# STRESS RELAXATION IN (0001) InGaN/GaN HETEROSTRUCTURES VIA V-SHAPE DISLOCATION FORMATION

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Suppression of stress relaxation in the mismatched InGaN/GaN multiple quantum well structures is currently of great interest that demands a clear understanding of the stress relaxation mechanism. In contrast to cubic III-V compounds having easy-glide planes inclined to the (001) epilayer interfaces, the biaxial strain in (0001) III-nitride heterostructures caused by lattice mismatch does not produce a resolved shear stress favorable for gliding of ***a***-type dislocations with the shortest Burgers vector $b = \frac{1}{3}a[11\bar{2}0]$. Therefore, the conventional mechanism of stress relaxation via misfit dislocation formation at the interfaces by gliding becomes out of play in such structures. Here, we report on alternative relaxation mechanism implying V-shape dislocation formation in the (0001) In(Al)GaN/GaN heterostructures using both experimental and theoretical approaches.

We studied two (0001) InGaN/GaN structures grown at the A. F. Ioffe Institute, St.Petersburg. The first structure contained 4×{2.5 nm $In_{0.28}Ga_{0.72}N$/11.5 nm GaN} superlattice covered in sequence by $Al_{0.15}Ga_{0.85}N$ and GaN layers. The second structure contained a single 2.3 nm-thick $In_{0.23}Ga_{0.77}N$ layer sandwiched between a bottom InGaN/GaN short-period superalttice and upper $Al_{0.15}Ga_{0.85}N$/GaN layers. The composition in the layers was determined from the strain measurements obtained by geometric phase analysis of high resolution TEM images and elastic theory calculations. The underlying GaN buffer layer of both structures contained threading dislocations of mixed and edge type with a density of ~3-6×$10^8$ $cm^{-2}$. Additionally, new V-shape dislocation half-loops (DHLs), with the density one order of magnitude higher than that observed in the buffer layer, appeared in both structures in InGaN layers. Using stereographic projections and a detailed analysis of the contrast of a V-shape HL at different weak-beam dark-field imaging conditions (Fig. 1), the dislocation lines were identified to lie along the $[01\bar{1}3]$ and $[\bar{1}103]$ directions in the same $(2\bar{1}\bar{1}0)$ plane and to be of pure edge type with the Burgers vector along the in-plane $[2\bar{1}\bar{1}0]$ direction. This finding confirms the validity of a hypothesis on the Burgers vector $b = \frac{1}{3}a < 11\bar{2}0 >$ of the V-shape DHLs applied in our recently developed model for the stress relaxation mechanism in (0001) InGaN/GaN layers (Fig.2a).

The model assumes growth of a strained layer up to a critical thickness above which the DHLs start to appear. DHLs nucleate likely at the growth surface and then penetrate down to the InGaN/GaN interface via climbing. At that, point defects necessary for climbing are released by the dislocation cores and diffuse back to the growth surface. We have applied the energy-balance approach to estimate the critical thickness for the stress relaxation by the above mechanism. The theoretical predictions are found to be in good agreement with the data provided in literature for single InGaN/GaN layers (Fig.2b).

Then we used the model to examine a possible way for suppressing stress relaxation in InGaN-based multiple quantum well structures via insertion of AlGaN interlayers. The modeling has shown that insertion of a 1 nm-thick $Al_{0.4}Ga_{0.6}N$ layers between InGaN quantum wells (QWs) and GaN barriers would not affect significantly the stress relaxation in the whole structure. In contrast, replacing of GaN by $Al_{0.2}Ga_{0.8}N$ barriers (both 10 nm thick) is predicted to increase remarkably the number of QWs critical for the V-shape dislocation formation (Fig. 3). Therefore, the use of AlGaN barriers instead of GaN ones is favorable for growing unrelaxed structures with larger number of QWs.

