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X-ray reciprocal lattice mapping and photoluminescence of GaN/GaAlN Multiple Quantum Wells; strain induced phenomena.

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Structural properties of GaN/GaAlN multiple quantum wells (MQW) grown by nitrogen plasma assisted MBE on MOCVD-grown GaN/sapphire (GaN pseudosubstrates) have been characterised by X-ray reciprocal lattice mapping to determine the strain and composition of ternary alloys. The results clearly demonstrate that the barriers of GaAlN with up to 17% of aluminium content grown by plasma assisted MBE on GaN are fully strained. Optical properties have been characterised by low temperature photoluminescence. Photoluminescence emission peaks corresponding to the GaN/GaAlN MQW structures revealed strong red-shift with respect to the GaN energy gap. This can be explained by a strong internal electric field present in the QW's which is attributed to a transfer of piezoelectric field due to Fermi-level alignment.

1 Introduction

GaAlN/GaN quantum wells (QW's) are subject of current investigations due to their potential for electronic and optoelectronic applications. Many publications report on the characterisation of MOCVD or MBE grown GaN/AlN and GaN/GaAlN superlattices and/or multi-quantum well (MQW) structures [1] [2] [3] [4]. Recently, a strong piezoelectric field has been evidenced in GaN/GaAlN heterostructures [5] [6] and attributed to strain related phenomena. In this work, we carefully characterise the strain configuration in GaN/GaAlN MQW's and based on that we analyse their optical emission spectra which seem to be dominated by piezoelectric effects.

2 Experimental

Growth of nitride films was performed in a RIBER MBE 2300 chamber. Standard Knudsen cells have been used for gallium and aluminium evaporation and the active nitrogen was generated by a commercial (EPI Unibulb) radio frequency (RF) cell. Samples were fixed with indium on a molybdenum sample holder. Growth was performed at a relatively low substrate temperature of 650°C, controlled by an infrared pyrometer. The composition of the GaAlN films was adjusted by varying the beam equivalent pressure of the gallium and aluminium fluxes. The thickness of the layers was controlled by RHEED oscillations. MBE growth was performed on 1.5 μm thick GaN layers grown by MOCVD on sapphire. The oxide on this MOCVD grown GaN surface can easily be removed by acid etching and heating prior to growth. A well defined RHEED pattern and intense RHEED oscillations show that the treated MOCVD surface is smooth on an atomic scale [7]. To completely get rid of the eventual influence from surface oxide or from a contamination layer, we interpose a few 1000 Å thick GaN layer. Finally, high resolution X-ray diffraction was performed on a 4-circle goniometer with a rotating anode at a wavelength of CuKα 1.54 Å.

3 Results and Discussion

A relatively high lattice mismatch between GaN and AlN (2.5%) induces a high degree of strain in GaN/GaAlN heterostructures which, depending on the substrate choice and whether or not strain relaxation has occurred, can be present as well in the wells as in the barriers. A good method for determining the strain configuration in a given heterostructure is the X-ray measurement of reciprocal lattice map around asymmetrical Bragg peaks. The MQW section of the sample we discuss here consists of eleven 70Å/90Å GaN/$Ga_{0.83}Al_{0.17}N$ periods. It is embedded between a 1500Å

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$Ga_{0.83}Al_{0.17}N$ buffer layer and a 200Å $Ga_{0.83}Al_{0.17}N$ cap layer. The whole heterostructure is MBE-grown on a GaN pseudosubstrate, which is the strain-imposing layer in this case. In figure 1 we show the reciprocal lattice map of the given sample around the (104) Bragg peak of the GaN substrate. Aside from the substrate peak, we distinguish two additional peaks. The uppermost in the figure is due to the $Ga_{0.83}Al_{0.17}N$ buffer and cap layer, and the middle one is the zero-order peak of the eleven period superlattice.

First important information that can be drawn from the map is that the alloy has the same in-plane lattice parameter (represented by the (h,k) axis in reciprocal lattice units of Al_2O_3) as the GaN substrate. This means that the GaAlN of this thickness and composition is fully strained to GaN. From the in-plane lattice parameter and from the lattice parameter along the growth axis (represented by the l axis), one can calculate precisely the aluminium concentration of this alloy. Using Vegard's law for the lattice parameter and a linear interpolation between the available Poisson ratios for GaN [8] and AlN [9] we find an aluminium content of 17% in our alloy, which is in fair agreement with the nominal value. From the above result we can conclude that the critical thickness of a GaAlN layer with Al content around 17% grown on a GaN substrate is higher than 1700Å.

