Development Strategies of eGaN HEMTs for Space Applications

BY

Jim Larrauri
Co-Founder & Chief Strategy Officer
CONTENTS

1. Introduction to Freebird Semiconductor
2. Development Strategies for eGaN Space Utilizations
   ▪ Core Development Controls
   ▪ Key Conformance Items
3. Discrete product definitions
4. How to Drive eGaN in Space Borne Applications?
   ▪ FBS-GAM Series (GaN Adaptor Modules)
   ▪ FBS-GAM Series Applications

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Introduction to Freebird Semiconductor
Freebird Semiconductor Corporation is a fabless manufacturing & design company dedicated to addressing High Reliability power management problems by using emerging semiconductor technologies.

We are focused on delivering Enhancement Mode Gallium Nitride Power Switching Transistors (eGaN HEMTs) and circuits with disruptive, (r)evolutionary advantages over silicon based solutions into the high reliability market.
Freebird Radiation Hardened Space Products

- FBG Ceramic Hermetic Discrete
- FDA Die Adaptor products
- GAM GaN Adaptor Modules with Dual Driver & Integrated output power HEMTs (Patented Designs)
Development Strategies of eGaN HEMTs for use in Space
Eliminate Variability in Space Level eGaN Designs

- Control Mask Set
- Control Process Run Card
- Control Bump Run Card
- Control Probing and Screen Programming
- Prevent unauthorized process modifications
- Wafer lot acceptance with radiation hardness assurance
- Continuous die supply Assurance

- Pre & Post Test
- Incorporate Industry Acceptable Test Methods
- Perform 100% Testing

Implementing Core Controls

- Hermetic Packaging (Cavity Devices)
- No Grounding of Packaging (Excellent Di-electric Properties)
- Creepage & Clearance to Rated Voltage
- Low Conduction Losses
- High Thermal Conductivity with near CTE to Silicon
- Low parasitic Inductance Connectivity
- Low DC resistance
- Fabricate & Source Domestically (USA)
Freebird Semiconductor High Reliability eGaN® Chip Die

• Sourced under a proprietary source control die agreement with “Efficient Power Conversion” (EPC), our fab source who manages wafer production- under this agreement Freebird Semiconductor Controls SCD Die:

✓ Mask Set
✓ Process Run Card
✓ Bump Run Card
✓ Probe and Screen Programming
✓ Modifications Require Approval
✓ Freebird also maintains a proprietary long-term-supply sourcing agreement with (EPC)
✓ Freebird processes all wafer/die lots are fully processed IAW our wafer lot acceptance RHA plans.
Semiconductor Ceramic Packaging

- Controlling advanced high reliability ceramic package developments are ideally achieved by domestically (USA) sourcing & fabricating - *Freebird’s proprietary package designs ARE!*

- **Aluminum-Nitride (AlN) material**, produced as **ceramic cavity-base and lid combinations** offer a **superior** package solution to traditional Alumina (Aluminum Oxide $\text{Al}_2\text{O}_3$) and can be integrated as a chip-scale interposer base design for BGA die adaption -

- **FREEBIRD has developed this packaging:**
  - Excellent Hermetic Sealing (Cavity Devices)
  - Non-metallic lids (Excellent Di-electric Properties)
  - Proper Creepage & Clearance to Rated Voltage
  - Low Conduction Losses
  - High Thermal Conductivity with near CTE to Silicon
  - Low parasitic Inductance Connectivity
  - Low DC resistance $<1\text{m}\Omega$ interface for BGA die interface adaptors
Basic Product Structure & Process Assembly

- **AlN cavity**
- **W/Ni/Cu/Au metallization**
- **High Lead solder paste**
- **High Lead PbSn (95/05) solder bars**
- **Freebird Rad Hard GaN on Si die**
- **AlN lid**
- **Lid seal rings** (AuSn 80/20)

**Processes:**
- Clean Packaging
- Solder deposition
- Die placement
- Solder Reflow
- Post reflow clean
- Lid seal

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### FREEBIRD SEMICONDUCTOR PROCESS SCREENING FLOW INCORPORATES ESTABLISHED SCREENING METHODOLOGIES

<table>
<thead>
<tr>
<th>Operation</th>
<th>Test</th>
<th>Base Standard</th>
<th>Test Methods</th>
<th>FBG SERIES Sample Size</th>
<th>FDA SERIES Sample Size</th>
<th>COMMENTS</th>
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Incorporate Space Level Conformance Qualification

- Reproducible Wafer Lot Acceptance Procedures
- Radiation Test With Qualified Personnel Versed in RHA With Technology Of DUT
- Single Event Test With Suitable ION Species
- Total Ionizing Dose Test To Suitable Levels
- Correlate ELDRs Performance Of Technology To TID Test Vehicles
- Validation of Neutron DD Conformance

