POLARIZATION EFFECTS IN GaN/ALN SHORT-PERIOD SUPERLATTICES FOR INTERSUBBAND OPTOELECTRONICS

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In the last several years, there has been phenomenal progress in the field of nitride semiconductor technology. The wide band gap of these materials motivated a huge international effort to develop light emitters, photodetectors, modulators and lasers in the visible and UV spectral regions. Recently, the extremely large conduction band offset of ~1.7eV in the GaN/AlN system impelled research in nitride-based intersubband (ISB) devices, with potentially interesting applications in the near-IR spectral region, covering the fibre optics telecommunications window (1.3 µm -1.55 µm) [1]. ISB transitions occur between the confined states of the conduction band in nitride nanostructures. The performance of ISB devices depends upon the ultra-fast ISB carrier relaxation time (150-300 fs in GaN/AlN quantum wells) attributed to Fröhlich (electron-LO phonon) interaction dominant in ionic materials. Along with operating speed, ISB devices also offer other advantages such as temperature insensitivity and large dipole moment. However, the large electron effective mass in GaN demands extremely thin (1-1.5 nm) QWs to reach 1.55 µm wavelength, which currently is only achieved by molecular beam epitaxy (MBE). Futhermore, spontaneous and piezoelectric polarization in nitride semiconductors induces an intrinsic electric field in the QWs. Therefore, strain management becomes a powerful design parameter which controls piezoelectric phenomena and defect formation, in a material system with huge piezoelectric constants (3-5 times those of GaAs(111)) and a significant lattice mismatch (~2.5%).

In this contribution we will present our latest achievements in terms of MBE growth of Si-doped GaN/AlN short-period superlattices (SL) for ISB optoelectronics [2]. We will discuss the effect of various growth and design parameters on the device performance, paying particular attention to the strain and polarization effects in the structures. The influence of the buffer and cap layers on the electronic profile and ISB absorption properties will be analyzed. Experimental results are interpreted by comparison with theoretical calculations of the electronic structure using a self-consistent 8-band-**k.p**-Schrödinger-Poisson solver.

All the samples show pronounced TM-polarized absorption in the near-IR, positioned at 1.55 µm (0.8 eV) for GaN/AlN (1.5 nm / 3 nm) quantum well. No shift of the absorption spectra was observed irrespective of the lattice parameter of the substrate, in disagreement with theoretical calculations which predict a blue shift under tensile strain. To clarify these odds, the structural properties were characterized with reflection high energy electron diffraction (RHEED), x-ray diffraction (XRD), transmission electron microscopy (TEM) and medium energy ion scattering (MEIS). Results point to periodic relaxation of the SL, which evolves to an average in-plane lattice parameter independent of the substrate and closer to that of AlN than predicted by elastic energy minimization.

In contrast with the observed insensitiveness to the buffer layer, the magnitude of ISB absorption depends drastically on the Al mole fraction of the cap layer. This behavior is attributed to the depletion or accumulation of charge in the QWs induced by the electric field due to difference in polarization between the cap layer and the SL. We demonstrate that polarization-

induced doping can result in a significant, and even dominant, contribution to the IR absorption in GaN/AlN MQW structures.

[1] M. Tchernycheva et al., Phys. Rev. B, **73** (2006) 125347
[1] P. K. Kandaswamy et al., submitted to Phys. Rev. B

Figures:

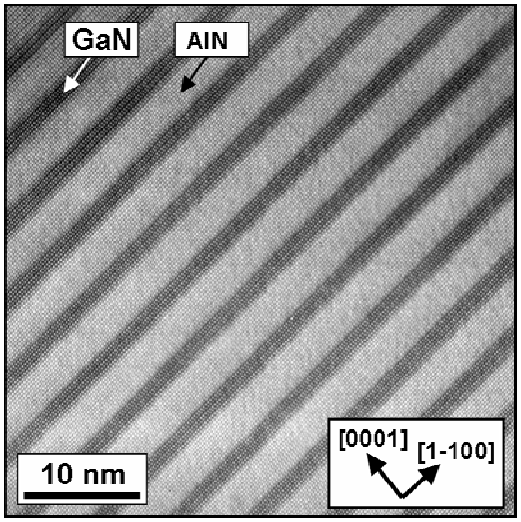

Fig. 1. High-resolution TEM image of a Si-doped GaN/AlN (1.5 nm / 3 nm) multi-QW structure (ISB absorption peak at 1.55 μm).

