4th RD50 - Workshop on radiation hard semiconductor devices for very high luminosity colliders

UNIVERSITY
of
GLASGOW

GaN for use in harsh radiation environments

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Outline

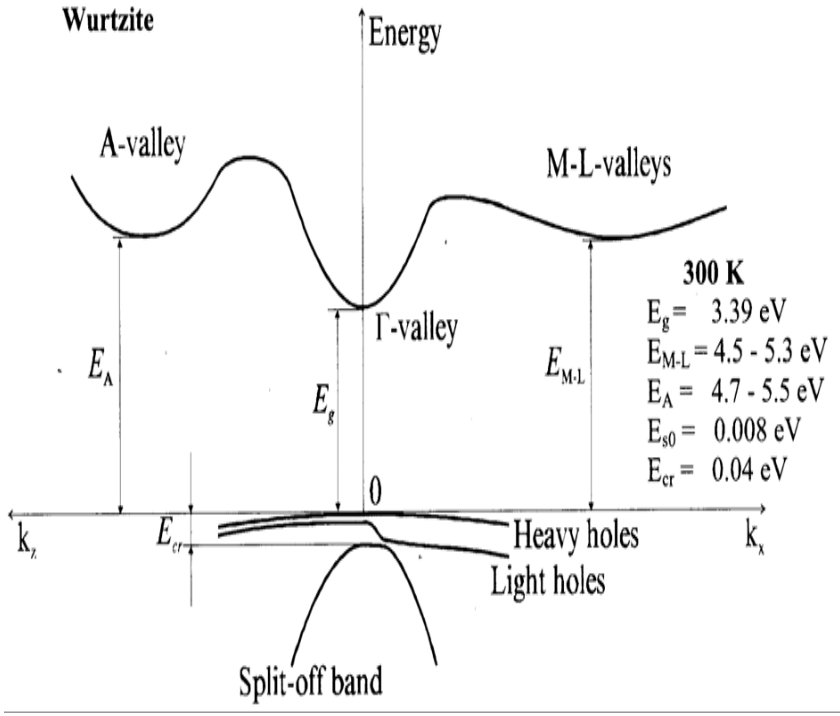
- Properties of GaN
- Material Characterisation
- CCE Experimental Setup
- Irradiation
  - X-Rays
  - Neutrons
  - Protons
- Comparisons to Existing Data
- Conclusions & Future Work

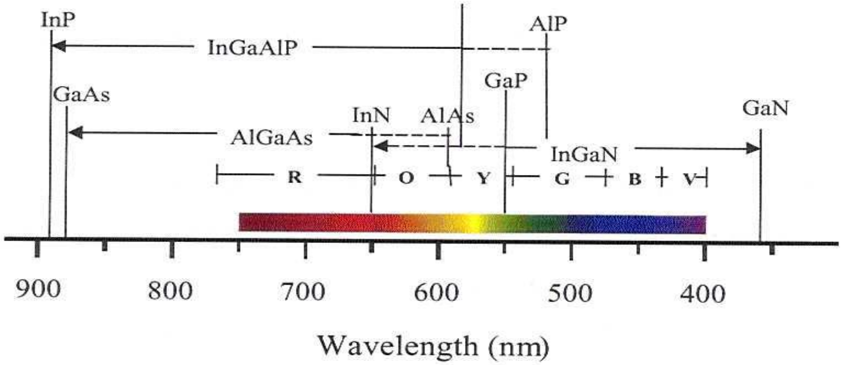
Properties of GaN

GaN (Gallium Nitride)

