Real-Time Advanced Process Control for GaN MOCVD

Rubloff Research Group Accomplishments
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
Publications


Presentations

Rubloff: Real-time advanced process control for GaN MOCVD

GaN Heterostructure Design

Crystal Quality

Material Quality ($n_{bkg} < 10^{14}$ cm$^{-3}$, even lower desired)

Thickness (~1 um thick)

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:

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

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

Al$_x$Ga$_{1-x}$N cap

GaN layer

AlN nucleation layer

4H-SiC(0001) substrate
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

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

**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\(_2\)H\(_6\)) 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
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