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III-nitride surface chemistry influence on band offsets of gate oxides on GaN

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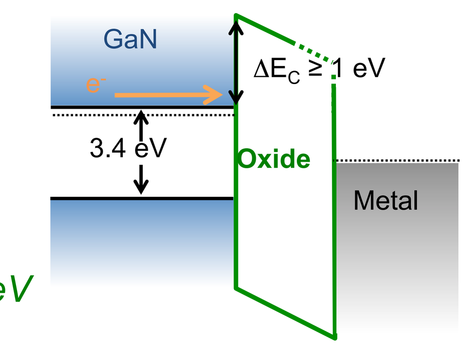
Motivation:

- Gate oxides offer the possibility of providing normally off GaN/AlGaN HEMT operation with simultaneous gate leakage suppression.
  - But, the oxide|nitride band offset must be sufficient and accurate band offset information is critical.
- **Band offsets give us expectations for:**

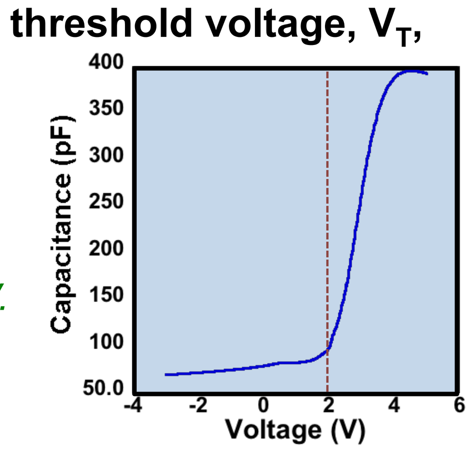
1. **Can we suppress gate leakage?**

For n-type GaN, we want the conduction band offset, $\Delta E_C \geq 1$ eV



2. **Can the oxide threshold voltage, V_T, enable a normally off operation?**

For n-type GaN, we want $V_T \geq 2$ V.



- **Many aspects of the interface can significantly change the oxide|nitride band offset. However, these effects are not well understood for oxides on GaN.**
- **Properties that can affect the band offsets of the oxide|nitride interface:**

A. **Surface chemistry** of the GaN surface: substrate cleaning and GaN growth procedure.

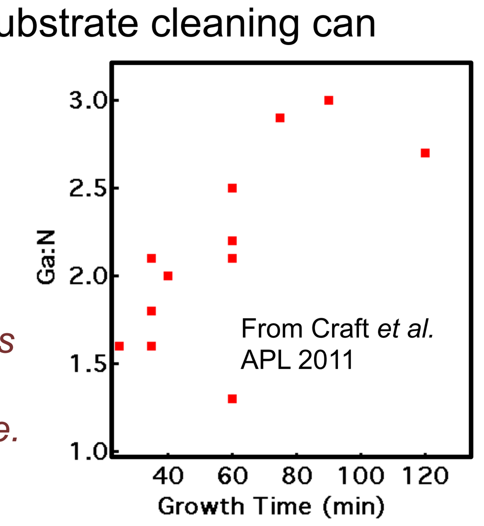
B. **Dislocation density** of the GaN template: GaN growth procedure.

C. **Interface state density (D_{it})** of the oxide|nitride interface: oxide growth procedure and substrate cleaning.

A. Surface Chemistry:

- GaN growth and substrate cleaning can influence the final surface chemistry of the GaN substrate.

Craft et al. show measured changes in Ga:N ratio v. reactor growth time.



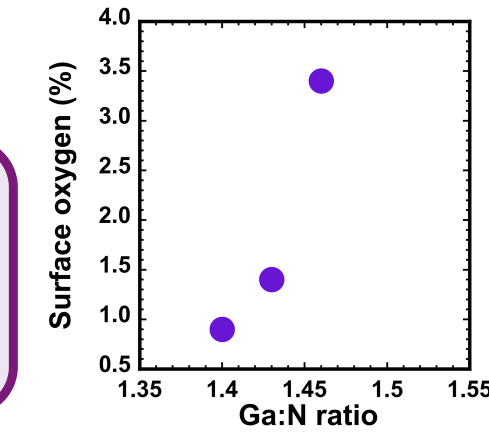
- A similar type effect is expected for GaN substrates from different vendors or substrates with different cleaning procedures.
- Three wide-ranging GaN substrates are cleaned with the identical procedure: acetone, methanol, and 5:95 HF:Di water.