Key Strategies

- Conformance Testing to Established Vehicles As Possible
- Qualification On All Die & Package Elements
- Incorporate Technology Specific Test Methodologies
- Embrace Aerospace Quality Management Systems
Freebird Wafer Lot Acceptance Testing

1. Wafer Lot Received Per FBS Agreements
   - Documentation Verification
   - Visual Inspection

   - SEM SAMPLE 8 die per wafer Lot
   - Assemble TID 17 die per wafer
   - Assemble SEE 12 die per wafer

   - DC Electrical Test
     - Pass
       - Group A
       - TID Test
       - SEE Test

     - Not enough Samples

2. Disposition
   - Reject for Space Grade . Accept for COTS Grade
   - Fails Rad Testing Requirement
   - Passes all RHA Requirements

3. Release to Production as Rad Hard Qualified DIE
Radiation Conformance Qualification

✓ Radiation testing is conducted by Freebird Semiconductor Personnel
  ✓ SEE testing performed at “Texas A&M” (TAMU on our complete portfolio)
  ✓ TID testing conducted at VPT Rad with standard testing up to 300kRads
  ✓ ELDRs – portfolio sample tested, with no deviation from TID
  ✓ Neutrons testing conducted on our technology completed & passed

<table>
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<tr>
<th>Operation Performed</th>
<th>Standard - Ref</th>
<th>Conditions</th>
<th>Reports Generated</th>
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<td>SEE Irradiation</td>
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<td>3 die per wafer and ion exposure</td>
<td>SEE report both XE / AU Species Reported</td>
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<td>25°C</td>
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</table>

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100V FBG10NXX Device Single Event Effect Result Examples

Small Size Die

- Xe Ion
- Au Ion

LET=50
1553 MeV
131.7 mm

LET=63.7
2482 MeV
130 mm

Larger Die Size

- Xe Ion
- Au Ion

LET=50
1553 MeV
191.7 mm

LET=83.7
2482 MeV
130 mm

Run Time (sec)

Fluence = 3.1E5 ions/cm²

Au ion Let=83.7 2482MeV 130um
VDS=100V VG=-4V

IDS <250μA

TEST | TYPICAL ENVIRONMENT

<table>
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<tr>
<th>SEE SOA</th>
<th>Ion</th>
<th>LET MeV/mg/cm²</th>
<th>Range mm</th>
<th>Energy MeV</th>
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<td></td>
<td>Xe</td>
<td>50.8</td>
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<td></td>
<td>Au</td>
<td>84.6</td>
<td>124</td>
<td>2365</td>
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</table>

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40V FBG04N30X TID Response Example

**FBG04N30 IGSSF**

- VDS = 32V VGS=0V
- VDS = 0V VGS=5V

**FBG04N30 IDSS**

- VDS = 32V VGS=0V
- VDS = 0V VGS=5V

**FBG04N30 VTH**

- VDS = 32V VGS=0V
- VDS = 0V VGS=5V

**FBG04N30 RDSON**

- VDS = 32V VGS=0V
- VDS = 0V VGS=5V
Freebird Semiconductor Manufacturing Assembly is conducted exclusively at our (USA) facilities located in Haverhill, Massachusetts (USA).

Freebird Semiconductor screening conformance qualifications performed at a domestic (USA) DLA lab suitable MIL-PRF-19500 facility equipped to perform qualification inspection, conformance inspection & screening tests on devices to MIL-STD-750 Test Methods. Conformance qualifications are also performed in Freebird manufacturing facilities. Our qualification methods are performed consistent with an equivalent MIL-PRF-19500 guideline for semiconductor devices;

<table>
<thead>
<tr>
<th>Operation</th>
<th>Test</th>
<th>Base Standard</th>
<th>Consistent Test Methods</th>
<th>Hermetic FBG Sample Size</th>
<th>Die Adapter FDA Sample Size</th>
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<tbody>
<tr>
<td>A-2</td>
<td>DC Static Tests at 25°C</td>
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<td>A-3</td>
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<td>A-7</td>
<td>Gate Charges &amp; Capacitance</td>
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- Group A Inspection (Conformance)

