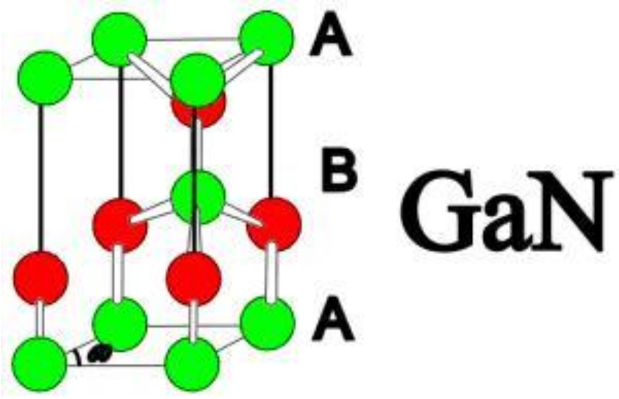
Selective Area Growth in Gallium Nitride

By Jose Barcenas

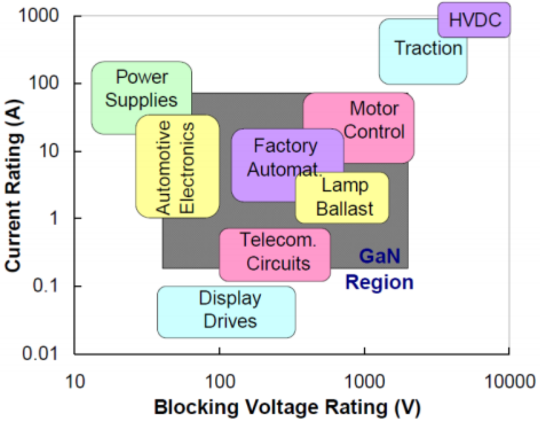
Overview

- Introduction to GaN
  - Crystal Structure
  - Advantages over silicon
    - HFET and HEMTS
  - Challenges in fabrication and performance
- GaN fabrication
  - Substrates
  - Epitaxy
  - Plasma Treatment
    - Dry etching, fluoride-based plasma,
- Selective Area Growth
  - Growth parameters
  - Gas flow
  - Epitaxial Lateral Overgrowth
  - HEMTS
  - Nanostructures

Introduction to GaN

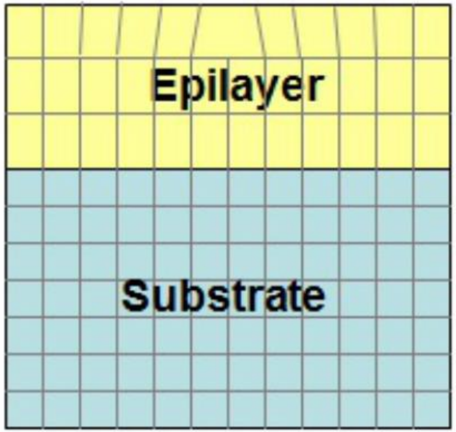


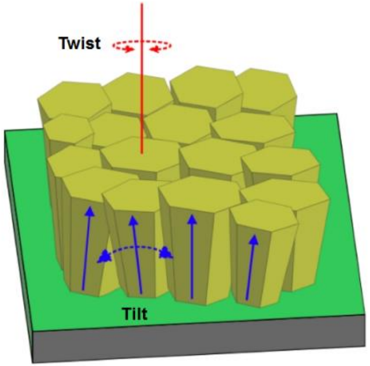
- Wurtzite or Zinc Blende structure
  - Wurtzite structure primarily used for high performance devices due to wide band gap
- High frequency and high power applications
  - High Electric field tolerated
- Used for military and space applications
  - Sensors, radar systems, missile defense



GaN fabrication

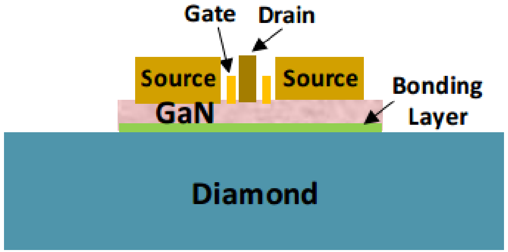
- GaN typically grown on Sapphire, SiC, or Silicon
  - Czochralski method not possible with GaN
  - MBE, MOCVD, MOVPE commonly used to form epitaxial layers
    - 3-5 semiconductors typically grown by heteroepitaxy
- Defects in GaN Heteroepitaxy
  - Lattice mismatch
  - Threading dislocations
    - Screw dislocation, mixed dislocation, edge dislocation
  - Defect density range between 10^9 cm-2 to 10^11 cm-2





