Engineered Gate Oxides for Wide Bandgap Semiconductor MOSFETs*

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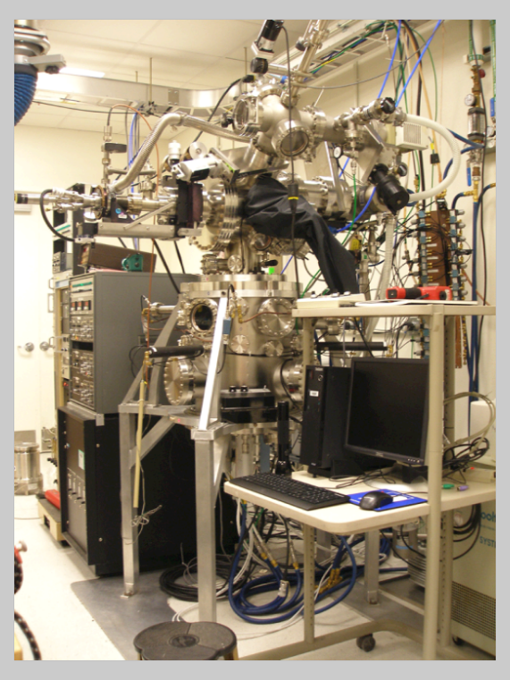

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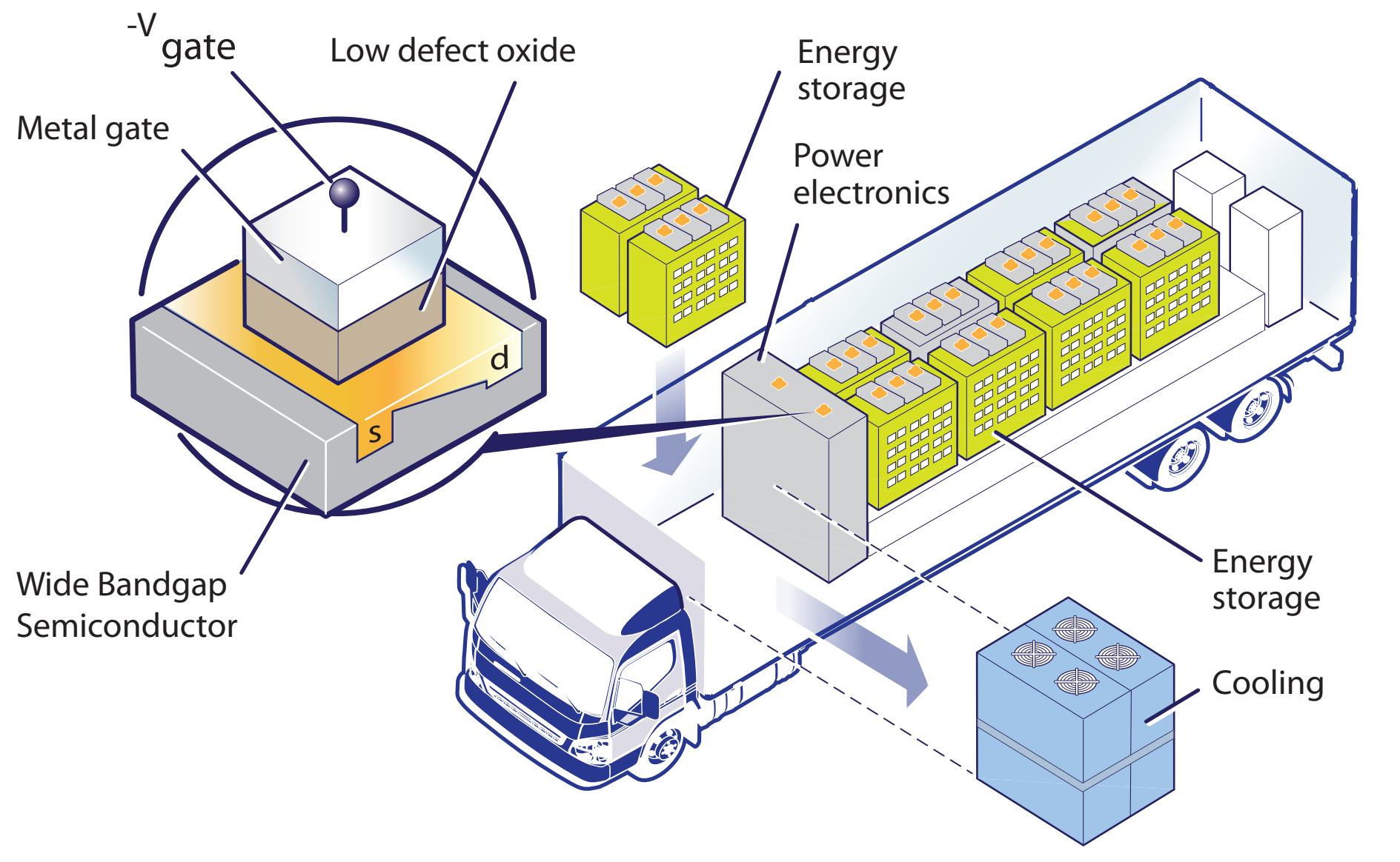
Project Overview

