AIP | Journal of Applied Physics

J. Appl. Phys. **89**, 294 (2001); http://dx.doi.org/10.1063/1.1328778 (*12 pages*)

Band-gap energies, free carrier effects, and phonon modes in strained GaNAs/GaAs and GaNAs/InAs/GaAs superlattice heterostructures measured by spectroscopic ellipsometry

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(Received 24 April 2000; accepted 4 October 2000)

Spectroscopic ellipsometry (SE) is employed to study the optical properties of compressively strained short-period GaAs/InAs/GaN$_x$As$_{1-x}$ (0%<x<2.4%) superlattice (SL) heterostructures for photon energies from 0.75 to 1.55 eV (NIR-SE), and for wave numbers from 250 to 700 cm^{-1} (IR-SE). The undoped SL structures were grown on top of undoped GaAs buffer layers deposited on Te-doped (001) GaAs substrates by metalorganic vapor phase epitaxy (MOVPE). The InAs sequences consist of single monolayers. Structure, composition, layer thicknesses, and parallel and perpendicular lattice mismatch of the samples are studied by high-resolution transmission electron microscopy and high-resolution x-ray diffraction investigations. We employ Adachi's critical-point composite model for data analysis in the near-band-gap spectral region (NIR-SE). For analysis of the IR-SE data we use the harmonic oscillator dielectric function model and the Drude model for free-carrier response. We report the direct band-gap energy E_0, and the complex index of refraction $N=n+ik$ of the (InAs)/GaN$_x$As$_{1-x}$ sublayers. We observe the well-known strong redshift of E_0 with increase in x, and the strong decrease of the E_0 transition amplitude. The E_0 values obtained for the SL structures are in good agreement with photoluminescence results. We observe no influence of the InAs monolayer on the spectral position of the fundamental GaN$_x$As$_{1-x}$ band-to-band transition E_0. We detect the transverse-optic (TO) lattice resonance mode of the GaN sublattice at 470 cm^{-1} within the (InAs)/GaN$_x$As$_{1-x}$ SL sublayers. The polar strength of the GaN TO mode increases linearly with x. The same techniques were used previously to study tensile strained GaAs/GaN$_x$As$_{1-x}$ (0%<x<3.3%) SL heterostructures grown by MOVPE. The dependencies of n and k and E_0 [Appl. Phys. Lett. **76**, 2859 (2000)], and the amplitude of the GaN TO modes [MRS Internet J. Nitride Semicond. Res. **5**, 3 (2000)] on the nitrogen concentration x for tensile strained GaAs/GaN$_x$As$_{1-x}$ SLs are compared to the results for compressively strained GaAs/InAs/GaN$_x$As$_{1-x}$ SLs obtained here. We find similar redshift and bowing parameters for E_0, but different slopes for the amplitudes of the GaN TO mode. The different slopes are due to the different strain states. From there we calculate the strength of the GaN TO amplitude versus x for strain-compensated InAs/GaN$_x$As$_{1-x}$ SLs, and the GaN TO mode amplitude can be used to monitor strain or concentration. We further obtain that the InAs monolayer effectively suppresses the effects of free carriers in the GaN$_x$As$_{1-x}$ sublayers. Absorption by free carriers was observed previously within the tensile strained GaN$_x$As$_{1-x}$/GaAs SL heterostructures. This can be explained by the predicted electronic properties of the InAs monolayer, which can effectively bind free holes and free electrons due to folding of the InAs bands along the growth direction [R. C. Iotti, L. C. Andreani, and M. Di Ventra, Phys. Rev. B **57**, R15072 (1998)]. The improvement of the morphology of InAs/GaN$_x$As$_{1-x}$ sublayers is reflected by the decrease of all broadening parameters within both NIR and IR dielectric function models used here, as well as by the occurrence of room-temperature photoluminescence emission. We also discuss IR resonance features due to transverse–magnetic interface modes observed between the Te-doped GaAs and the undoped GaAs buffer layer. We find that these TM interface modes are extremely sensitive to the existence of free carriers within the SL structures. © 2001 *American Institute of Physics.*

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Superlattices

ARTICLE DATA

Digital Object Identifier

http://dx.doi.org/10.1063/1.1328778

PUBLICATION DATA

ISSN

0021-8979 (print)
1089-7550 (online)

Publisher

American Institute of Physics crossref Member

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