Performance of semi-insulating metal-semiconductor-metal GaN prototype devices as ionizing radiation detector

Elizabeth George, Pradeep Sarin- Department of Physics, IIT Bombay
Ravindra Singh, Apurba Laha- Department of Electrical Engineering, IIT Bombay
We have tested a novel Gallium Nitride (GaN) wide bandgap semiconductor device for detecting alpha particles.

• In this talk:
  • GaN features and Device geometry
  • Electronic characterization
  • Charge Collection Efficiency for ionizing radiation

• Context and Summary
General properties of GaN

• GaN is a binary III-V direct band-gap semiconductor with $E_g = 3.39 \text{eV}$
• Wurtzite crystal structure
• GaN has a high melting point $\sim 2500^\circ \text{C}$ [*] & has high thermal conductivity
• Superior candidate in electronics R&D, opto-electronic, high power RF

• We test it as an ionizing radiation detector


Notable features of GaN as an ionizing radiation detection medium:

- Low leakage current & low thermal noise.
- Simple device geometry: no doping is required due to large band-gap
- Average energy to create e-h pair is 8.9eV. So a MIP should deposit an average 90 signal e-h pairs per μm depth of GaN
- Large breakdown field of the order of 5 MV/cm. So a large bias field can be applied to improve signal timing.
- Fast signal response < 10ns
- Expect it to be Radiation hard:
  Displacement energy for GaN is Ga:18eV and N:22eV + higher ionic bond strength

[1]: 10.1016/j.nima.2006.05.001
[2]: 10.1016/j.nima.2005.10.128
Growth of GaN films

- GaN crystals: free-standing 2” wafers (commercial)
  - or thin epitaxial layers on inert substrate (our prototypes)
- Commonly used epitaxial growth methods are:
  - Metal Organic Chemical Vapor Deposition (MOCVD)
  - Hybride Vapor Phase Epitaxy (HVPE)
  - Molecular Beam Epitaxy (MBE)

Choice of suitable substrate & buffer layers

<table>
<thead>
<tr>
<th>Crystal (symmetry)</th>
<th>Lattice constant (a;c) (nm)</th>
<th>Thermal expansion coefficient($\times 10^{-6}/K^0$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GaN (W)</td>
<td>0.3189; 0.5185</td>
<td>5.59; 3.17</td>
</tr>
<tr>
<td>Sapphire (H)</td>
<td>0.4758; 1.299</td>
<td>7.5; 8.5</td>
</tr>
<tr>
<td>6H-SiC (W)</td>
<td>0.308; 1.512</td>
<td>4.2; 4.86</td>
</tr>
<tr>
<td>AlN (W)</td>
<td>0.3112; 0.4982</td>
<td>4.2; 5.3</td>
</tr>
</tbody>
</table>
Our GaN Metal-Semiconductor-Metal (MSM) device prototypes for ionizing radiation

• Epitaxially grown 3µm GaN on sapphire(0001) substrate by MOCVD

• Signal generation and charge transport occurs laterally in a shallow semiconductor layer < 3µm

Cross section
Metal Contacts (a pair of IDT fingers)

Top view of a single patterned GaN MSM device
Active drift area: 8µm
Electrical characterization & Device mounting

- Electrical contact: Ni/Pt/Au (10/30/80nm) metal stack is deposited using Electron Beam Evaporator
- I-V characteristics: leakage current @ +30V is $\approx 0.03\mu A$ & @ +60V is $\approx 0.5\mu A$
- Back-to-back Schottky diodes at metal-semiconductor-metal junctions
Signal profiling with $\alpha$ particles

- We made a direct measurement of the current pulse induced in the electrodes by the injection of Am$^{241}\alpha$ particles
- The generated e-h pairs drift laterally in applied field 0.4 V/µm up to 5.6 V/µm
- The collected current signal is amplified with a broadband amplifier
  - Gaussian signal
  - Fast signal response (2ns)
  - With increase in bias voltage, signal strength increases and saturates at -45V bias
Specific energy loss simulated in SRIM*

- SRIM simulation for 5.486MeV Am-241 α on GaN
- α is NOT absorbed in such a thin GaN layer → acts like a MIP

α – Energy spectra of GaN MSM devices

Charge sensitive amplifier (Cividec) is used to obtain the total energy deposited – the alpha particle does not stop in 3μm thickness active area.

For -40V bias

As seen on previous slide, it is expected to deposit \( \sim 0.86\text{MeV} \) average energy on 3μm GaN

For obtaining the α energy spectrum, we have taken 10,000 events for each bias voltages ranging from -3V to -45V
CCE of GaN MSM devices

Energy deposited by Am-241 α (eV)

Normalized α energy spectrum as a function of bias voltage

Charge collection efficiency as a function of bias voltage
Earlier work on GaN for radiation detection

• J. Vaitkus et.al (2003), first reported the application of epitaxially grown GaN as an α particle detector

\[10.1016/S0168-9002(03)01550-X\]

They used a double Schottky device structure and demonstrated the charge collection during the detection of α particles for different bias voltages

• J. Wang et.al (2015) published a review on the research developments in using GaN for ionizing radiation detection, describing various device prototypes used so far and the limitations hindering the commercialization of these devices as high radiation environment detectors

\[Appl\ Phys. Reviews 2 031102 (2015)\]
Summary

• We have investigated the properties of 3µm thick GaN MSM devices for ionizing radiation detection

• Detectors were characterized by performing I-V & charge collection efficiency measurements

• CCE of GaN MSM detector saturates ~78% at –40V

• Good signal response from thin GaN device at low reverse bias voltages

• Improvements in growth techniques and optimization of device parameters is providing a promising future for GaN as radiation hard particle detector.