Real-Time Advanced Process Control for GaN MOCVD

Rubloff Research Group Accomplishments

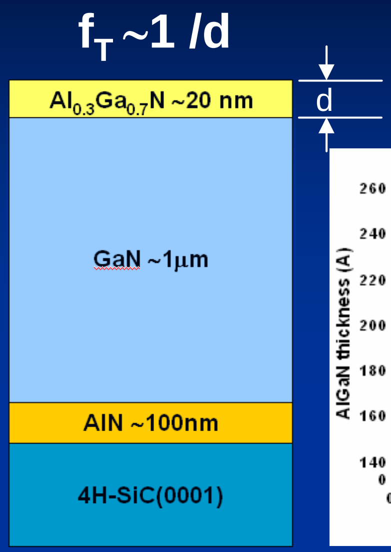
Real-Time APC for GaN MOCVD Processing

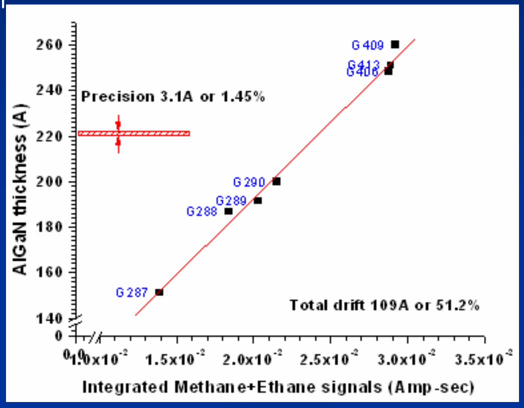
Accomplishment

- Mass spectrometric sampling of reaction products provides real-time measurement of layer growth rates and thickness
- Real-time end point control demonstrated at 1-2% precision for critical 20nm AlGaN cap layer
- Sensing also enables prediction of crystal quality

Significance

- GaN HEMT technology requires precise control of AlGaN thickness for device speed and manufacturability
- Advanced process control (APC) now essential in semiconductor manufacturing
- Mass spectrometry sensing platform supports real-time APC for metrology, material quality, and fault detection





Researchers involved

- Soon Cho, Gary W. Rubloff
- Rinku Parikh, Ray A. Adomaitis
- Collaborations with Northrop Grumman group: Deborah Partlow, Michael Aumer, Darren Thomson

Support

- Northrop Grumman

Real-Time APC for GaN MOCVD Processing

Publications

“In-situ chemical sensing in AlGaN/GaN high electron mobility transistor metalorganic chemical vapor deposition process for real-time prediction of product crystal quality and advanced process control”, Soon Cho, Gary W. Rubloff, Michael E. Aumer, Darren B. Thomson, Deborah P. Partlow, Rinku Parikh, and Raymond A. Adomaitis, J. Vac. Sci. Technol. B 23 (4), 1386-1397 (Jul/Aug 2005).

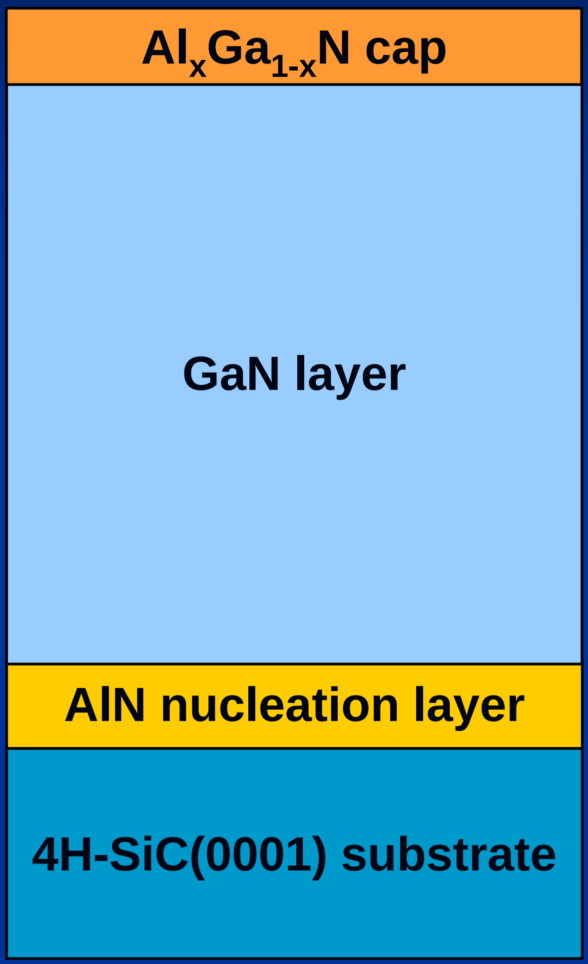
“In-situ chemical sensing in AlGaN/GaN metal organic chemical vapor deposition process for precision film thickness metrology and real-time advanced process control”, S. Cho, D. S. Janiak, G. W. Rubloff, M. E. Aumer, D. B. Thomson, and D. P. Partlow, J. Vac. Sci. Technol. B 23 (5), 2007-2013 (Sep/Oct 2005).

