EAG has a broad range of analytical services developed exclusively for LED characterization. Our analytical staff, in combination with our specialized instrumentation are ready to help with your research & development, process control, failure analysis and construction analysis needs.

Construction Analysis — Package Level
Identification and measurement of the materials, structure, composition and dopant profiles that comprise an LED.

**ENCAPSULANT**
Polymer materials can be evaluated and identified using FTIR (Fourier Transform Infrared) spectroscopy. In this case the material is a modified epoxy.

**PACKAGE**
The structural integrity of LED packages and wire connections can be evaluated non-destructively using RTX (Real Time X-ray) analysis.

**STRUCTURE**
Materials and layout of the package and support structures can be examined in cross-section using SEM (Scanning Electron Microscopy) imaging and EDS (Energy Dispersive X-ray Spectroscopy) analysis.

**PHOSPHORS**
Materials identification in and around the LED chip can include evaluation of the phosphors. In this case STEM (Scanning Transmission Electron Microscopy)/EDS identified the phosphor as Gd doped YAG. Lattice imaging and d-space measurements confirm YAG.

**Construction Analysis — Die Level**

**CONTACTS**
n and p contact evaluation by Auger (Auger Electron Spectroscopy) depth profiling

**STEM/EDS Analysis (at%) - Semi-quantitative**

<table>
<thead>
<tr>
<th>Location</th>
<th>Al</th>
<th>In</th>
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<tbody>
<tr>
<td>1 - GaN</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2 - AlGaN</td>
<td>9</td>
<td>-</td>
</tr>
<tr>
<td>3 - InGaN-QW</td>
<td>-</td>
<td>6</td>
</tr>
<tr>
<td>4 - GaN-QW</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>5 - superlattice InGaN/GaN</td>
<td>-</td>
<td>2</td>
</tr>
</tbody>
</table>

Composition of InGaN and GaN within the QW can be partially resolved by STEM/EDS. Composition within the superlattice layers cannot be resolved.

**DOPING PROFILE**
SIMS (Secondary Ion Mass Spectrometry) depth profile analysis for Mg and Si doping profiles in GaN / AlGaN / InGaN epi-layers.
Failure Analysis

PACKAGE AND WIRE INTEGRITY
RTX examination of LED can reveal open wires.

DECAP
LED packaging can be difficult to remove. EAG has developed methods to decapsulate while preserving electrical functionality.

DEFECT LOCALIZATION

HOT SPOTS
Examination by OBIRCH (Optical Beam Induced Resistance Change) can reveal defect sites.

FURTHER DEFECT INVESTIGATION
EAG can find and characterize many types of defects. These include:
- Discoloration - XPS investigation of surfaces, GC/MS study of trapped gases
- Metal migration - FIB cross-section and investigation by Auger or STEM/EDS
- Voids - FIB cross-section and investigation by SEM
- Particles - surface imaging or FIB cross-section and investigation depending on size and possible organic content
- Cracks - FIB cross-section and investigation by SEM
- Delaminations - FIB cross-section and investigation by SEM

FINDING DEFECTS
EBIC (Electron Beam Induced Current) imaging is an excellent complement to standard SEM imaging. EBIC can find defects that cannot be seen using standard SEM. Here EBIC reveals a ‘bright spot’ defect, not seen in the standard SEM image.

DEFECT ANALYSIS
A closer view of the defect shows large and small bright spots in the EBIC image. A cross section of the defect was prepared using FIB. A TEM image of the defect cross-section is shown aligned on the same scale as the EBIC image. A pit defect is present under the small bright spot.

PIT DEFECT
A TEM view of the pit defect shown above reveals v-shaped defects in the quantum well leading to pit formation in p-GaN that extended through the ITO to the surface.

NANOPipe DEFECT
Examination of the full TEM cross-section also reveals a nanopipe defect underneath the quantum well disruption shown above by EBIC and TEM.

SEM examination of the defect site identified by OBIRCH shows a large void has formed under a blister. The sample was then prepared and imaged using Dual Beam FIB (Focused Ion Beam).

EBIC (Electron Beam Induced Current) imaging is an excellent complement to standard SEM imaging. EBIC can find defects that cannot be seen using standard SEM. Here EBIC reveals a ‘bright spot’ defect, not seen in the standard SEM image.
**GaN Epi-layer Structure**

**Dislocation Density**
Dislocation density at various stages of growth can be characterized by TEM. Plan view samples were prepared from this cross-section sample at locations 1, 2 and 3 as indicated.

Plan view samples show dislocations (1) close to the QW layers, (2) in the middle of the GaN growth and (3) next to the sapphire substrate.

**RAPID DEFECT TYPING**
The character of dislocations can be determined using STEM imaging. By utilizing specific sample tilts, threading dislocations can be identified as having screw, edge, or mixed character.

**Superlattice and Quantum Well**
Aberration Corrected STEM can provide high resolution images and composition measurements.

**Doping Profiles**
P type and n type dopants can be profiled by SIMS to measure concentration and distribution relative to the epi-layer structure.

**Contaminant Profiles**
Contaminants can also be profiled by SIMS. These profiles can reveal growth issues layer by layer. Good detection limits for the ‘atmospheric elements’ (H, C, O) can be achieved with dedicated instrumentation.

Accurate quantification can be achieved using standards and controlled analytical procedures.

**Detection Limits in GaN**
Very low detection limits for SIMS can be achieved using optimized analytical conditions and by using dedicated instrumentation.

**Dopant Profile in QW**
High depth resolution SIMS can reveal the doping profile within the quantum well structure. The best quantification is achieved using PCOR-SIMS™, a protocol that provides accurate quantification in all matrix layers.
DOPING PROFILES
SIMS depth profiles can be used to monitor reactor performance over time. Monitoring profile features such as concentrations and thicknesses can be a powerful method for process control.

SOFTWARE
EAG SIMSview™ software for SIMS is routinely used to calculate dopant levels and layer thickness. We can customize and automate calculations to your specifications. Data is rapidly evaluated and can be compared to previously established benchmarks.

EAG EMview™ software allows you to make measurements on SEM and TEM images. Brightness, contrast and gamma can be adjusted. Images can be rotated and annotated.

ADDITIONAL SERVICES
AlGaN - InGaN Composition: Improved accuracy by RBS.
LM-80: Many environments for accelerated aging tests.
Sapphire, SiC and other substrates: Surface contamination. Bulk contamination.

EAG — Your Source for Analysis of Advanced LEDs
WORLD LEADING EXPERTISE IN MATERIALS ANALYSIS
UNMATCHED RANGE OF SERVICES FOR LEDS:
A POWERFUL COMBINATION FOR ALL YOUR ANALYTICAL NEEDS

All data obtained from commercially purchased LEDs.

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