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

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# We have tested a novel Gallium Nitride (GaN) wide bandgap semiconductor device for detecting alpha particles.

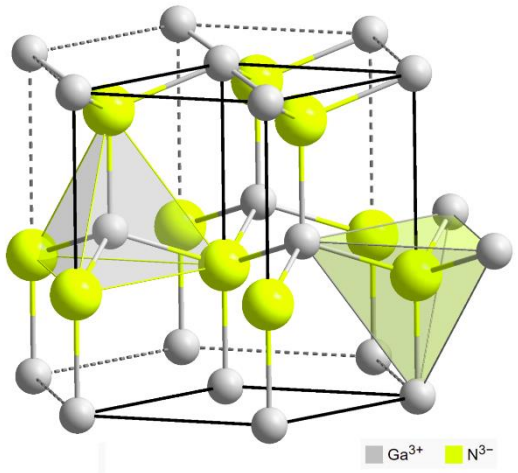
- In this talk:
  - GaN features and Device geometry
  - Electronic characterization
  - Charge Collection Efficiency for ionizing radiation

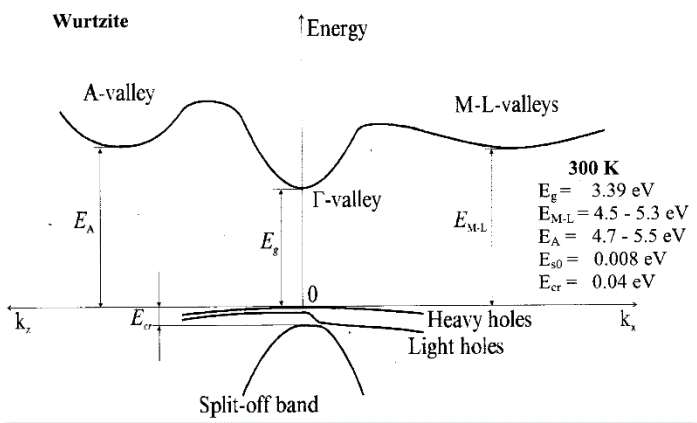
- Context and  Summary

# General properties of GaN

- GaN is a binary III-V direct band-gap semiconductor with $E_g$=3.39eV
- Wurtzite crystal structure
- GaN has a high melting point ~2500$^0$C [*] & has high thermal conductivity
- Superior candidate in electronics R&D, opto-electronic, high power RF

- **We test it as an ionizing radiation detector**




Phys. Rev. B, 52:8132–8139, Sep 1995.

* Journal of Applied Physics **96**, 2501 (2004)

# 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 [1]

- Large breakdown field of the order of 5 MV/cm [2]. So a large bias field can be applied to improve signal timing.
- Fast signal response < 10ns

- Expect it to be Radiation hard [3]:
  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

[3]: Nuclear Instruments and Methods in Physics Research A 546 (2005) 213–217

# 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

| Crystal (symmetry) | Lattice constant (a;c) (nm) | Thermal expansion coefficient($\times 10^{-6}/K^0$) |
|---|---|---|
| GaN (W) | 0.3189; 0.5185 | 5.59; 3.17 |
| Sapphire (H) | 0.4758; 1.299 | 7.5; 8.5 |
| 6H-SiC (W) | 0.308; 1.512 | 4.2; 4.86 |
| AlN (W) | 0.3112; 0.4982 | 4.2; 5.3 |

