Achieving sub-nm precision in plasma etch end-pointing by reflectance-based in-situ metrology

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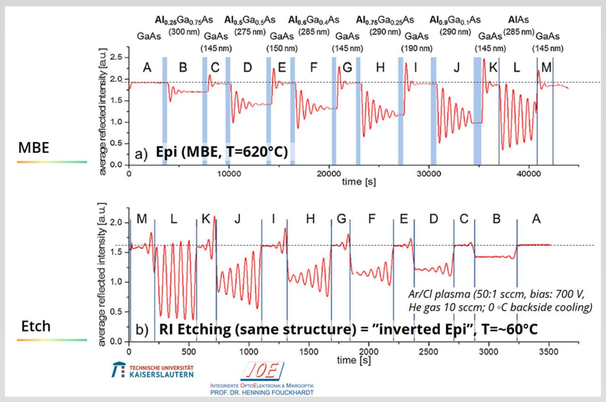
Motivation: Analogy of deposition and etch monitoring



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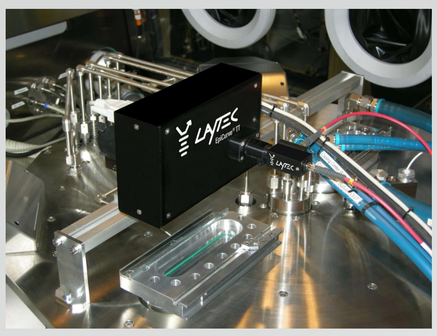
- Interpreting etching as "inverted epitaxy"
- Applying identical methods for in-situ monitoring
  - Model-based analysis
  - Highly precise n,k data
  - Choice of suitable wavelength for a given material system

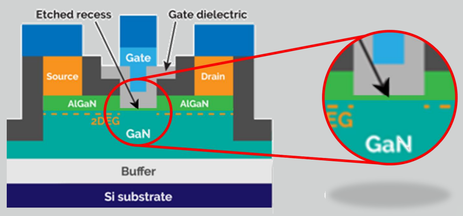


LayTec in-situ metrology applied for monitoring MOCVD epitaxial growth processes

LayTec in-situ metrology applied for monitoring atomic layer etching processes

LayTec in-situ metrology for GaN/Si device

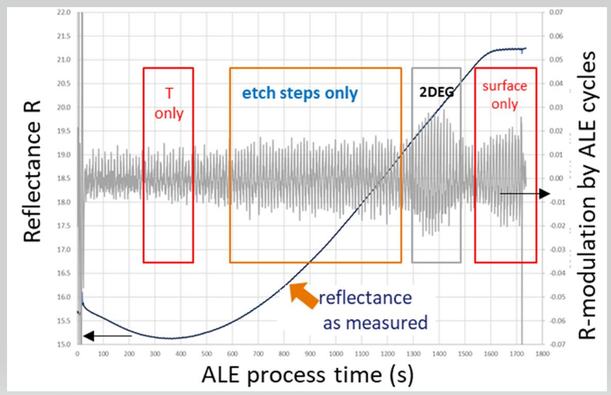
- EpiCurveTT for AIXTRON's Planetary™ MOCVD reactors
  - Control of full HEMT device stack epitaxy (wafer temperature, strain-engineering, layer thicknesses, …)
- LayTec EPD for OIPT's plasma etching tools
  - Control of Atomic Layer Etching (ALE) of recess and p-GaN structures within HEMT's active region
- For normally-off power transistors, MISHEMT structure would offer significant performance advantages
  - Oxford Instruments' ALE processes allow for highly precise etching
  - Automated LayTec in-situ EndPoint Detection (EPD) fully integrated into the production tools.
  - Thickness control of AlGaN and p-GaN layers with absolute accuracy better 1nm.
  - Enabling comprehensive statistics process control (SPC) for maximum yield in manufacturing.



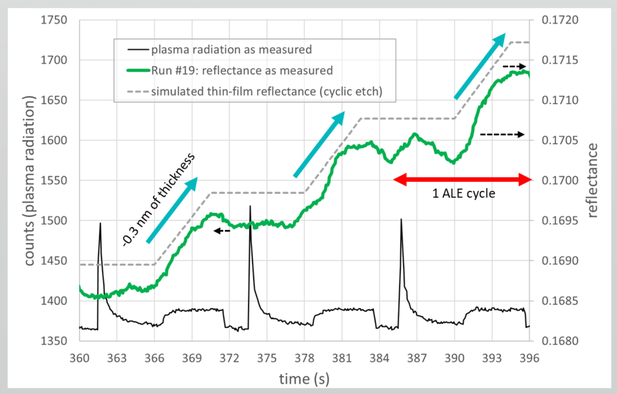
Active region
~2…100nm GaN cap or p-GaN
~10…30nm AlGaN
~1…2nm AlN interlayer
~3-4 µm GaN epitaxial
GaN buffer GaN/AlGaN thin interlayers and/or SL for strain-engineering and defect reduction
~600µm Silicon substrate

