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Wide Bandgap Semiconductor Detectors for Harsh Radiation Environments

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Outline

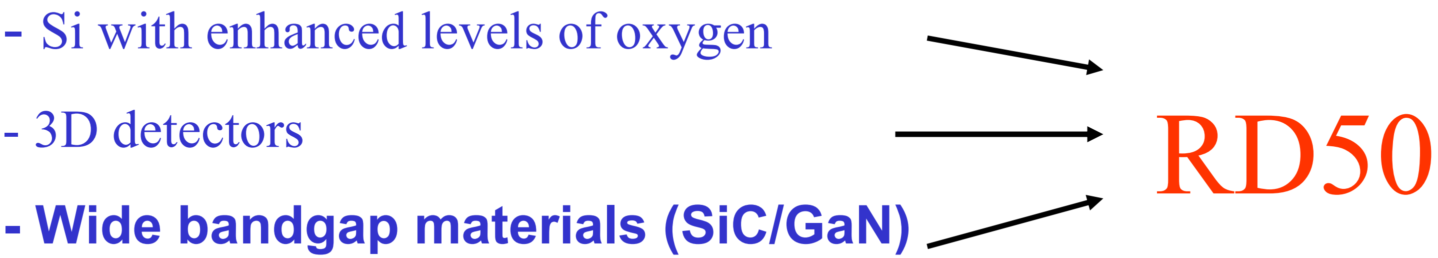
- Background and motivation
- Materials investigated
- Fabrication steps (brief)
- Characterisation of detectors
- SiC irradiations, results and analysis
- GaN irradiations, results and analysis
- Conclusions

Background and Motivation

- Stable operation of detector with current Si detector technology not possible beyond fluences of 3×10^{14} fast hadrons/cm^2

  - LHC at CERN fluences of ~ 3×10^{15}/cm^2
  - sLHC (2012) fluences of ~ 1.6×10^{16}/ cm^2

- Number of strategies possible for improving radiation tolerance of systems placed in harsh radiation environments



  - Si with enhanced levels of oxygen
  - 3D detectors
  - **Wide bandgap materials (SiC/GaN)**

RD50

s/c Material Investigated

- *SiC*
  - Vanadium doped 4–H SiC (Cree)

    Vanadium concentration ~ 10^{18}cm^{-3} =>ρ ~ 10^{11}Ωcm
  - Okmetic Semi-Insulating (SI) 4-H SiC (no vanadium doping)

    SI => Highly resistive
- *GaN*
  - eptiaxial SI (2μm active region) grown by MOCVD
  - Bulk GaN – RARE! (low resistivity ~ 16Ωcm)

Characterisation

- I – V measurements of detector pre/post irradiations

- Charge Collection Efficiency (CCE) measurements using

  5.48 MeV α source

  - measurements done in vacuum (<20 mbar)
  - calibration carried out with Si reference diode

