Systematic Approach to GaN Power IC Reliability

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World’s First GaNFast™ Power ICs

Fastest, most efficient GaN Power FETs
- >20x faster than silicon
- >5x faster than cascoded GaN
- Proprietary design
- Gate is fragile and sensitive to noise

First & Fastest Integrated GaN Gate Drivers
- >3x faster than any other gate driver
- Proprietary design
- 30+ patents granted
- Fast, protected gate, no need for negative drive

World’s First Power ICs

Up to 40MHz switching, 5x higher density & 20% lower system cost

Simple, fast and reliable
Easy to use and package
Reliability corners defined using reliability physics based lifetime models

Robust PDK = successful integration

Increasing Integration

Design corners

Process corners

Reliability corners

Enabling Advanced Technologies
PDK Analysis

<table>
<thead>
<tr>
<th>Device element</th>
<th>Reliability model requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacitor</td>
<td>Guaranteed by proprietary design, verified by characterization – reliability models not required</td>
</tr>
<tr>
<td>Resistor</td>
<td>Mature process and Foundry qualified</td>
</tr>
<tr>
<td>Electro-migration</td>
<td>Reliability models required</td>
</tr>
<tr>
<td>LV GaNFET</td>
<td>Reliability models need to replicate stresses seen in real application</td>
</tr>
<tr>
<td>HV GaNFET</td>
<td></td>
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</table>
Typical Application: Mobile Chargers

MacBook <100 kHz
<6.5 W/in³, 92%

• ACF (ZVS) Topology
• 300kHz – 1 MHz
• 120 V – 240 V AC

Navitas ~300 kHz
Power density = 39 W/in³

65W USB-PD
Application Profile for ACF Charger

Full Power ($T_{DUT} = 100^\circ C$)

Light Load ($T_{DUT} = 50^\circ C$)

Burst Mode ($T_{DUT} = 25^\circ C$) (No Load)
Full Power Stress Breakdown

Stress seen by HV GaNFET:
- High Temperature
- High Frequency
- High Voltage (Switching)
- High Current

Stress seen on LV GaNFET:
- High Temperature
- High Frequency
Burst Mode Stress Breakdown

**Burst Mode (T\text{\textsubscript{DUT}} = 25°C) (No Load)**

- Voltage
- Current

500 us/div

**Stress seen on HV GaNFET:**
- Low Temperature
- Low Frequency (~static)
- High Voltage (Blocking)
- Low/No Current

**Stress seen on LV GaNFET:**
- Low Temperature
- Low Frequency (~static)
## Reliability Stresses to Model

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<thead>
<tr>
<th>Relevant stress to model</th>
<th>Test method used to characterize</th>
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<td>High Temperature Reverse Bias</td>
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**HTRB Acceleration & Lifetime Models**

**Voltage/ Temperature** | 100°C | 125°C | 150°C
--- | --- | --- | ---
650V | ✓ |
700V | ✓ ✓ ✓ |
750V | ✓ |

**Time to Fail**

\[
\text{Time to Fail} \propto \frac{1}{(\text{Voltage})^{n=18.6}}
\]

\[
\text{Time to Fail} \propto e^{(\frac{E_a=0.91eV}{kT})}
\]

**Projected Application Condition Using Model**

**Lifetime in no load condition is >1E8 years, significant built-in margin**

\[
\text{Lifetime} = A \times (V^{-n}) \times \left(e^{\frac{E_A}{kT}}\right)
\]
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Gate Reliability Acceleration Models

Static and switching stresses have same acceleration factors.
Frequency Acceleration

Frequency ↓ / Duty cycle ↑ / Pulse width ↑ ⇔ Closer to static stress

Typical applications for GaN devices operate at >100KHz
Gate Reliability Lifetime Estimation

Integrated regulator guarantees operation with 10+ years of estimate life
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Mission Profile Driven HTOL (ZVS)

Full Power ($T_{DUT} = 100^\circ C$)

- Current
- Voltage

1 us/div

ZVS test bench replicates stresses seen in ACF application
Failure Mode Matters

650V, 150°C HTOL

Group 1: In-situ system power loss monitoring

Group 2: Measure parameters at interim intervals

System degradation

Device degradation

Normalized Power loss per cell

Stress Time

Parametric failure probability

Stress Time

Navitas Proprietary & Confidential
Failure Mode Matters

650V, 150°C HTOL

System degradation

Device degradation

Parametric failure = minor efficiency degradation

Lifetime estimation using parametric failure → conservative approach

Group 1: In-situ system power loss monitoring

Group 2: Measure parameters at interim intervals
**HTOL-based Lifetime Model**

<table>
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<tr>
<th>Voltage/Temperature</th>
<th>100°C</th>
<th>125°C</th>
<th>150°C</th>
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</thead>
<tbody>
<tr>
<td>550V</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>575V</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>600V</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>625V</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>650V</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
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- **Voltage Acceleration**
  - T=150 °C, Voltage Acceleration
  - Time to Fail (hrs) $\propto \frac{1}{(Voltage)^{n=172}}$

