Modified Oxide Tool

System Capabilities
- Vertical Injection chamber
- Water cooled Head
- Upto 4 MO sources
- Process Gas: \( \text{O}_2 \)
- Carrier Gas: \( \text{N}_2 \)
- Dopant Gas: \( \text{NH}_3, \text{N}_2\text{O}, \text{SiH}_4, \text{PH}_3 \)
- Liquid injection capability with upto 2 Liquid Injection Sources
- New Control System with all the features

Control Software Capabilities
- Complete monitoring of all system parameters
- Advanced Recipe making and manipulation options
- Pulsed growth control and steps looping options
Effect of ZnO MOCVD growth conditions on point defect formation

Large variation in reported growth conditions

- **Substrate material** - bare Sapphire, GaN-templates, ScAlMgO₄, ZnO, LiNbO₃
- **Growth Temperature** - 200 - 780°C, ~550-600°C
- **Precursor** -
  - Oxygen: O₂, alcohols (t-BuOH, i-PrOH), CO₂, N₂O, NO₂, NO, H₂O, H₂O₂, tetrahydro furan
  - Zinc: DMZn, DEZn, Alkylzinc alkoxides (MeZn(OPri), MeZn(OBut)), Zn acetate
- **Carrier gas** - N₂, Ar, O₂, He, H₂, Air, H₂O

Understanding of point defect formation essential to achieving stable p-type ZnO

Data from Table 1 in Y. Ma et al., J. Cryst. Growth 255 (2003) 303-307
Electrical and optical properties

- Undoped films are nominally n-type with low electron mobilities
- Higher VI/II $\rightarrow$ few $V_O$ $\rightarrow$ fewer deep defect centers
- Carrier concentration v. rms surface roughness suggests surface states as source of carriers
- Increase in VI/II ratio: red-shift of near band-edge emission of PL spectrum
- LO phonon replica (increase in Huang Rhys factor) and/or additional defect bands with increasing VI/II ratio
ZnO Overview

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Raman

ZnO modes at 330 cm\(^{-1}\), 375 cm\(^{-1}\), and 437 cm\(^{-1}\)

ZnO:N modes at 275 cm\(^{-1}\), 510 cm\(^{-1}\), 570 cm\(^{-1}\), 640 cm\(^{-1}\)
Pioneer Research In Nuclear Detection

Each area requires specific applications & technologies

Each threat & pathway yields different signatures

High Yield Explosives Detection

Threat & Pathway-based Analysis

Loose Nuke Signatures Detection

Dirty Bomb Signatures Detection

PRIND Specialized Research, Development & Prototyping

Leading to Game Changing Technology
Multiferroics Overview

Magnetism, Ferroelectricity, and Electromagnetic waves interplay can revolutionize optoelectronic devices.

Integrated ferroelectric/ferromagnetic devices in only complex oxides

Integrated ferroelectric in complex oxides and ferromagnetic devices in semiconductors

Complex oxide/ZnO

Complex oxide/GaN

New device technology in existing devices and manufacturing infrastructure

Multiferroic Materials
Growth and Integration

Waveguide

BiMnO$_3$

Single Phase Vs Multiphase

BaTiO$_3$

CoFe$_2$O$_4$

BaTiO$_3$

p-GaN

Active Region

n-GaN

Sapphire

p-ZnO:N

Active Region

n-ZnO

Sapphire

New Properties of Existing Materials

BiMnO$_3$

MOCVD-grown Multifunctional oxides

Titanate-Spinel ferroelectric-ferromagnetic composites

Engineered layered oxides

ZnO Overview
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