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

=> Ideal material for ionising radiation detector





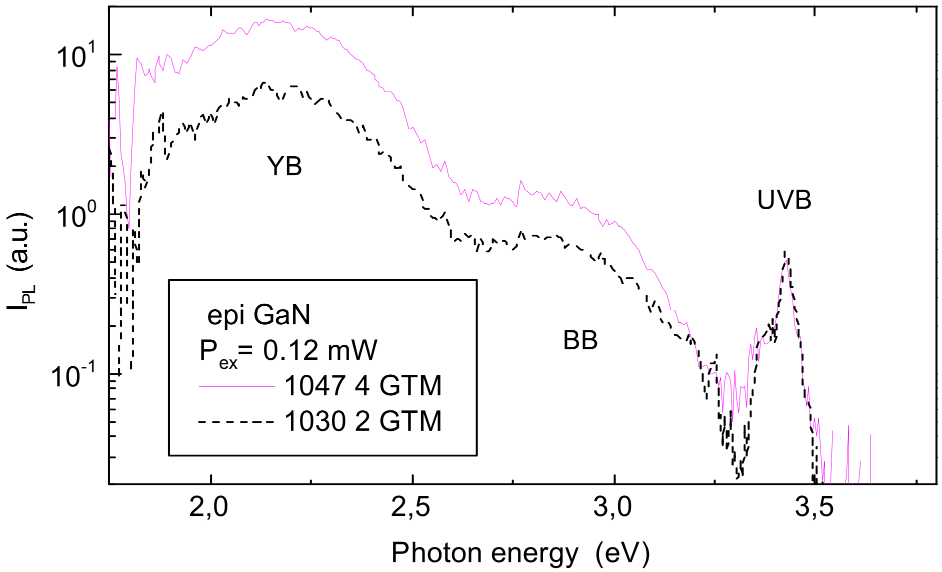
Also applications in blue and UV wavelengths such as lasers and high-brightness LEDs.

Material Properties

- Material used was Semi-Insulating (SI) GaN
- Grown by MOCVD on Sapphire (Al_2O_3) substrate
- Increased resistivity caused by altering TMG flow rates and growth temperature for growth capping layer

Photoluminesence

- 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

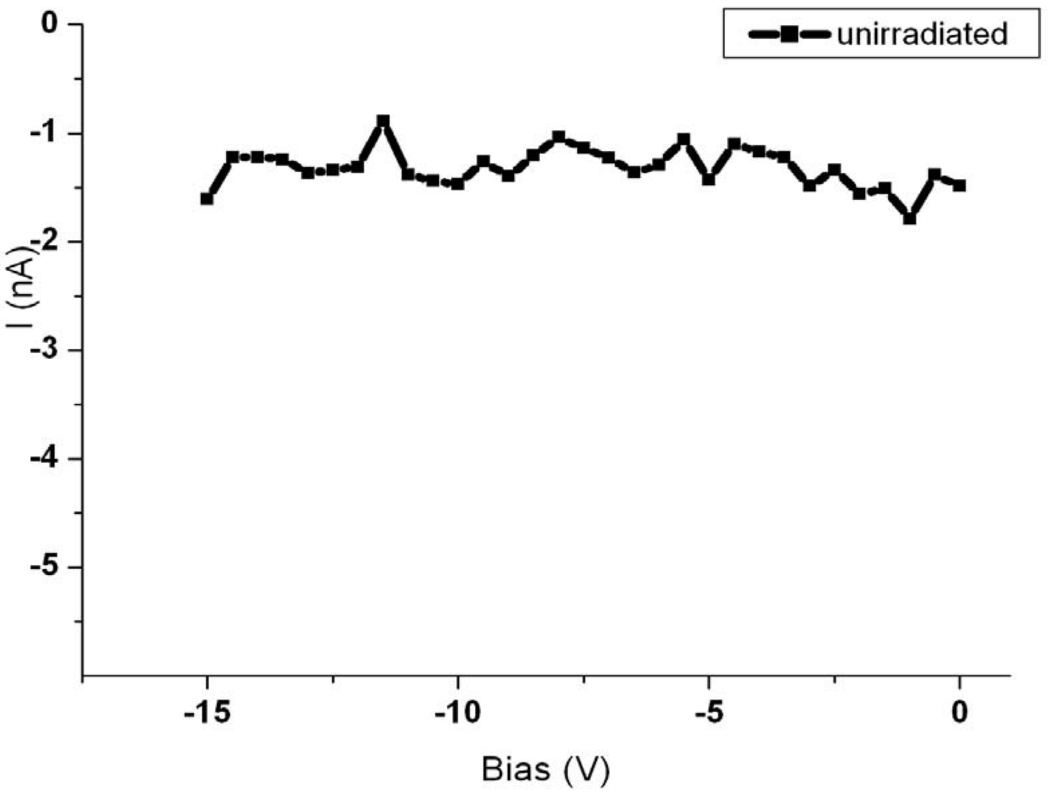
PL Intensity α Defect Concentration =>

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

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

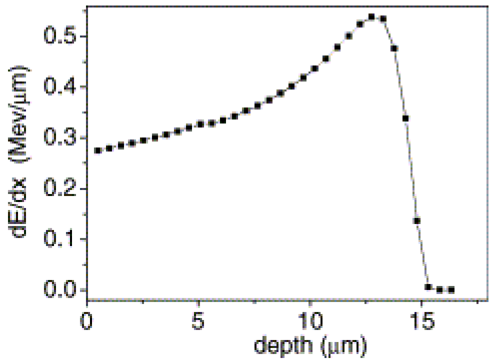
Detector and Source housed in vacuum chamber (P ~20 mbar)

