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

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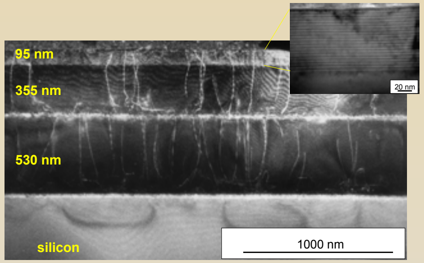
→ Outline & main results

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.

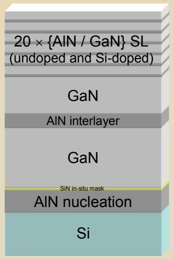
Infrared ellipsometry spectra reveal a superlattice-related LO phonon mode of A_1 symmetry, which is subject to a distinct blue shift towards the respective value for AlN with increasing SL sublayer dimensions. On the other hand, the SL E_1(TO) phonon frequency of the SL remains unaffected by the SL period thickness.

Regarding the SL´s as effective homogeneous mediums, their UV dielectric function properties are examined by spectroscopic ellipsometry. For the SL´s 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.

→ Samples



TEM cross section of sample C.



TEM bright-field image of dislocations in sample C, $(111)_{Si}$ plane-view orientation.

Growth:
Metalorganic chemical vapor phase epitaxy
(University of Magdeburg)

sample	intentional doping	d^{AlN} [Å]/d^{GaN} [Å] (nominal)	d^{AlN}/d^{GaN} (X-ray)	average SL Al content	d^{AlN} [Å] + d^{GaN} [Å] (X-ray)
A	none	7 / 22.2 = 0.32	0.44	0.31	17.5
B	none	14 / 44.4 = 0.32	-	-	35
C	none	28 / 88.8 = 0.32	0.25	0.20	84
D	Si	7 / 22.2 = 0.32	0.46	0.32	15.2
E	Si	14 / 44.4 = 0.32	-	-	33
F	Si	28 / 88.8 = 0.32	0.27	0.21	81

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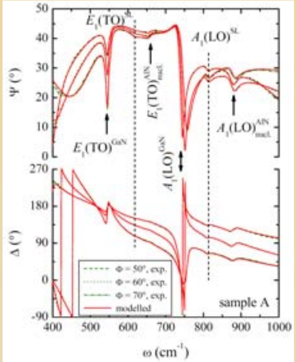
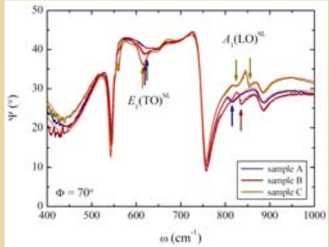
This work was partly supported by the EU project CLERMONT as well as the Wenner-Gren Foundation (Sweden). Furthermore, we thank G. Wagner (University of Leipzig) for the TEM investigations.

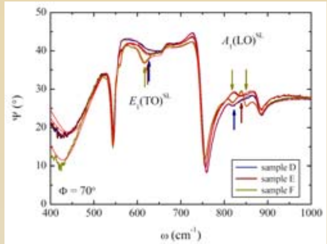
→ IR properties



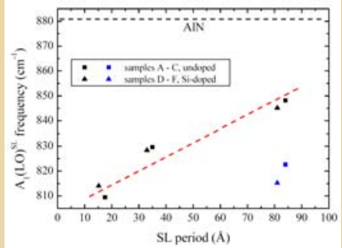
Mid-infrared ellipsometric Ψ and Δ spectra of sample A at different angles of incidence.
Besides phonon signatures from the buffer and nucleation layers, the E_1(TO) and the A_1(LO) superlattice phonons (vertical dashed lines) are observed.



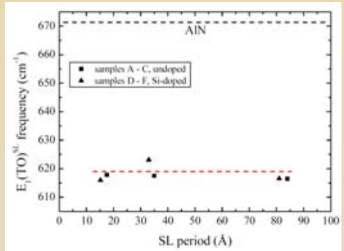
Ellipsometric Ψ spectra of samples A – C (undoped SL´s) at 70° angle of incidence.
The E_1(TO) SL mode position stays approximately constant, while the mode oscillator strength increases with increasing SL period thickness.
On the other hand, the A_1(LO) SL mode is clearly shifted towards higher energies 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.



Ellipsometric Ψ spectra of samples D – F (Si doped SL´s) at 70° 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.

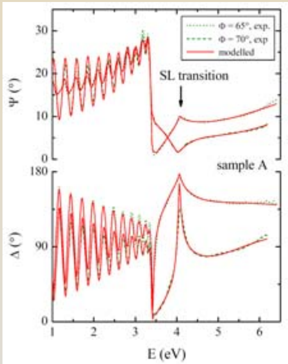


A_1(LO) SL mode frequency vs. the SL period determined by X-ray measurements. The mode is subject to a distinct blue-shift towards the respective mode frequency of (stress-free) AlN with increasing SL period thickness.
For the SL´s with the largest period, a second A_1(LO) SL mode is observed.

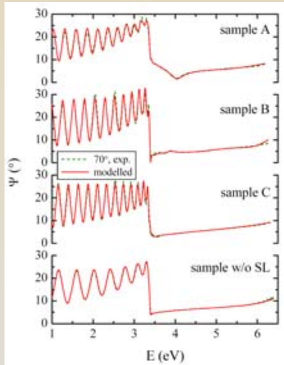


E_1(TO) SL mode frequency vs. the SL period determined by X-ray measurements. No significant dependence of the mode position can be found.
The SL mode position corresponds to that expected for unstrained $Al_{0.69}Ga_{0.31}N$ [Grille *et al.*, Phys. Rev. B 61, 6091 (2000)], which is however far beyond the average Al contents of the SL´s, or to that of AlN being tensile in-plane strained by σ_{xx} = ~15 GPa. [The in-plane biaxial stress of AlN pseudomorphically strained with respect to relaxed GaN would be σ_{xx} = 12.6 GPa.]

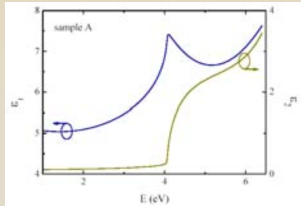
→ VIS/UV properties



UV-VIS ellipsometric Ψ and Δ 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 Ψ spectra of samples A – C (undoped SL´s) at 70° angle of incidence.
Above the GaN band gap, merely 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.



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 though.
Further studies involving SL structures with an in fact constant effective Al content, but different dimensions are needed so as to clarify this issue.

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.