Characterization of P-type Dopants in III-Nitrides by SIMS

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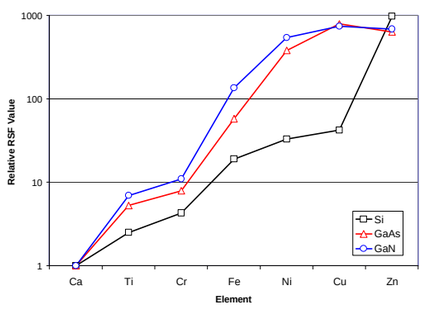
INTRODUCTION

- SIMS: Secondary Ion Mass Spectrometry
- Challenges:
  - New materials
  - Improved accuracy
    → develop new implant reference materials
  - Thin films & smaller device geometries
    → improved instrumentation
    → new protocols
- SIMS Instrumentation
  - Sector Cameca IMS 4F & 4.5F
    - "Normal" Sector conditions
    - GaN, III-V bulk and thick films
  - Sector Cameca IMS 6F
    - Reduced beam energy (2-8 keV)
    - Small areas (30x30 µm) and LED chip
  - Quad PHI Adept1010
    - Low beam energy (0.75-3 keV)
    - Near surface, pHEMT

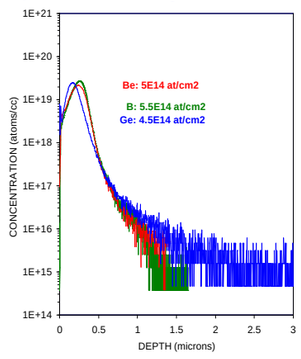
SIMS QUANTIFICATION

- Concentration A = RSF_A x $Signal_A/Signal_R$
  - RSF: Relative Sensitivity Factor
- Relies on reference materials
- Material dependent – element dependent
  → complete element/material matrix required
- Reference Material
  - Implanted or bulk doped
  - Characterize
    - Material composition: RBS, XRD
    - Implant dose or concentration: RBS, SIMS vs. Si and GaAs reference

Relative RSFs for Si, GaAs and GaN



Example Reference Material
Be, B and Ge implants into GaN



Current RSF library for GaN

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB	IB	IIB	IIIA	IVA	VA	VIA	VIIA
H														
	Be									B	C		O	
Na	Mg									Al	Si		S	Cl
	Ca		Ti		Cr		Fe	Ni	Cu	Zn		Ge	As	
									Cd	In				

Lanthanide: Pr, Nd, Er

DETECTION LIMITS IN GaN (at/cm³)

1. O2/SIMS
Positive Secondary Ion Detection

Element	Detection Limit
Be	1e14
Li	1e14
B	5e14
Na	5e14
Mg	5e14
Al	1e15
Ca	1e15
Ti	1e15
Cr	1e15
Fe	5e15
Ni	5e15
Cu	1e16
Zn	1e16
In	6e16

2. Cs/SIMS
Negative Secondary Ion Detection

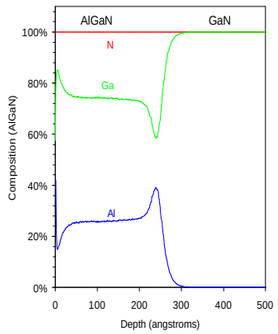
Element	Detection Limit
H	8e16 - 2e17
C	5e15 - 2e16
N	1e16 - 3e16
O	1e16 - 3e16
Si	3e15
S	5e14
Cl	1e15
Ge	1e15
As	5e15