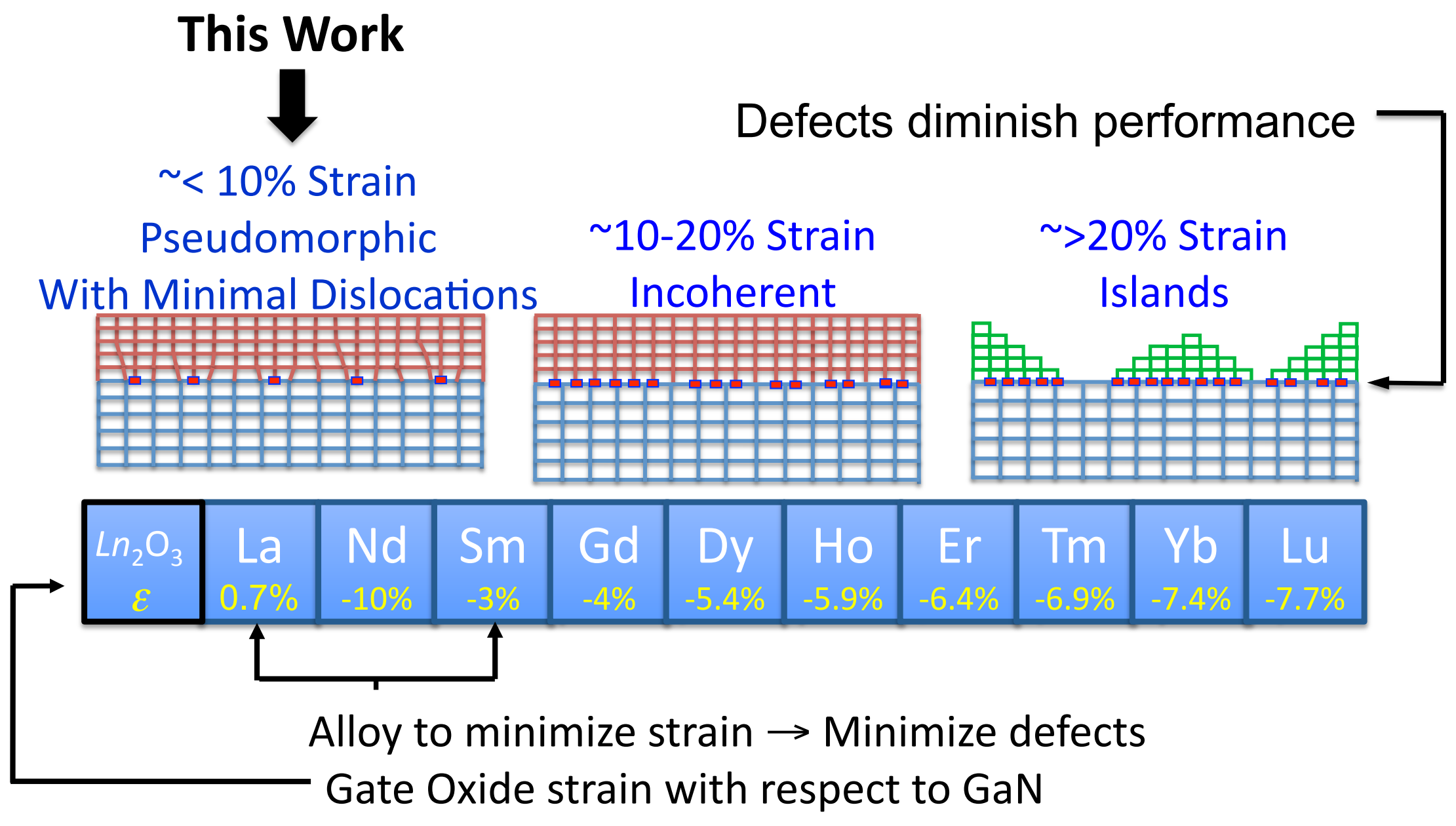


Purpose

- Wide bandgap semiconductor devices such as SiC and GaN can improve the performance of existing power conversion systems used in energy storage applications.
- Wide bandgap semiconductor devices can operate efficiently at higher temperatures, can have higher switching speeds, and have longer performance life.
- New devices such as SiC and GaN MOSFETs lack a robust gate oxide – a key material that enables power switching