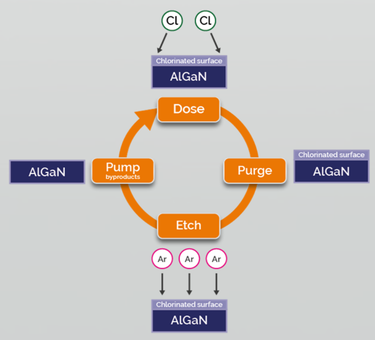
Typical (simplified) GaN/Si HEMT layer structure

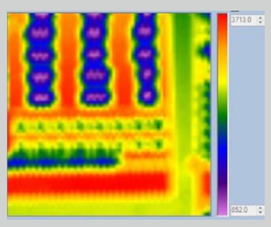
In-situ metrology data for GaN/Si device I

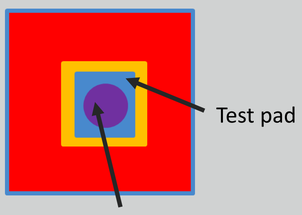


- ±0.002 absolute accuracy in reflectance
- GaN and AlGaN optical properties change with layer properties (quantum size effects, 2DEG changes of GaN band gap, …)
- UV reflectance resolves 'digitized' AlGaN





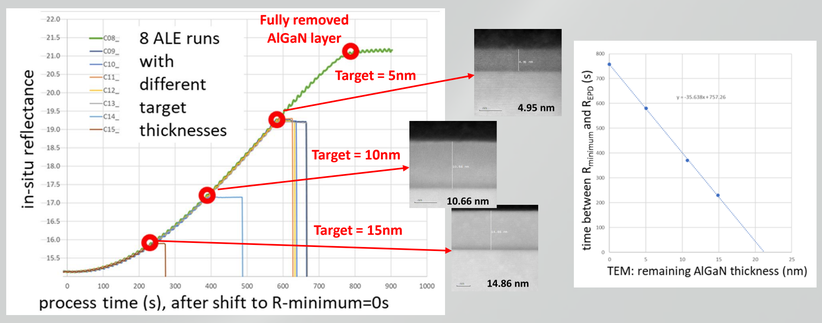




- Measurement on 0.25mm² test pad with reflectance-based pad recognition

In-situ metrology data for GaN/Si device II

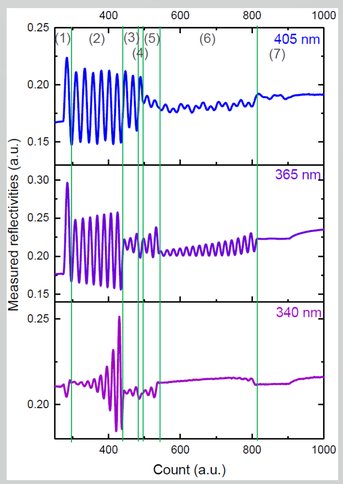
- AlGaN target thickness of 5 nm, 10 nm and 15 nm verified by TEM



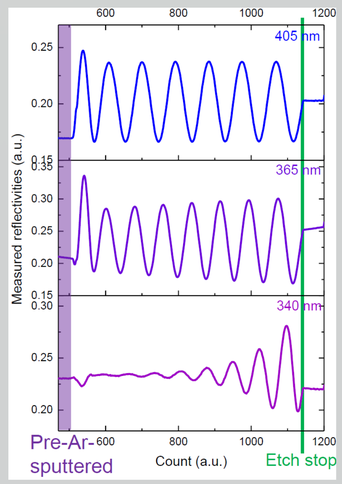
- Perfect match between TEM-deduced thickness and target AlGaN thickness

Application to GaN laser structures

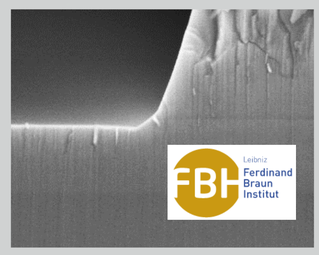
Etch through whole structure:



Etch stop at end-point within layer:



- In-situ Reflectance: 340/405/365 nm
- FPOs: shrinking layer thickness during etching



To be submitted, M. Binetti, C. Lörchner-Gerdaus, R.-S. Unger, S. Einfeldt, J.-H. Kang, O. Krüger, V. Blank, 2022

Summary

- Similar to deposition processes, also etching processes can be monitored by in-situ reflectance with sub-nm-accuracy
- Here, modeled-based algorithms, highly precise optical dispersion data as well as choice of the most suitable wavelengths allow for unprecedented accuracy in determination of in-layer etch depth
- Full integration of LayTec's EPD in-situ metrology allows for fully exploiting the capability of Oxford Instruments' ALE chamber
- Novel in-situ metrology for ALE may enable industrial roll-out of gate recessed normally-off MISHEMT as an alternative to pGaN HEMT

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