Measurement setup consisted of

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

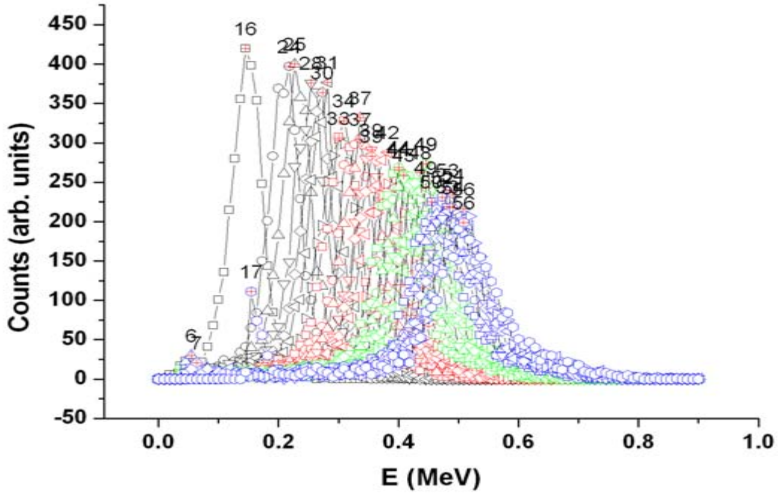
Energy calibration of the detection system was carried out using Si surface barrier diode assumed to have 100% CCE

Correcting for difference between electron-hole pair creation energy in Si (3.62eV) and GaN (8.9eV)
=> Assign energies to the peaks of the observed spectra.
=> Calculate the c.c.e. of the detector

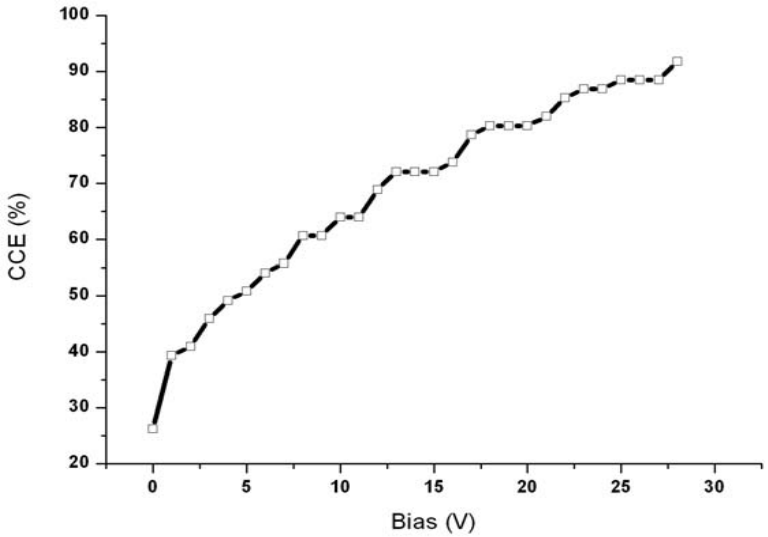


Energy deposition vs. Penetration depth (Bragg curve) of 5.48 MeV α, particles in GaN calculated, calculated using the SRIM code

