Leading the GaN Revolution

Assessing Early Life Failures of High Voltage GaN

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As HV GaN Devices Transition from Technology to Product

Rel. Engineers Must Transition from Intrinsic to Extrinsic Reliability

Extrinsic Reliability
Early Life Failure
Infant Mortality

Failure Rate Decreases with time

Intrinsic Reliability
Wear Out Failure

Failure Rate Increases with Time

Observed Failure Rate
Constant Failure

Failure Rate
Time

Infant Mortality
Wear Out
Intrinsic vs. Extrinsic Reliability (both important)

**Extrinsic Reliability**
- Failure prior to designed lifetime of device
- Can be strongly influenced by quality of manufacturing, fab process, defectivity
- Requires relatively large numbers of devices and moderate stress during testing.
- Quality / Reliability Metric
- FITs or PPM/Year

**Intrinsic Reliability**
- Designed lifetime of the device
- Theoretical lifetime
- Data is generated with relatively small numbers of devices failing under high stress conditions
- Model driven
- Physics of Failure
- Lifetime (100 ppm failure rate)
Process Defects are a Major Cause for Premature Failure
Present in All Semiconductor Processes Including Si, GaN and SiC

• Three types of defects
  • Killer defects: impacts test yields
  • Nuisance defects: “show up” during inspection but do not kill the device
  • Latent defects: escape test but impact reliability

• Resist residue, stringers, corrosion spots, delamination, particles, particles, particles!

“For 100 killer defects that cause yield loss, there are approximately 1-2 latent defects that will result in a reliability failure.”

JESD47 (Commercial) and/or AEC-Q101 (auto)

*Enough to address risk of extrinsic failures?*

- Typical sample sizes for qualification 231 parts divided equally between three lots (3 X 77)
- Commercial qualification allows failures, auto qual does not
- Two types of failures during qualification
  - Parametric Failure (leakage, $R_{DS(on)}$, $V_{th}$, etc.)
    - Failure of process control, poor uniformity, test escapes
    - Can range from a single failure to the entire sample
  - Electrical Over Stress or EOS (catastrophic failure)
    - Defect driven, low frequency, shifts from lot to lot
- JESD47 and/or Q101 can do a good job of catching parametric failures (especially Q101), but are limited in what they can do for EOS failures
JESD47 and AEC-Q101 use Limited Sample Sizes and Limited Ability to Screen for Defects.

<table>
<thead>
<tr>
<th>Sample Size</th>
<th># Failures</th>
<th>Defectives Parts per Million (DPPM) @ 60%</th>
<th>Quality Level Degradation</th>
</tr>
</thead>
<tbody>
<tr>
<td>231</td>
<td>0</td>
<td>3967</td>
<td>1X</td>
</tr>
<tr>
<td>231</td>
<td>1</td>
<td>8755</td>
<td>2.2X</td>
</tr>
<tr>
<td>231</td>
<td>2</td>
<td>13,440</td>
<td>3.4X</td>
</tr>
</tbody>
</table>

• DPPM = $10^6 \times \text{ChiSquare}_{(C_l, d_F)} / 2 \times \text{Sample Size}$

• In fact, JESD47 requires **Early Life Failure Testing** in addition to recognition of the limitation of the “usual” three lot test

• WBG industry has not adopted this methodology despite it being a JEDEC requirement
Early Life Failure Testing Evaluates “Health” of the Manufacturing Process and its Ability to Produce Reliable Devices

• Test large numbers of devices
  • Multiple devices
  • Multiple lots
  • Sample steady state production over time

• Utilize temperature and/or voltage acceleration
  • Transphorm focus is on voltage acceleration at typical use temperature

• Test for “reasonable” number of accelerated hours
  • Based on expected mission profile for device
HVOS Test is “Worse Case” Compared with Switching Reliability and is a Relevant ELF Test Condition

- HVOS results in shorter lifetimes than switched, and is the more conservative choice
- From a “practical” standpoint off state testing much easier to implement
- Enables simple large-scale testing from production line
- “Matches up” with conventional silicon testing
Early Life Failure Testing Demonstrates Transphorm’s Outstanding Process Capability

*Results on 50 mΩ Device*

\[
\begin{align*}
F(\text{ELF}) &= \text{Fraction Failing from time } = 0 \text{ to time } = t_{\text{ELF}} \\
\text{CDF} &= \chi^2_{c,d} / 2N \quad \text{Statistical uncertainty} \\
\eta &= t_U / ((-\ln[1-\text{CDF}])^{1/\beta}) \quad \text{Weibull Characteristic Time} \\
F(\text{ELF}) \text{ in ppm} &= 10^6 \times (1-\exp(-(t_{\text{ELF}}/\eta)^\beta))
\end{align*}
\]

<table>
<thead>
<tr>
<th>Voltage</th>
<th>F (1st Year) PPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>800 V</td>
</tr>
<tr>
<td>Temperature</td>
<td>85°C</td>
</tr>
<tr>
<td>Device #</td>
<td>2200</td>
</tr>
<tr>
<td>Test Time (t_A)</td>
<td>500 hours</td>
</tr>
<tr>
<td>Device Hours</td>
<td>1.1 million</td>
</tr>
<tr>
<td>Failures</td>
<td>0</td>
</tr>
<tr>
<td>Degrees of Freedom</td>
<td>2f + 2</td>
</tr>
<tr>
<td>Confidence Interval (%)</td>
<td>60</td>
</tr>
</tbody>
</table>

Samples taken from ~30 different lots across months of production to sample consistency of the process.

“Early Life Failure Rate Calculation Procedure for Semiconductor Components” JESD 74A
Offering Best-in-Class Field Reliability Across Power Levels

Only WBG Supplier to Publish ELF Results

Field return rate definition:
We “discount” the number of device hours by ½ (so that we do not take “credit” for parts that have not actually shipped to users yet)

<table>
<thead>
<tr>
<th>Field Data</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Installed Power (devices)</td>
<td>&gt; 250 MW</td>
</tr>
<tr>
<td>Device Hours</td>
<td>&gt; 12 billion (6e⁹)</td>
</tr>
<tr>
<td>Field Returns</td>
<td>2</td>
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</table>

<table>
<thead>
<tr>
<th>Field Failure Rate</th>
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<tbody>
<tr>
<td>dppm</td>
<td>&lt; 2.2</td>
</tr>
<tr>
<td>FIT*</td>
<td>&lt; 1.0</td>
</tr>
</tbody>
</table>

*Failure in time: failures per billion hours
Summary

- Extrinsic reliability has been part of silicon product development for decades, and should be adopted by WBG suppliers
- Process defects are a common cause for premature failures of devices in the field and are referred to as “latent” defects
- Latent defects potentially exist in all semiconductor processes, including Silicon, SiC and GaN
- Early Life Failure Testing at moderate voltages can be an effective tool for demonstrating the reliability of WBG devices in the same way that it is used for Silicon devices
Final Word

“WBG suppliers who claim quality and reliability equivalent or superior to silicon who are not publishing ELF data are doing their customers a disservice.”