Toward High-Performance UV Emitters Grown by MOCVD

U. Chowdhury, M. M. Wong, K. S. Kim, J. C. Denyszyn, T. G. Zhu,

and R. D. Dupuis

The University of Texas at Austin

Microelectronics Research Center

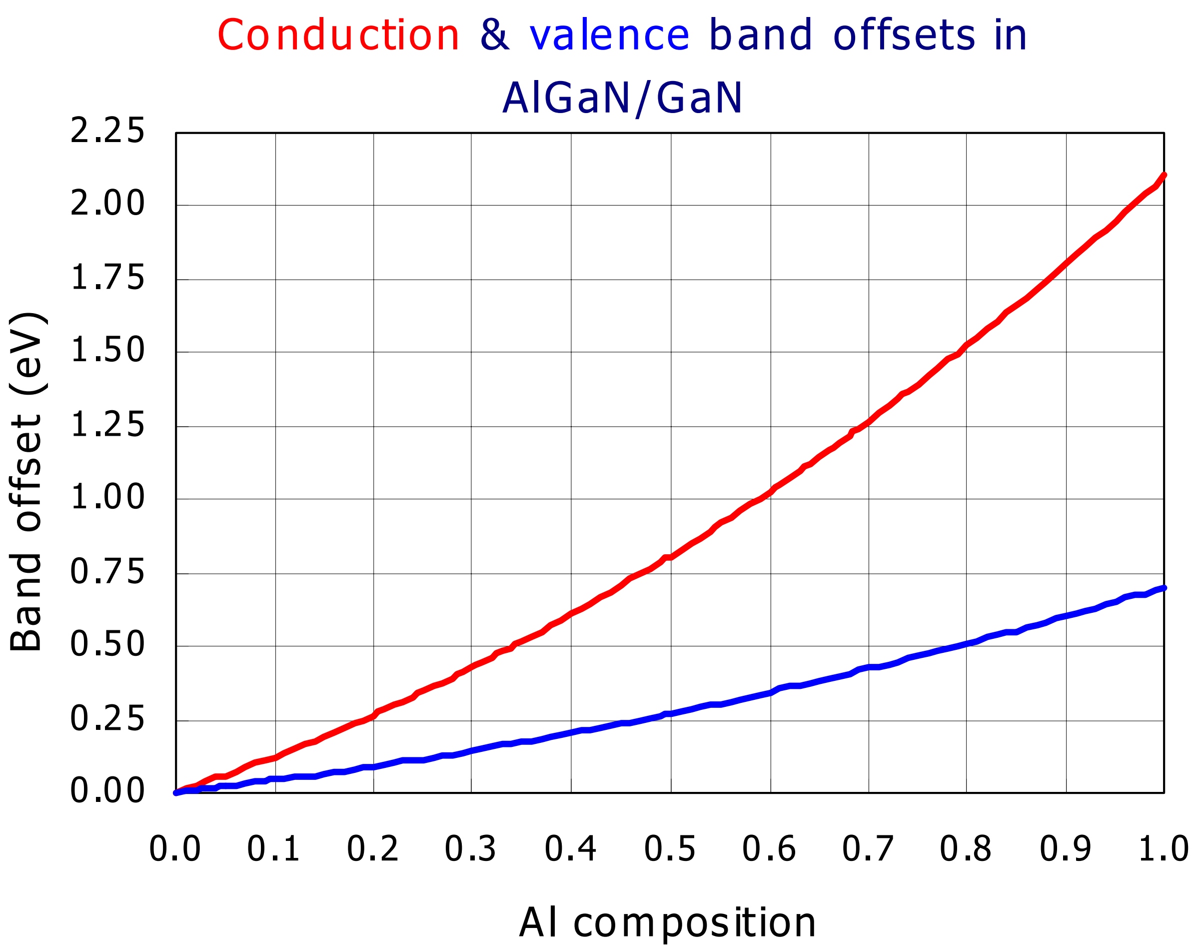
Outline

- Introduction
- AlGaN Heterojunction Growth
  - AlGaN/GaN and AlGaN/AlGaN growth
  - Experimental structures
- AlGaN *p-n* Growth, Materials Characterization, and Device Analysis
  - X-Ray diffraction
  - Cathodoluminescence and PL measurements
  - SIMS analysis
  - TEM analysis
  - *I-V* characteristics
- Summary

Introduction

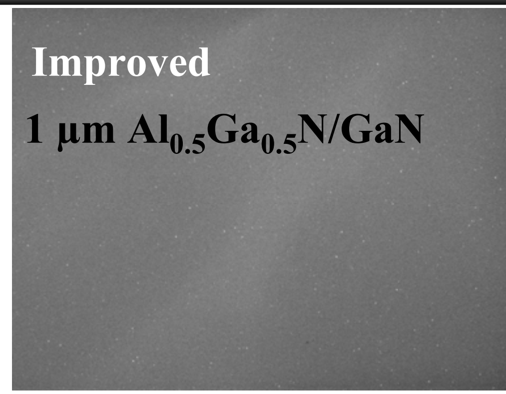
- Properties of InAlGaN/GaN heterostructures
  - Direct bandgap, 200 < λ < 650 nm, high T, compatible with hostile environments
- InAlGaN UV emitters for chemical detection
  - Improved efficiency, weight, and no cooing water required
  - Compact systems with battery power possible
  - Capable of emission in the LIF regime (λ~280nm)
- Problems to be solved
  - Lattice mismatched epitaxial layers
  - Numerous defects reduce material quality
  - Background electron concentration for unintentionally doped material can be relatively high
  - *p*-type doping in AlGaN alloys x>0.20 is difficult

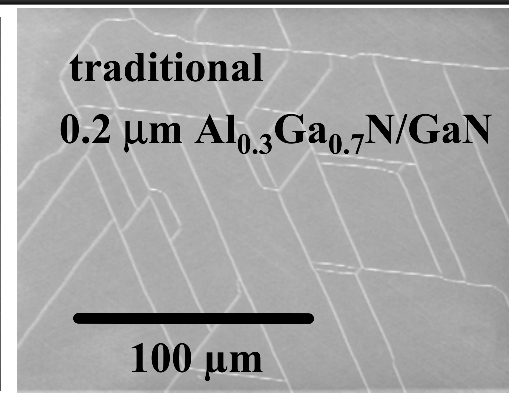
Conduction Band Offset Energies for AlGaN/GaN Heterojunctions



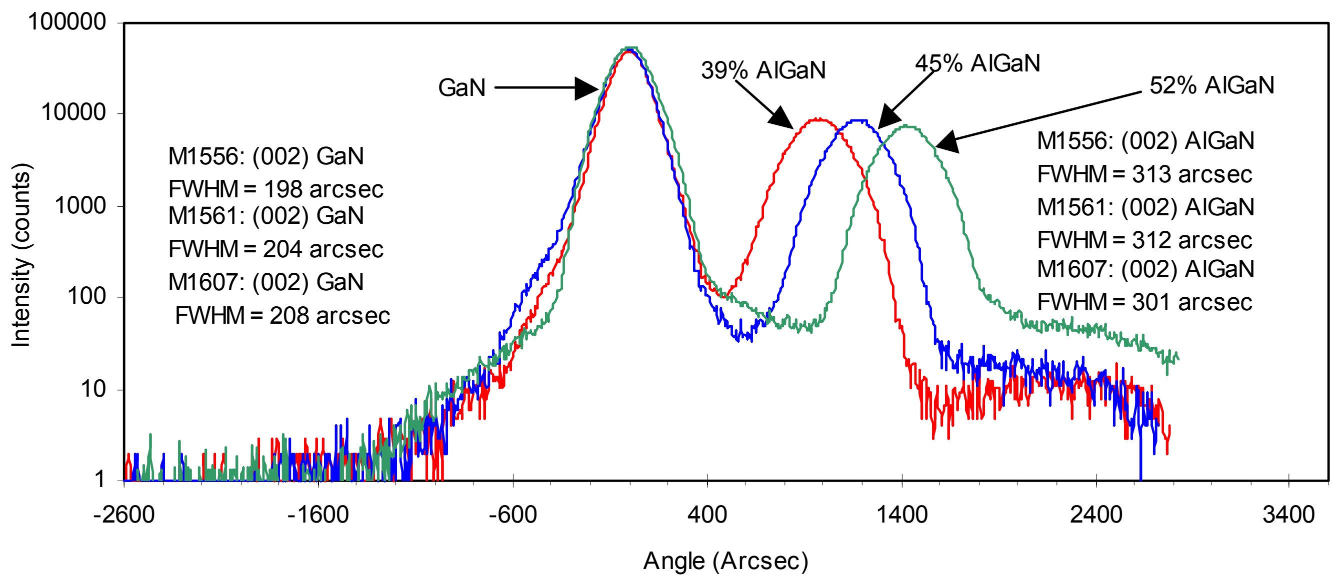
High Quality $Al_xGa_{1-x}N$ Heterostructure Grown by Improved MOCVD