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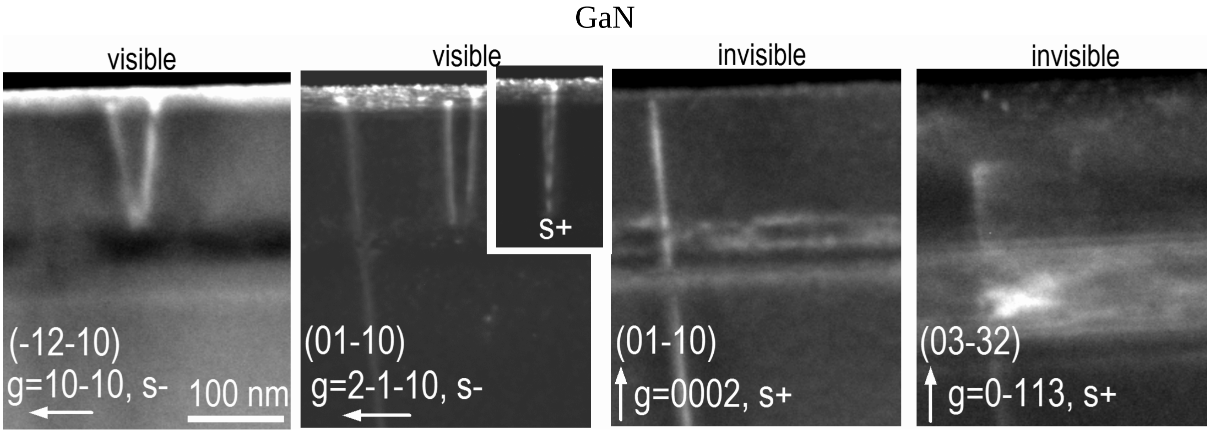

**Figure 1.** Cross-sectional weak-beam dark field images of the pair of V-shape dislocations in the structure with a single 2.3 nm-thick $In_{0.23}Ga_{0.77}N$ quantum well sandwiched between a bottom InGaN/GaN short-period superalttice and upper $Al_{0.15}Ga_{0.85}N$/GaN layers. The dislocation contrast analysis allows determining their Burgers vector direction, their habit plane and line directions.

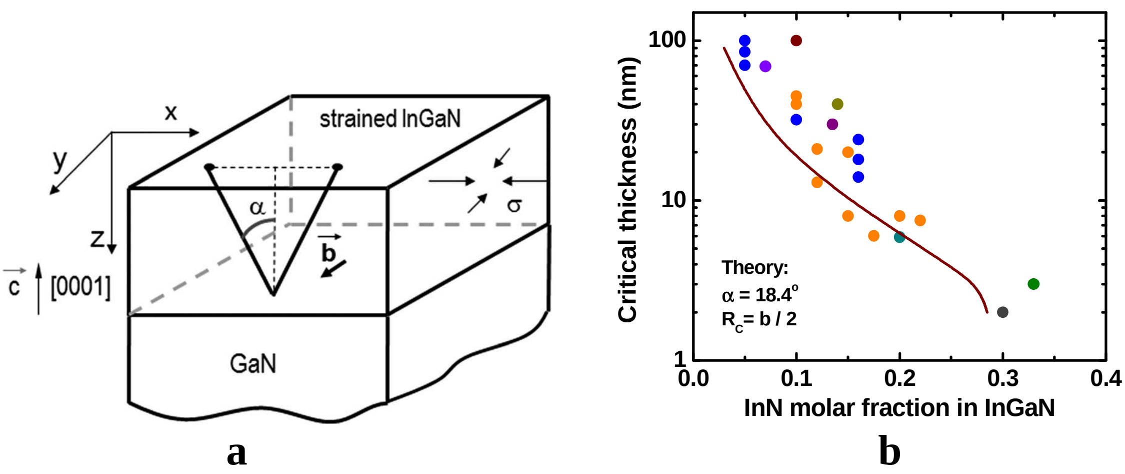

**Figure 2.** Schematic view of a V-shape edge-type dislocation half-loop (a) and critical thickness versus InGaN composition (b): gray shadow indicates theoretical predictions, symbols are the experimental data from different papers.

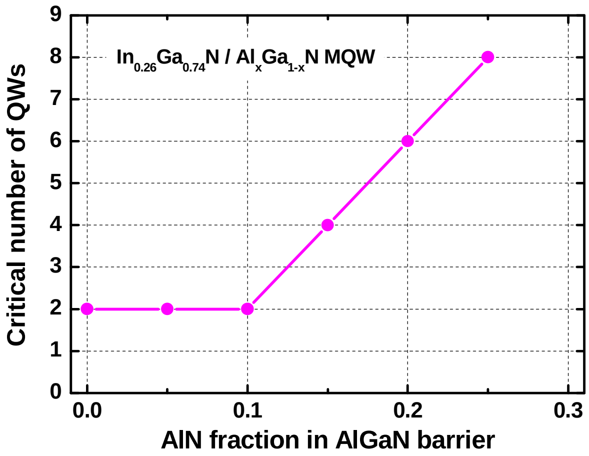

**Figure 3.** Calculated dependence of the critical number of quantum wells (QWs) in 3 nm $In_{0.26}Ga_{0.74}N$ / 10 nm $Al_xGa_{1-x}N$ structure on the $Al_xGa_{1-x}N$ composition of the barriers.