“Real-time material quality prediction, fault detection and contamination control in AlGaN/GaN high electron mobility transistor metalorganic chemical vapor deposition process using in-situ chemical sensing”, Soon Cho, Gary W. Rubloff, Michael E. Aumer, Darren B. Thomson, and Deborah P. Partlow, J. Vac. Sci. Technol. B 23 (5), 1849-1855 (Sept/Oct 2005).

Presentations

“Real-time In-situ Chemical Sensing in GaN MOCVD for Advanced Process Control”, S. Cho, G. W. Rubloff, M. E. Aumer, D. B. Thomson, and D. P. Partlow, AVS 50th Natl. Symp., Baltimore, MD, Nov. 2-7, 2003

GaN Heterostructure Design



Composition (~30 to 35% AlN)
- High: breakdown suffers
- Low: 2DEG diminished

Thickness (~20 to 25 nm)
- Thick: pinch-off voltage increases
- Thin: 2DEG diminished

Cap layer thickness is directly related to transconductance and the frequency of unit current gain

$$f_T \propto g_m \propto \frac{1}{d}$$

Crystal Quality
Material Quality ($n_{bkg} < 10^{14}$ cm^{-3}, even lower desired)
Thickness (~1 um thick)

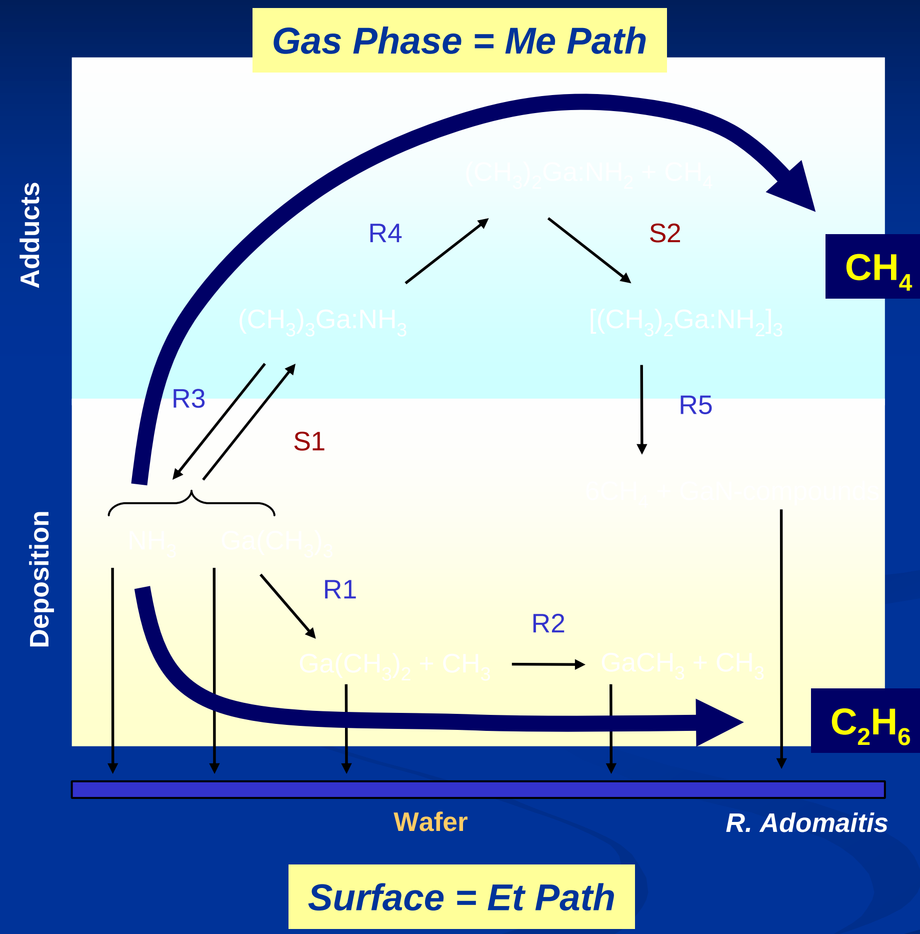
Abrupt, high quality interfaces required for all layers