- High Al alloy composition required to achieve λ ≤ 300 nm
- Grown by an improved MOCVD method

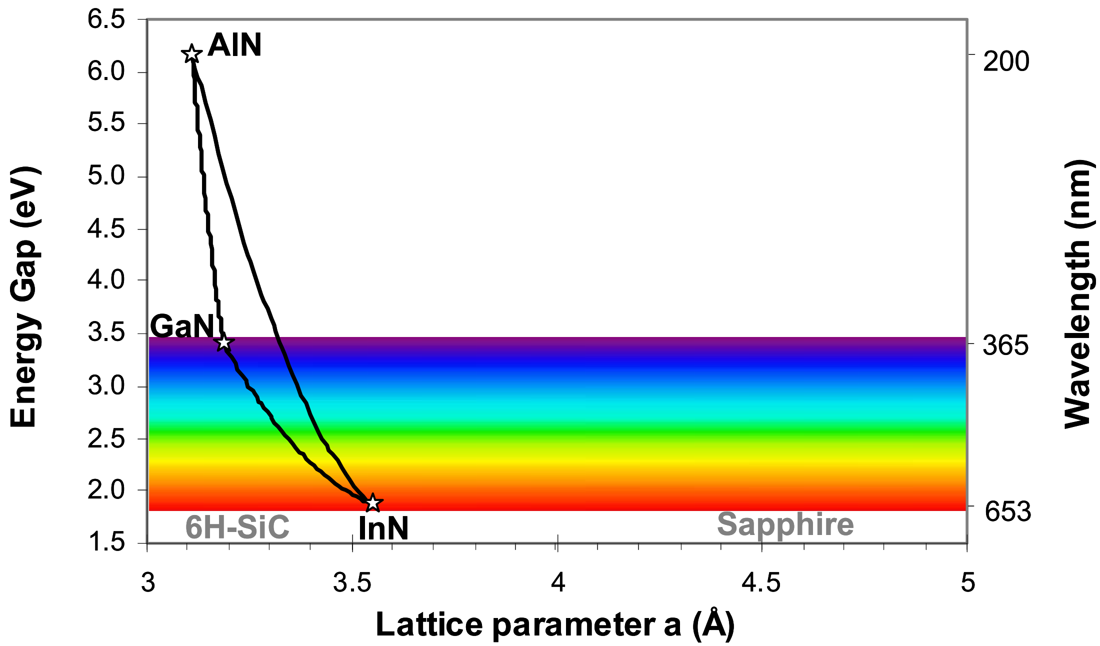


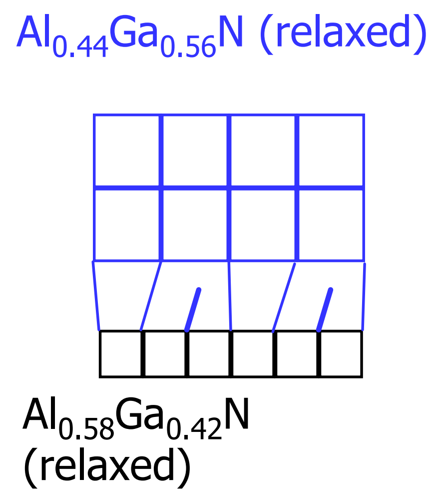


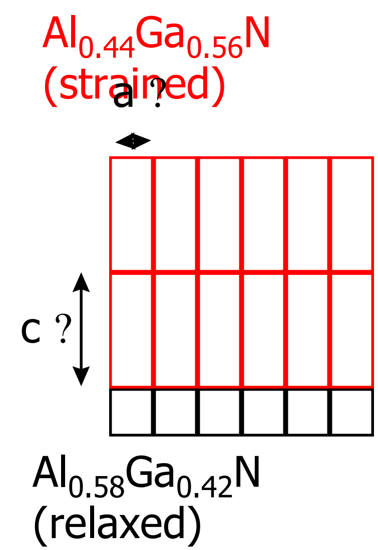
X-Ray Scan (002) Omega-2Theta

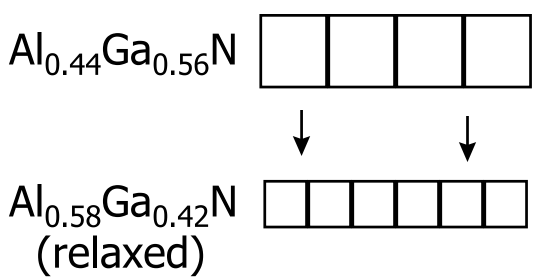


Strain Effect on $Al_{0.44}Ga_{0.56}N/Al_{0.58}Ga_{0.42}N$ Heterojunctions









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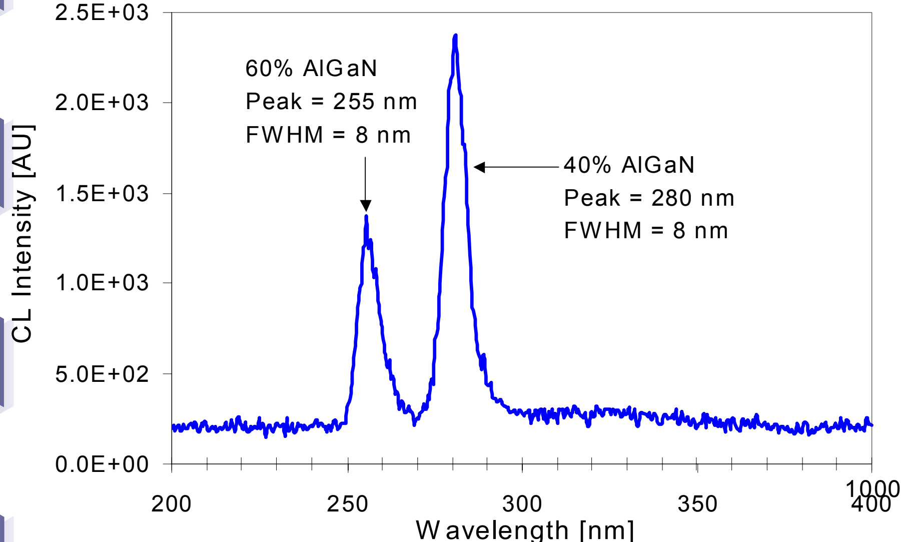
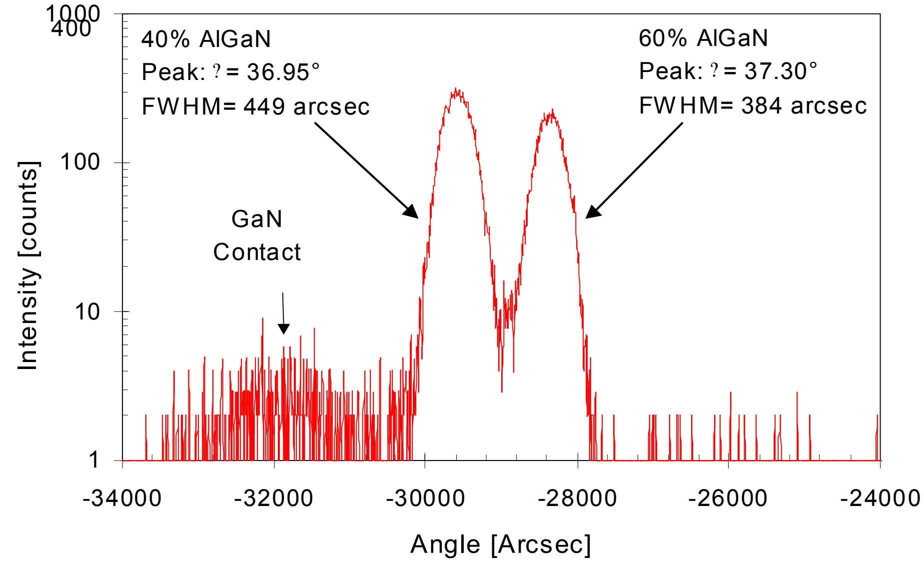
AlGaN SH 4K CL Spectra and X-Ray Diffraction (004) ω-2θ Scans