CCE for Unirradiated GaN



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

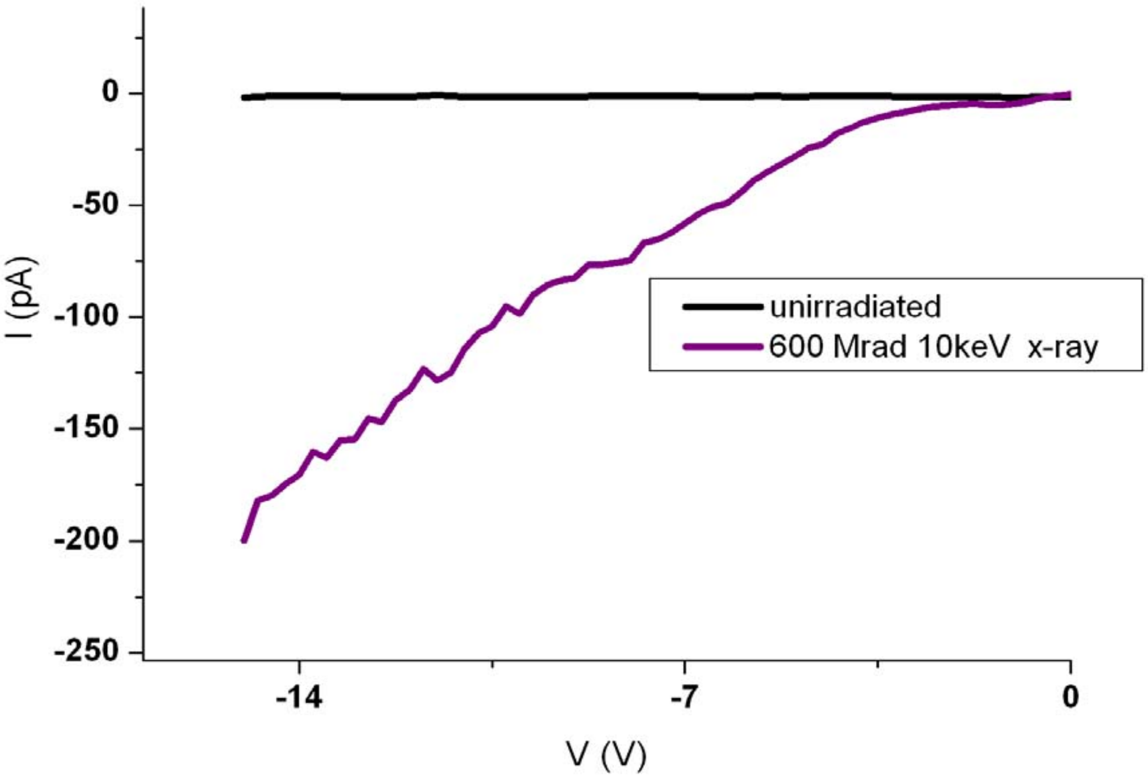


X-rays

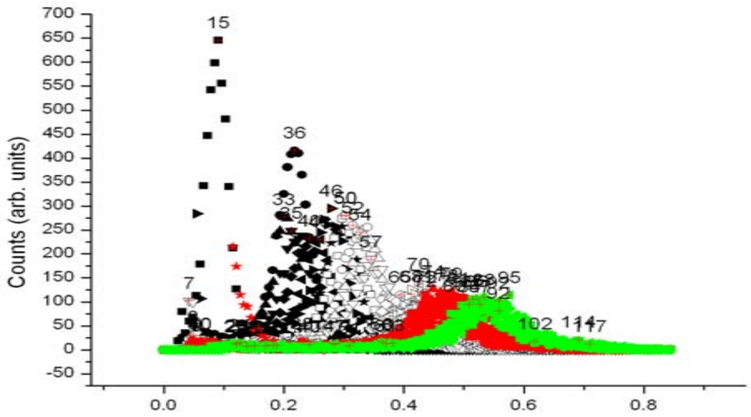
- Material irradiated at Imperial College London