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<th>Base Standard</th>
<th>Consistent Test Methods</th>
<th>Hermetic FBG Sample Size</th>
<th>Die Adapter FDA Sample Size</th>
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<tr>
<td>B-1</td>
<td>Physical Dimensions</td>
<td>750</td>
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<td>B-2</td>
<td>Solubility</td>
<td>750</td>
<td>15 15</td>
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<td>B-3</td>
<td>Resistance to Solvents</td>
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<td>22 22</td>
<td>3411,3413,3421,3404</td>
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<td>Temperature cycling</td>
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<td>22 22</td>
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<td>N.A N.A</td>
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<tr>
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<td>Bond strength</td>
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<td>22 22</td>
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<tr>
<td>Cross Section</td>
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<td>B-4 Pre-Electricals</td>
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- Group B Inspection (Conformance)
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<th>FBS Part Number</th>
<th>$V_{DS}$ (V)</th>
<th>$I_D$ (A)</th>
<th>$R_{DS(ON)}$ (mΩ)</th>
<th>$Q_G$ (nC)</th>
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### Freebird Radiation Hardened Die Adaptor (FDA) Product

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**Package Dimensions**

- **FDA-1**
  - Width: 0.182” (4612µm)
  - Height: 0.084” (2183µm)

- **FDA-2**
  - Width: 0.628” (1595µm)
  - Height: 0.084” (2139µm)

- **FDA-3**
  - Width: 0.870” (2210µm)
  - Height: 0.084” (2139µm)

- **FDA-4**
  - Width: 0.056” (1428µm)
  - Height: 0.087” (2220µm)

- **FDA-7**
  - Width: 0.097” (2459µm)
  - Height: 0.097” (2459µm)

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Certificate of Registration

Intertek

This is to certify that the quality management system of
Freebird Semiconductor Corporation

Main Site/Central Function: 17 Parkridge Road, Unit E, Haverhill, MA 01835 USA

has been assessed and registered by Intertek as conforming to the requirements of

AS9100C and ISO 9001:2008

The quality management system is applicable to

Design and manufacture of high-reliability semiconductors devices and circuits.

Certificate Number: 0059164-00
Initial Certification Date: 03 February 2017
Certificate Issue Date: 03 February 2017
Certificate Reissue Date: 14 September 2018
Certificate Expiry Date: 14 September 2022

Calin Moldovan - President, Business Assurance
Intertek Testing Services NA, Inc. dba Intertek -
4700 Broadmoor Avenue S.E., Kentwood, MI 49512 USA

This assessment was performed in accordance with the requirements of AS9100/1:2015-01. Intertek is accredited under the Aerospace Registrar Management Program and IAOG ICOP scheme.

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CT. AS9110C:2000-AS9100B.1-4 LT-EN-08 jan. 15

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Conforming Space eGaN discrete products

- Freebird uses source controlled die from foundry
- Proprietary processes for die
- High lead content solder bumps
- Radiation tested die

- Domestic Hermetic Packaging and “Chip Scale” Die Adaptors developed in AlN ceramic material.
- Elimination of Wire-Bonds
- 40V to 300V Hermetic eGaN portfolio qualified & available!
- Short form abstract qualification reports are now available on our web-sites [www.freebirdsemi.com](http://www.freebirdsemi.com)
HOW TO DRIVE eGaN- in Space Borne Applications?
Radiation Hardened GaN Adaptor Modules (Drivers with Logic)

Advanced Detail Release of Freebird Semiconductors

Radiation Hardened GaN Driving GaN MULTI-FUNCTION
½ Bridge Configuration or
Independent High & Low Side Driver
Logic Protection Circuitry
Integrated Output Power GaN HEMT’s

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GaN Adaptor Module (GAM) Products

• **FBS-GAM02-P-C50**
  - 50V Fully de-rated, 10A Half-Bridge **Multi-function** Module
    - (100V FDA Chip Scale Series GaN Driving GaN Die Technologies internally utilized)
    - Two Independent Power Switches w/High Speed Gate Driver Circuits and “Catch” Diodes
    - Input UVLO, Input OVP Shut Down, Power Good Status Detection
    - Operation up to +1Mhz
      - High-Side Driver
      - Low-Side Driver

• **Multi-Function- Possible Connections**
  - Half-Bridge w/ Shoot Through Protection
  - Single Low-Side Power Driver
  - Single High-Side Power Drive
  - Dual Independent Low- and High-Side Power Drivers

• FBS-GAM02-P-C50 Commercially Screened Development Vehicle
• FBS-GAM02-P-R50 (Radiation Hardness Assured Commercially Screened AEC-Q10X Plan)

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FBS-GAM02P-C-PSE (Power Switch External Variant)

- Allows (External) HEMTs of Different Ratings to be Used
- Allows (External) Paralleled HEMTS for Higher Current-Carrying Capability
- PSE Module provides both Independent Low- and High-Side Gate Drivers
GaN Adaptor Module (GAM) Products

