

# REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE 10-3-2000	3. REPORT TYPE AND DATES COVERED Final Technical 3-1-99 to 2-28-00	
4. TITLE AND SUBTITLE Alternative Approaches to p-type Doping of GaN			5. FUNDING NUMBERS	
6. AUTHOR(S) Gary W. Wicks				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Rochester Rochester, NY 14627			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of Naval Research Ballston Centre Tower One Arlington, VA 22217-5660			10. SPONSORING / MONITORING AGENCY REPORT NUMBER N00014-99-1-0383	
11. SUPPLEMENTARY NOTES				
a. DISTRIBUTION / AVAILABILITY STATEMENT Unrestricted			12. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)				
14. SUBJECT TERMS			15. NUMBER OF PAGES 5	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT	

20001017 012

DTIC QUALITY INSPECTED 4

## Final Report

N00014-99-1-0383

### Alternative Approaches to p-type Doping of GaN

UR Account No. 5-27979

G. W. Wicks

*The Institute of Optics, University of Rochester, Rochester, NY*

#### 1. The problem being addressed: P-type doping of GaN

- Conventional (column II) acceptors produce low hole concentrations.
- High hole concentrations are needed for low resistivity p-type material and p-type ohmic contacts.

#### 2. Technical Approach: Boron doping

##### Background: Boron doping

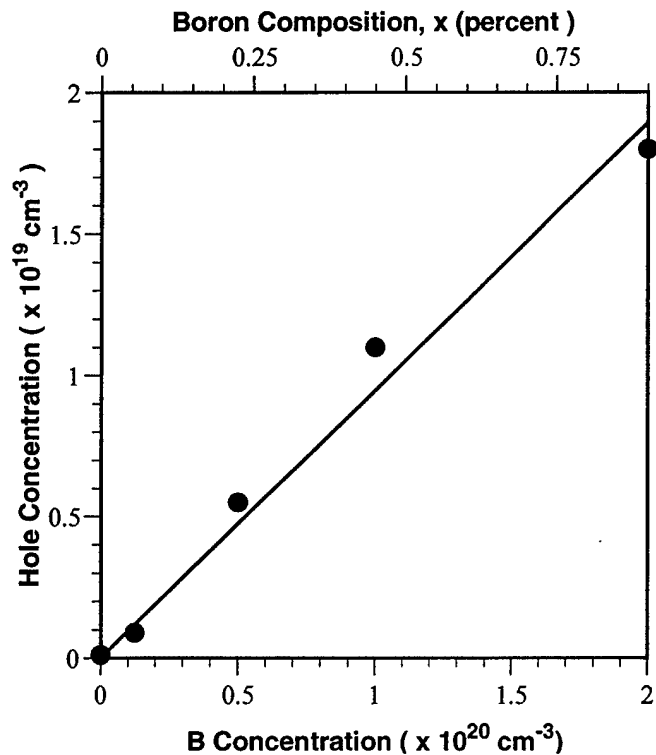
III	IV	V
B		N
Al		P
Ga		As
In		Sb

##### Boron Doping in GaAs

###### •Experimental Evidence: 2 Sites for Boron

1.  $B_{III}$  forms the ternary,  $B_xGa_{1-x}As$ . Bandgap increases with x (33 meV/%)
2.  $B_V$  is a double acceptor. Hole concentrations  $> 10^{19} \text{ cm}^{-3}$  (!) are possible.

### Hole Concentrations in Boron-doped GaAs



~5% of the boron atoms incorporate as B<sub>As</sub>

### 3. Activities in this program: Boron Doping in GaN

- MBE Growth
  1. Ammonia source of nitrogen
  2. Plasma source of nitrogen
- High temperature (<2200°C) Effusion Cell for Boron

#### *Findings in the program*

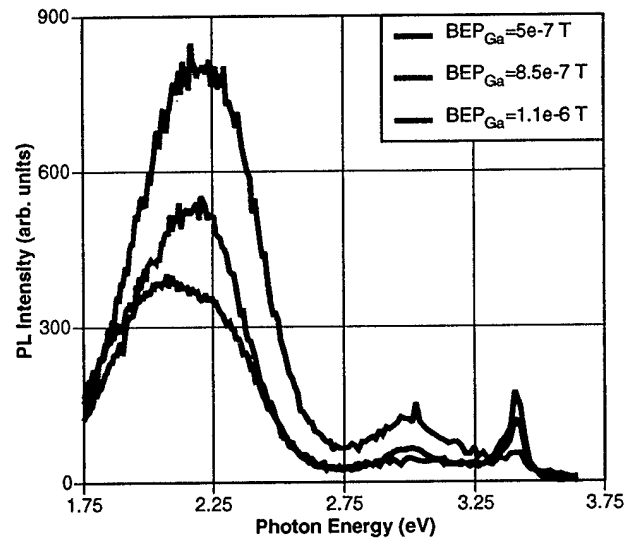
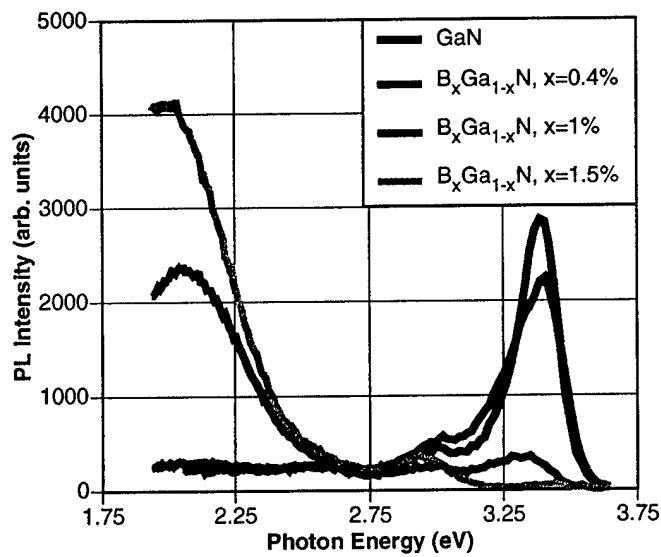
- Boron doping of GaN does *not* produce p-type conductivity.
- Boron antisite double acceptor exists in GaN, but it is too deep (~1.3 eV above valence band) to produce valence band holes.