Methodology

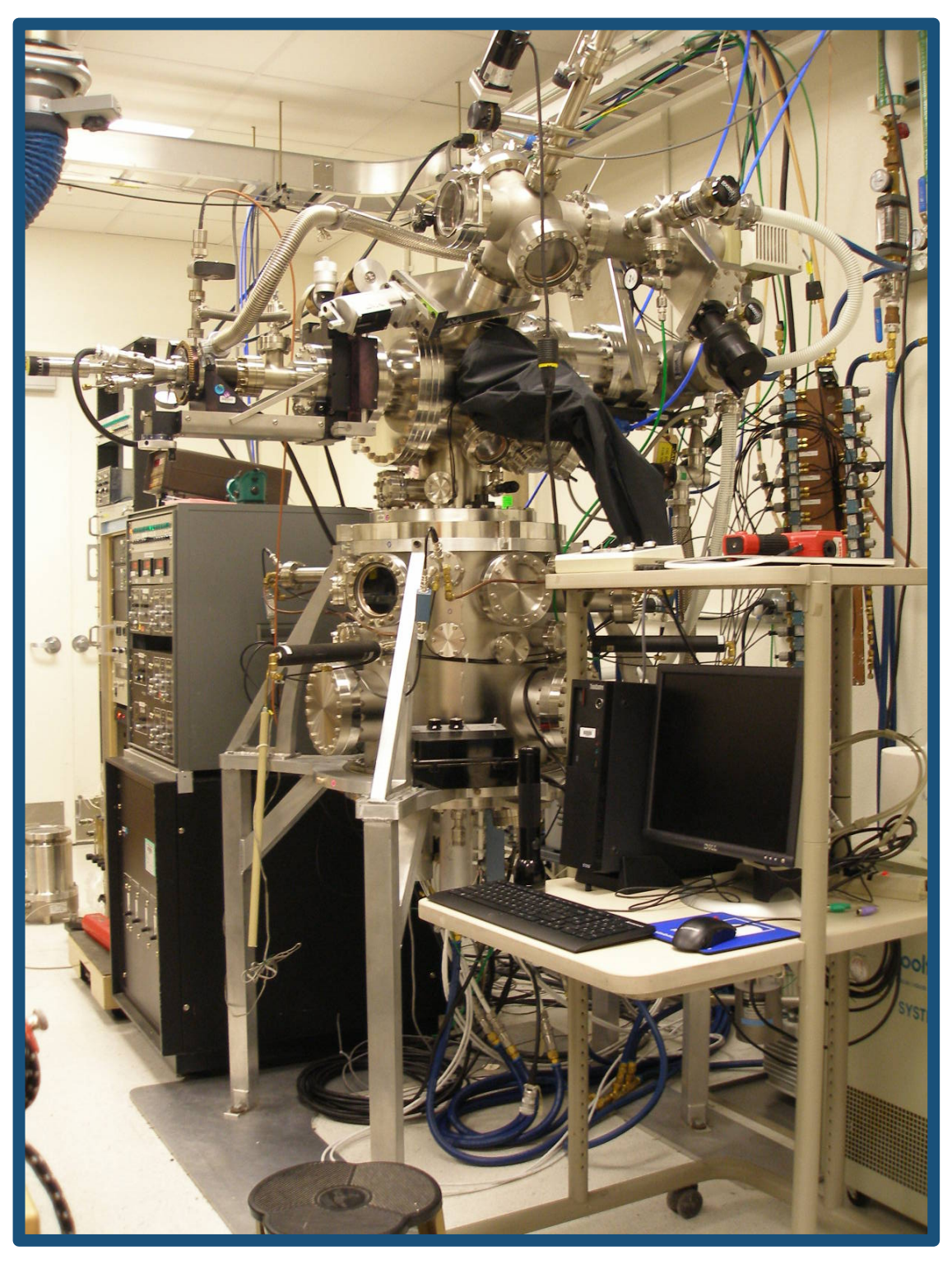
- Defects in gate oxide layer can adversely affect performance and reliability:
  - Dislocations ➔ Leakage + Breakdown
  - Unsatisfied Bonds ➔ Charge traps
  - Grain Boundaries ➔ Leakage + Breakdown
- Minimizing defects will enable reliable, efficient, high-performance devices
- Ln_2O_3 oxides may be grown in low strain states on GaN and SiC



