Reliable High-Performance Gate Oxides for Wide Band Gap Devices

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Motivation

- Wide bandgap semiconductor devices such as SiC and GaN can improve the performance of existing power conversion systems used in energy storage applications.
  - Significant thermal management reduction
  - Increased power density
  - Increased reliability (all electronic systems)
- Voltage control devices based on GaN have seen limited deployment
- Devices suffer from:
  - Low channel mobility ➔ poor switch conduction
  - Threshold voltage instability ➔ unpredictable switch performance
  - High drain resistance ➔ poor switch conduction
  - *All of these issues are related to defects in the oxide layer*
- *Overall goal: Develop the materials and processes to prepare high quality, reliable gate oxides for wide band gap semiconductor devices*

Important Parameters for Performance and Reliability:

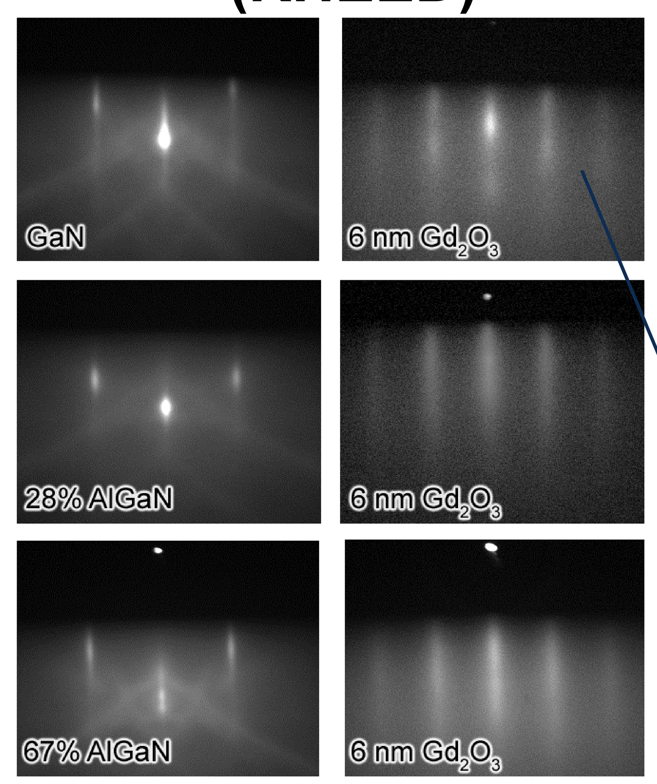
- Minimal Defects:
  - Dislocations ➔ Leakage + Breakdown
  - Unsatisfied Bonds ➔ Charge traps
  - Grain Boundaries ➔ Leakage + Breakdown
- Band Offsets:
  - Band offsets greater than 1 eV required for high performance efficient switching at high temperatures

FY14 Activities:

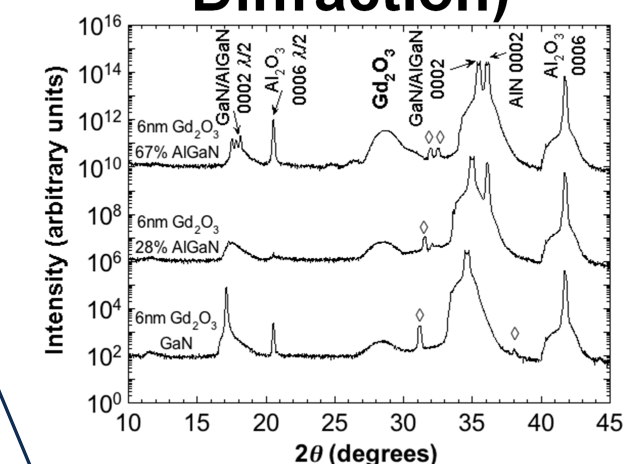
- Identify band offset dependence on semiconductor bandgap for future device design considerations
- Assess performance of MgO and CaO surfactant epitaxy oxides on GaN

Lanthanide Gate Oxides: $Gd_2O_3/Al_xGa_{1-x}N$

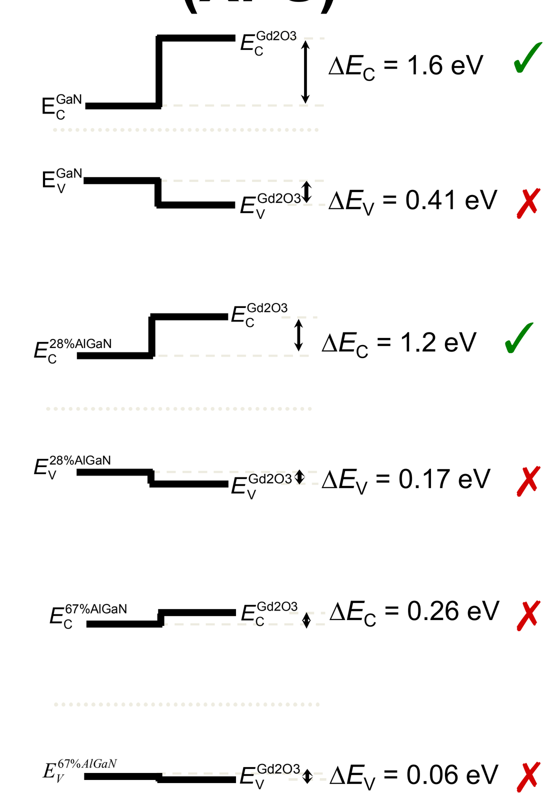
Growth Mode (RHEED)