## Influence of V:III Flux Ratio on Boron Site Selection (Nitrogen flux constant for all growths)

### Interpretation:

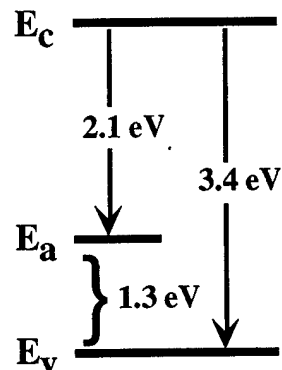
- Gallium rich growth conditions enhance the formation of  $B_N$ ; Nitrogen rich growth conditions enhance the formation of  $B_{Ga}$ .
- Increased  $B_N$  increases the compensation of the n-type background.

## Room Temperature Photoluminescence of $B_xGa_{1-x}N$

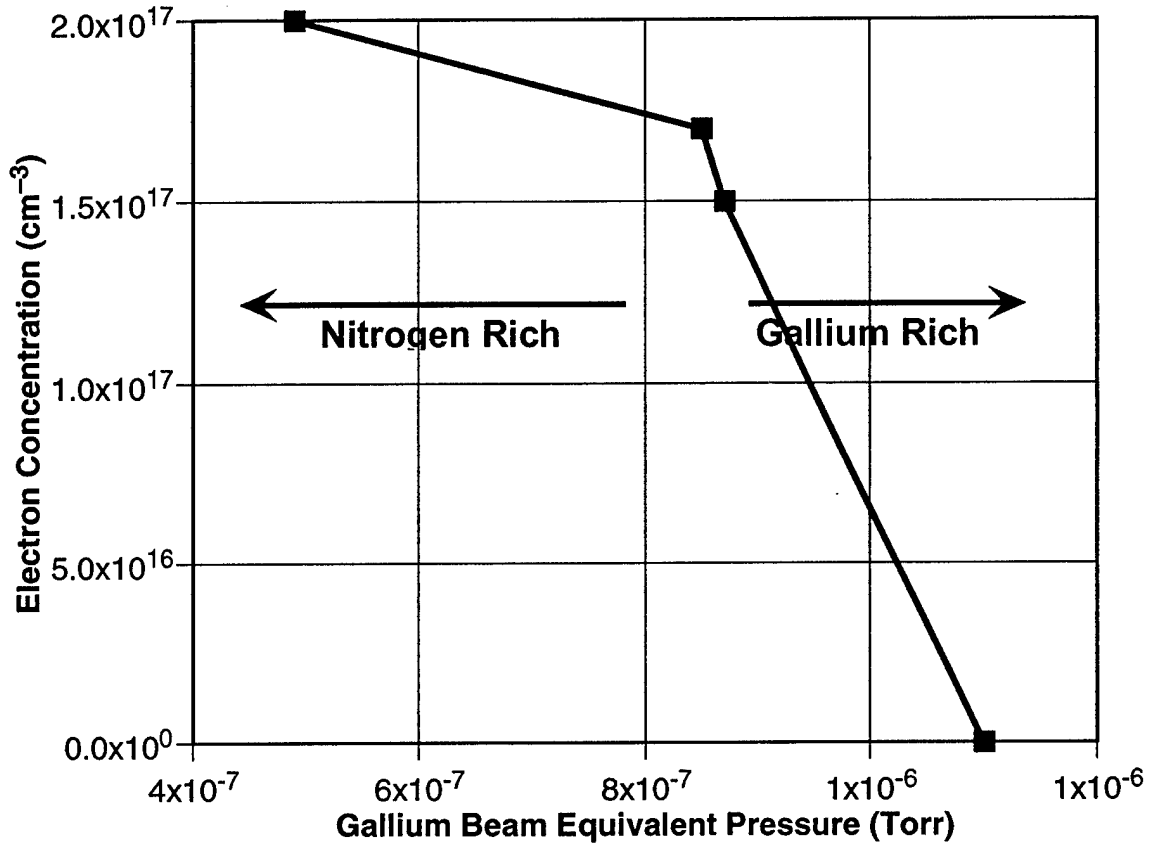


### Interpretation:

Observed PL spectra are consistent with the existence of a B acceptor level around 1.3 eV above the valence band.



### Evidence



- 40 GaN:B growths done (NH<sub>3</sub> and N-plasma sources)—no p-type GaN

- N-type conductivity ranging from:

  - typical high conductivity:  $n=10^{20} \text{ cm}^{-3}$  and  $\mu=12 \text{ cm}^2 \cdot \text{v/s}$

    - to

  - typical low conductivity:  $n=10^{17} \text{ cm}^{-3}$  and  $\mu=90 \text{ cm}^2 \cdot \text{v/s}$

    - to

  - highly resistive

- Electron concentration in GaN:B determined by:

  - ⇒unintentional donors (oxygen and nitrogen vacancies) and B<sub>N</sub>

  - ⇒affected by T<sub>B</sub>, V/III, T<sub>S</sub>, and outgasing

***Summary: GaN:B***

- B antisite double acceptor exists in GaN, but it is too deep (~1.3 eV) to be useful for producing large hole concentrations.
- The site occupancy of B is easily influenced by V/III
- The B antisite double acceptor produces strong, red PL