Ln_2O_3	La	Nd	Sm	Gd	Dy	Ho	Er	Tm	Yb	Lu
ε	0.7%	-10%	-3%	-4%	-5.4%	-5.9%	-6.4%	-6.9%	-7.4%	-7.7%

Alloy to minimize strain → Minimize defects
Gate Oxide strain with respect to GaN

Progress

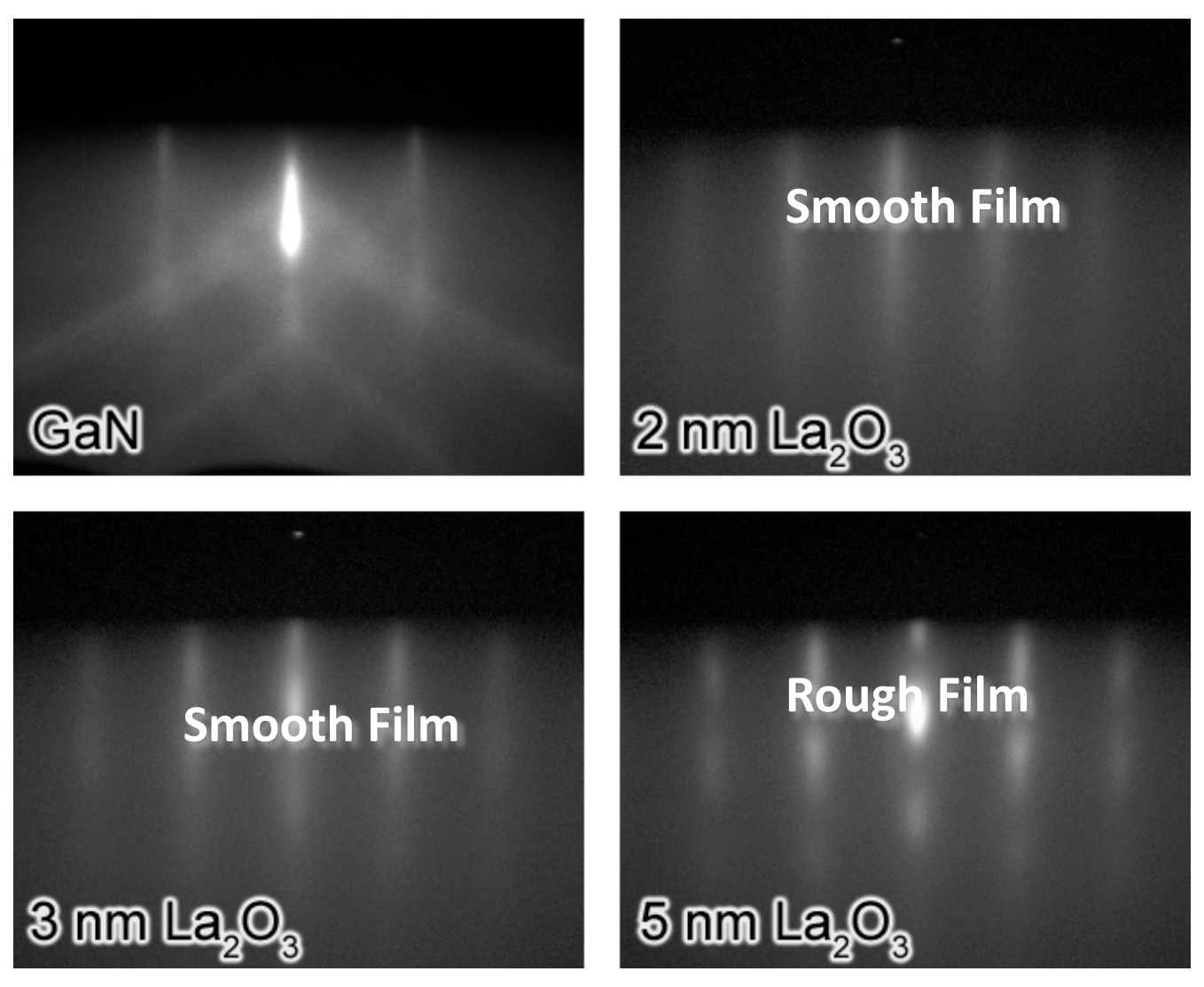


- Molecular-beam epitaxy system refurbished for oxide growth
  - Manipulator converted for oxide compatibility
  - *In-situ* RHEED growth diagnostics added; imperative for understanding defects
  - Sources refurbished for oxide growth