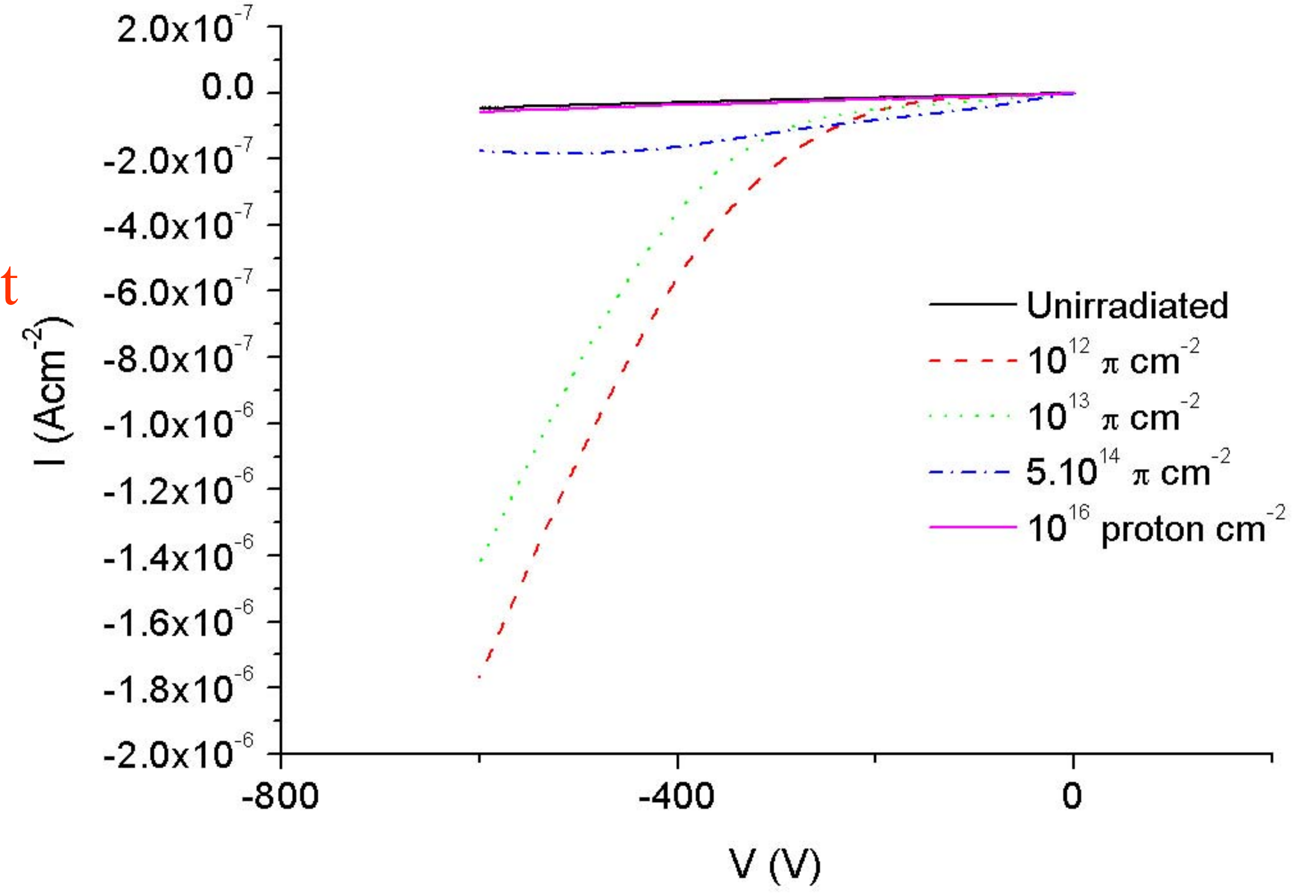
SiC Irradiations

- Vanadium doped SiC irradiated with:
  - 300MeV/c pions at the Paul Scherrer Institut
  - Fluences of $10^{12}\,\pi\text{cm}^{-2}$, $10^{13}\,\pi\text{cm}^{-2}$, $5\text{x}10^{14}\,\pi\text{cm}^{-2}$

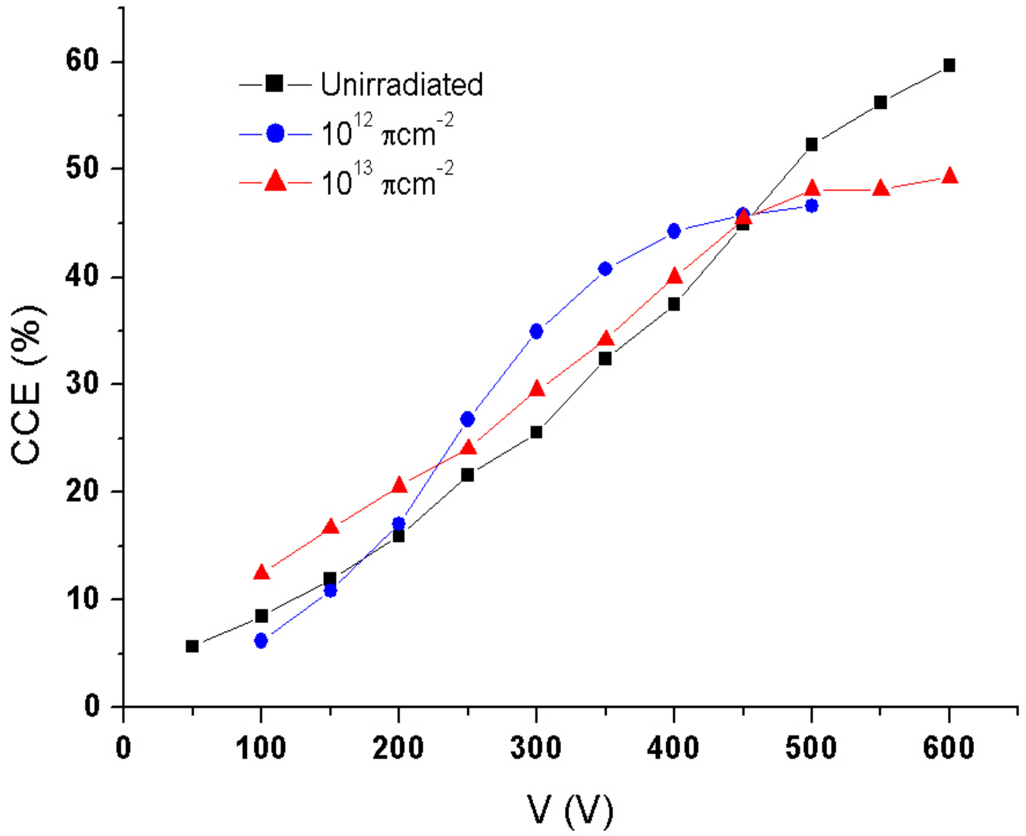
  - 24GeV/c protons at CERN
  - Fluence of $10^{16}\,\text{pcm}^{-2}$
- Non-Vanadium doped SI Okmetic SiC detectors not yet been irradiated