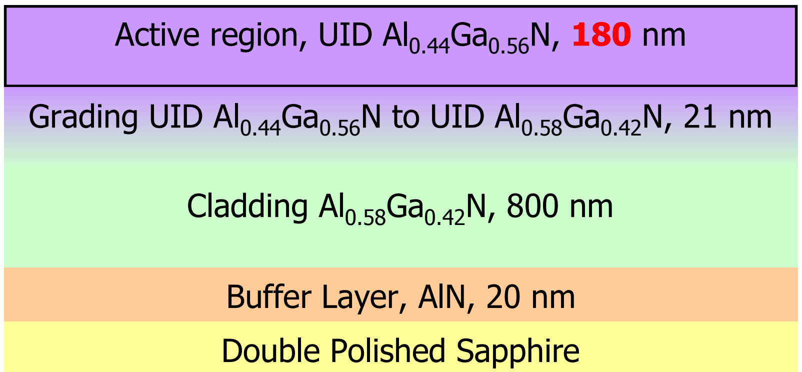


- 4K cathodoluminescence characteristics for AlGaN x=0.40/x=0.60 single heterostructure

- (004) X-ray data for AlGaN x=0.40/x=0.60 single heterostructure

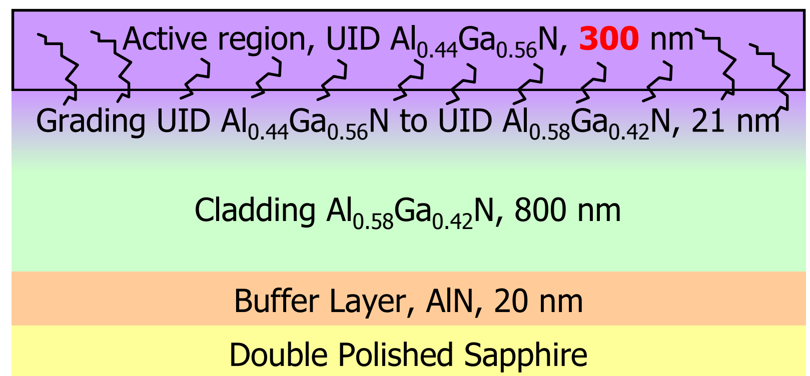


AlGaN Single Heterostructure – Effects of Variation of Thickness

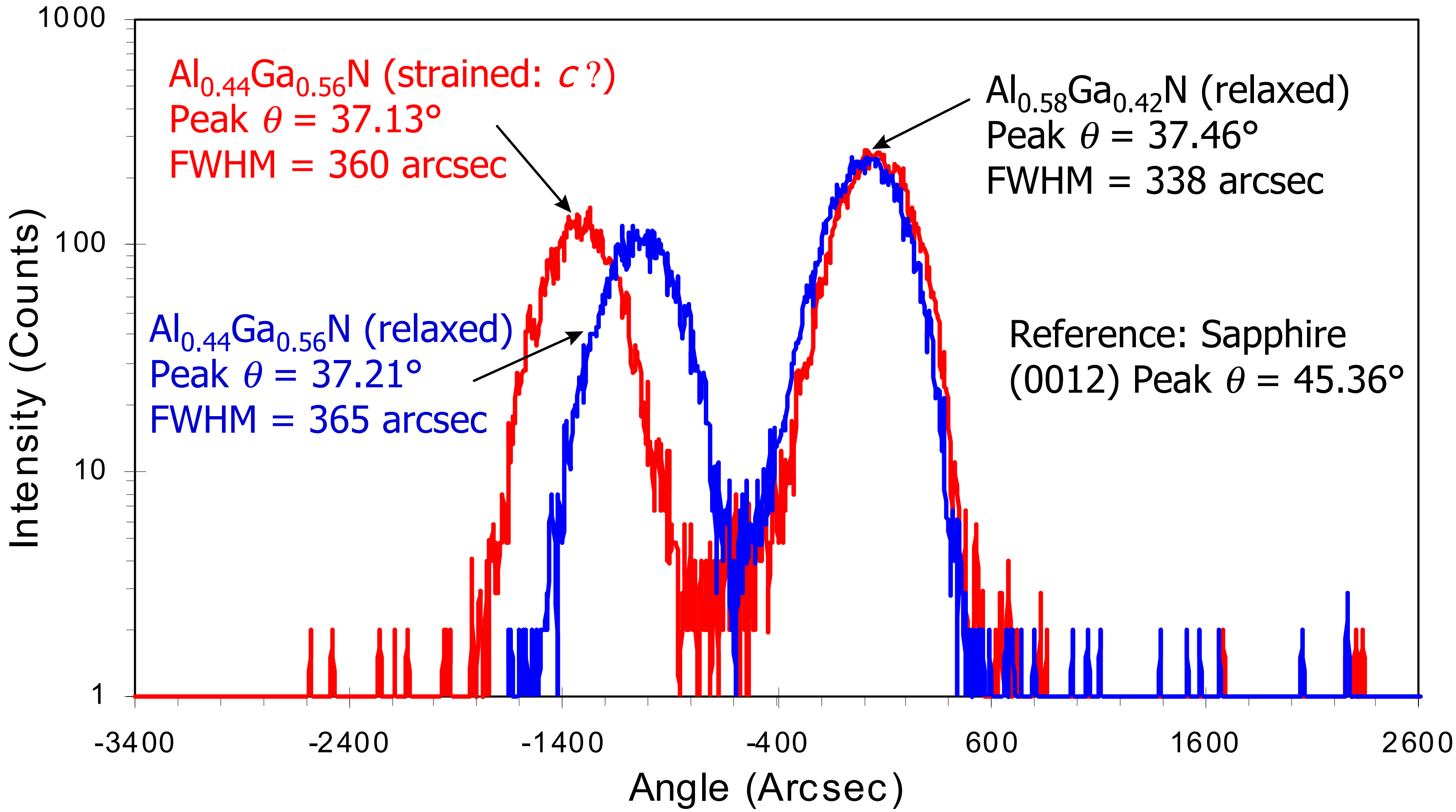


- Identical growth conditions
- Identical substrates
- Identical window layer and BL