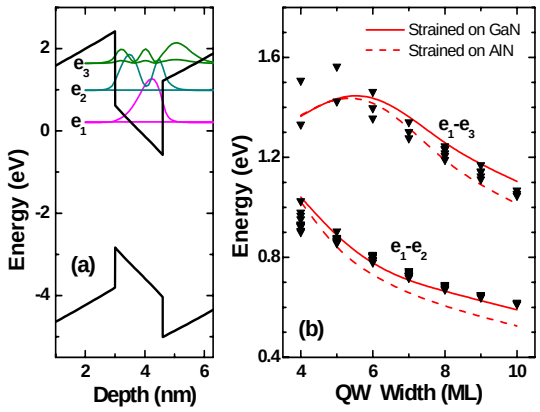

Fig. 2. (a) Band diagram of a GaN / AlN (1.5 nm / 3 nm) QW. (b) Variation of e_2-e_1 and e_3-e_1 transition energy for different QW thickness. Solid and dashed lines represent the ISBTs for SLs strained on GaN and AlN, respectively. Triangles correspond to experimental data.

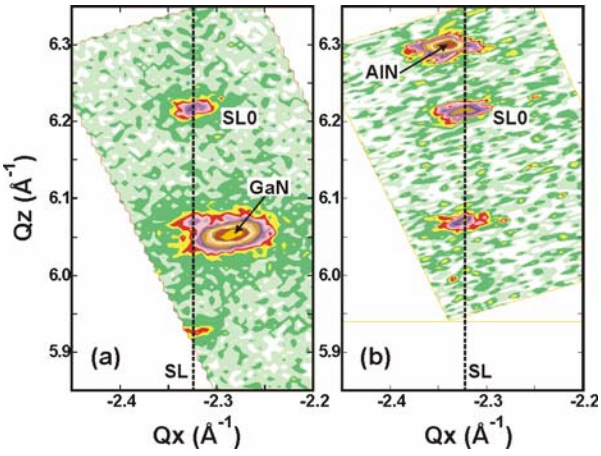

Fig. 3. Reciprocal space map around the (10-15) x-ray reflection of GaN/AlN MQW structures grown (a) on GaN and (b) on AlN templates. The average lattice parameter –i.e. the strain state- of the superlattice remains the same irrespective of the substrate.

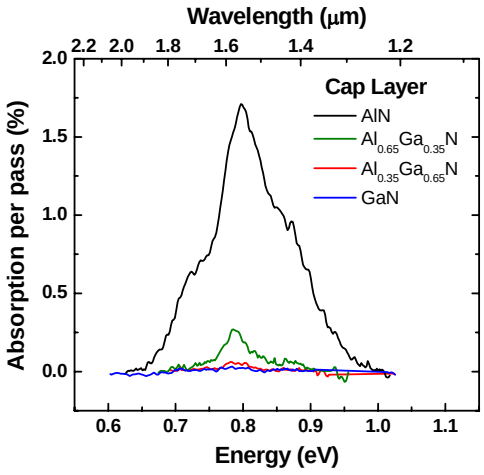

Fig. 4. Room temperature TM-polarized ISB absorption spectra of non-intentionally doped GaN/AlN (1.5 nm / 1.5 nm) MQW structures finished with a 50 nm thick $Al_xGa_{1-x}N$ cap layer with different Al content. The magnitude of the absorption increases with the Al mole fraction of the cap layer as a result of polarization-induced doping.