SiC I-V's and CCE's

Comparisons of
I-V measurement
For irradiated
Cree
V doped SiC



SiC CCE

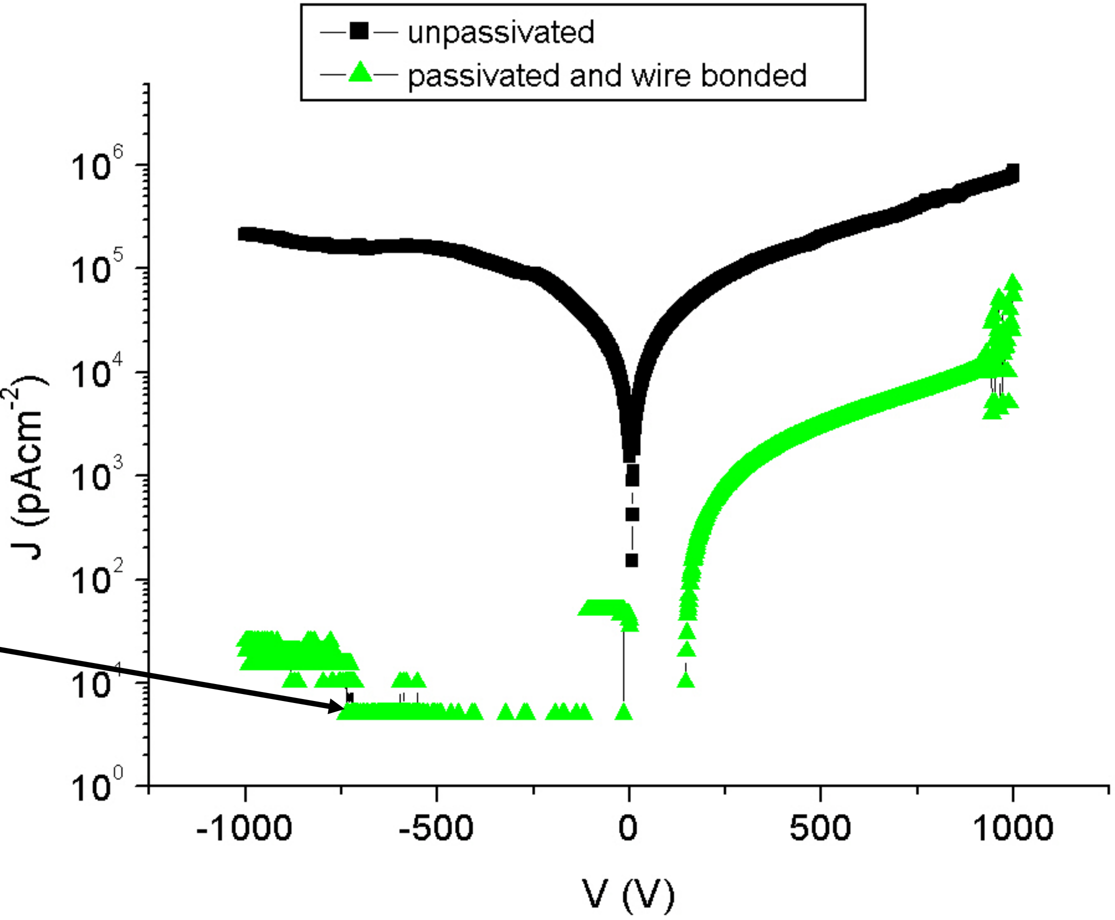


- No CCE for $5x10^{14}$ πcm^{-2} No CCE for $1016pcm^{-2}$ (wasn't bonded up)

- Non Vanadium doped initial CCE measurements ~ 100%.