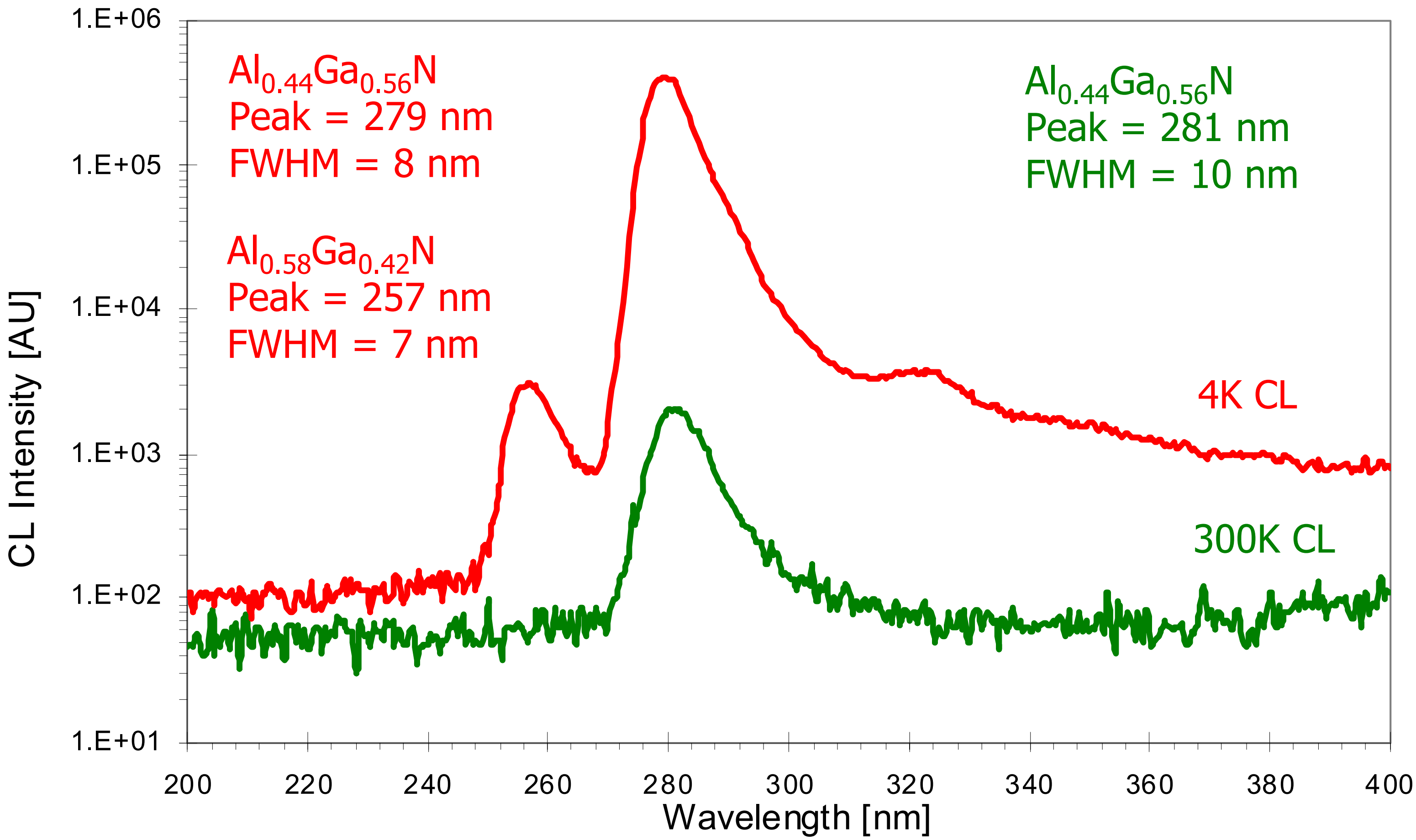
- Thin active region ~180 nm
  - Possibly strained
- Thick active region ~300 nm
  - Possibly relaxed
  - Defects and dislocations



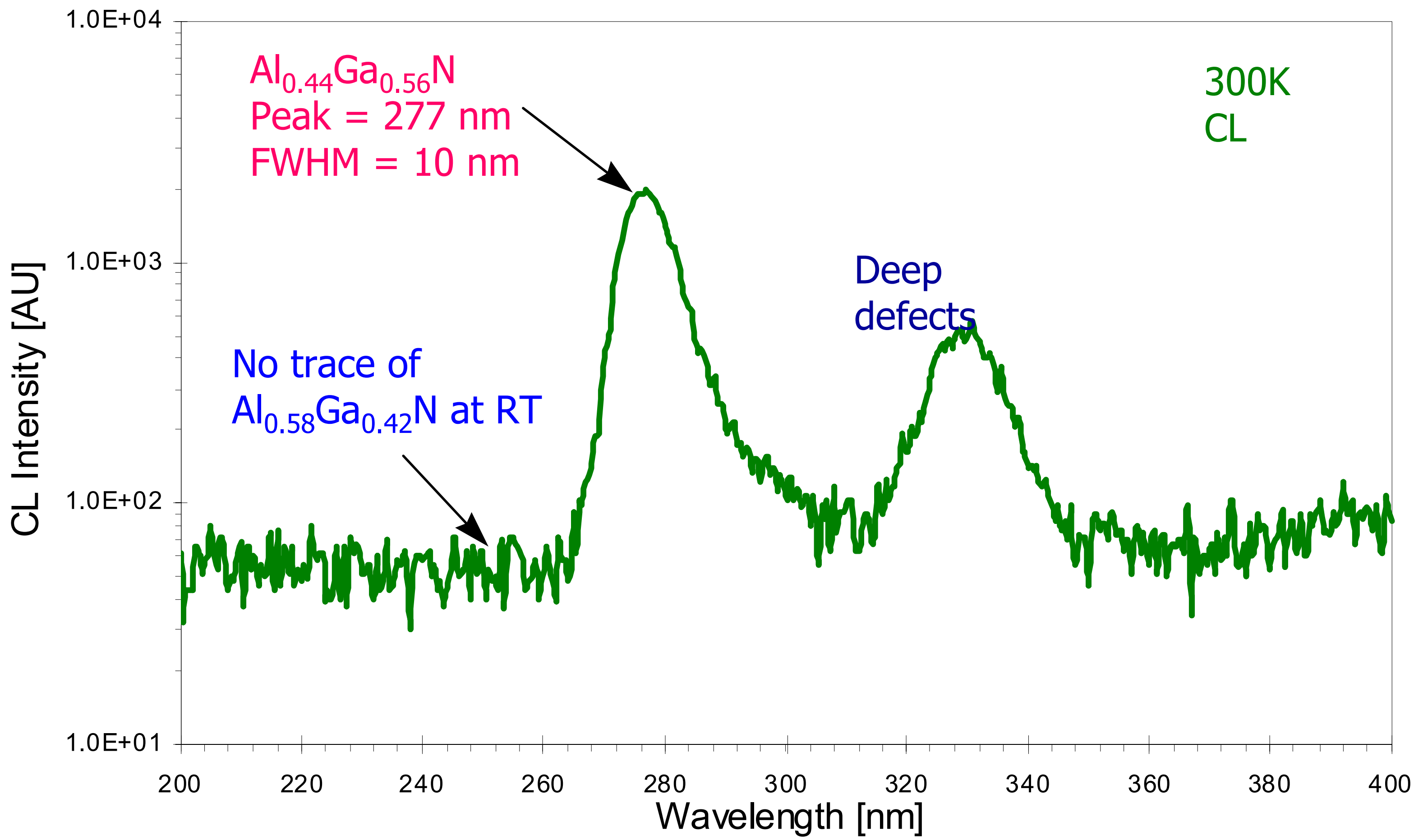
AlGaN:UD Heterostructure X-Ray Diffraction: (004) ω-2θ Scans



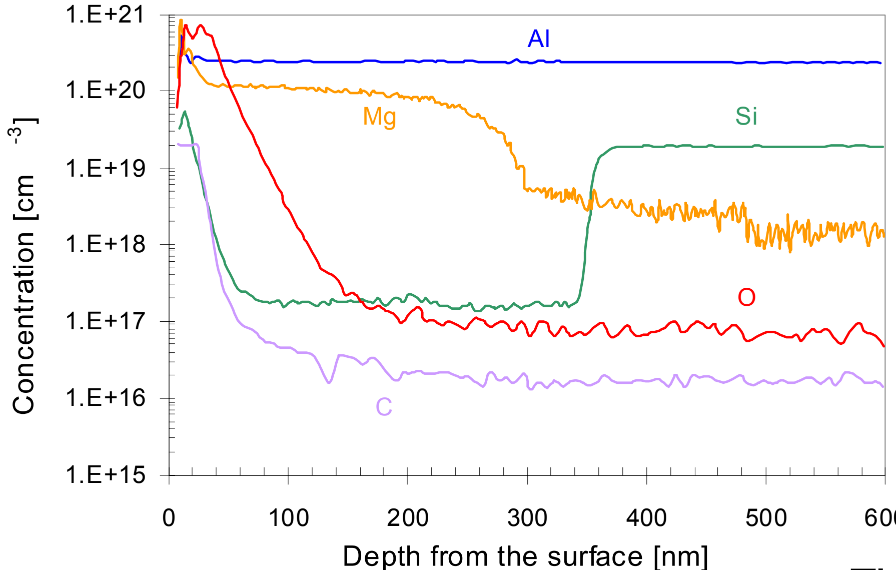
Cathodoluminescence (4K) – Strained Case



