Infrared and VIS/UV optical properties of GaN/AlN superlattices grown on Si substrate

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Outline & main results

We report optical properties of 20-period GaN/AlN superlattice (SL) structures from the mid-infrared to the ultraviolet spectral range. The MOCVD-grown hexagonal SL structures with an effective nominal Al-content of 24% were either intentionally undoped or Si-doped, and deposited on Si substrate using AlN interlayers.

Infrared ellipsometry spectra reveal a superlattice-related LO phonon mode of A\(_1\) symmetry, which is subject to a distinct blue shift towards the respective value for AlN with increasing SL sublayer dimensions. On the other hand, the SL E\(_1\)(TO) phonon frequency of the SL remains unaffected by the SL period thickness. Regarding the SL's as effective homogeneous mediums, their UV dielectric function properties are examined by spectroscopic ellipsometry. For the SL with the shortest period, a strong absorption onset emerges at ~4.0 - 4.2 eV possibly being related to a quantum-size affected electronic band-to-band-transition in the SL structure.

IR properties

Ellipsometric V spectra of samples A – C (undoped SL) at 70° angle of incidence. The E\(_1\)(TO) SL mode position stays approximately constant, while the mode oscillator strength increases with increasing SL period thickness. On the other hand, the A\(_1\)(LO) SL mode is slightly shifted towards higher energies with increasing SL period thickness, and at the same time the mode oscillator strength increases. For the SL with the largest period, a second, low-energy A\(_1\)(LO) SL mode emerges.

VIS/UV properties

Ellipsometric V spectra of samples D – F (Si-doped SL) at 45° angle of incidence. Both the E\(_1\)(TO) and the A\(_1\)(LO) SL modes behave very similar to those observed for the undoped SL sample set. In particular, a second, low-energy A\(_1\)(LO) SL mode component shows up as well.

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Growth: Metallorganic chemical vapor phase-epitaxy

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Complex dielectric function of the undoped SL of sample A, deduced from the ellipsometric data analysis. The absorption onset at ~4.0 eV may be related to a quantum-size affected electronic interband transition in the short-periodic SL. Due to possible interdiffusion effects within the SL, the formation of an alloy with an effective band gap energy giving rise to the observed absorption cannot be excluded through.

Electronic transition energy vs. the SL period. While the SL's with the larger SL periods show an absorption onset close to that of GaN, a strong transition above 4.0 eV emerges in the case of the short-periodic SL's.

Electronic transition energy vs. the SL period.

(A\(_1\)(LO) SL mode frequency vs. the SL period determined by X-ray measurements. No significant dependence of the mode position can be found. The SL mode position corresponds to that expected for unstrained Al\(_{0.31}\)Ga\(_{0.69}\)N [Grille et al., Phys. Rev. B 61, 6091 (2000)], which is however far beyond the average Al contents of the SL's, or to that of AlN being tensile in-plane strained by \(\sigma = -15\) GPa. The interplane tensile stress of AlN pseudomorphically strained with respect to relaxed GaN would be \(\sigma = +12.6\) GPa.

Electronic transition energy vs. the SL period.

The SL was treated as an effective homogeneous medium in the data analysis.

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ULV-VIS ellipsometry V and \(\Delta\) spectra of sample A at different angles of incidence. Above the GaN band gap, a strong SL-related electronic transition occurs. The SL was treated as an effective homogeneous medium in the data analysis.

Ellipsometric V spectra of samples A – C (undoped SL) at 70° angle of incidence. Above the GaN band gap, mainly sample A shows a strong SL-related electronic transition, whereas the other SL's do not exhibit any distinct transition in this region, but show an absorption behavior similar to that of GaN.

Ellipsometric V spectra of samples D – F (Si-doped SL) at 45° angle of incidence. Complex dielectric function of the undoped SL of sample A, deduced from the ellipsometric data analysis. The absorption onset at ~4.0 eV may be related to a quantum-size affected electronic interband transition in the short-periodic SL. Due to possible interdiffusion effects within the SL, the formation of an alloy with an effective band gap energy giving rise to the observed absorption cannot be excluded through.

Ellipsometric V spectra of samples D – F (Si-doped SL) at 45° angle of incidence. Complex dielectric function of the undoped SL of sample A, deduced from the ellipsometric data analysis. The absorption onset at ~4.0 eV may be related to a quantum-size affected electronic interband transition in the short-periodic SL. Due to possible interdiffusion effects within the SL, the formation of an alloy with an effective band gap energy giving rise to the observed absorption cannot be excluded through.

Complex dielectric function of the undoped SL of sample A, deduced from the ellipsometric data analysis. The absorption onset at ~4.0 eV may be related to a quantum-size affected electronic interband transition in the short-periodic SL. Due to possible interdiffusion effects within the SL, the formation of an alloy with an effective band gap energy giving rise to the observed absorption cannot be excluded through.