- **Temperature Acceleration**
  - V= 650 V, Temperature Acceleration
  - Time to Fail (hrs) $\propto e^{\frac{Ea}{kT}}$

*Navitas Proprietary & Confidential*
Stress Profile in ACF

### Mode | Voltage | DUT $T_{case}$ | Typical time spent (1 charge/day) | Relevant reliability stress
---|---|---|---|---
Full Power | 460V | 100°C | 8 hours (33%) | HTOL
Light Load | 460V | 50°C | 4 hours (17%) | HTOL
No Load (burst) | 340V | 25°C | 12 hours (50%) | HTRB HTOL

Assuming worst case scenario at 240VAC

HTOL is more aggressive than HTRB
# Lifetime Estimation Methodology

## Mode Details

<table>
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<tr>
<th>Mode</th>
<th>Voltage</th>
<th>DUT $T_{\text{case}}$</th>
<th>Typical time spent (1 charge/day)</th>
<th>Relevant reliability stress</th>
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<td>8 hours (33%)</td>
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<td>340V</td>
<td>25°C</td>
<td>12 hours (50%)</td>
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### Temperature Acceleration Factor

\[
AF_{\text{temp}} = e^{\frac{E_a}{k_B(T_{\text{application}} - T_{\text{reliability}})}},
\]

where $E_a = 0.71\text{eV}$

### Voltage Acceleration Factor

\[
AF_{\text{voltage}} = \left(\frac{V_{\text{reliability}}}{V_{\text{application}}}\right)^n
\]

$n = 17.2$

### Total Acceleration Factor

- **Full power** $AF_{\text{Total}} = AF_{\text{temp}} \times AF_{\text{voltage}}$
- **Light load** $AF_{\text{Total}} = AF_{\text{temp}} \times AF_{\text{voltage}}$
- **No Load (burst)** $AF_{\text{Total}} = AF_{\text{temp}} \times AF_{\text{voltage}}$

### Weighted Average

Weighted average for each mode

\[
\text{Lifetime estimate in application} = AF_{\text{Total}} \times \text{Time to failure in reliability (TTF}_{\text{reliability}})
\]
Lifetime Estimation in Charger Application

Significant built-in reliability margin \(\rightarrow\) even at worst case conditions (exceeds 10+ year lifetime requirement)
Reliability → Qualification → Release

**Reliability models on IC building blocks**
- Robust design

**Mission profile driven reliability**
- Protected Customer

**Comprehensive reliability monitoring**

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**GaNFast™**

**POWER ICs**
- Quality
- Speed
- Efficiency

**Now in high volume production!**

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**Reliability Models and Results**

<table>
<thead>
<tr>
<th>Reference</th>
<th>Test Conditions</th>
<th>Duration</th>
<th>Lots</th>
<th>S.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>JESD22-A113 J-STD-020</td>
<td>Preconditioning (MEL1): Moisture Preconditioning + 3x reflow: HAST, UHAST, TC &amp; PC</td>
<td>N/A</td>
<td>3</td>
<td>308</td>
</tr>
<tr>
<td>JESD22-A104</td>
<td>Temperature Cycle: -65°C / 150°C</td>
<td>1,000cy</td>
<td>3</td>
<td>77</td>
</tr>
<tr>
<td>JESD22-A122</td>
<td>Power Cycle: Delta Tj = 100°C</td>
<td>10,000cy</td>
<td>3</td>
<td>77</td>
</tr>
<tr>
<td>JESD22-A110</td>
<td>Highly Accelerated Stress Test: 130°C / 85%RH / 100V Vgs</td>
<td>98hrs</td>
<td>3</td>
<td>77</td>
</tr>
<tr>
<td>JESD22-A108</td>
<td>High Temperature Reverse Bias: 150°C / 520V Vgs</td>
<td>1,000hrs</td>
<td>3</td>
<td>77</td>
</tr>
<tr>
<td>JESD22-A108</td>
<td>High Temperature Gate Bias: 150°C / 8V Vgs</td>
<td>1,000hrs</td>
<td>3</td>
<td>77</td>
</tr>
<tr>
<td>JESD22-A108</td>
<td>High Temperature Operating Life</td>
<td>1,000hrs</td>
<td>3</td>
<td>77</td>
</tr>
<tr>
<td>JESD22-A108</td>
<td>Early Life Failure Rate</td>
<td>24 hrs</td>
<td>3</td>
<td>1,000</td>
</tr>
<tr>
<td>JS-001-2014</td>
<td>Human Body Model ESD</td>
<td>N/A</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>JS-002-2014</td>
<td>Charged Device Model ESD</td>
<td>N/A</td>
<td>1</td>
<td>3</td>
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**Metric**

<table>
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<th>Result</th>
<th>Description</th>
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<tr>
<td>1.5 billion hours</td>
<td>Equivalent device hours tested*</td>
</tr>
<tr>
<td>0.6</td>
<td>FIT*</td>
</tr>
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*Statistics calculated from HTOL tests
GaNFast Chargers now in production

Fast
Up to 3x more power
Up to 3x faster charging

Mobile
Half the size & weight of traditional chargers

Universal
One charger for ALL your devices
One and Done!!
Let’s go GaNFast™