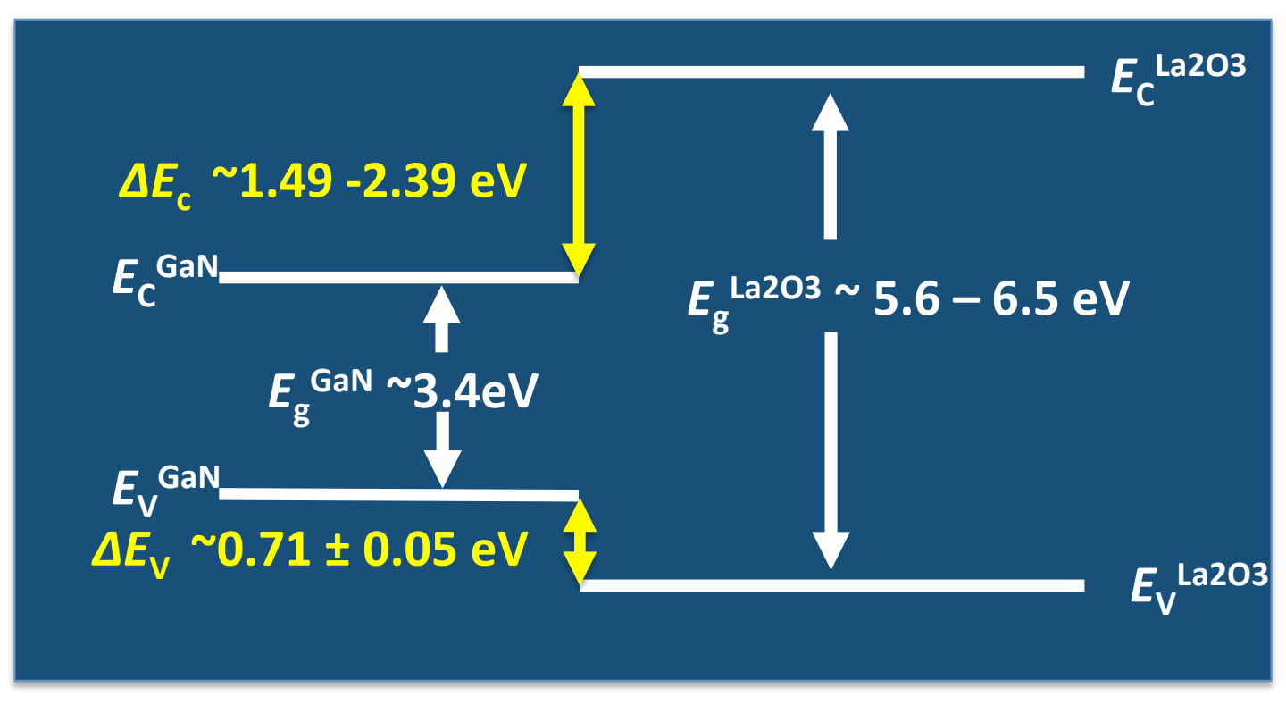
La_2O_3 Growth on GaN

- Limited information exists the properties of La_2O_3 on wide bandgap semiconductors. Films were prepared to establish:
  - Growth characteristics
  - Band Offsets
