SAND2012-9870P

Materials Issues for Wide-Bandgap Power Electronics Devices

Oak Ridge National Laboratory Automotive Wide-Bandgap Devices and Applications Workshop

November 15, 2012

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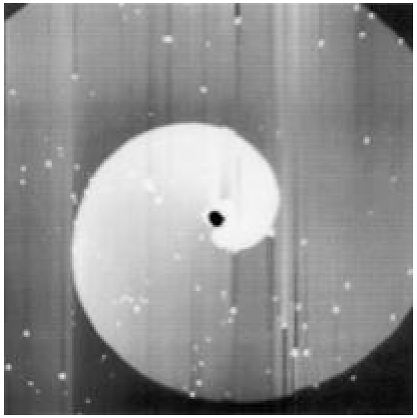
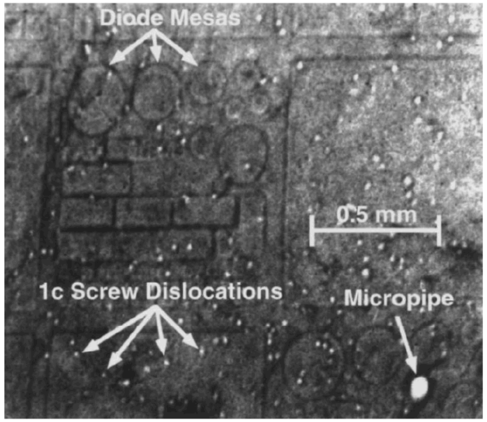
Materials Issues for SiC: Bulk Defects

- 6" SiC wafers are now available
- Bulk defects can limit yield, reliability, and area of individual devices (e.g. for high-current capability)
- Micropipe density is now very low
- Densities of other defects (e.g. stacking faults, various types of dislocations) are also low, and decreasing (may affect reliability, e.g. V_F degradation)



Growth spiral due to micropipe in 6H-SiC
N. Ohtani et al., J. Crystal Growth **226**, 254 (2001)

Defects in 4H-SiC p^+n junctions grown on SiC
P. G. Neudeck et al., Solid-State Elect. **42**, 2157 (1998)



Materials Issues for SiC: MOS D_{IT} / μ_n

- **SiO_2 may be grown thermally on SiC**
- High interface state density(10^{13} $cm^{-2}eV^{-1}$) at the conduction band edge; density decays exponentially with energy below E_C
- Post-oxidation NO anneal reduces D_{IT} by a factor of roughly 10