• FBS-GAM04-P-C50
  - 50V, (fully de-rated) 10A Dual Low-Side Switch Module
    - (Internal FDA Series Chip Scale Series 100V rated GaN Driving GaN Die Technologies)
  - Independent Power Switches
  - DC to 1MHz+ Operation
  - Possible Applications:
    - Synchronous Rectifiers w/Primary-Side Control in Isolated Forward/Flyback Converter
    - Primary Power Switches for Push-Pull Converter
    - Actuator PWM Controllers
    - FBS-GAM04-P-C50 Development Vehicle
    - FBS-GAM04-P-R50 (Radiation Hardness Assured)

(Internal FDA Series Chip Scale Series 100V rated GaN Driving GaN Die Technologies)
Radiation Hardness Assurance FBS-GAM0X

• FBS-GAM0X-P-C50 is the development vehicle to our form-fit function RHA versions:
  ➢ FBS-GAM0X-P-R50 Commercial Space, Epoxy Over-molded, Extreme Copper units
  ➢ FBS-GAM0X-C-R50 Hermetic AlN Ceramic form-fit function unit in process.

• RHA versions incorporate FDA Series 100V Rated eGaN HEMT technologies designed, fabricated & tested according to Mil-Std-750 Method 1019 for total ionizing dose with total ionizing in-situ Gamma Bias for (i) $V_{GS} = 5.1V$, (ii) $V_{DS}=V_{GS}=0V$ and (iii) $V_{DS}=80\% \text{ B}_{VDS}$, devices are “guaranteed by design” to no less than 100 kRad (Si)

• Single Event Immunity Heavy Ion: Au, ~LET= 83.7, 2482 MeV, Range = 130um

➢ Freebird incorporating “Hard Switch Testing Techniques” of FBS-GAM0X design for robustness validation in-situ. Radiation Hardness Assured test-bed conducts full switching functionality on a ½ Bridge configuration in total ionizing environment
GAM Applications – Power Supplies

- Power Supplies!
  - Forward, Flyback, Boost, Full-Bridge,
  - Buck, Weinberg, Cůk
  - Non-Isolated, Isolated
    - Primary-Side, Secondary-Side

- Isolated Synchronously-Rectified Push-Pull Converter

\[ V_{OUT} = \frac{V_{DD}}{N} \times (ton / T) \times 2 \]
GAM Applications – Power Supplies

<80V, <250W
Non-Isolated

<80V, <250W
Isolated Primary Secondary

• Non-Isolated Synchronous Buck Converter (POL)

• Isolated Synchronously-Rectified Forward Converter

VOUT = \sim VDD \cdot (t_{on}/T)

t_d = \text{dead time}

VOUT = \sim (VDD / N) \cdot (t_{on}/T)
GAM Applications – Motors

• Motors! Single ➔ Three Phase
  • Single Phase Motor: Pump (Tank to Load)
  • Two Phase Motor: Bidirectional Actuator (L/R, U/D. In/Out)
  • Three Phase Motor: Regulated Speed Control (Reaction Wheel)
  • Motor Voltage Increases w/Power Requirements

• 50V/0.5kW Motors
  • FBS-GAM02-P-C50 // FBS-GAM02-P-R50
    • Single Phase Motor – 1x GAM02, Low Side Drive ONLY
      • High-Side Power Switch DC NOT Possible
    • Two Phase Motor – 2 x GAM02, Half-Bridge One Per Phase
    • Three Phase Motor – 3 x GAM02 Half-Bridge. One Per Phase
Additional GAM Applications

• Actuators\Power Switches\Squib Drivers
  • Low-Side/High-Side – FBS-GAM02
    • DC Operation Possible, Low Side
  • High-Side – FBS-GAM02
  • Low-Side – FBS-GAM02
    • DC Operation Possible
  • Dual Low Side – FBS-GAM04

• Load Dump Switches
  • Battery Discharge
  • Battery Conditioning
  • Fault Protection
  • Controlled Current Path
Key Qualifications
- Freebird Qualified
- RHA Validated Die
- Hermetic and Chip Scale Devices
- Integrated GaN HEMT Driver Modules

Freebird Qualified RHA Validated Die
Radiation Hardened eGaN HEMT Technology

RAD HARD DISCRETE PRODUCTS
- FBG30N04C2 FDA30N04CX 300 Volt, 04 Amp
- FBG20N18B2 FDA20N18BX 200 Volt 18 Amp
- FBG20N04B2 FDA20N04BX 200 Volt 04 Amp
- FBG10N30B2 FDA10N30AX 100 Volt 30 Amp
- FBG10N05A2 FDA10N05AX 100 Volt 05 Amp
- FBG04N30B2 FDA04N30BX 40 Volt 30 Amp
- FBG04N08A2 FDA04N08AX 40 Volt 08 Amp

RAD HARD Modules
- FBS-GAM02 FBS-GAM04
THANKS

Visit our website at www.freebirdsemi.com
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Freebird semiconductor:
Offering
(r)evolutionary GaN High Reliability Technologies TODAY

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