Structural properties of InAlN single layers nearly lattice-matched to GaN grown by plasma assisted molecular beam epitaxy

Ž. Gačević[1,*], **S. Fernández-Garrido**[1,**] **and E. Calleja**[1]
D. Hosseini[2], **S. Estradé**[2, 3] **and F. Peiró**[2]

[1] *ISOM, Universidad Politécnica de Madrid, Avda. Complutense s/n, 28040 Madrid, Spain*
[2] *LENS-MIND-IN2UB, Departament d'Electrònica, Universitat de Barcelona, Martí i Franquès 1, 08028 Barcelona, Spain*
[3] *TEM-MAT, SCT- UB, Solé i Sabarís 1, 08028 Barcelona, Spain*

The high lattice mismatch between III-nitride binaries (InN, GaN and AlN) remains a key problem to grow high quality III-nitride heterostructures. Recent interest has been focused on the growth of high-quality InAlN layers, with approximately 18% of indium incorporation, *in-plane* lattice-matched (LM) to GaN. While a lot of work has been done by metal-organic vapour phase epitaxy (MOVPE) by Carlin and co-workers, its growth by molecular beam epitaxy (MBE) is still in infancy.

In our recent publications we reported on: the growth map for InAlN single layers and the growth of 10-period LM InAlN/GaN DBRs [1-3] with highest reported reflectivity (~60%, Fig. 1), within MBE growth technique. However, successful growth of $In_{0.18}Al_{0.82}N$/GaN DBRs is followed by two difficulties, first, to obtain flat InAlN layers with good homogeneity and high crystalline quality and, second, to find a compromise between different growth temperature ranges required for a good $In_{0.18}Al_{0.82}N$ (~535 ºC) and GaN (~700 ºC) growth. This work addresses the first commented issue, i. e. the properties of InAlN nearly LM to GaN, grown by MBE.

The two samples under study (S1 and S2) are grown on c-plane GaN-on-sapphire templates, under exactly same growth conditions (at 535 ºC, under effective stoichiometry, [1-3]) apart from their growth times, being their thicknesses approximately 70 and 420 nm, respectively.

Figure 2 shows ω/2Θ and ω-rocking scans around [0002] Bragg spot. Note that there is no indication of crystalline InN or AlN. The reciprocal space maps (RSMs) around symmetric [0002] and asymmetric [10-15] reflections (Fig. 3) reveal that the samples have grown pseudo-morphically on the underneath GaN, i. e. with the same *in-plane* lattice constant. Making use of linear approximation of the III-nitrides elasticity theory we estimate the indium content to be around 19%. Note that the full width of half maximum (FWHM) of ω-rocking curves of the InAlN and the underneath GaN are practically equal: 0.1º/0.11º, for [0002], and 0.58º/0.55º, for [10-15] reflections, respectively. These results confirm excellent crystalline quality of the InAlN layers. In addition, there is no evidence of structural deterioration of the material with the layers' increasing thickness.

Figure 4 features tapping-mode AFM measurements of the samples comparing them to a reference GaN template. Root mean square (RMS) surface roughnesses, over 2.5×2.5 μm^2 scan area, are found to be: 0.41, 0.59 and 0.61 nm for the GaN, S1 and S2 sample, respectively. While we appreciate certain increase in RMS (from GaN to InAlN), there is no evidence of progressive surface roughening with increasing InAlN thickness.

The InAlN/GaN DBRs exhibit much inferior refractive index contrast when compared to their AlN/GaN counterparts (8% and 16%, respectively). This difference provokes much deeper penetration of the incident light into the former structures and consequently, their higher sensitivity to the presence of residual absorption (i. e. absorption at lower-than-band-gap energies). To estimate optical properties of the layers, we performed absorption measurements. The residual absorption was found to be as high as 1.6% and 14%, at 600 nm, in S1 and S2 samples, respectively. To determine actual origin of this unwanted effect, our samples are currently under thorough transmitting electron microscopy studies.

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[2] Ž. Gačević, S. Fernández-Garrido, and E. Calleja, Phys. Stat. Sol (c) Vol. **6**, S643-S645 (2009)
[3] Ž. Gačević, S. Fernández-Garrido, D. Hosseini, S. Estradé, F. Peiró and E. Calleja, accepted for publication in JAP (2010)

* Contact: gacevic@die.upm.es
** Present address: Paul-Drude-Institut for Solid State Electronics, Hausvogteiplatz 5-7, 10117 Berlin, Germany

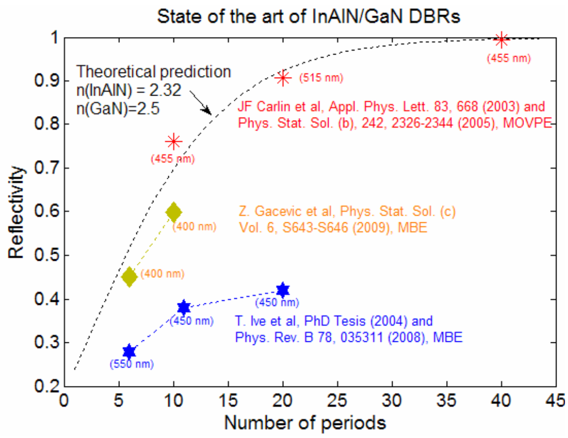

Fig 1: State of the art of InAlN/GaN DBRs grown by either MBE or MOVPE.