- Irradiated to a fluence of 600MRad 10keV x-rays

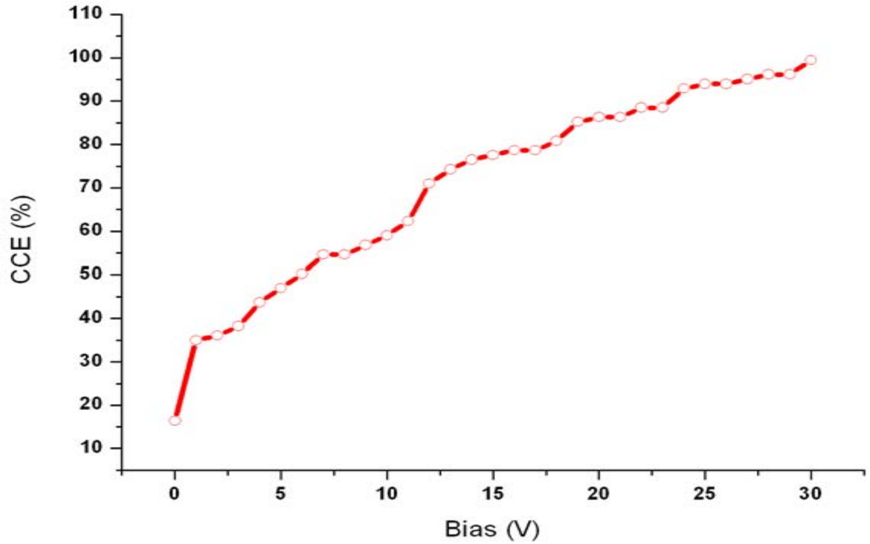
I-V, CCE for x-rays



CCE for x-rays



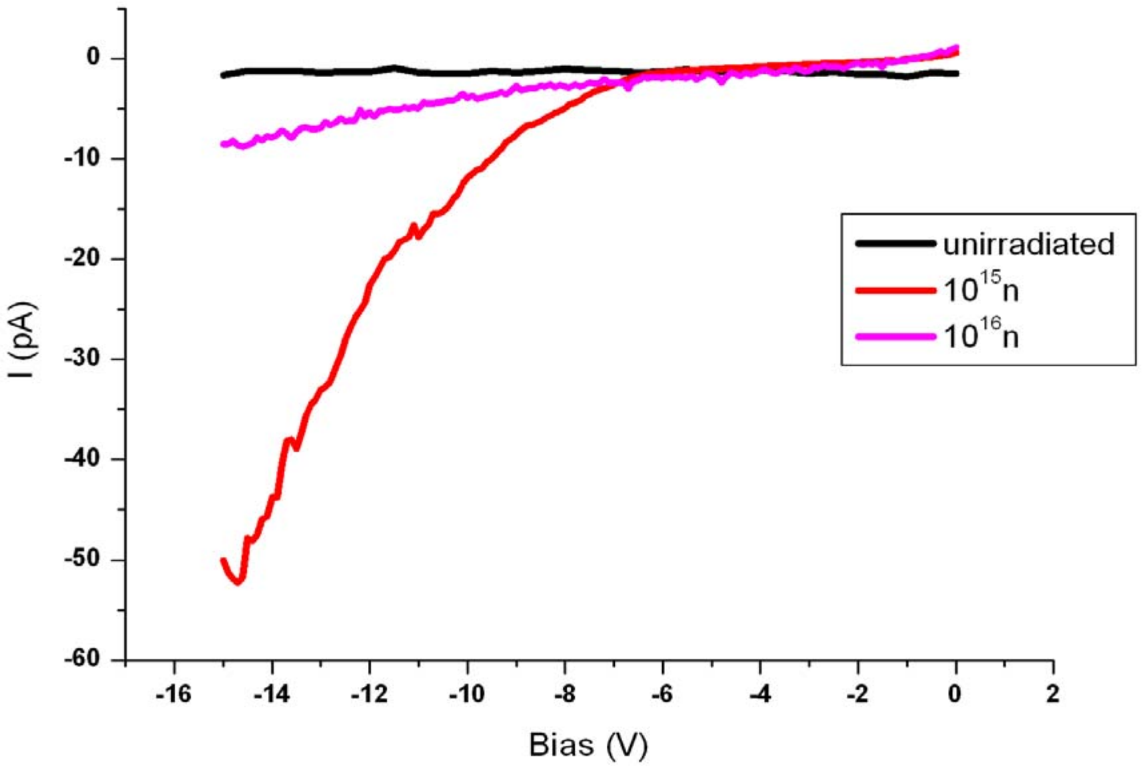
- Range of Voltage 0-28V
- CCE ~ 100%



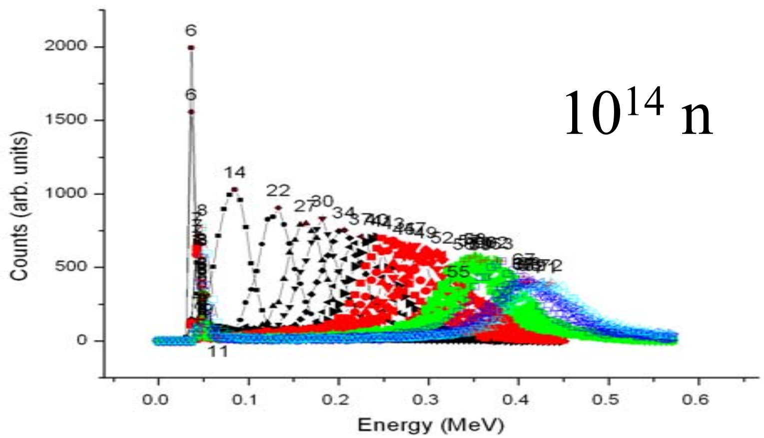