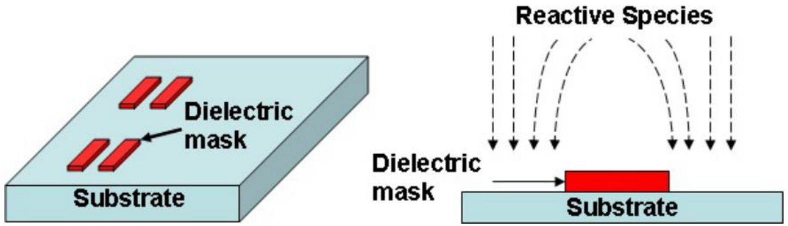
Substrate Solutions

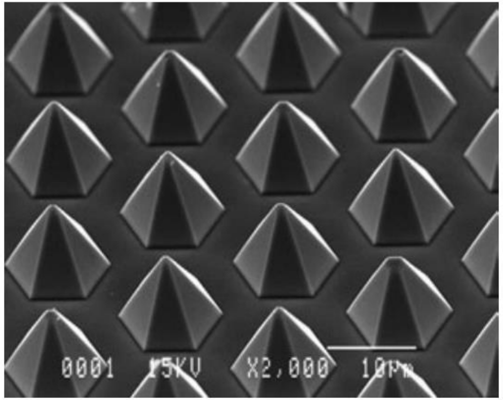
- Sapphire Substrate
  - Used due to low cost, availability, and compatibility to GaN growth process
  - Lattice mismatch 13%
- SiC lattice mismatch 3.4%
- Lithium Gallate
  - Lattice mismatch .19%
  - Dislocation density decreases
  - Thermal stability an issue in MOVPE growth environment
- Diamond Substrate
  - Lattice mismatch 11%
  - High thermal conductivity, nearly 5 times more than SiC
  - GaN thickness can be reduced



Selective Area Growth(SAG)

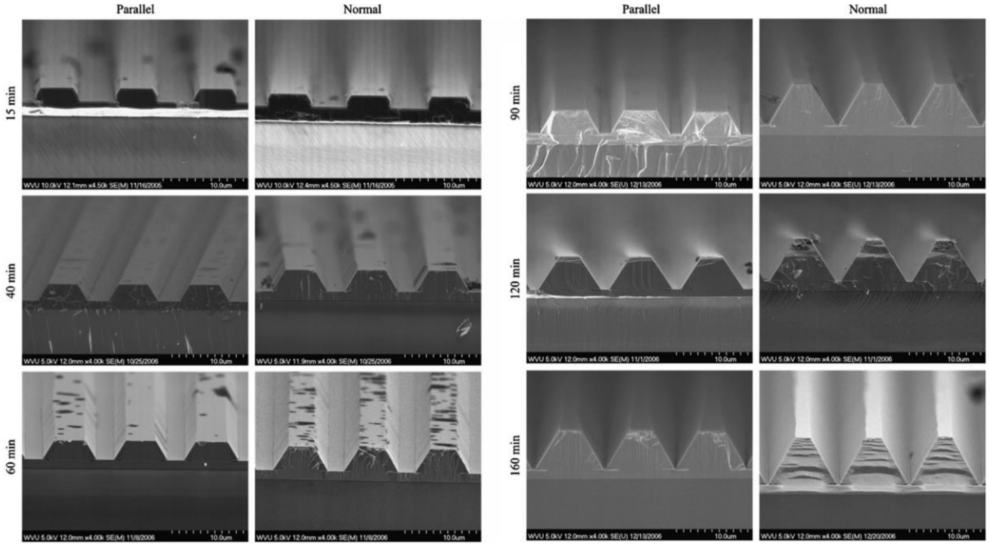
- Combination of lithography and MOVPE growth
  - Dielectric mask deposited and etched to expose areas for selective growth
  - Allows for spatially controlled growth of epitaxial layer
  - Growth rate depends primarily on:
    - Temperature
    - Pressure
    - Molar fraction of reactive species