Structure (X-ray Diffraction)



Band Offsets (XPS)



Streaks = smooth films ✓

X-ray Diffraction shows the same structure of Gd_2O_3 on each AlGaN semiconductor

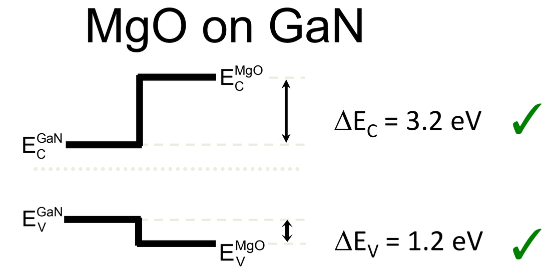
- Valence band offsets decrease as AlN composition increases
- Band offsets are too low for high performance devices
- Combined with FY13 work, La_2O_3 and Gd_2O_3 look great on paper (high *k*, large band gaps + reports of high band offsets) – but are not likely viable gate oxides for reliable high-performance devices

MgO-CaO Gate Oxides with Surfactant Epitaxy

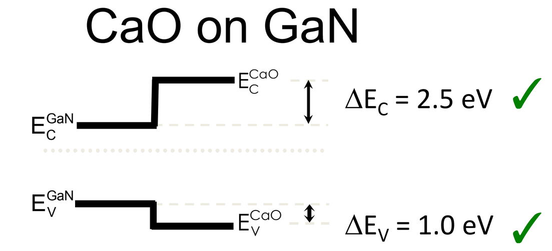
- MgO-CaO have large band offsets with GaN ➔ Less leakage under operation at high temperatures
- Can growth strain free ➔ Minimize threading dislocations (less leakage, fewer traps)
- Can satisfy interface bonds ➔ Minimize interface traps (allow channel inversion)