**14% lattice mismatch**

**3.4% lattice mismatch**

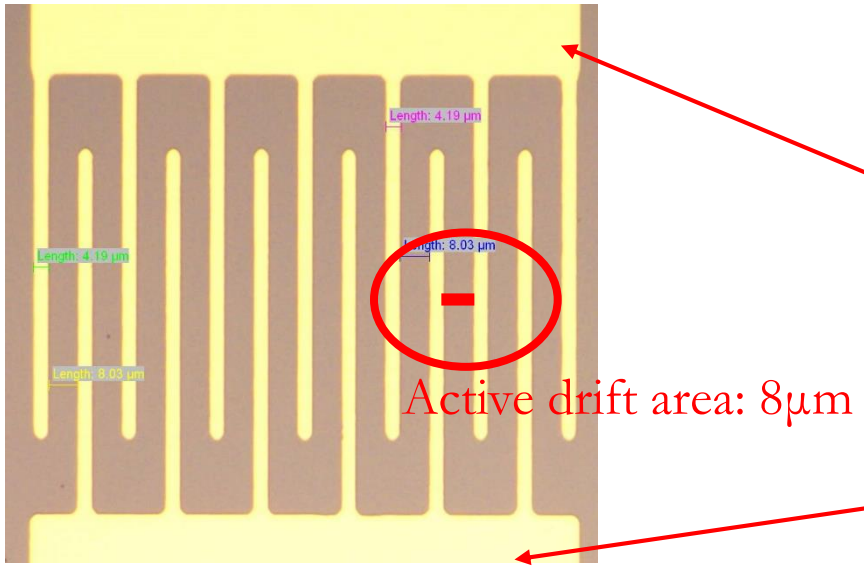
**Buffer layer**

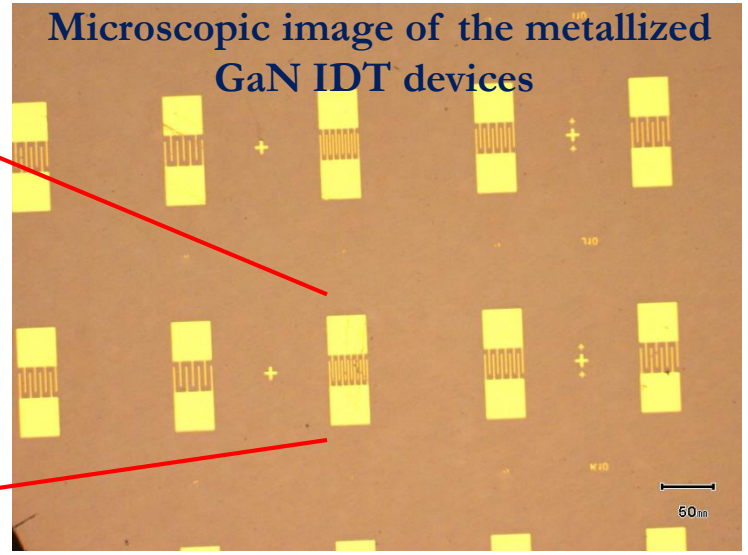
# Our GaN Metal-Semiconductor-Metal (MSM) device prototypes for ionizing radiation

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

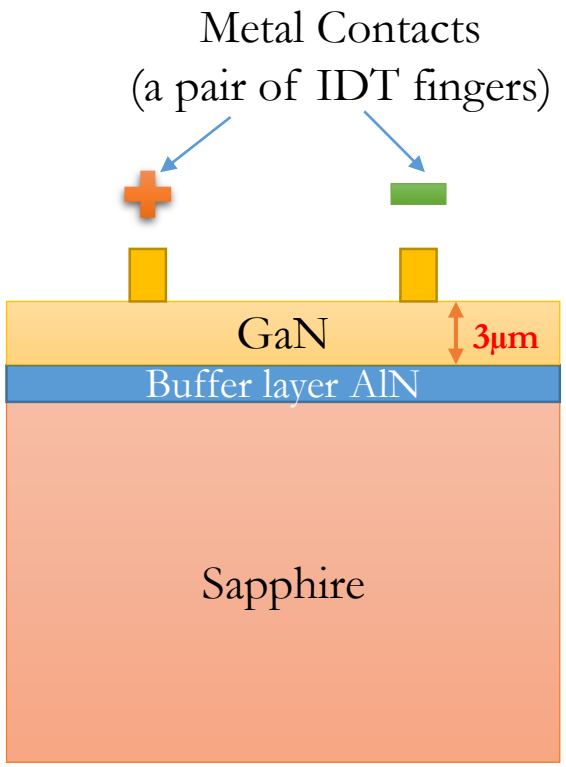
- Signal generation and charge transport occurs laterally in a shallow semiconductor layer < 3μm