Cathodoluminescence (300K) – Relaxed Case

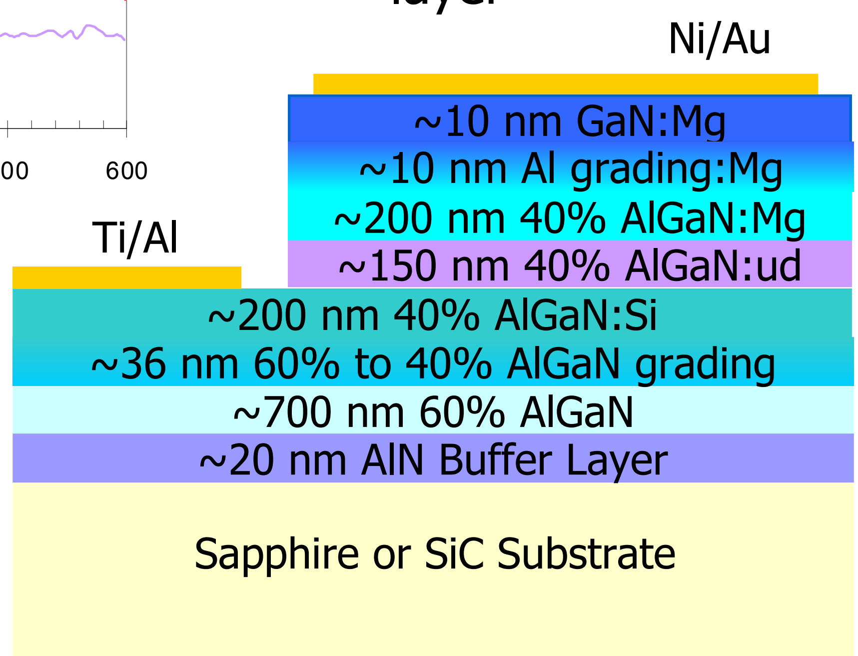


AlGaN Light-Emitting Diode Structure and SIMS Data

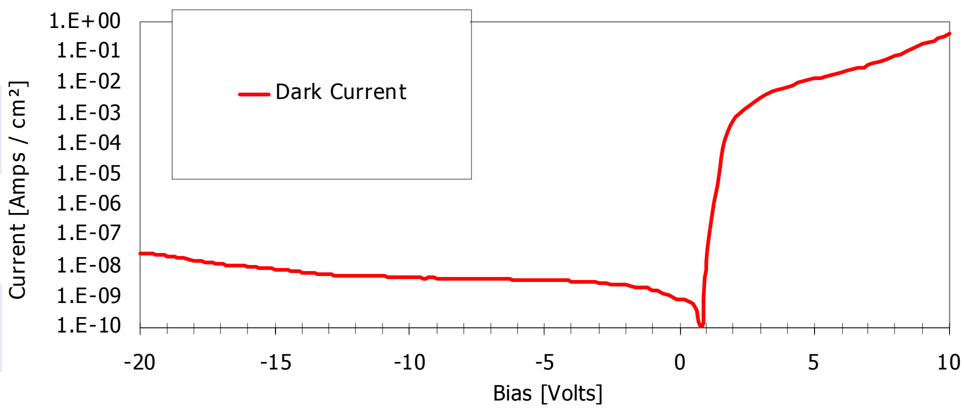


- SIMS data for AlGaN x=0.40 *p-n* junction grown on an x=0.60 cladding layer

- Schematic diagram for AlGaN x=0.40 *p-n* junction with a x=0.60 single heterostructure