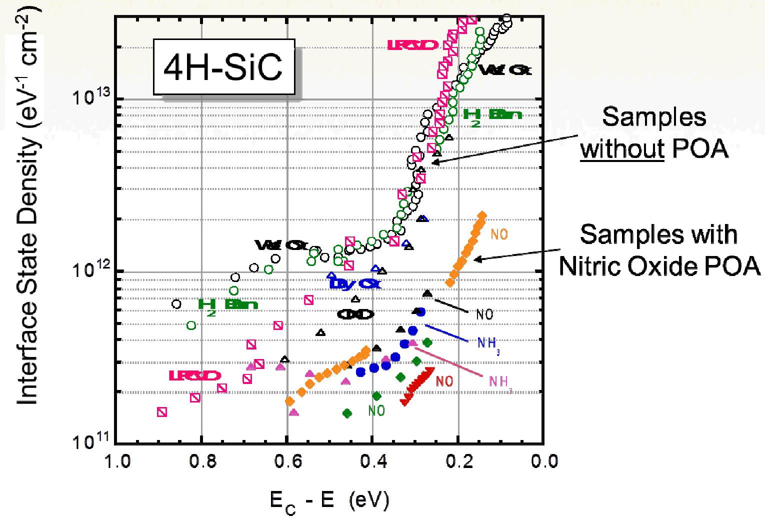


Figure courtesy of Jim Cooper, Purdue University

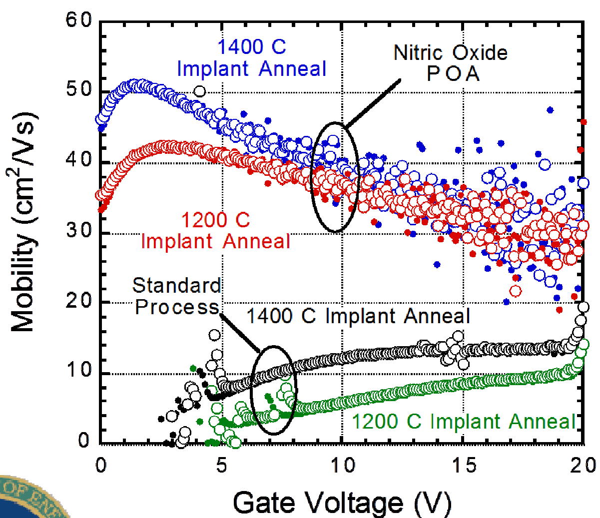


Figure courtesy of Jim Cooper, Purdue University

- Low channel electron mobility as-grown (10 cm^2/Vs; bulk μ_n ~ 600-800 cm^2/Vs)
- Post-oxidation NO anneal may increase μ_n to around 50 cm^2/Vs
- Recent work is investigating P anneal (μ_n ~ 80 cm^2/Vs, $D_{IT} < 10^{12}$ $cm^{-2}eV^{-1}$)

Y. K. Sharma et al., Solid-State Electronics **68**, 103 (2012)

Materials Issues for SiC: V_T Instability

Small conduction band offset;
potentially susceptible to high-T degradation

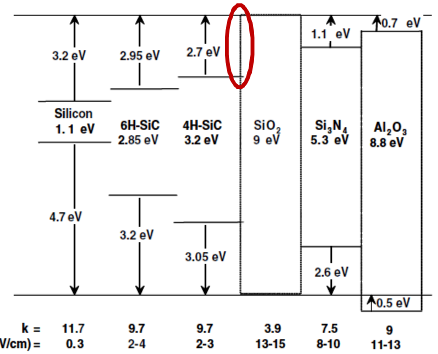
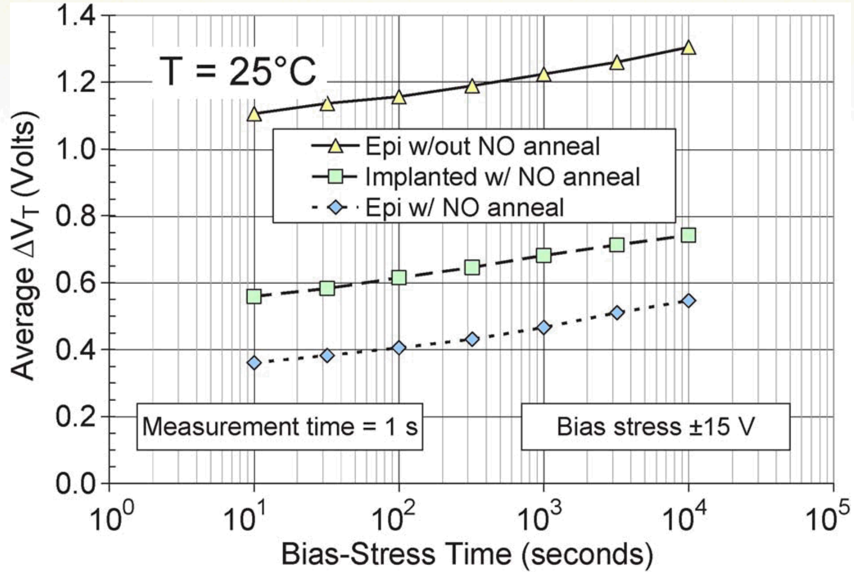
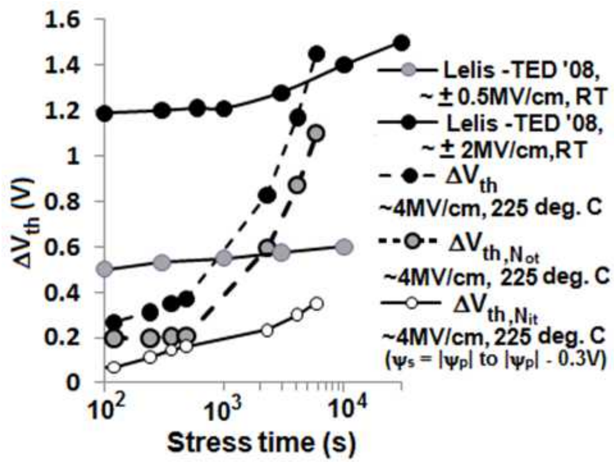


Fig. 1. Dielectric constants, and critical electric fields of various semiconductors (Si, 6H-SiC, 4H-SiC) and dielectrics (SiO_2, Si_3N_4 and Al_2O_3). Conduction and valence band offsets of these are also shown with respect to SiO_2.