**Top view of a single patterned GaN MSM device**



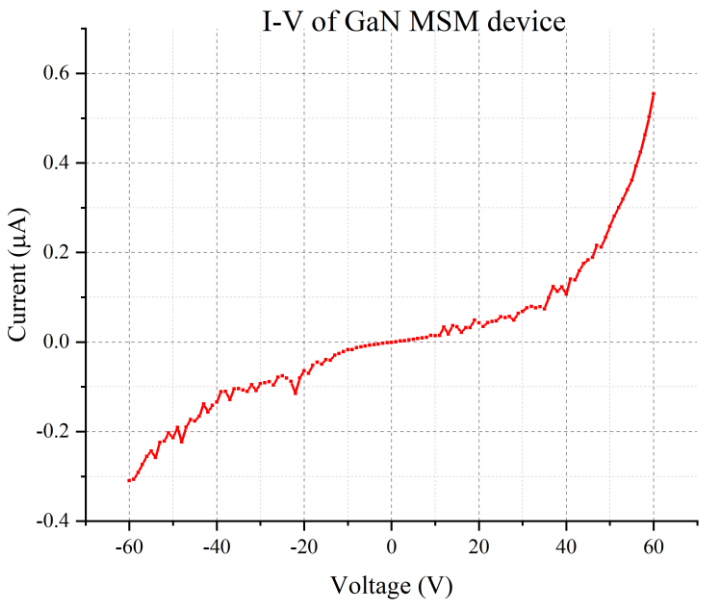




**Cross section**

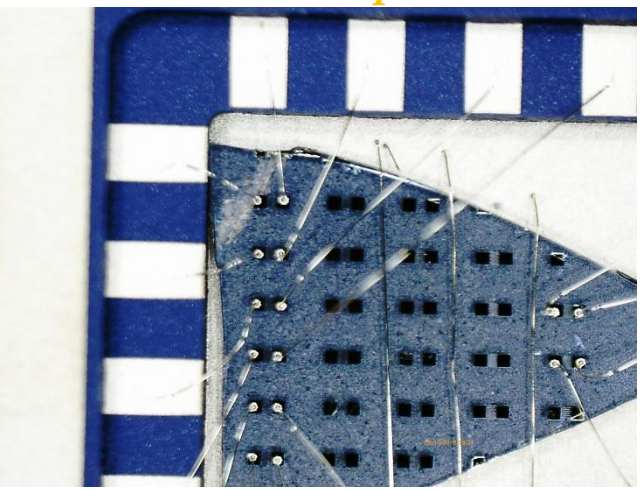


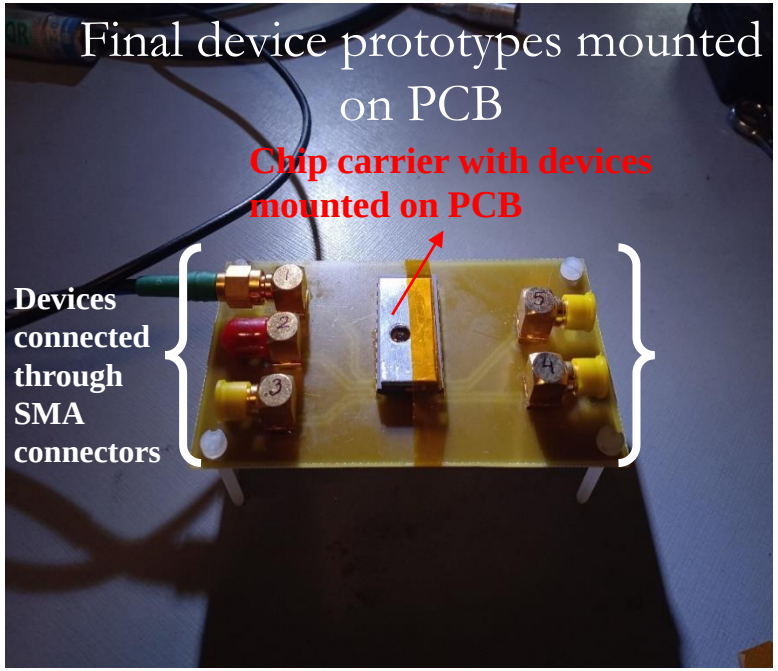
# Electrical characterization & Device mounting

