SAND2015-7534C

Reliable High-Performance Gate Oxides for Wide Band Gap Devices

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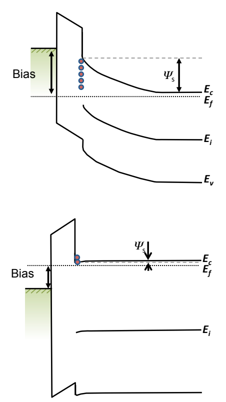

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Motivation

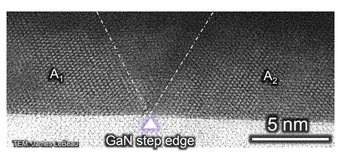
- Wide band gap semiconductor devices can improve the performance of energy conversion systems.
- Voltage control, normally-off devices based on GaN have seen limited deployment
- Lack of deployment stems from issues related to switching stability/repeatability/reliability and conduction.
- All of these issues are related to defects in the insulating component of the device (gate oxide/ passivation layer)

FY15 Activities

- Identify means to reduce threading defect density in GaN
- Quantify band offsets at MgO/GaN interface
- Quantify interface trap density at MgO/GaN and CaO/GaN interfaces

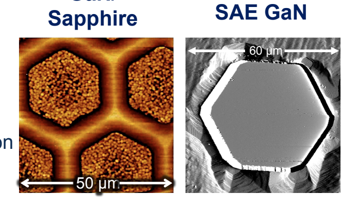
Eliminating GaN Interface Defects

- GaN surface steps lead to defects in insulating layer – potential source of breakdown and traps
- Selected area epitaxy (SAE) of GaN and controlling growth via supersaturation allows for growth of atomically flat material over large areas



GaN/ Sapphire

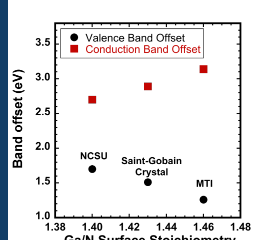
SAE GaN

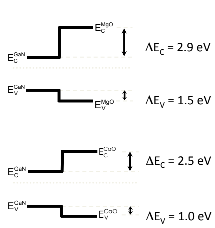


SAE eliminates step edges

Band Structure: MgO/GaN

- Band structure measured using X-ray photoelectron spectroscopy in molecular-beam grown MgO/GaN
- Several sources of GaN were investigated to identify design principles needed for different GaN device manufacturers





- ***Band offsets > 1 eV***
  - Suitable for both *n*- and *p*-type devices

Dielectric | GaN	*VBO (eV)*	CBO (eV)	CBO
La_2O_3	0.63	1.5	SNL
Gd_2O_3	0.41	1.6	SNL
MgO	**1.5**	**2.9**	**SNL**
CaO	**1.0**	**2.5**	**NCSU**
Ga_2O_3	1.4	0.1	[1]
SiO_2	2.4	3.0	[2]
Al_2O_3	1.8	1.3	[3]
HfO_2	0.5	1.5	[2]

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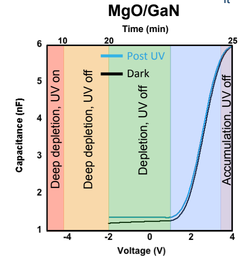
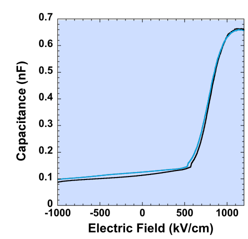
Electronic Properties: CaO & MgO/GaN

- MgO&CaO (30 nm)/GaN (N_d≅2×10^{18} cm^{-3}) devices prepared and C-V and I-V characteristics measured
- UV-assisted C-V technique utilized
  - Provides one of the most conservative and complete measures for D_{it}

MgO/GaN



CaO/GaN



Average D_{it} across band gap:

$$D_{it} = \frac{C_{ox}}{qA}\left(\frac{\Delta V}{E_g}\right)$$

MgO D_{it}: 4×10^{11} eV^{-1} cm^{-2}

CaO D_{it}: 3×10^{11} eV^{-1} cm^{-2}

Dielectric | GaN	D_{it} (eV^{-1} cm^{-2})	Reference
La_2O_3	8×10^{11}	SNL
MgO	**4×10^{11}**	**SNL**
CaO	**3×10^{11}**	**SNL**
Ga_2O_3	4.2×10^{11}	[4]
Si_3N_4	5×10^{12}	[5]
Al_2O_3	3×10^{12}	[6]
Al_2O_3	5×10^{11}	[7]
SiO_2	$2 \times 10^{11*}$	[8]

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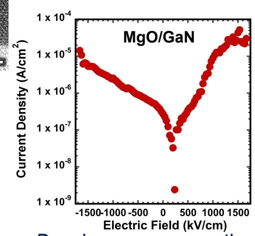
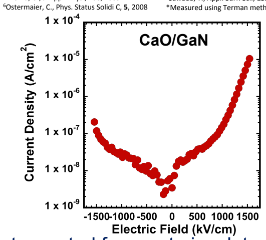
*Measured using Terman method





- D_{it} values are among the lowest reported for a gate insulator on GaN
- Positive threshold voltages observed
  - Implications for safe (enhancement mode, normally off) operation
- Low leakage current in both depletion and accumulation
  - High performance operation with efficient switching

FY15 Publications and Impact

- E.A. Paisley, M. Brumbach, A. Allerman, A. Armstrong, R. Kaplar, A. Baca, S. Atcitty, and J.F. Ihlefeld, "Spectroscopic investigations of band offsets of MgO|AlGaN heterostructures with varying AlN content," Applied Physics Letters, *Accepted*
- Developing a new understanding of semiconductor surface chemistry and impact on device properties (band offsets)
- Developed growth techniques for smooth GaN with low surface and threading defect concentrations
- *Have shown that MgO and CaO on GaN have among the lowest reported interface defect state densities*
  - *Will minimize issues resulting in performance limitations in GaN enhancement-mode devices.*

FY16 Goals and Milestones:

- Complete D_{it} study for MgO and CaO on GaN
- Prepare and measure performance of lattice matched MgO-CaO alloys on GaN
- Investigate MgO-CaO on defect-free GaN to find a maximum performance limit
- Investigate industrial partnership for device preparation

We gratefully acknowledge Dr. Imre Gyuk and the DOE Office of Electricity Energy Storage Program for funding this work

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NNSA National Nuclear Security Administration