Substrate Source	Growth Method	Polarity	Si doping (cm^{-3})	Thickness (μm)
NCSU	MOCVD	Ga-polar	UID	1.2
Lumilog	HVPE	Ga-polar	1.9×10^{18}	3.5
MTI	HVPE	Ga-polar	UID	5.0

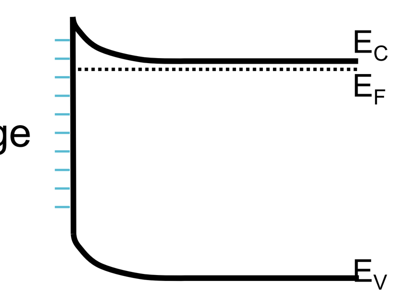
A. Surface Chemistry:

- **GaN surface chemistry, Ga:N ratio and oxygen surface concentrations were measured using XPS:**

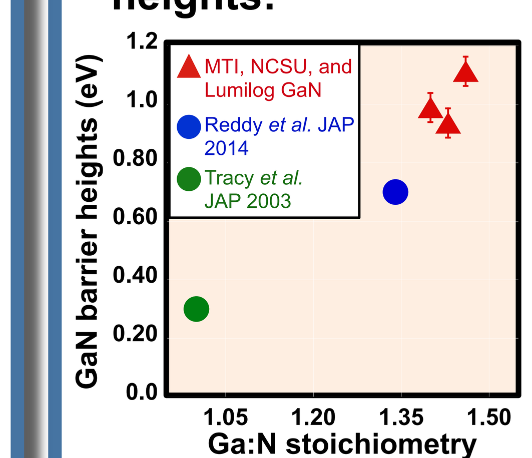
Surface oxygen content increases for higher Ga surface stoichiometries.



- An increase in native oxide forms more negative surface charge causing upward band bending of the GaN surface.



- We test this by measuring the GaN barrier height of each substrate by XPS.
- **Influence of Ga:N ratio on GaN barrier heights:**

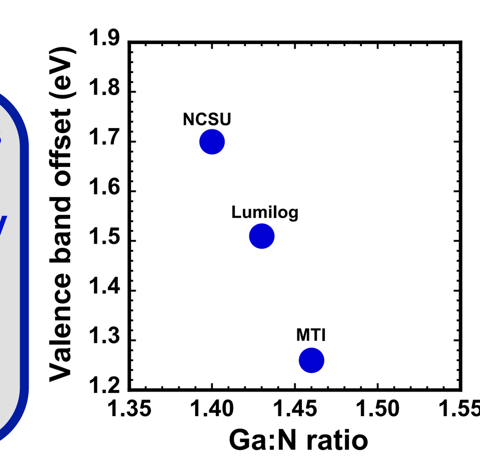


As Ga:N ratio increases, band bending at the CNL increases.

- This implies Ga:N ratio will affect Schottky barrier heights to metal contacts and band offsets to gate oxides.

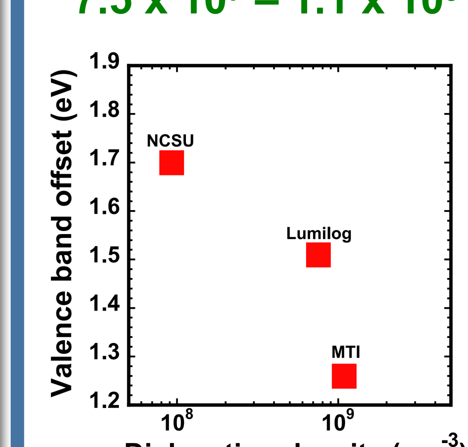
- A similar effect of surface stoichiometry is then expected for band offsets between GaN and gate oxides.
- We test this by measuring the valence band offset of MgO to each GaN substrate by XPS.
- **Influence of Ga:N ratio on band offsets to MgO:**

Valence band offsets of the MgO|GaN interface decrease by ~ 0.44 eV for small changes in GaN surface stoichiometry.