- Electrical contact: Ni/Pt/Au (10/30/80nm) metal stack is deposited using Electron Beam Evaporator
- I-V characteristics: leakage current @ +30V is ≈0.03μA & @ +60V is ≈0.5μA
- Back-to-back Schottky diodes at metal-semiconductor-metal junctions

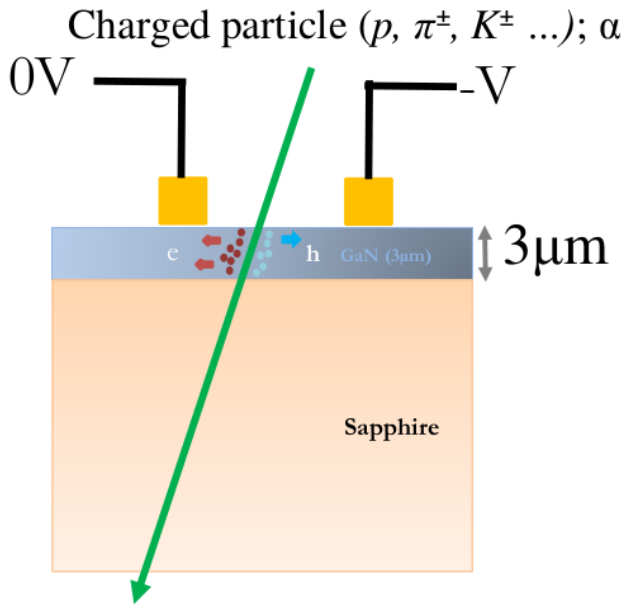



Au wire bonded GaN device on ceramic PDIP chip carrier

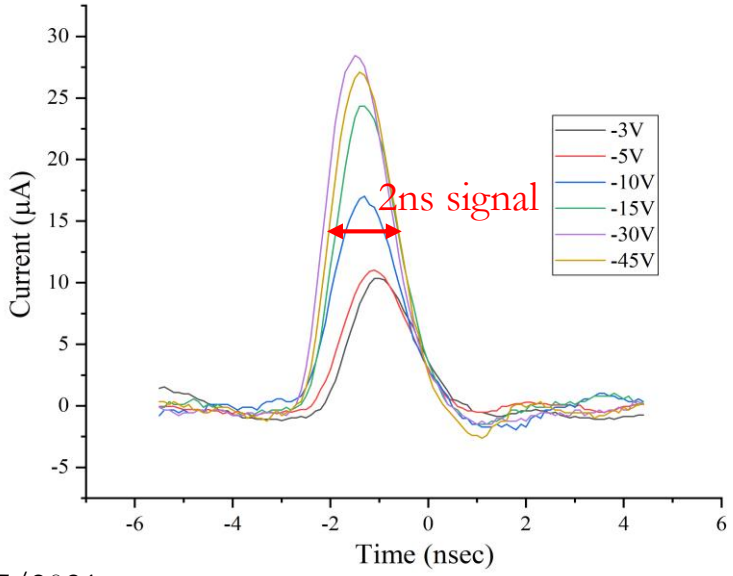




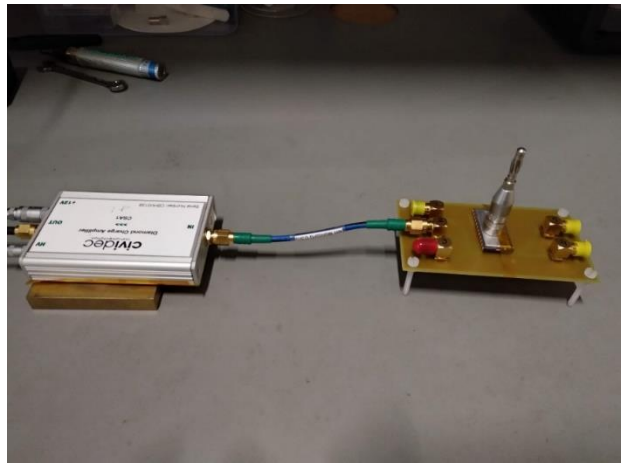
# Signal profiling with α particles




- We made a direct measurement of the current pulse induced in the electrodes by the injection of $Am^{241}$α 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