Crystal Quality
Thickness (~100 nm desired)
- Thin: GaN crystal quality suffers
- Thick: GaN cracks

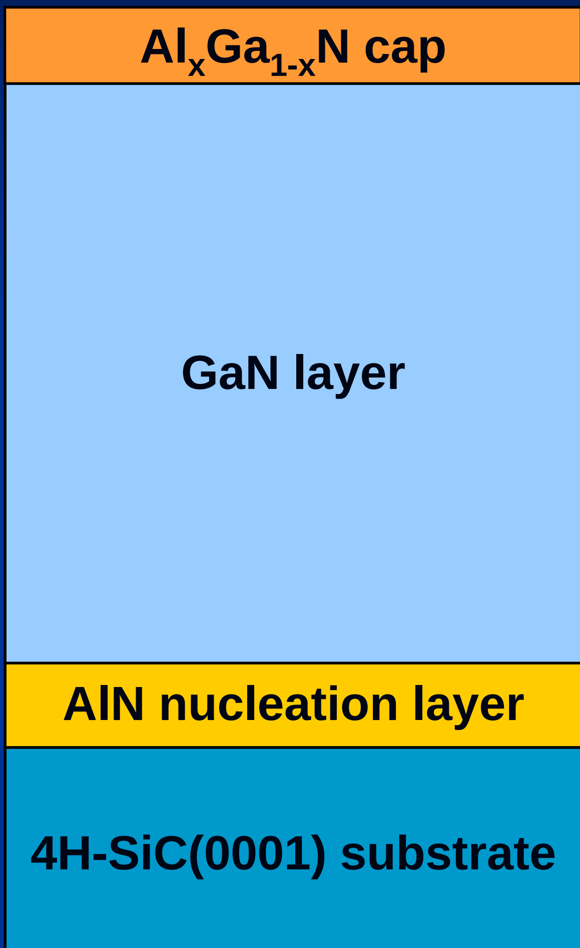
Desire pitted surface for stress relief in GaN layer

GaN MOCVD Chemistry

- Chemistry is complex – adducts, gas phase and surface reactions
- Overall pathways distinguishable by reaction product distributions
- Real-time mass spectrometry provides quantitative measures of adduct vs. surface pathways
- Benefits obtained from new methods for real-time APC without complete understanding of reaction chemistry