3. Cs/SIMS
Positive Secondary Ion Detection (CsM+)

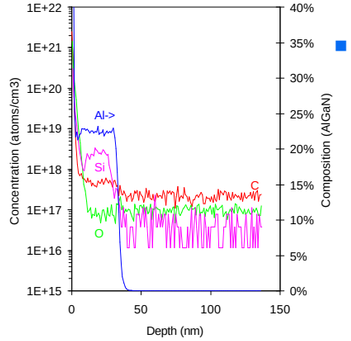
Element	Detection Limit
Mg	5e15
Zn	1e16

SIMS APPLICATIONS

Composition – Mole Fraction
AlGaN/GaN

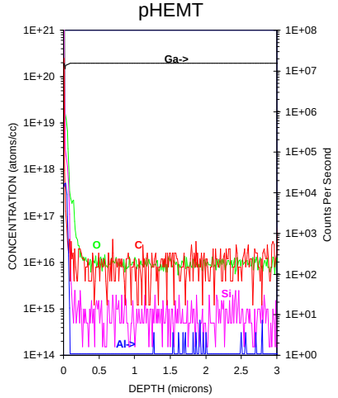


Dopant Profiles
pHEMT
C, O and Si concentration – AlGaN composition



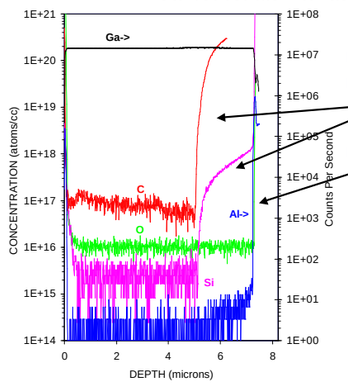
- Quadrupole SIMS
  - Low energy
  - Excellent depth resolution

Impurities
pHEMT



- Cameca SIMS at "normal" condition, 14.5 keV
  - Poor depth resolution
  - Excellent detection limits

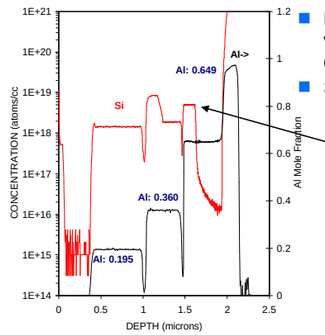
Failure Analysis
GaN/substrate interface



- GaN film defects
- Dislocations – pin holes cause early rise in profiles
- Not uniform – O and Al profiles are OK

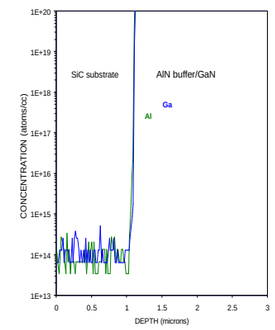
SIMS APPLICATIONS

Production Monitoring
GaN / $Al_{0.2}$GaN / $Al_{0.35}$GaN / $Al_{0.65}$GaN / AlN



- Measured Al_X values are very close to expected
- Si in $Al_{0.65}$GaN
  - Hall: 3.7E18 carriers/cm³
  - SIMS: 5.0E18 at/cm³

Process Development
Backside Polished GaN/AlN on SiC



- Diffusion of Ga into SiC substrate?
  1. Polished SiC substrate
  2. SIMS analysis

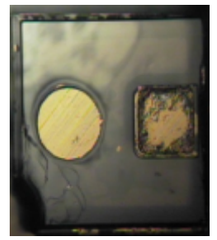
→ NO diffusion

Reverse Engineering/Small Area Analysis

Blue LED

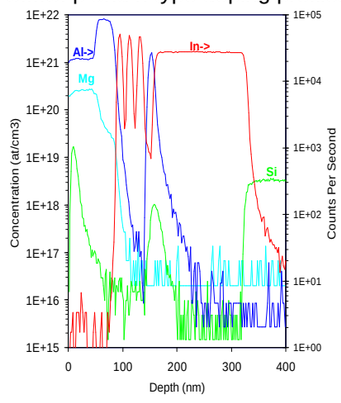
Deprocessed

Polished

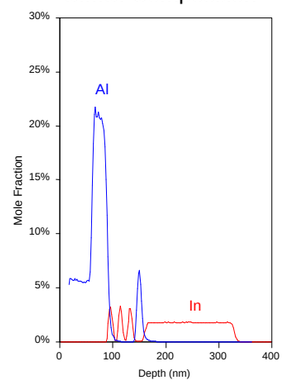


300 micron

AlGaN/InGaN LED
SIMS: p and n type doping profiles



AlGaN/InGaN LED
SIMS: Composition



ACKNOWLEDGEMENT

The implanted GaN and AlGaN samples used for this study were made with the support of ARPA/SUVOS.