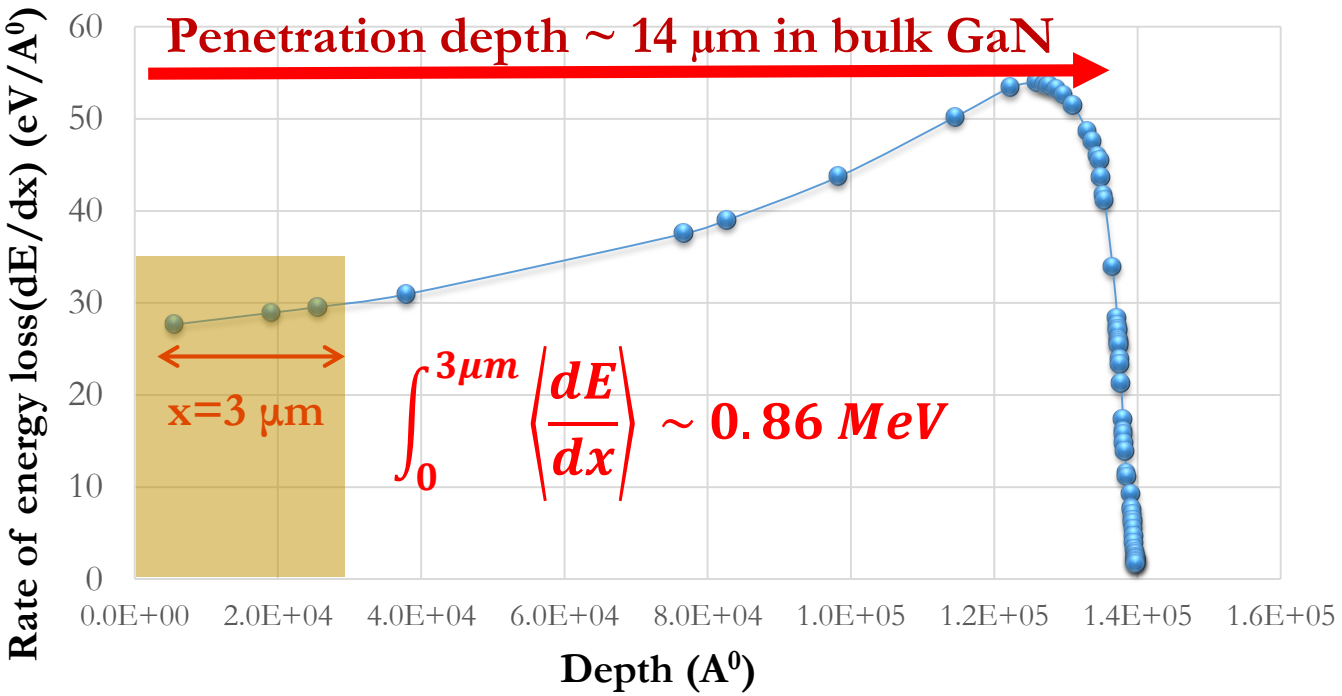

- Gaussian signal
- Fast signal response (2ns)
- With increase in bias voltage, signal strength increases and saturates at -45V bias