B. Dislocation Density:

- Dislocation densities of the GaN substrates were measured using HR-XRD.
- **Dislocation densities range from 7.5×10^7 – 1.1×10^9 cm^{-3}.**

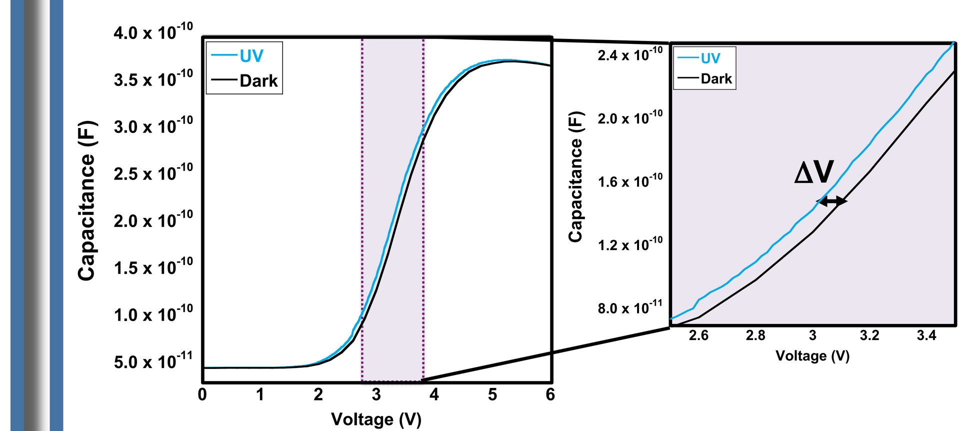


- A similar effect to surface stoichiometry is seen for substrate dislocation density.
- **Valence band offsets to the gate oxide decrease with increasing GaN dislocation density.**

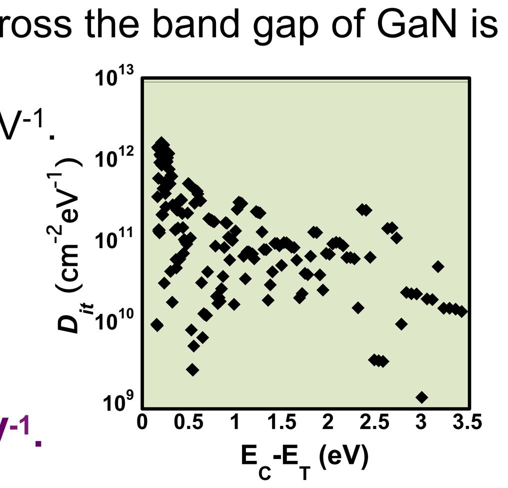
C. Interface State Density:

- Changes in the GaN surface alter the surface screening charge of the polar substrate.
- However, it is likely that the resultant change in band offset to the gate oxide is only observable if the interface state density is low.
- We test this by measuring the interface state density (D_{it}) of the MgO|GaN interface.
- **Photo-assisted capacitance-voltage D_{it} analysis:**
  - UV light is used to photo-populate interface states.
    - ΔV between dark and post UV curves yields information on D_{it}:

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



- An average D_{it} across the band gap of GaN is found to be ~9.3×10^{10} cm^{-2} eV^{-1}.
- **At 0.23 eV from the conduction band edge, D_{it} reaches a maximum of 1.6×10^{12} cm^{-2} eV^{-1}.**



- **Comparison with literature D_{it} values:**

Dielectric | GaN	D_{it} ($eV^{-1}cm^{-2}$)
La_2O_3	1×10^{12}
MgO	**9.3×10^{10}**
CaO	**2.2×10^{11}**
Ga_2O_3	4.2×10^{11}
Si_3N_4	5×10^{12}
Al_2O_3	5×10^{11} - 3×10^{12}

***Average values* for MgO and CaO are low compared to other systems in the literature.**

- We hypothesize that the low D_{it} value of MgO allows observation of changes to the oxide|nitride band offset.
- Current efforts focus on measuring higher D_{it} materials to see if D_{it} can screen the surface charge effect of the GaN.

Conclusions:

- For high quality oxide|GaN interfaces, the GaN substrate surface chemistry and dislocation density influence band offsets.
- Valence band offsets of MgO on GaN ranging from 1.26 to 1.70 eV were measured for small changes in oxygen content and Ga:N ratio.
- Current efforts focus on extending analysis to Al_2O_3 | GaN to confirm the screening factor proposed higher D_{it} interfaces.

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