Growth Parameters

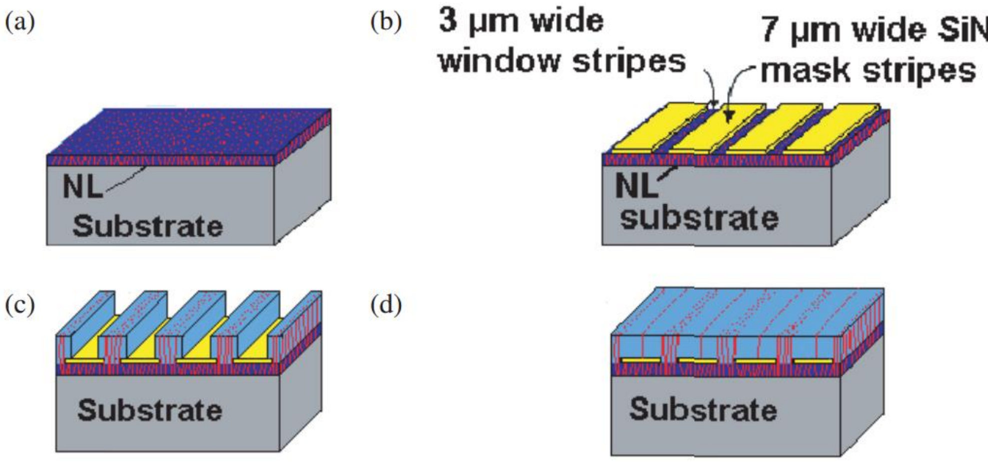
- Various growth parameters effect the morphology of GaN SAG
  - Temperature
    - Low growth temperatures result in poor surface morphology
    - Higher temperatures lead to formation of favorable crystal orientation
  - 3-5 ratios
    - Depending on crystal orientation, low 3/5 ratio is the most stable
    - 3/5 ratio increases with lateral growth extending over mask
  - Normal orientation experienced enhanced growth rate due to increased diffusing to the growth site



L.E Rodak et al. 2007

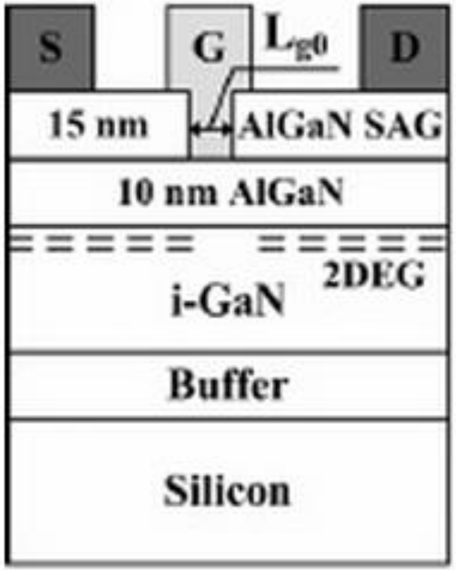
Epitaxial Lateral Overgrowth(ELO)

- Dependent process on SAG, reduces dislocation density
- Implemented only using vapor phase epitaxy systems
  - a) Thin layer formed
  - b) Mask deposited into wide mask strips
  - c) SAG
  - d) Lateral growth
- Useful for achieving long lifetime GaN LEDs



GaN HEMTS

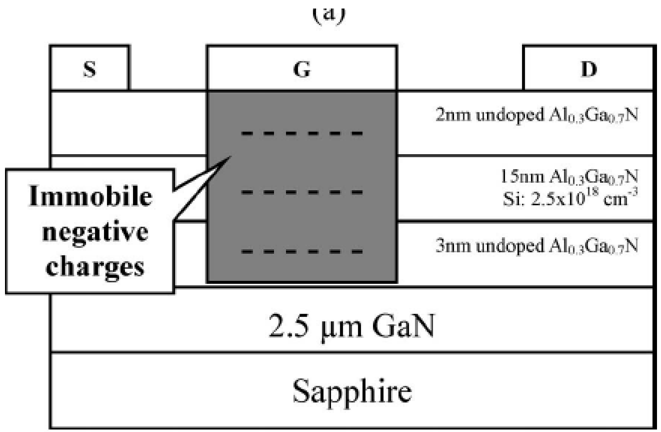
- D or E mode HEMTS
- Recessed-Gate Structure
  - Shift the gate threshold voltage toward positive voltage
    - Device is normally on
  - Small on-resistance expected by the reduction of the 2DEG
  - Gate typically etched by electron cyclotron resonance reactive ion beam etching(ECR-RIBE)
  - Plasma treatment unavoidably introduces damage to the active region of the device
    - Reduces reliability and stability of the device