# Specific energy loss simulated in SRIM*

- SRIM simulation for 5.486MeV Am-241 α on GaN

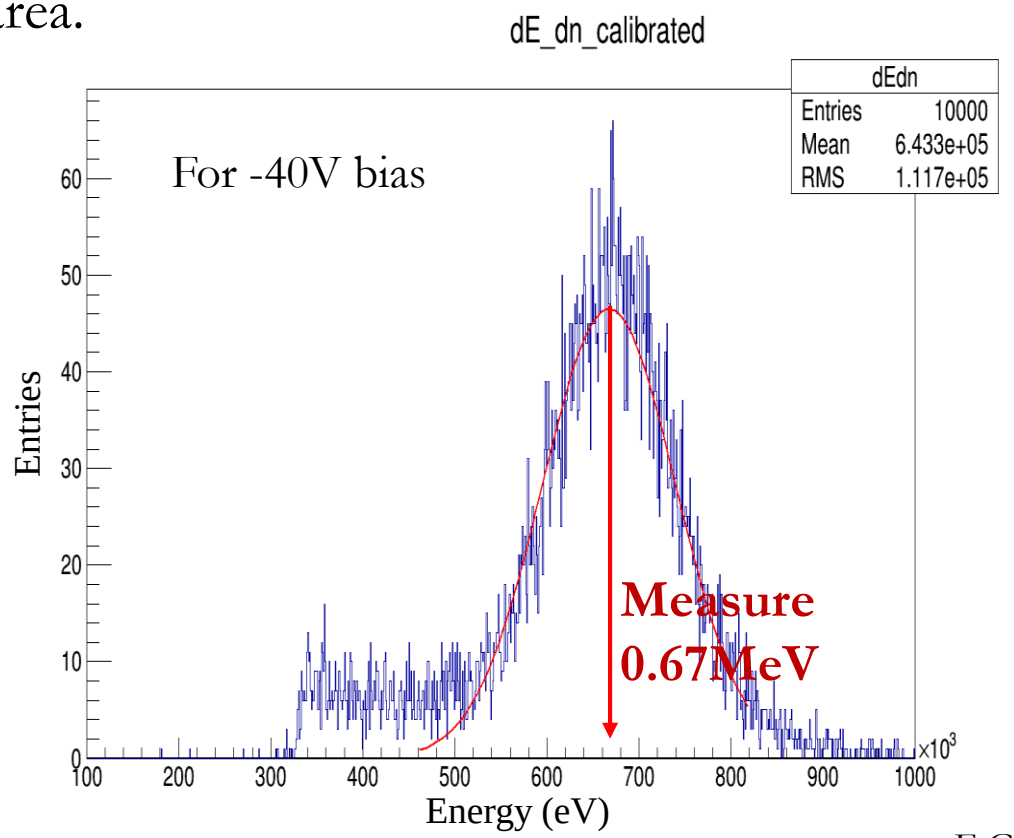
- **α is NOT absorbed in such a thin GaN layer → acts like a MIP**

