GaN for use in harsh radiation environments

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Outline

- Properties of GaN
- Material Characterisation
- CCE Experimental Setup
- Irradiation
  - X-Rays
  - Neutrons
  - Protons
- Comparisons to Existing Data
- Conclusions & Future Work

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Properties of GaN

GaN (Gallium Nitride)

- Compound Semiconductor (n-type)
- Direct Wide Bandgap (~3.4eV)
- High Density (6.15gcm⁻³)
- High Threshold Voltage

=> Ideal material for ionising radiation detector

Also applications in blue and UV wavelengths such as lasers and high-brightness LEDs.

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Material Properties

- Material used was Semi-Insulating (SI) GaN
- Grown by MOCVD on Sapphire ($\text{Al}_2\text{O}_3$) substrate
- Increased resistivity caused by altering TMG flow rates and growth temperature for growth capping layer
Photoluminescence

- Excitation by cw HeCd laser, 20mW @ 325nm
- PL signal dispersed by double monochromator
- Signal detected using UV enhanced photomultiplier

The observed spectra consist of 3 bands.

(UVB) band 3.42eV => Band-to-band recombination

Blue (BB) band 2.85eV => The 60°-type basal plane dislocations

Yellow (YB) band 2.19eV => Point Defects e.g. complexes of Ga vacancy

PL Intensity $\propto$ Defect Concentration

Concentration of point (Y PL) and structural (B PL) dislocations increases with TMG flow rate

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Technique

- To test material’s performance in harsh radiation environments
  - Perform material characterisation (I-V, CCE)
  - Irradiate diodes to a range of known fluencies
  - Repeat I-V, CCE measurements
I-V characteristics
**α setup for CCE measurements**

5.48 MeV α particles from Am$^{241}$ source
Energy Deposited in 2μm of GaN ~ 553keV

Detector and Source housed in vacuum chamber (P ~20 mbar)

Measurement setup consisted of
- Charge sensitive pre-amplifier
- Shaper amplifier with a shaping time of 1μs,
- Connected to a pulse height analyser

Energy calibration of the detection system was carried out using Si surface barrier diode assumed to have 100% CCE

Correcting for difference between electron-hole pair creation energy in Si (3.62eV) and GaN (8.9eV)

$\Rightarrow$ Assign energies to the peaks of the observed spectra.

$\Rightarrow$ Calculate the c.c.e. of the detector

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CCE for Unirradiated GaN

- Range of Voltage 0-28V
- CCE = 95%

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X-rays

- Material irradiated at Imperial College London

- Irradiated to a fluence of 600MRad 10keV x-rays
I-V, CCE for x-rays

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CCE for x-rays

- Range of Voltage 0-28V
- CCE ~ 100%

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n irradiation

- Material irradiated at Ljubljana Neutron Irradiation Facility
- Samples irradiated to fluences of
  - $10^{14}$ n/cm$^2$
  - $10^{15}$ n/cm$^2$
  - $10^{16}$ n/cm$^2$
- Fluences quoted are 1MeV neutron NIEL equivalent
I-V for n irrad

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CCE for n irrad

$10^{14}$ n, CCE $\sim 77$

$10^{15}$ n, CCE $\sim 10$

$10^{16}$ n/cm$^2$, CCE $\sim 5$

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p irradiation

- Material irradiated at CERN
- Samples irradiated to fluence of $10^{16}$ p/cm$^2$
- 24GeV/c proton beam
I-V for p irrad.
## Comparisons

<table>
<thead>
<tr>
<th>Material</th>
<th>Unirradiated CCE</th>
<th>Irradiated CCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>GaAs</td>
<td>100 % (MIPS) [2]</td>
<td>50 % ($2 \times 10^{14}$ 24GeV protons/cm²) [2]</td>
</tr>
<tr>
<td>SiC (100 µm bulk V doped)**</td>
<td>60 % (5.486 Am²¹⁺ alpha) [3]</td>
<td>50 % ($10^{13}$ 300 MeV/c pions/cm²) [3]</td>
</tr>
<tr>
<td>SiC (epi layer 30 µm)</td>
<td>90 % (5.486 Am²¹⁺ alpha) [4]</td>
<td>60 % ($10^{14}$ 24 GeV/c protons/cm²) [5]</td>
</tr>
<tr>
<td>Diamond</td>
<td>24 % (Mips) [6]</td>
<td>18 % ($10^{13}$ 300 MeV/c pions/cm²) [6]</td>
</tr>
<tr>
<td>GaN</td>
<td>95 % (5.486 Am²¹⁺ alpha)</td>
<td>77 % ($10^{14}$ 1 MeV neutrons/cm²) 10% ($10^{15}$ 1MeV neutrons/cm²) 5% ($10^{16}$ 1MeV neutrons/cm²)</td>
</tr>
</tbody>
</table>

Si assumed to have 100 % CCE for all radiation types before irradiation
** $10^{18}$ cm⁻³ Vanadium (V) doped SiC maximum CCE 60 % [7]

[7] Simulations carried out by T. Quinn et al to be presented
Results

- Evidence of increased TMG flow rate proportional to defect density

- Increase in leakage currents is non linear for increased irradiation levels

- CCE measurements
  - Unirradiated, CCE ≈ 95%
  - 600Mrad X-ray, CCE ≈ 100%
  - $10^{14}\text{n/cm}^2$, CCE ≈ 77%
  - $10^{15}\text{n/cm}^2$, CCE ≈ 10%
  - $10^{16}\text{n/cm}^2$, CCE ≈ 5%
Conclusions and Future Work

• Demonstrated the potential of SI GaN for room temperature ionising radiation detectors

• Require further tests beyond preliminary results shown until now
  – Full range of n/p irradiations between $10^{14}$-$10^{16}$
  – Perform CCE measurements at varying temperatures

• Further improvement possible as the growth technology of GaN develops.
  – Begin testing on fabricated diodes on Bulk GaN
  – Use different material (CST, compensated)

• Detailed investigation of defects post irradiation
  – DLTS
  – MWA / PC
  – TSC