  - MOSCap Electrical Properties

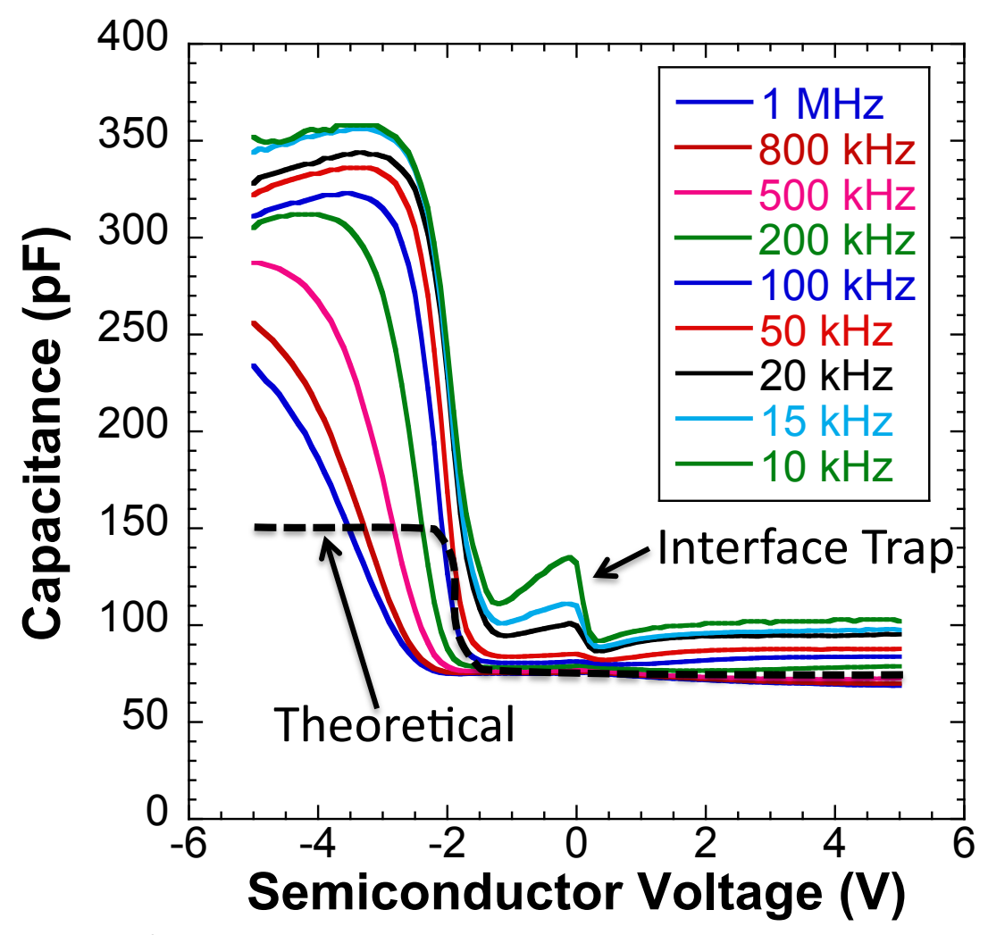
- La_2O_3 growth parameters established
  - 550°C required for crystalline films
  - Films smooth up to 3 nm in thickness
  - Strain relaxation causes roughening by 5 nm