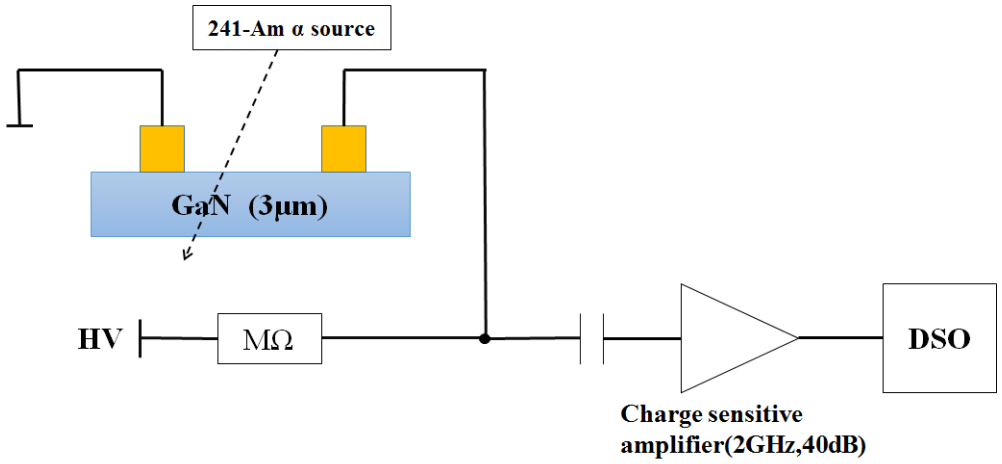


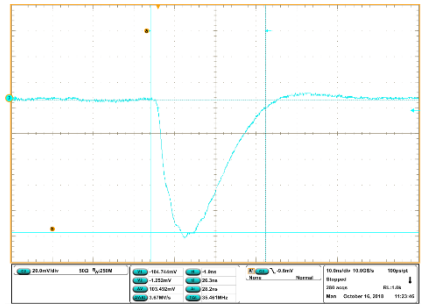

* SRIM (2013) – Stopping Range of Ions in Matter, http://www.srim.org

# 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.



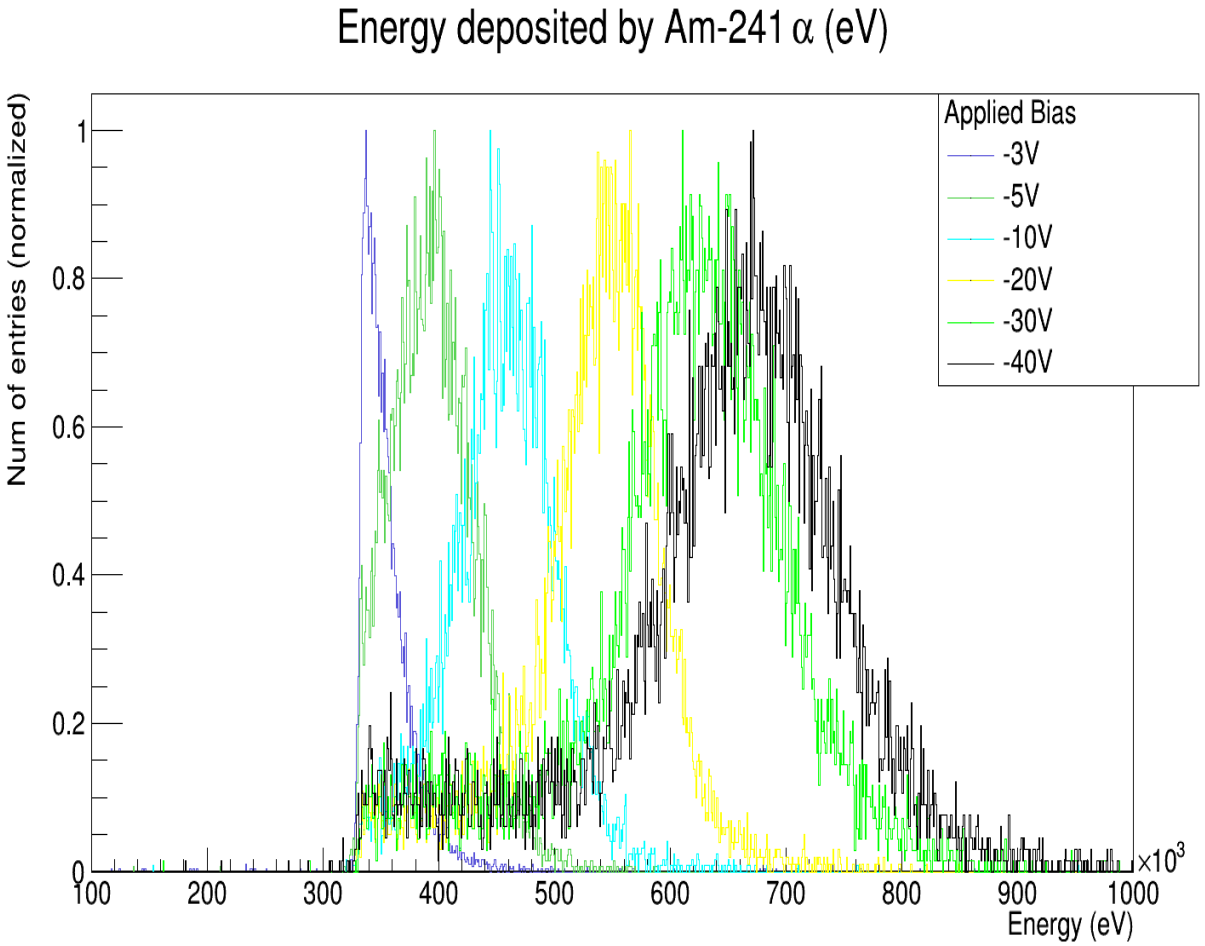



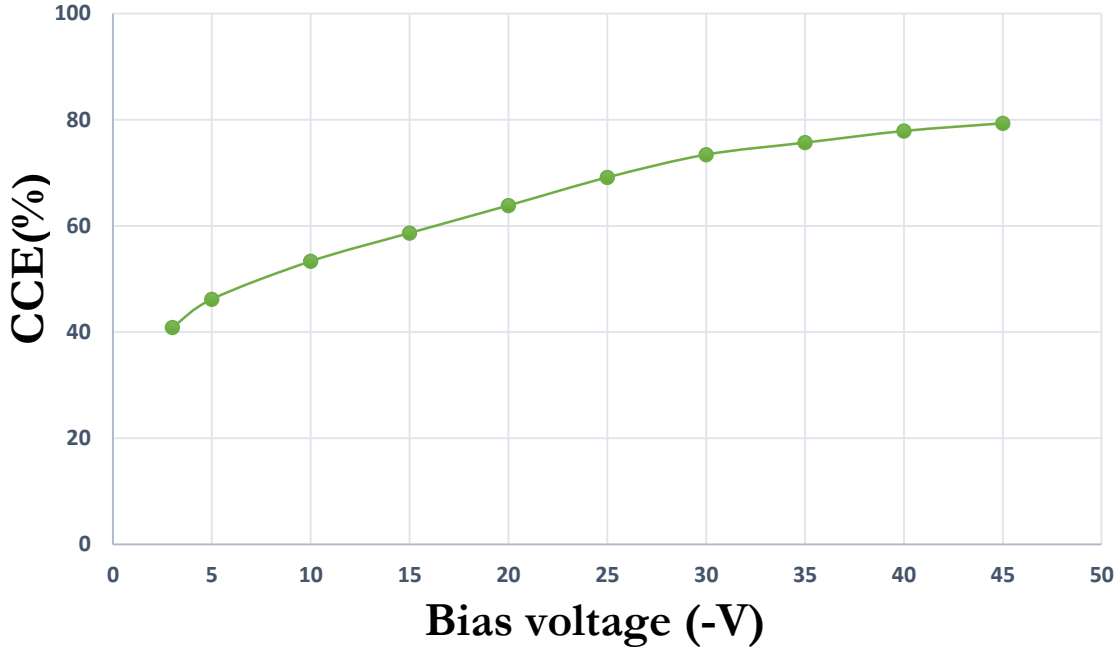
As seen on previous slide, it is expected to deposit ~ 0.86MeV average energy on 3μm GaN

