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Invited talk

Strain relaxation in semiconductor heteroepitaxial layers

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The III-nitrides (AlGaN, InGaN, and AlInN) band gaps cover from deep ultraviolet (UV) to near infrared (IR) across the visible range of wavelengths. Thus, they are suitable for numerous applications from efficient light emission for public lighting to high power high frequency transistors for telecommunication. In the most stable form, they crystallize in the wurtzite structure; the nitrogen occupies one HCP sublattice and moving from one compound to the other is due to the change in the occupation of the second sublattice by a different metallic atom. These atoms exhibit a large difference in size and electronic structure. This is obviously reflected in the properties of the compounds such as growth temperatures, lattice, piezoelectric or elastic constants, as well as the thermal expansion elastic coefficients. Their growth is carried out along the [0001] axis in the form of alloys and heterostructures, and it should be optimized in order to relax the residual strains resulting from the above differences.

In a combination of experimental and theoretical investigations we have studied the strain relaxation in InAl(Ga)N and InGaN/GaN heterostructures. Indeed AlInN, and InAl(GaN) alloys are expected to replace the more conventional AlGaN/GaN High Electron Mobility Transistors (HEMT) barriers as higher performances have been theoretically demonstrated. In this work, the studied AlInN and AlGaInN/GaN systems were grown by metal organic vapor phase epitaxy (MOVPE), whereas the InGaN/GaN could be from MOVPE or molecular beam epitaxy. The experimental investigations consisted of High Resolution X-Ray Diffraction and Transmission Electron Microscopy; the theoretical work was carried out in the scope of multiscale atomistic modelling from ab initio to molecular dynamics. In the case of InAlN/GaN heterostructures, the relaxation of the strain was found to take place inside the alloy throughout the formation of defects that have been classified as extrinsic and intrinsic. The dislocations and inversion domains from the GaN buffer layer generate extrinsic defects, while, pinhole not connected to dislocations and individual hillocks responsible of surface roughening are termed as intrinsic. These systematic degradations happen also with optimized growth conditions as soon as the nominal composition is changed and/or the thickness is increased. Our work proposes different mechanisms to explain defects generation processes. In the growth of InGaN/GaN, many mechanisms govern the strain relaxation, the MBE growth leads to a two dimensional growth mode in the whole composition range from GaN to InN. There is a formation of misfit dislocations at the InGaN/GaN interface, and structural degradations takes

place for compositions starting above 25-30 In%, in the form of random stacking sequence disruption. In MOVPE which is carried out a slightly higher temperature, the formation of misfit dislocation is in competition with the relaxation of the strain through formation of surfaces (V defects, porosity, clear three dimensional growth). The formation of porous material dominates at the medium range compositions (~50%) in attempts to grow thick layers. When high indium content InGaN/GaN quantum wells are grown by MOVPE, as one does not reach the critical thickness for plastic relaxation, the relaxation is initiated by the formation of strained hexagonal domains inside the GaN Barriers.