n irradiation

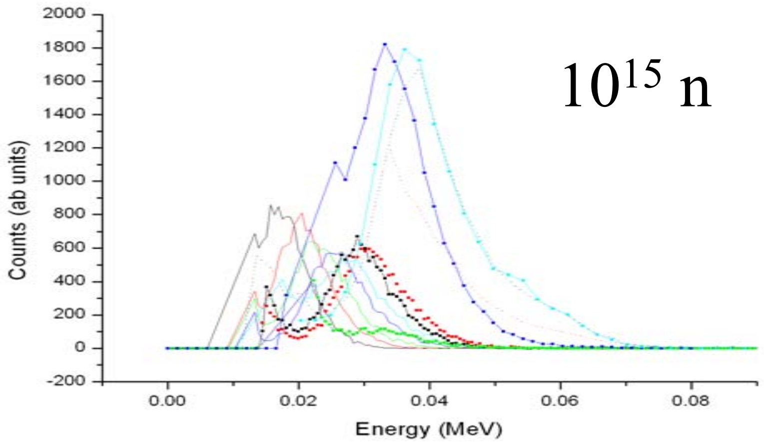
- Material irradiated at Ljubljana Neutron Irradiation Facility
- Samples irradiated to fluences of
  - 10^{14} n/cm^2
  - 10^{15} n/cm^2
  - 10^{16} n/cm^2
- Fluences quoted are 1MeV neutron NIEL equivalent