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



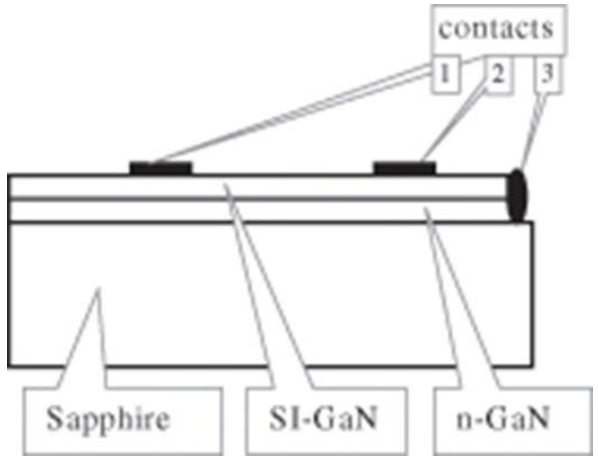

**Normalized α energy spectrum as a function of bias voltage**



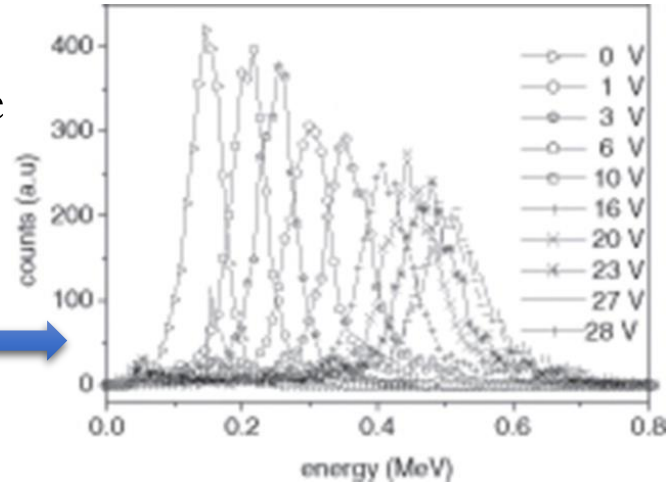

**Charge collection efficiency as a function of bias voltage**

# 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.