R. Singh, Microelectronics Reliability, **46**, 713 (2006)



A. Lelis et al., IEEE TED **55**, 1835 (2008)



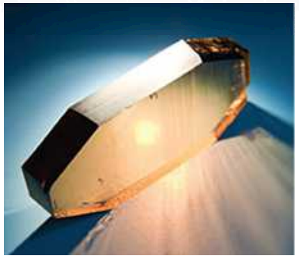
S. DasGupta et al., APL **99**, 023503 (2011)

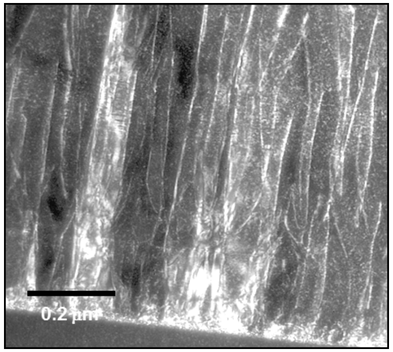
- Small band offset between SiO_2 and SiC
- Bias-temperature instability is potentially an issue
- Sensitive to post-growth annealing conditions

Materials Issues for (Al)GaN: Bulk

- Bulk substrates (HVPE, Ammono-Thermal) are not widely available and are limited to small sizes
- Vast majority of (Al)GaN growth is heteroepitaxy on Al_2O_3, SiC, or Si
- Precludes vertical device as is common in Si and SiC technology
- Lateral HEMT taking advantage of (Al)GaN polarization and high μ_n at AlGaN/GaN interface is used instead

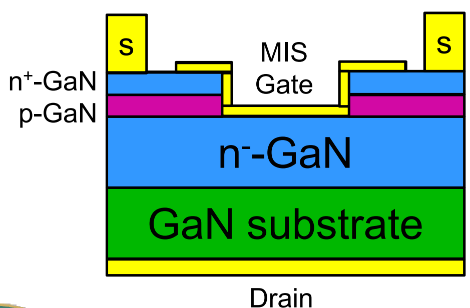
(Ammono) **GaN**





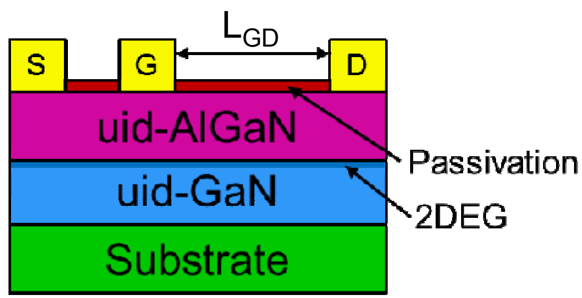
High dislocation density for heteroepitaxial GaN (10^9-10^{10} cm^{-2})

Image courtesy of Andy Allerman, Sandia National Labs



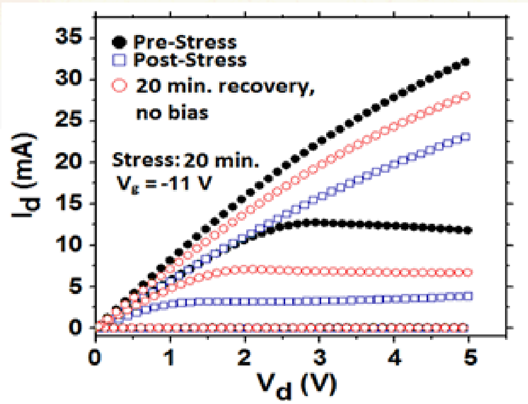
Vertical

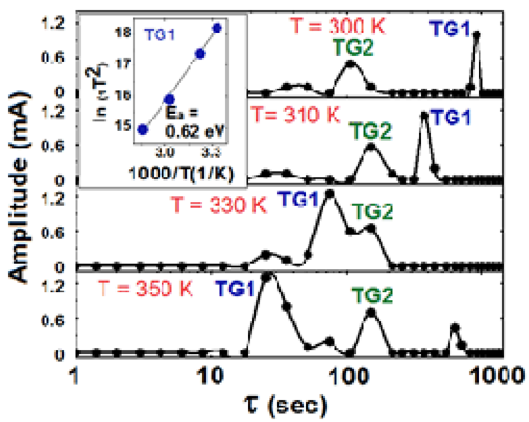
vs.