Band Offsets

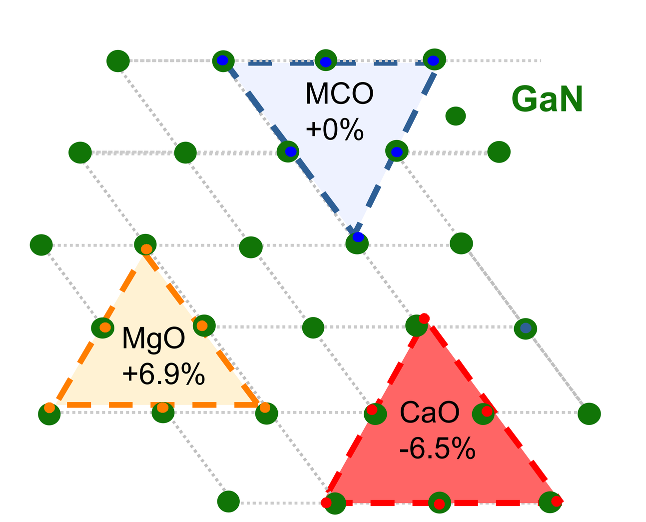
MgO on GaN



CaO on GaN

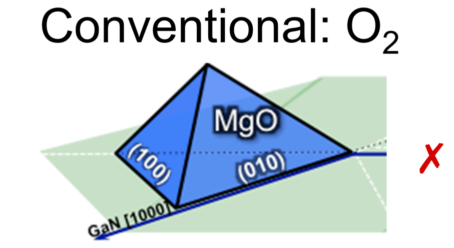


Surface Atomic Alignment

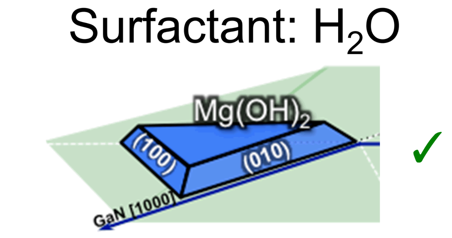


Growth Mode

Conventional: O_2

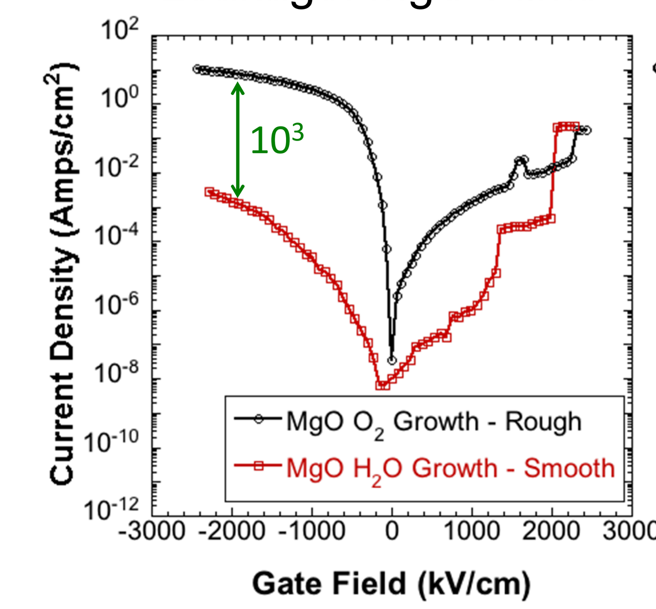


Surfactant: H_2O

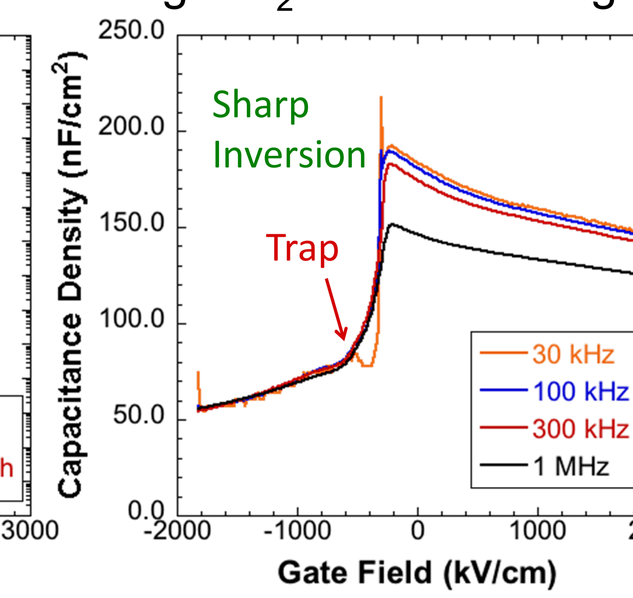


- Surfactant epitaxy enables smooth growth ➔ minimizing threading defects
- Will improve performance and reliability due to less gate leakage