APC Implementation

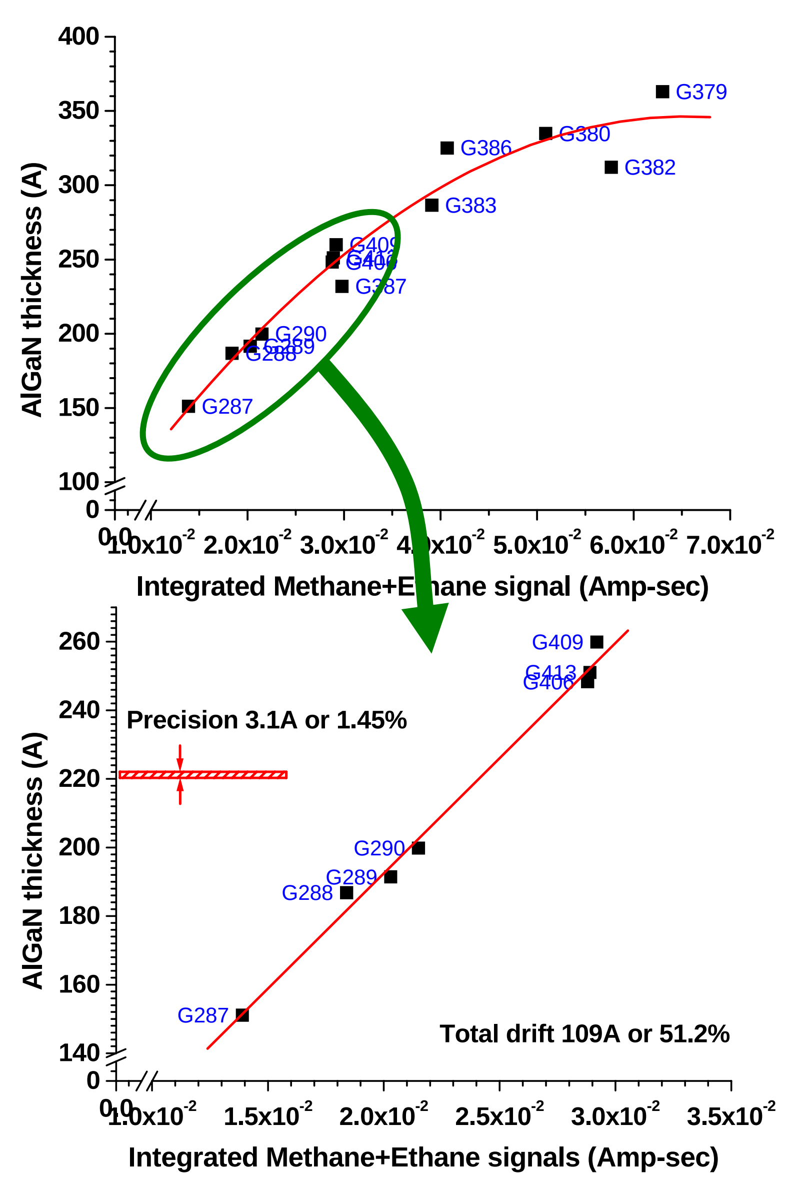


Metric	*Real-time in-situ measurement*	*Post-process characterization*
Film Thickness	**Time-integration of selected byproduct generation signals (e.g. methane, ethane)**	XRR (AlGaN), PL (GaN), SEM (AlN)
Crystal Quality	**Ratio of selected byproduct signals (e.g. methane/ethane)**	XRD, PL
Impurities (C & O)	**Impurities in gas phase**	PL, Sheet Resistance, SIMS
Composition	**Upstream acoustic sensing for TMA & TMG**	PL

APC:
Early identification of process excursions and equipment faults

Real-Time AlGaN Thickness Metrology

- **In-situ mass spectrometry provides real-time thickness metrology**
  - Integrated methane (CH_4) and ethane (C_2H_6) product signals quantitatively reflect deposited AlGaN
  - Actual (post-process) thickness measurements determined by mass spec to 1-2% precision
- **Implemented and applied routinely in Northrop Grumman's GaN technology development**
  - Real-time mass spectrometry used for process end point control of AlGaN cap layer thickness
  - Prototype for advanced process control application in GaN HEMT manufacturing



Real-Time GaN Quality Control

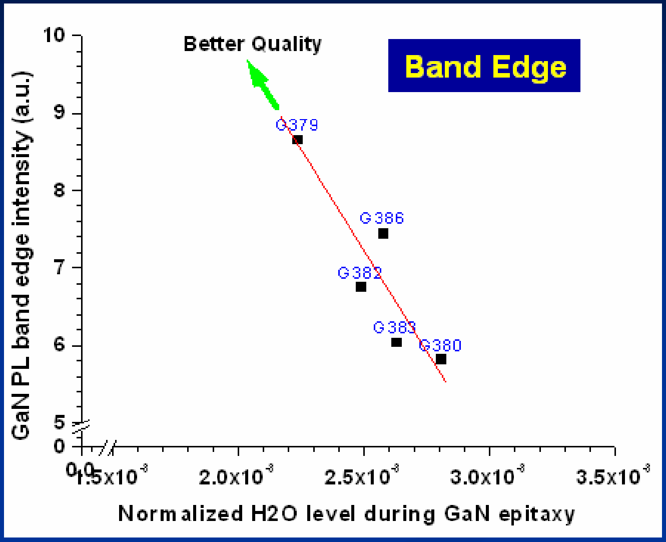
In-situ mass spectrometry indicates GaN material quality in real time

Electronic quality

- Determined post-process by photoluminescence spectroscopy
- Correlated with impurity levels in gas phase measured by mass spec

Crystal quality

- Determined post-process by x-ray diffraction
- Indicated by mass spec methane/ethane ratio



Photoluminescence