Lateral

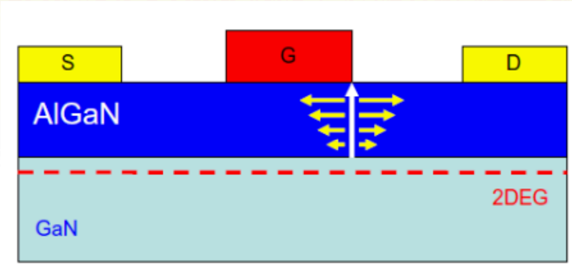
Materials Issues for (Al)GaN: Epitaxy





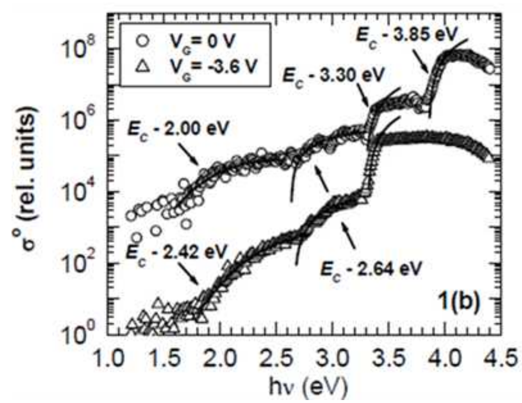
Deep levels give rise to current collapse with slow recovery

S. DasGupta et al., IEEE TED **59**, 2115 (2012)



Inverse piezoelectric effect

J. A. del Alamo and J. Joh, Microelectronics Reliability **49**, 1200 (2009)



Deep level defect spectroscopy in GaN and AlGaN

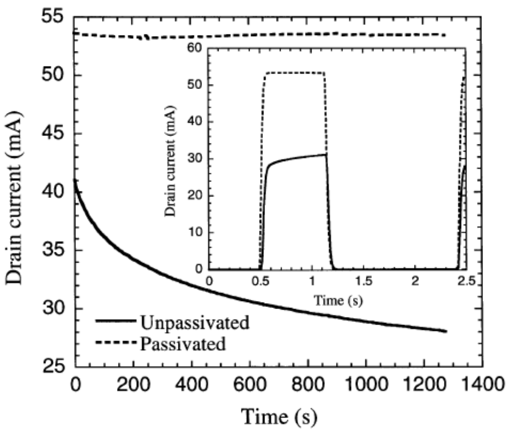
A. Armstrong et al., APL **89**, 262116 (2006)

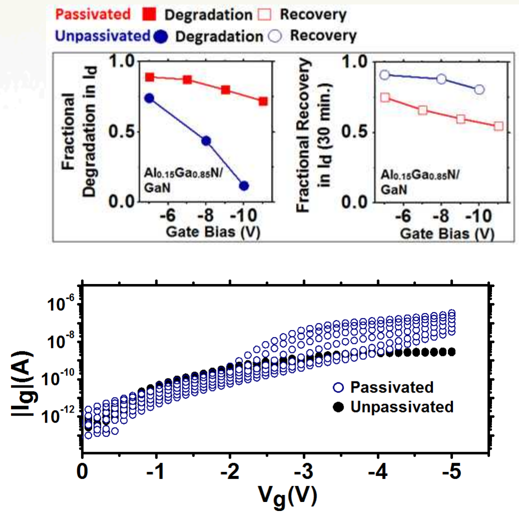
Control of unintentional donors (O, V_N) and compensating acceptors (C, V_{Ga}) during growth

Materials Issues for (Al)GaN: Dielectrics

Surface passivation:
Current collapse and
"virtual gate"

G. Koley et al., IEEE TED **50**, 886 (2003)





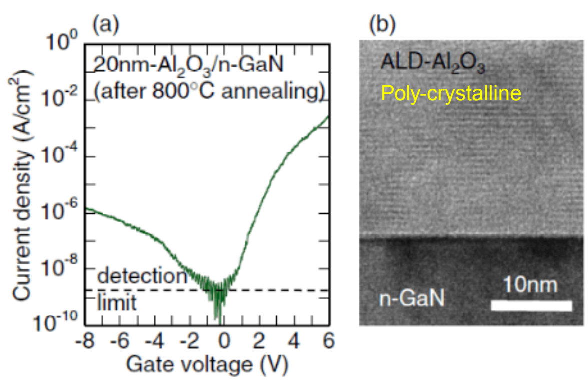
Surface passivation:
Device stability vs.
gate leakage current

S. DasGupta et al., IEEE TED **59**, 2115 (2012)

Robust gate dielectrics

Y. Hori et al., JJAP **49**, 080201 (2010)

Ohmic last



Ohmic first