation of 3D islands after growth of a relatively thick fully strained 2D layer. Much more detailed investigations are necessary to fully explain the observed phenomena. Additionally, the X-ray reflectivity and X-ray diffraction analysis for AlN epilayers of different thickness gave the information of surface roughness evolution, domain size and mosaicity as a function of layer thickness.
5. For a $\mathbf{Ga_{0.8}Al_{0.2}N}$ alloy grown on GaN pseudosubstrates by ECR-MBE, the critical thickness is higher than 3000 A. This can be clearly observed in figure 2 which shows the reciprocal lattice map of (224) Bragg peak for GaN and GaAlN, with alignment of both peaks on the K axis. The GaAlN is totally strained by the GaN substrate.

In conclusion, the high resistance of $\mathbf{Ga_{1-x}Al_xN}$ alloys to relaxation was demonstrated by surface X-ray diffraction. Work is under progress to confirm our result by high resolution electron transmission microscopy. AlN relaxation on bulk single crystals has been investigated for the first time. Bulk single crystals offer the starting surface of extremely high crystallographic quality, suitable for our investigations. Careful analysis of very thin epilayers (below 200 A) grown in different conditions on bulk crystals (i.e. with different substrate temperature, different N to Ga flux ratio) is clearly necessary to fully understand the relaxation mechanism for AlN on GaN. It will be the subject of our new proposal.

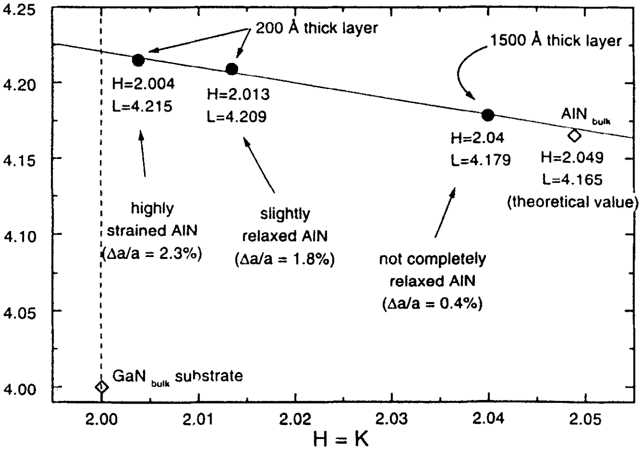

Figure 1; AlN: reciprocal lattice map around (224) Bragg peak from GaN

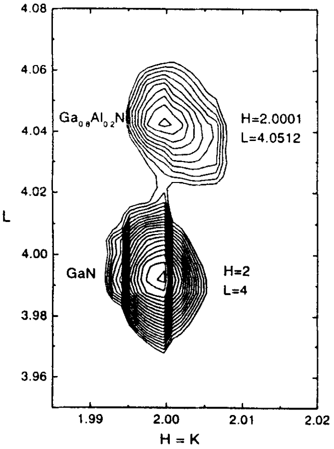

Figure 2; GaAlN: reciprocal lattice map around (224) Bragg peak from GaN