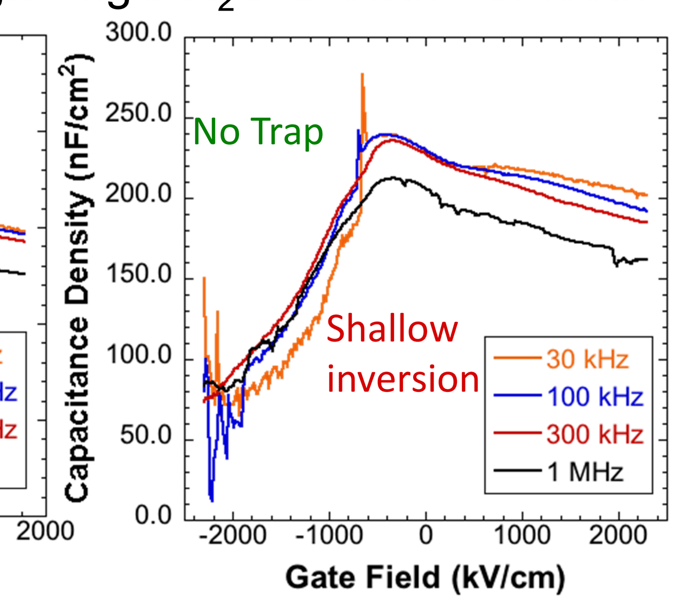
Leakage: MgO Films



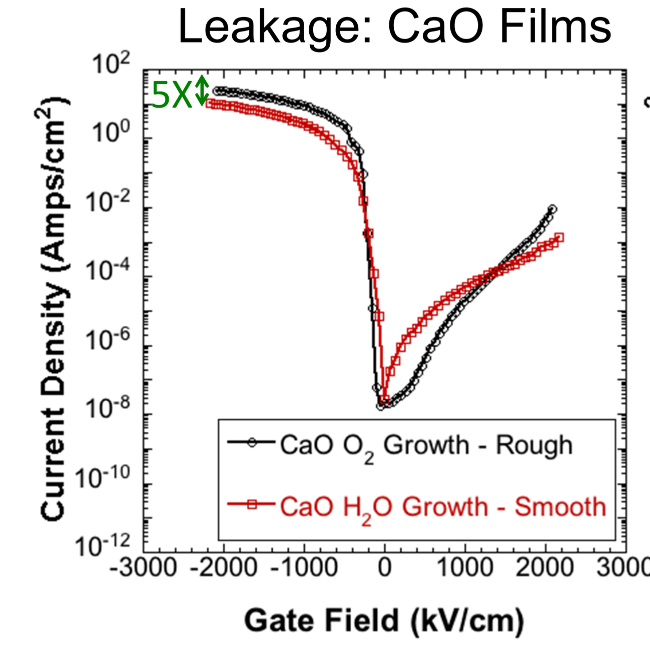
MgO O_2 Growth - Rough



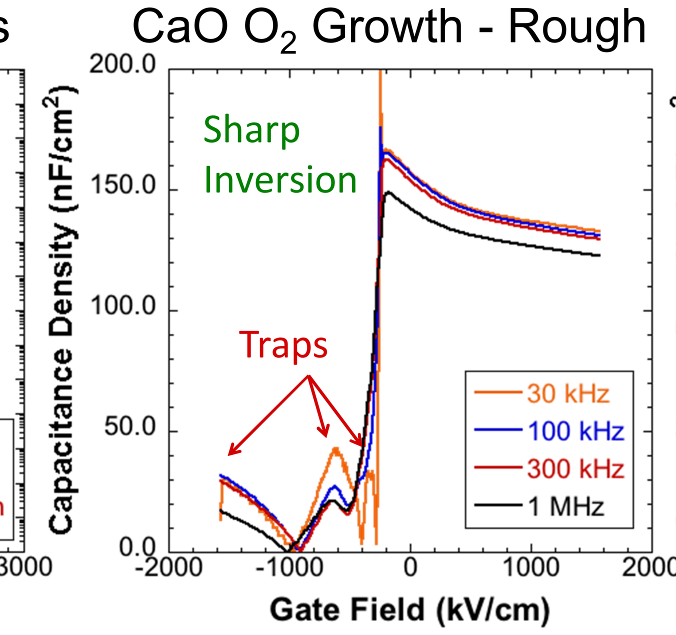
MgO H_2O Growth - Smooth



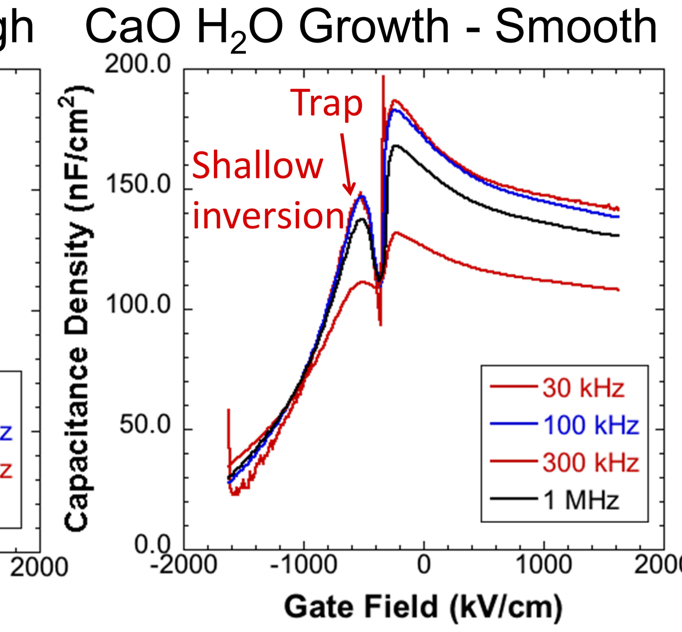
Leakage: CaO Films



CaO O_2 Growth - Rough



CaO H_2O Growth - Smooth



- Significant leakage current improvements for smooth films
  - Less leakage = greater reliability
- Clear trap states for rough films in MOS-Caps
- Graded inversion for smooth oxides in MOS-Caps

FY15 Goals and Milestones:

- Investigate source of hindered inversion in surfactant epitaxy gate oxides
- Prepare and measure performance of lattice matched (low defect density) MCO gate oxides
- Investigate performance and reliability of gate oxides under target application relevant conditions

FY14 Publications and Impact

- J.F. Ihlefeld, M. Brumbach, A. Allerman, D.R. Wheeler, S. Atcitty, "AlGaN composition dependence of the band offsets for epitaxial $Gd_2O_3/Al_xGa_{1-x}N$ ($0 \leq x \leq 0.67$) heterostructures," Applied Physics Letters, 105, 012102 (2014)
- Decreasing valence band offsets for oxides with AlGaN is an important device design criteria
- *Surfactant epitaxy shown to be a promising path forward toward realizing high-qualtiy gate oxides for WBG Semiconductors*

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