SAG-HFET

Fluoride-Based Plasma Treatment

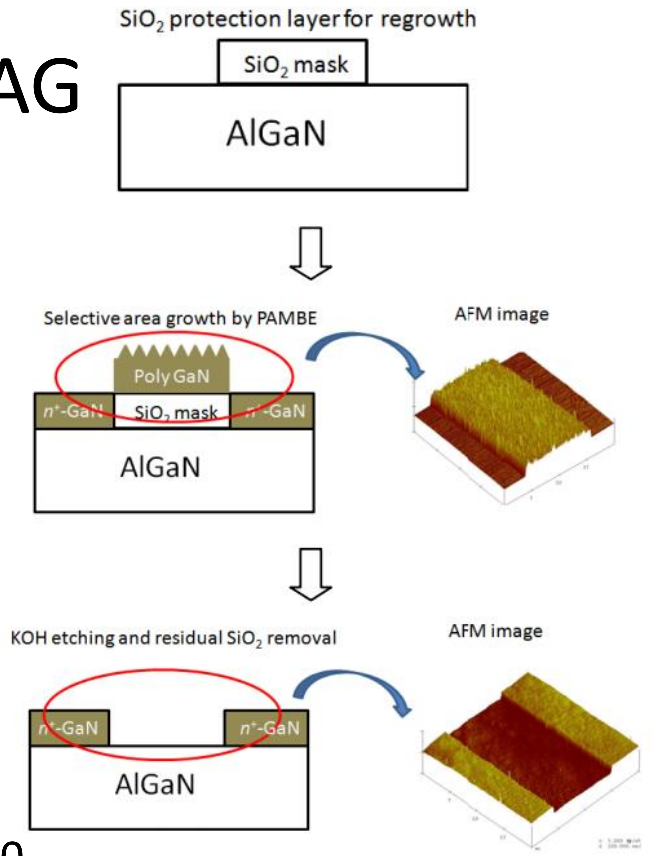
- Similar to Recessed gate structure
  - goal is to shift the threshold voltage to change device to normally off
- No change in physical thickness of active region
  - Modulation of energy band by Fluoride ions implanted in the AlGaN heterostructure during plasma treatment
- Plasma Induced damages



Improvements in HEMTS using SAG

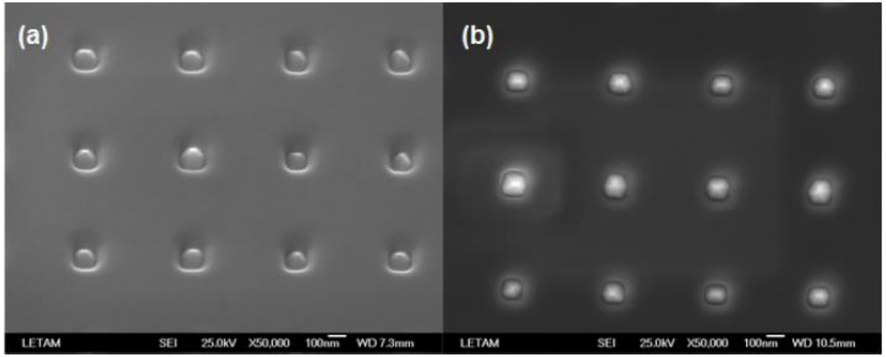
- Significant improvements in current density and on-state resistance were observed
  - Favorable characteristics for HEMTS with high current density and low on-state resistance
- Suppresses drain leakage current and improves breakdown behavior
- Etched using Inductively Coupled Plasma Reactive Ion Etcher
- Ti/Al/Ti/Au then deposited on doped GaN Source Drain

- HEMT device with SAG resulted in a higher maximum current, due to better ohmic contacts



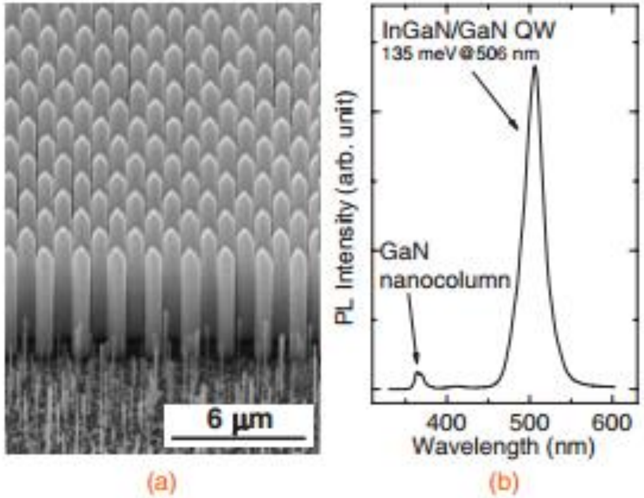
Lian Pang .et al, 2010

Optical Nanostructures



- High material quality is needed
  - Very strong internal polarization fields
  - Quantum-Confined Stark Effect
    - Very thin layers of 3-5 materials change the optical absorption spectrum due to quantum confinement of carriers
  - Decreased quantum efficiency
- Nanodots/nanocolumns grown by SAG
  - Growth has high selectivity
  - Smooth morphology and homogenous
  - Quantum efficiency increased

H. Sekiguchi et al, 2008



Conclusion

- SAG is only one improvement in GaN Devices
  - Promising technique for nanowires/nanodots
  - Does not completely eliminate defects in the epilayer
  - ammono-thermal GaN substrate has dislocation densities around 10^4cm-2

Questions?