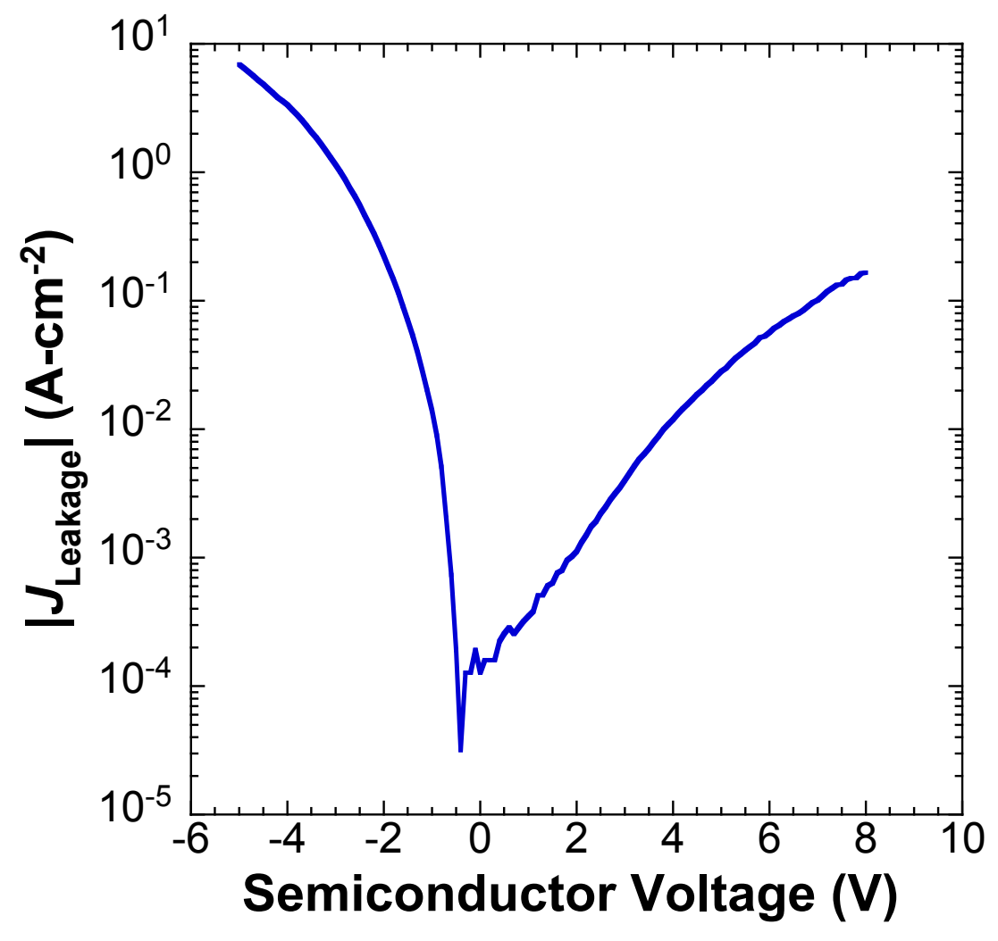


- La_2O_3-GaN band offsets measured via X-ray photoelectron spectroscopy on film thickness series
  - 0.71 ± 0.05 eV Valence Band Offset
  - 1.49-2.39 ± 0.05 eV Conduction Band Offset



- 50 nm La_2O_3-*n* GaN MOSCap
  - Capacitance exceeds theoretical indicating device leakage (comparable to La_2O_3-*p* Si)
  - One interface trap peak
  - Leakage in depletion due to injection from metal gate (Pt)
  - Leakage in accumulation due to tunneling into oxide.





Future Plans

- Utilize strain engineering to improve film roughness and decrease device leakage on GaN and SiC
  - *Ln_2O_3* alloys and MgO-CaO alloys
- Integrate alloy oxides into test architectures to validate performance under representative conditions
- Optimize material interface to eliminate trap states and enable high performance devices

Impact on DOE OE Energy Storage Mission

Efficient and reliable power conversion system based upon GaN and SiC can enable overall increased performance and decreased cost, size, and weight resulting from decreased device cooling requirements. Key to this is the development of wide bandgap semiconductor MOSFET devices with high-quality gate oxides, which this program aims to develop.

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