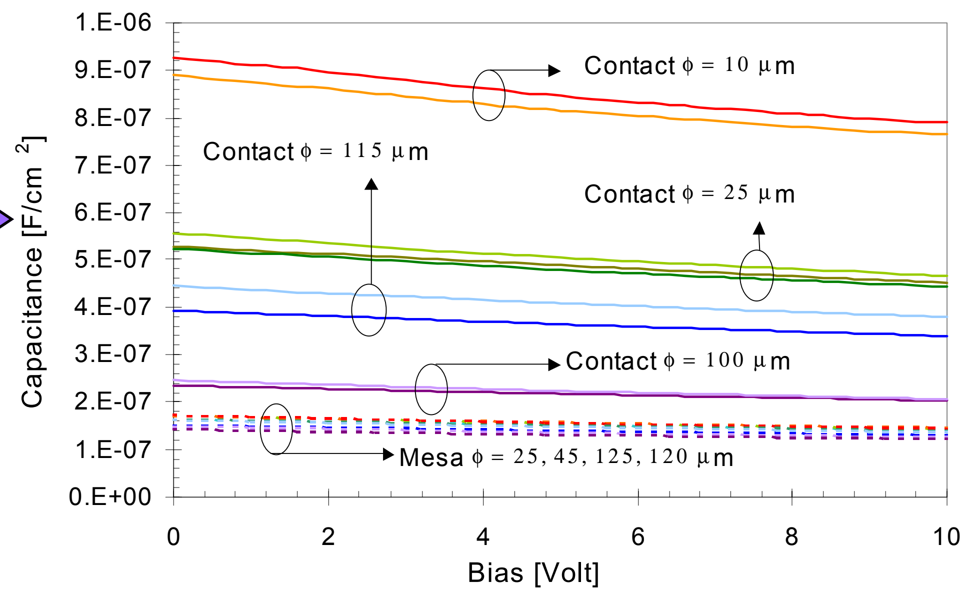


I-V and C-V Data for an AlGaN p-n Junction

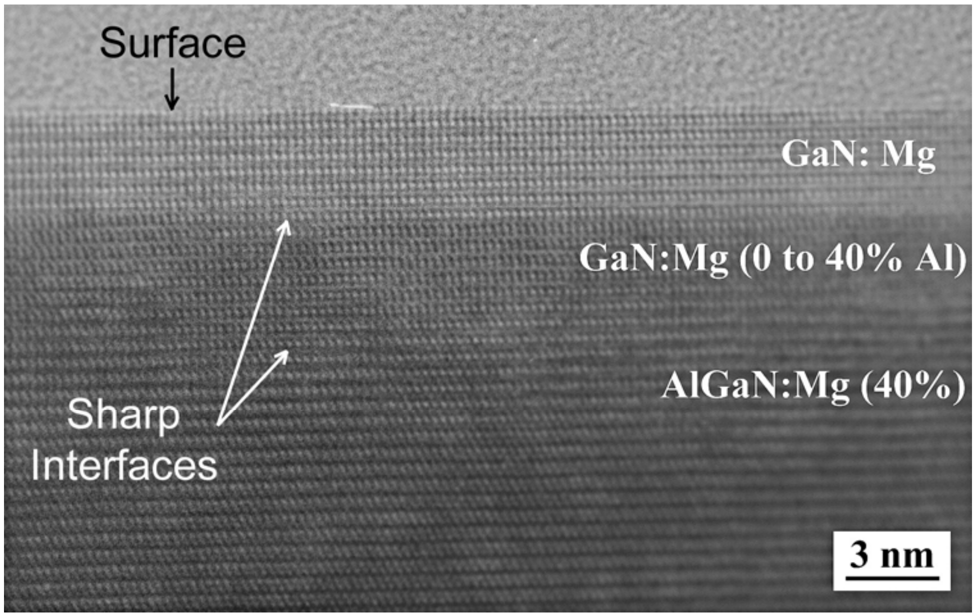


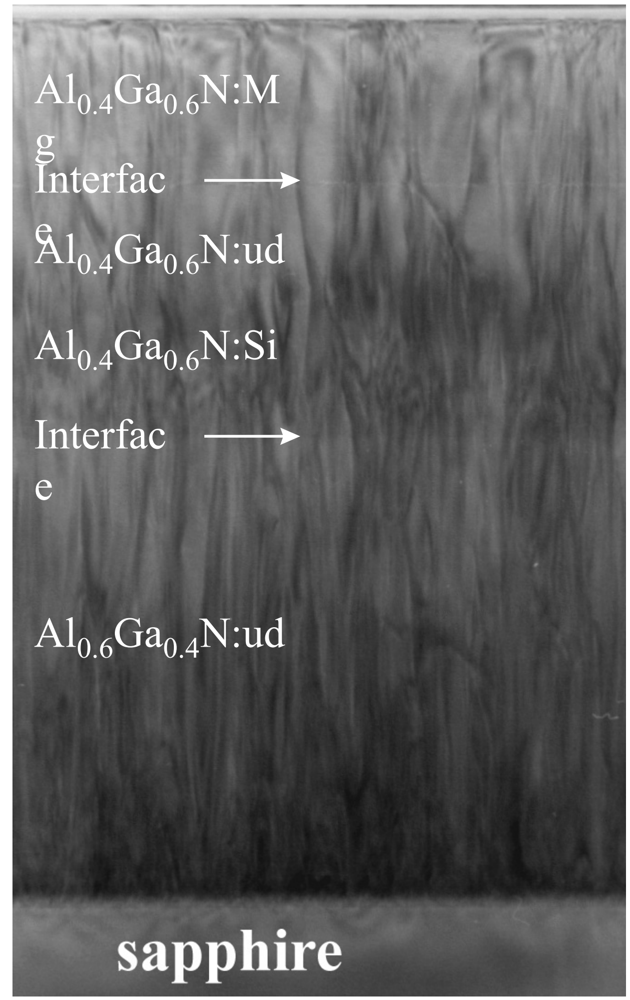
- *I-V* characteristics for AlGaN x=0.45 *p-n* junction—low leakage current but high forward resistance

- *C-V* characteristics for AlGaN x=0.45 *p-n* junction—capacitance/area scales with mesa diameter, not contact diameter



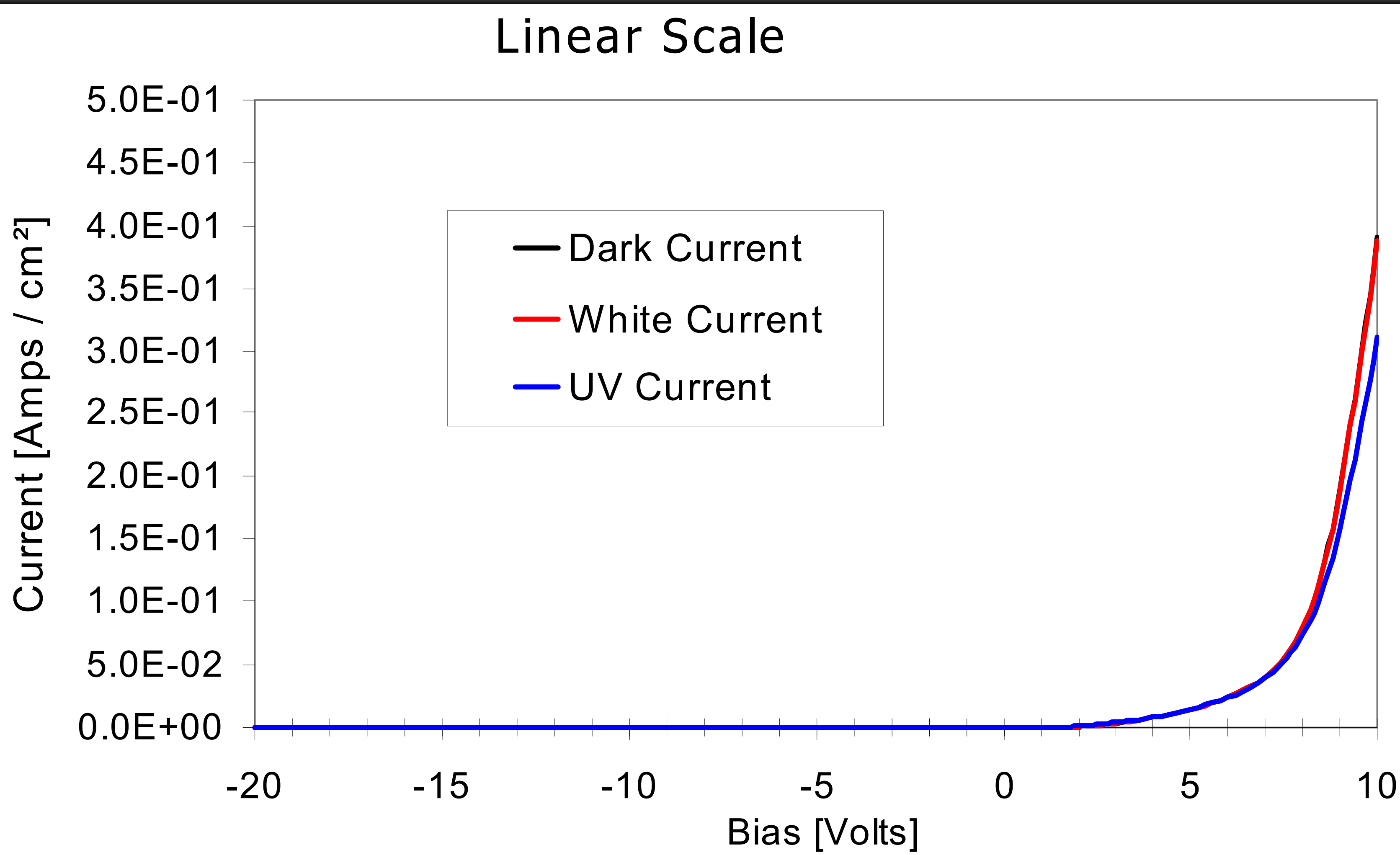
Transmission Electron Microscopy Analysis of AlGaN (x=0.45) p-n Diode





- ✯ High-quality top GaN:Mg layer
- ✯ Sharp interfaces
- ✯ Dislocation density: 5×10^{10} cm^{-2}

