Relation Between:
Growth, Microstructure & Morphology, and Properties

Materials
GaN and related alloys
III-As, III-P, III-Sb …
Functional oxides

Growth
MBE: III-N, III-As
MOCVD: III-N (DenBaars, Nakamura)
HVPE: III-N (Nakamura)
Sputtering: Oxides

Characterization
TEM
X-Ray Diffraction
AFM …
Electrical (Basic)
Optical (Basic)
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*Mike Craven (III-N MOCVD - DenBaars)
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*Tadao Hashimoto (Bulk GaN - Nakamura)
*Ben Haskell (III-N HVPE - Nakamura)
*John Kaeding (MOCVD – Nakamura, DenBaars)
*Tom Katona (III-N MOCVD - DenBaars)
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Crosshatch Surface Morphology in Mismatched

A.M. Andrews, J.S. Speck, A.E. Romanov, M. Bobeth, and W. Pompe

*Funded by AFOSR and DARPA*

**Objective**

1. Propose a model for the formation of crosshatch surface morphology resulting from surface step elimination

2. Incorporate film relaxation resulting from misfit dislocation formation and the resulting surface stresses and strains

**Approach**

1. Use analytic equations for stress and surface displacement at the film surface

2. Use Monte Carlo Algorithm to simulate random dislocation nucleation in 1-D

3. Compare effects of relaxation and thickness

**Accomplishments**

1. The slip-step only surface has been modeled as a function of relaxation and thickness

2. The slip-step eliminated surface has been modeled as a function of relaxation and thickness

3. Experimental film surface displacements are between the two limiting cases modeled

**Proposed Model for Crosshatch Formation**

1. Strained epitaxial film

2. Film relaxes

3. Surface steps form

4. Step flow results in thickness change

- Proposed Real Process
- Hypothetical ‘Eshelby-like’ Process
Impurity Incorporation in GaN MBE Growth

Authors: C. Poblenz, T. Mates, M. Craven, S.P. DenBaars and J. S. Speck

Sponsor: ONR and AFOSR

Objective

1. To understand the high level of unintentional doping in MBE-InGaN films revealed through transport measurements of bulk films.

2. To investigate impurity levels and mechanisms of incorporation during MBE growth of InGaN and GaN, focusing on oxygen as a dopant in InGaN.

Approach

- Perform Secondary Ion Mass Spectroscopy (SIMS) to track impurity levels in MBE InGaN and GaN films grown with varying growth conditions.

Accomplishments

1. Demonstrated dramatic increase in oxygen incorporation in InGaN as compared to GaN films.

2. Quantified O levels in InGaN using SIMS and found good agreement with measured sheet carrier concentrations (~1 x 10^{18} \text{ cm}^{-3}) revealing O as a donor in InGaN.

3. Related impurity incorporation to surface structure and wetting layer characteristics.

Figures
Objective

Subsurface stressors can exist either intentionally (e.g. buried quantum dot) or unintentionally (e.g. In composition cluster in an (In,Ga)N/GaN quantum well.

Here: Examine impact of such stressors on electronic properties of surrounding matrix.

Accomplishments

Weak localization of electrons and strong localization of holes above stressor.

These localization effects can be utilized to realize a strain induced quantum dot in a quantum well close to the stressor. Carrier are localized away from non-radiative centers, higher quantum efficiency expected.

Approach

Mechanics
Known solution for point source used as approximation of strain far field originating from stressor

kp calculations
Conduction band (CB) and valence band (VB) changes using kp approach

Figure

Geometry

CB

VB
Objective

- Tunable $\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$ (BST) thin films for microwave varactor applications
- Electric field dependent dielectric permittivity ($\varepsilon_r$)
- Scalable deposition technique and process with low cost microwave substrates (glass, sapphire) to compete with GaAs MMICs

Dielectric tunability

$\varepsilon_r$ dependent on BST composition and thickness

Accomplishments

- Pt base electrode integration
- BST film growth on platinized sapphire
- Fabricated tunable capacitors
# BST Integration with GaN for Microwave Devices

Cofunded by ONR CANE MURI and DARPA CNID

## Objective

Reduce noise and increase device reliability by reducing gate leakage in AlGaN/GaN HEMTS while maintaining high transconductance.

## Approach

Use a high K (Barium Strontium Titanate, BST) dielectric under the gate to maintain high gate capacitance while reducing gate leakage.

## Accomplishments

Gate leakage reduced by four orders of magnitude with transconductance loss of ~20%.

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<tr>
<td><img src="image1" alt="I-V curves for device following 600C anneal" /></td>
<td><img src="image2" alt="Transconductance of standard device, as deposited BST, and post anneal BST under gate" /></td>
<td><img src="image3" alt="Gate leakage for standard device and device with BST under gate" /></td>
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### a) I-V curves for device following 600C anneal  
### b) Transconductance of standard device, as deposited BST, and post anneal BST under gate  
### c) Gate leakage for standard device and device with BST under gate