GaN-Based Magnetic Field Sensors for Space Exploration

Researcher: Ms. Karen Dowling
EXtreme Environment Microsystems Lab (XLab)
Electrical Engineering Department
Stanford University

PI: Prof. Debbie G. Senesky
Aeronautics and Astronautics Department
Electrical Engineering Department (by Courtesy)
EXtreme Environment Microsystems Lab (XLab)
Stanford University

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Extreme Environments

Space Based

Europa

Image Credits: NASA.gov

Earth Based


Industrial Applications

300°C  400°C  500°C  600°C

- Oil & Gas Exploration
- Geothermal
- Space Exploration Engines
- Aircraft Engines
- Automotive Engines
- Gas Turbines
- Thermal Protection Systems
Sensing Magnetic Fields

Space Based

- Earth
  - Tilt of rotation axis: 23°
  - Tilt of magnetic axis: 12°
  - Offset of magnetic axis: 8%
  - Field at equator: 31,000 nT
  - Magnetosphere: 10 R_{Earth}

- Jupiter
  - Tilt of rotation axis: 3°
  - Tilt of magnetic axis: -10°
  - Offset of magnetic axis: 10%
  - Field at equator: 428,000 nT
  - Magnetosphere: 65 R_{Jupiter}

Earth Based

- Drone with sensors:
  - Accelerometers
  - Engine intake flow sensors
  - Inertial measurement unit

- Hall effect IC

MEMSIC Inc.

AKM Inc.
Principle of Operation: The Hall Effect

\[ F = q \left( \vec{v} \times \vec{B} \right) \]

Specifications
Field Range: -5 to 5 mT
Temperatures: -200 °C to 500 °C
Temp Drift: 0.3 ppm/°C
Power: < 1 mW
Accuracy: < 10 μT
Size: 0.9 mm²

Dowling et. al, 2018, in Preparation
## AlGaN/GaN for Hall Sensing/ Extreme Environments

<table>
<thead>
<tr>
<th>Property</th>
<th>GaN</th>
<th>Si</th>
<th>SiC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Gap (eV)</td>
<td>3.4</td>
<td>1.1</td>
<td>2.4 - 3.2</td>
</tr>
<tr>
<td>Mobility</td>
<td>2000*</td>
<td>1400</td>
<td>1020</td>
</tr>
<tr>
<td>Strain Sensitivity (unitless)</td>
<td>90</td>
<td>150</td>
<td>31</td>
</tr>
<tr>
<td>Electrical Operational Failure (°C)</td>
<td>600</td>
<td>150</td>
<td>900</td>
</tr>
<tr>
<td>Melting Point (°C)</td>
<td>2500</td>
<td>1400</td>
<td>2700</td>
</tr>
<tr>
<td>Young's Modulus (GPa)</td>
<td>390</td>
<td>188</td>
<td>450</td>
</tr>
<tr>
<td>Chemical Resistance</td>
<td>Good</td>
<td>Poor</td>
<td>Great</td>
</tr>
</tbody>
</table>

![Graph showing magnetic fields and temperature relationship](image.png)

Koide, 2012

### Energy Gap
- **GaN**: 3.4 eV
- **Si**: 1.1 eV
- **SiC**: 2.4 - 3.2 eV

### Mobility
- **GaN**: 2000* cm²/Vs
- **Si**: 1400 cm²/Vs
- **SiC**: 1020 cm²/Vs

### Strain Sensitivity
- **GaN**: 90
- **Si**: 150
- **SiC**: 31

### Electrical Operational Failure
- **GaN**: 600 °C
- **Si**: 150 °C
- **SiC**: 900 °C

### Melting Point
- **GaN**: 2500 °C
- **Si**: 1400 °C
- **SiC**: 2700 °C

### Young's Modulus
- **GaN**: 390 GPa
- **Si**: 188 GPa
- **SiC**: 450 GPa

### Chemical Resistance
- **GaN**: Good
- **Si**: Poor
- **SiC**: Great
AlGaN/GaN Hall Sensing

High Mobility
(2000 cm$^2$/V-s)

Tunable Electron density
(1x10$^{13}$ electrons/cm$^2$)

Phase A
Phase B
Phase C
Phase D

V_{Hall} = \frac{V_a + V_b + V_c + V_d}{4}

Dowling et al., 2018, in Preparation
Test Set Up

(a) ALD Al₂O₃ Buffer
(b) <111> Silicon AlGaN GaN 2DEG 100 µm
(c) Bond Metal Ohmic Contact GaN AlGaN Ohmic Contact Bond Metal

Helmholtz Coil Pair (vertical)
Extreme Environments: Temperature

Cryogenic Testing
Collaborators: Goldhaber-Gordon
Group, Applied Physics

XLab High Temperature
Preliminary Results

Prepublication Data: Do Not Distribute
Extreme Environments: Sub Orbital Flight

SHARK-I

Senesky

Hannah

Anthony

Ramirez

Karen

Dowling et. al,
International
Interplanetary Probe
Workshop, 2018,
Accepted
Payload Test

Room Temperature
Gain = 500
$V_{\text{supply}} = 1\text{V}$

Dowling et al, International Interplanetary Probe Workshop, 2018, Accepted
Summary
- Fabricated & tested GaN based magnetic field sensors.
- Tested in room temp and from -200 °C to +200 °C
- Developed payload for suborbital test flight

Applications
- Space exploration/ navigation
- Robotics, vehicles, and power electronics

Future Work
- 3D sensing
- Higher temperatures
- Radiation environment tests
- Tuning materials for optimal sensing

Image Credits: NASA.gov
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