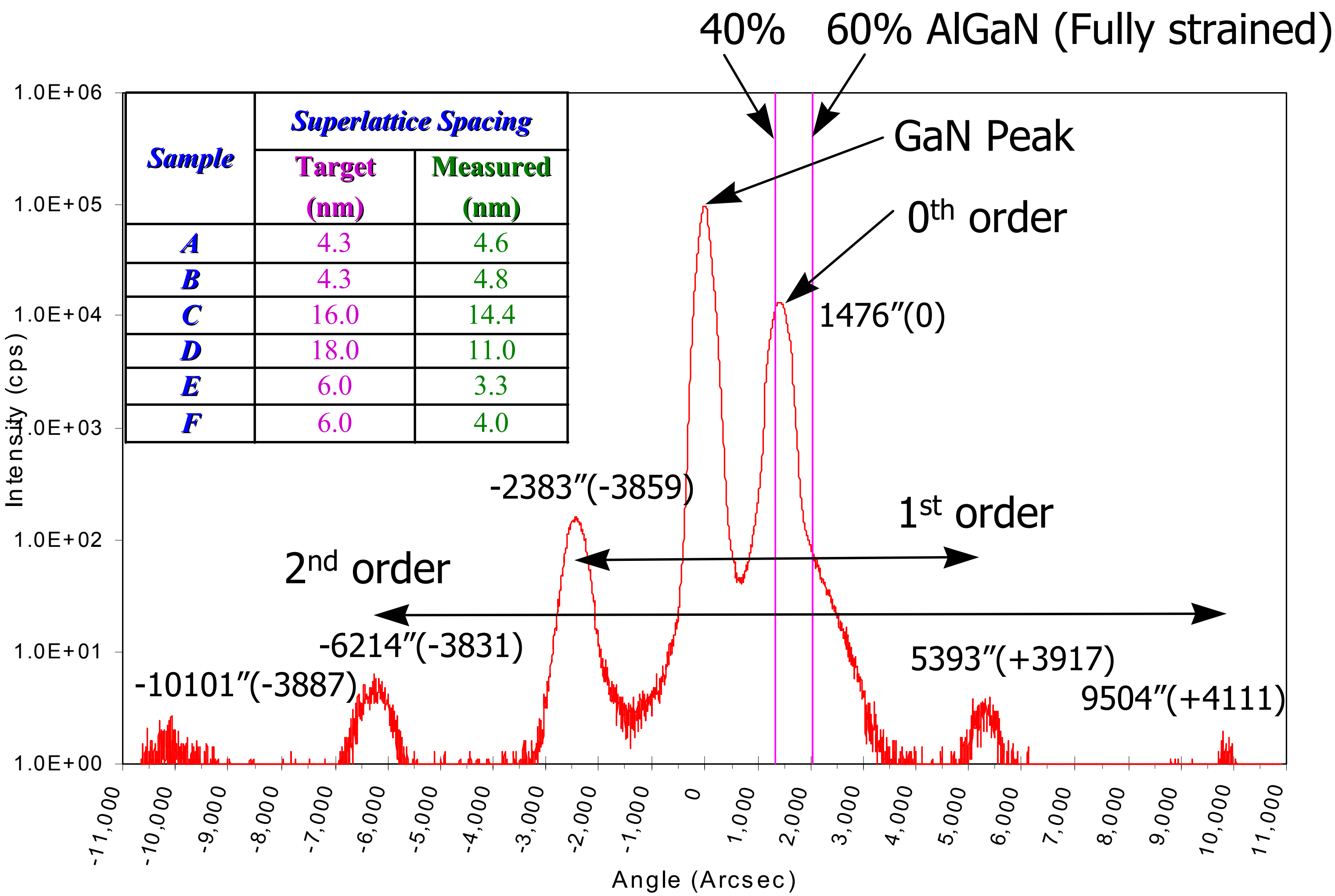
Linear I-V Characteristics of an AlGaN (x=0.45) p-n Diode



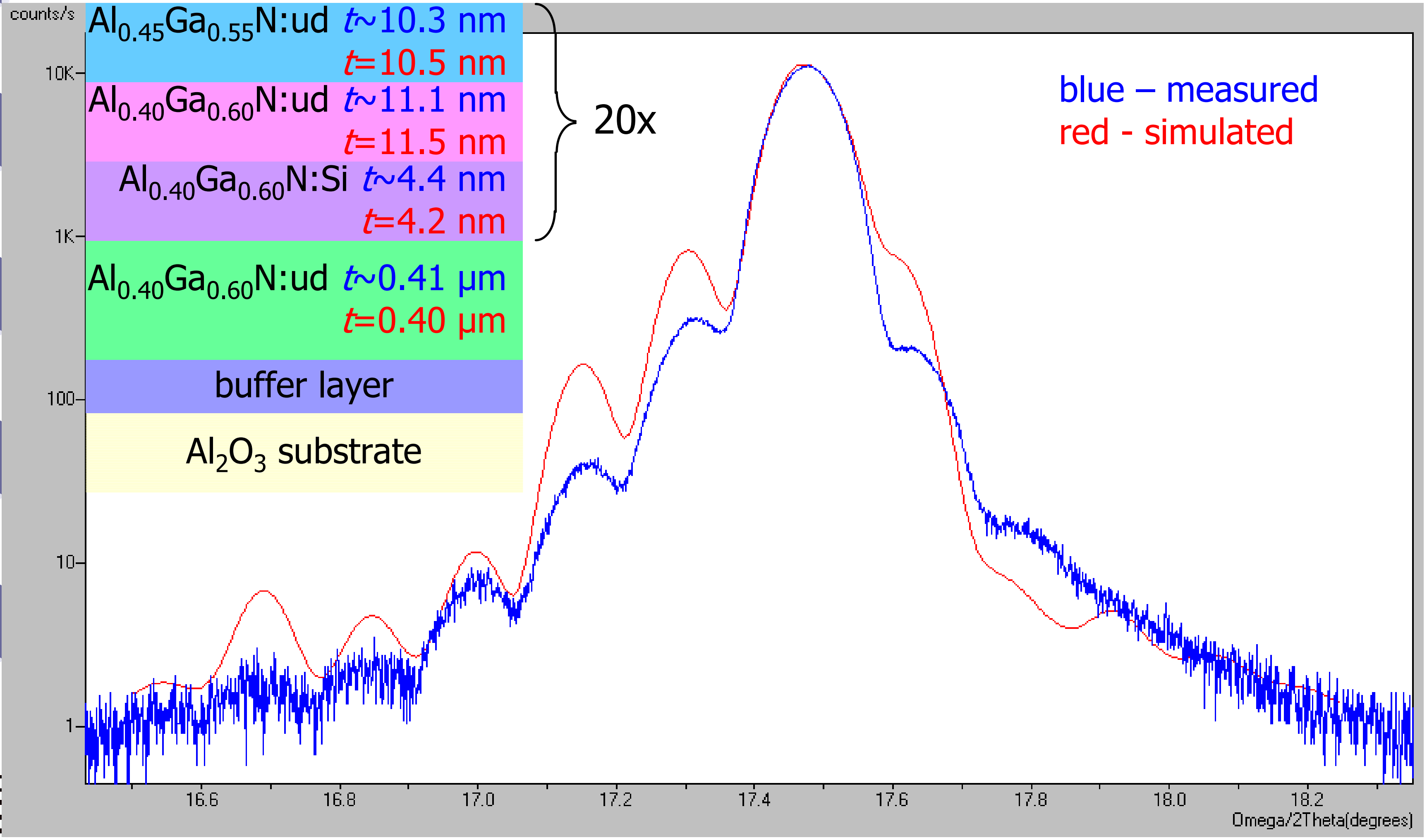
AlN/GaN Superlattices—
Symmetric (0002) ?-2? X-ray Scan