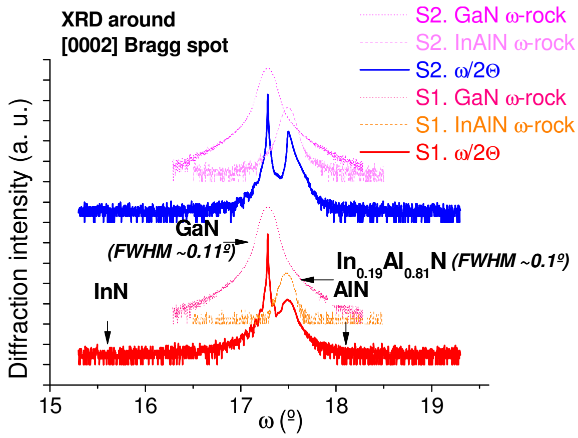

Fig 2: ω/2Θ and ω-rocking scans around [0002] Bragg spot. The scans are characterized by no trace of phase separation and good FWHM of InAlN ω-rocking curves.

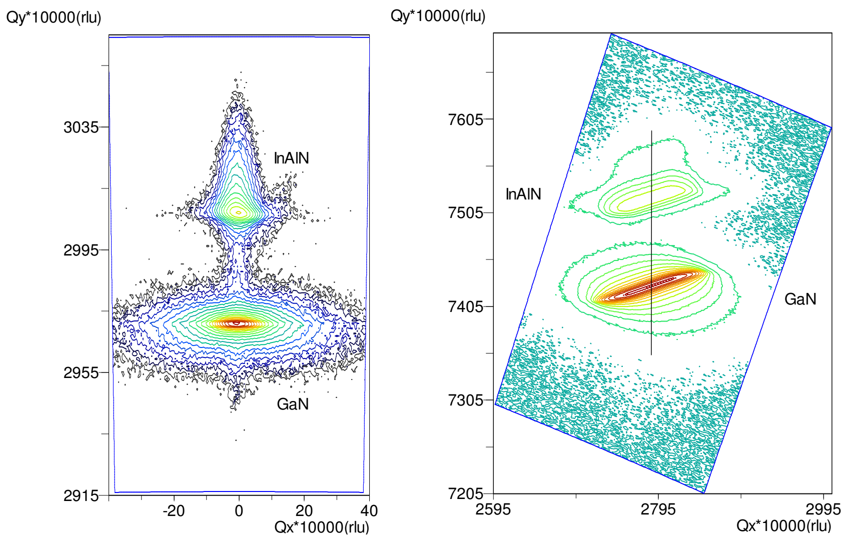

Fig 3: RSMs around symmetric [0002] (left) and asymmetric [10-15] (right) reflections (sample S2). (Left) ω/2Θ scan (Fig. 2) corresponds to the scan along Q_x=0 line, whereas GaN and InAlN ω-rocking scans (Fig. 2) correspond to Q_y*10000 = 2971 and 3007 lines. (Right) The InAlN layer is *in-plane* LM to GaN.

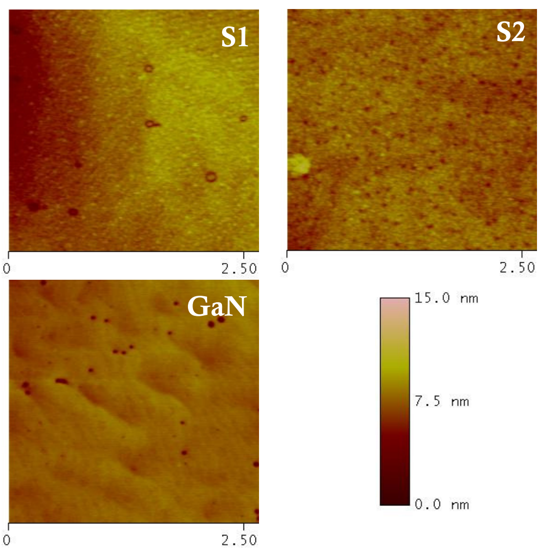

Fig 4: 2.5×2.5 μm^2 AFM images of the samples under study.

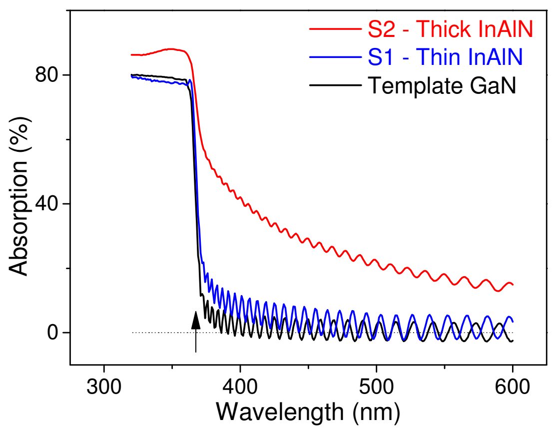

Fig 5: Absorption measurements of the samples under study. The onset of GaN absorption is marked by the arrow.