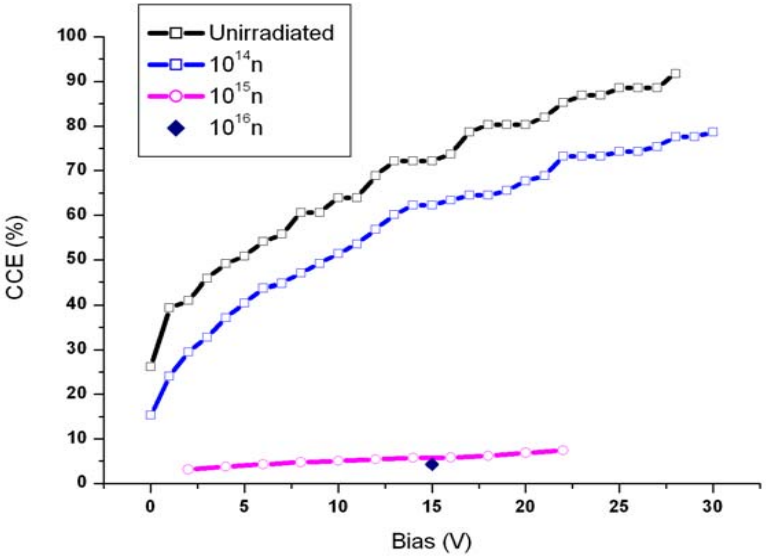
I-V for n irrad



CCE for n irrad







10^{14}n/cm^2, CCE ~ 77%

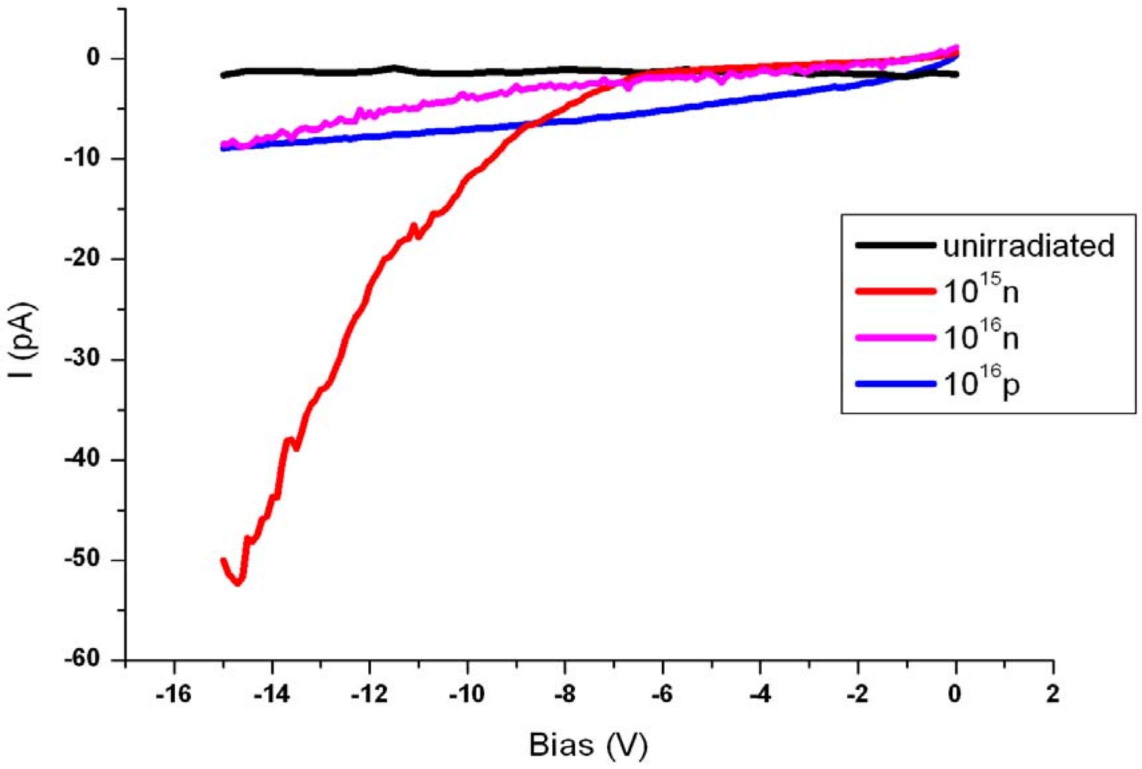
10^{15}n/cm^2, CCE ~ 10%

10^{16}n/cm^2, CCE ~ 5%

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

Material	Unirradiated CCE	Irradiated CCE
GaAs	100 % (MIPS) [2]	50 % (2x 10^{14} 24GeV protons/ cm^2) [2]
SiC (100 µm bulk V doped) **	60 % (5.486 Am^{241} alpha) [3]	50 % (10^{13} 300 MeV/c pions/cm^2) [3]
SiC (epi layer 30 µm)	90 % (5.486 Am^{241} alpha) [4]	60 %(10^{14} 24 GeV/c protons/cm^2) [5]
Diamond	24 % (Mips) [6]	18 % (10^{15} 300 MeV/c pions/cm^2) [6]
GaN	95 % (5.486 Am^{241} alpha)	77 % (10^{14} 1 MeV neutrons/cm^2) 10% (10^{15} 1MeV neutrons/cm^2) 5% (10^{16} 1MeV neutrons/cm^2)

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

[2] U. Biggeri et al, ‘Noise behaviour of semi-insulating GaAs particle detectors before and after proton irradiation’, Nucl. Phys. B (Proc. Suppl.) 78 (1999), 527- 532
[3] W. Cunningham et al, ‘Performance of irradiated bulk SiC detectors’, Nucl.Instr.and Meth. A 509 (2003), 127- 131
[4] G. Verzellezi et al, ‘Investigation on the charge collection properties of a 4H-SiC Schottky diode detector’, Nucl.Instr.and Meth. A 476 (2002), 717- 721
[5] F. Nava et al, ‘Radiation tolerance of epitaxial silicon carbide detectors for electrons,protons and gamma-rays’, Nucl.Instr.and Meth. A 505 (2003), 645- 655
[6] W. Adam et al, ‘Radiation tolerance of CVD diamond detectors for pions and protons’, Nucl.Instr.and Meth. A 476 (2002), 686- 693
[7] Simulations caried 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%

  $10^{14}n/cm^2$, CCE ~ 77%

  $10^{15}n/cm^2$, CCE ~ 10%

  $10^{16}n/cm^2$, 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