Sample F: (3nm AlN+3nm GaN) × 40 periods on GaN

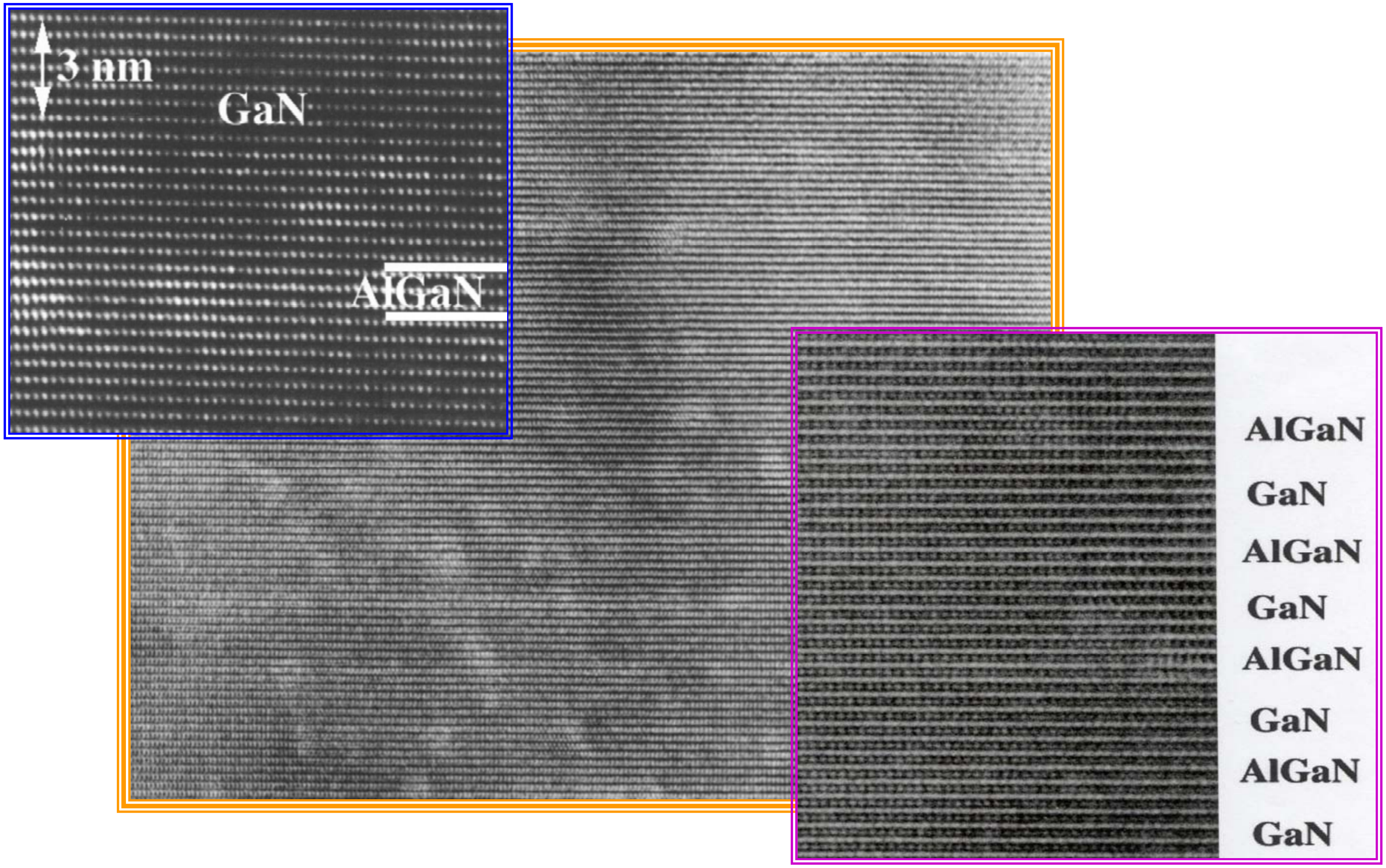
Sample	Superlattice Spacing	
	Target (nm)	Measured (nm)
A	4.3	4.6
B	4.3	4.8
C	16.0	14.4
D	18.0	11.0
E	6.0	3.3
F	6.0	4.0



(002) ?-2? X-Ray Diffraction Pattern Simulation of AlGaN Superlattice

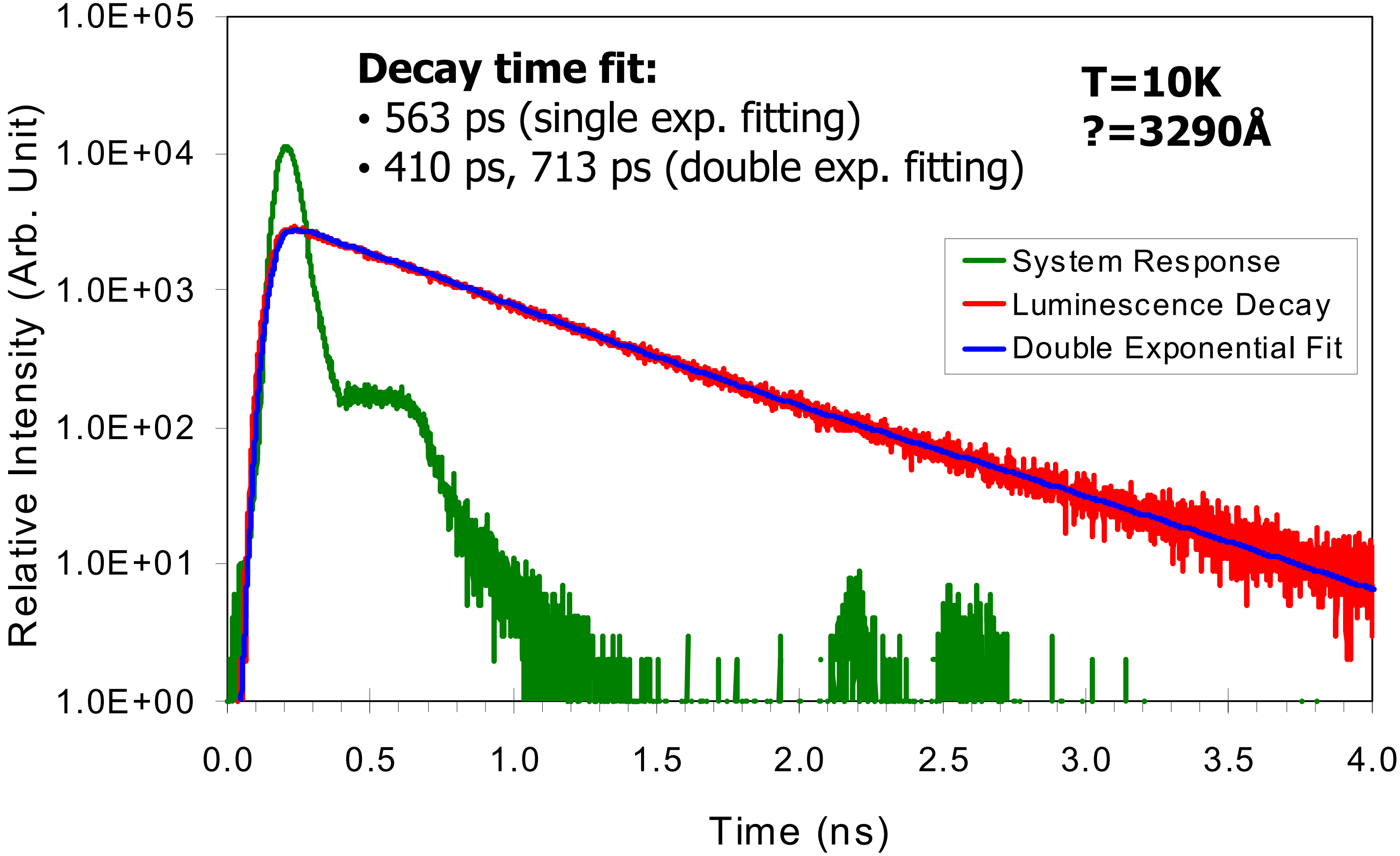


(3.3nm 30%AlGaN+1.0nm GaN) × 20 Periods



AlGaN/GaN SL: Time-Resolved Photoluminescence Data

(3.3nm 30% AlGaN + 1.0nm GaN) × 20 Periods



Problems/Solutions?

- Lattice mismatched epitaxial layers
  - Use quaternary device layers
  - Intermediate buffer layers
- Numerous defects reduce material quality
  - Employ selective-area lateral epitaxial overgrowth, pendeo or cantilever epitaxy
  - Use GaN or AlN substrates
- Background electron concentration for unintentionally doped material can be relatively high
  - Improved purity of sources
  - Optimize growth conditions
- *p*-type doping in AlGaN alloys x>0.20 is difficult
  - Use doped superlattices
  - Use "co-doping tricks"?

Summary and Conclusions

DARPA

- Demonstration of $Al_xGa_{1-x}N$/ $Al_yGa_{1-y}N$ heterostructures
- AlGaN material quality *for* x=0.60 and x=0.45 studied
- AlGaN x=0.46 *p-n* junctions fabricated
- Observed *C-V* for *p-n* diode x=0.46 AlGaN:Mg/AlGaN:Si
- Cracking observed for active region t >200 nm
- AlN/GaN and AlGaN/GaN superlattices grown
- Long TRPL decay times observed for superlattices
- Further work on AlGaN emitters is needed
  - Superlattice cladding layers (improved conduction)
  - Quaternaries (for cladding and active region)
  - "LEO" type growth (reduced dislocations)