The zero-order superlattice peak is also aligned to the in-plane lattice parameter of GaN substrate; this proves that the whole heterostructure is pseudomorphic on the GaN substrate. This means that, neglecting the small residual strain in the GaN pseudo-substrate induced by the sapphire, the GaN QW's are not subjected to tetragonal distortion. In the X-ray diffraction scan along the growth axis shown in figure 2, one can see satellites of the superlattice structure. From the position of the zero-order peak and the positions of the satellites one can calculate the exact thickness of well and barrier layers (73.5Å / 87.3Å) and the aluminium composition (16.6%).

Low temperature photoluminescence (PL) was measured on the MQW sample. In figure 3 we identify the QW luminescence along with its phonon replicas. If we took into account only quantum confinement effects, the QW luminescence should be blue-shifted with respect to the GaN energy gap (=3.47eV). However, as we can see in figure 3, the PL of these QW's is red-shifted by 158 meV with respect to the gap of GaN. This strong red-shift of the QW PL peak can be explained by a strong internal electric field present in the QW's. The electric field, which is necessary inside the wells to obtain such a strong red shift, is around 500 kV/cm. Considering that in our samples the QW layers are unstrained and only the barrier layers are strained and hence dispose of a piezoelectric field, the 500 kV/cm effective electric field present in the QW's results from a " transfer " of the barrier piezoelectric field in the QW's due to Fermi-level alignment. It should be noted that the observed redshift can not be attributed to exciton localisation by structural fluctuations of the quantum wells, since the quantum well recombination is still expected above the gap of bulk GaN. Finally, we can exclude the case of a donor-acceptor transition as our structures are undoped.

4 Conclusion

Growth of GaAlN/GaN multiple quantum wells was performed on GaN pseudo-substrates. By X-ray measurements of reciprocal lattice maps around asymmetrical Bragg peaks, we showed that a GaAlN layer with aluminium content up to 17% and with thickness lower than 1700Å is fully strained to a GaN pseudosubstrate. In addition, we verified by the same method that a MQW sample of eleven GaN/GaAlN periods and 17% aluminium content in the barriers is pseudomorphic to GaN. Photoluminescence from the wells on this sample revealed strong red-shift with respect to the GaN energy gap. This can be explained by a strong internal electric field present in the QW's which we attribute to a transfer of piezoelectric field in the QW's due to Fermi-level alignment.

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FIGURES

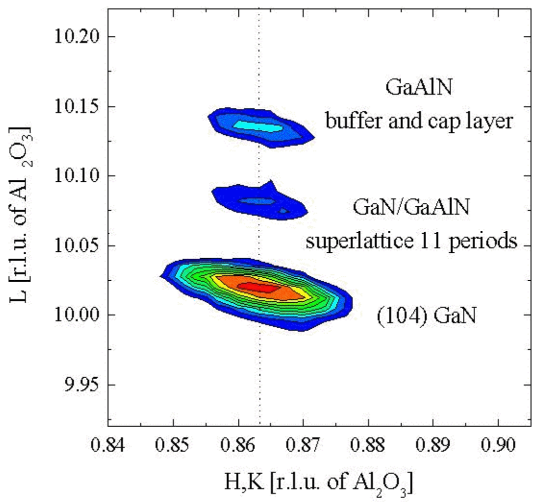

Figure 1. Reciprocal lattice map of the GaN/GaAlN MQW sample grown on GaN substrate. The GaAlN buffer and cap layers and the zero-order peak of the superlattice corresponding to the MQW section have the same in-plane lattice parameter as GaN. Measurement was performed in reciprocal lattice units of sapphire.

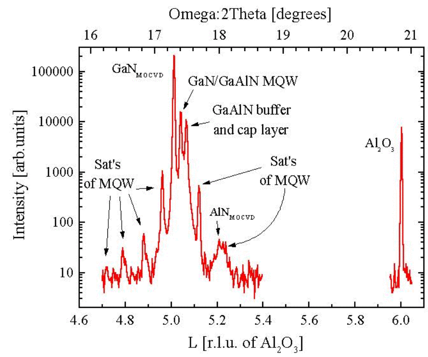

Figure 2. Reciprocal lattice scan of GaAlN/GaN MQW along growth axis. Satellites of the superlattice corresponding to the MQW section allow to calculate thickness of each layer. Measurement was performed in reciprocal lattice units of sapphire.

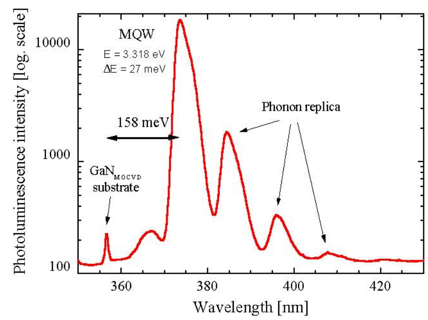

Figure 3. Low temperature photoluminescence spectra of multi-quantum well.

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