J – V of Okmetic Non V Doped SiC

Current density measurements of diodes fabricated on Okmetic S.I. SiC



Measurment limit of Keithley 237 SMU ~10^{-14} A

SiC Analysis and Summary

- High resistivity gives low leakage current
- V dopant reduces maximum CCE due to trapping effects
- Has good radiation hard properties compared to GaAs and Si
  - SiC CCE reduced 15% after pion irradiation
  - GaAs CCE reduced 50% after similar dose
  - Si CCE reduced 30% after similar dose

Important point:

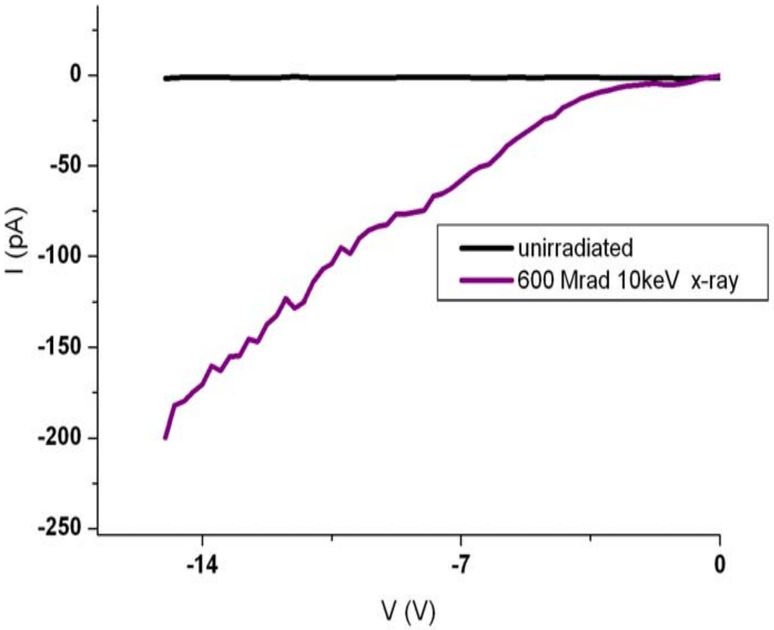
Changes in CCE are for operation under constant bias conditions

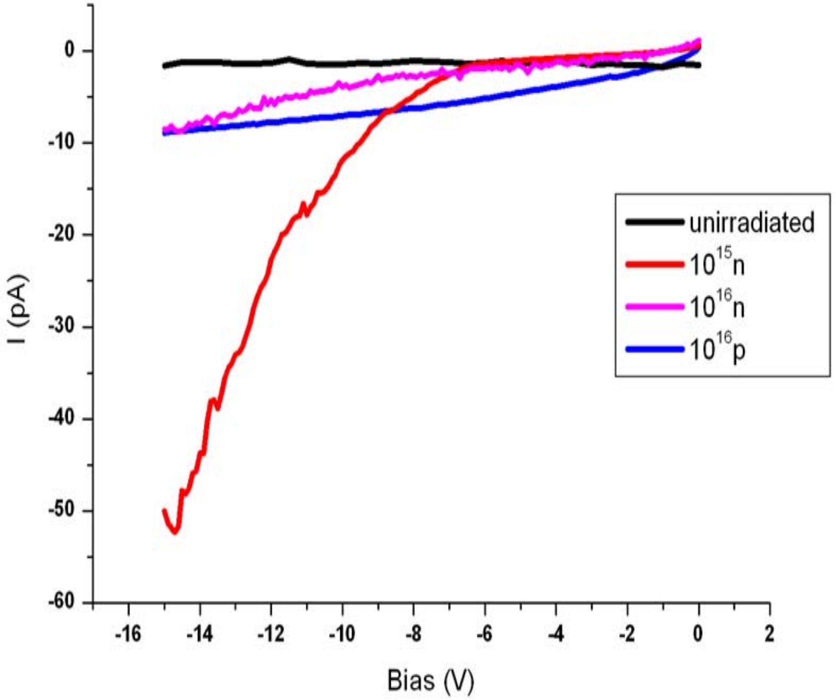
GaN Irradiations

- SI epitaxial GaN irradiated with:
  - 10keV X-Rays up to a dose of 600MRad at Imperial College
  - Neutrons at Ljubljana, Slovenia
  - Neutron fluences of 10^{14}ncm^{-2}, 10^{15}ncm^{-2} and 10^{16}ncm^{-2}
  - 24GeV/c protons at CERN at a fluence of 10^{16}pcm^{-2}

- Bulk GaN devices yet to be irradiated

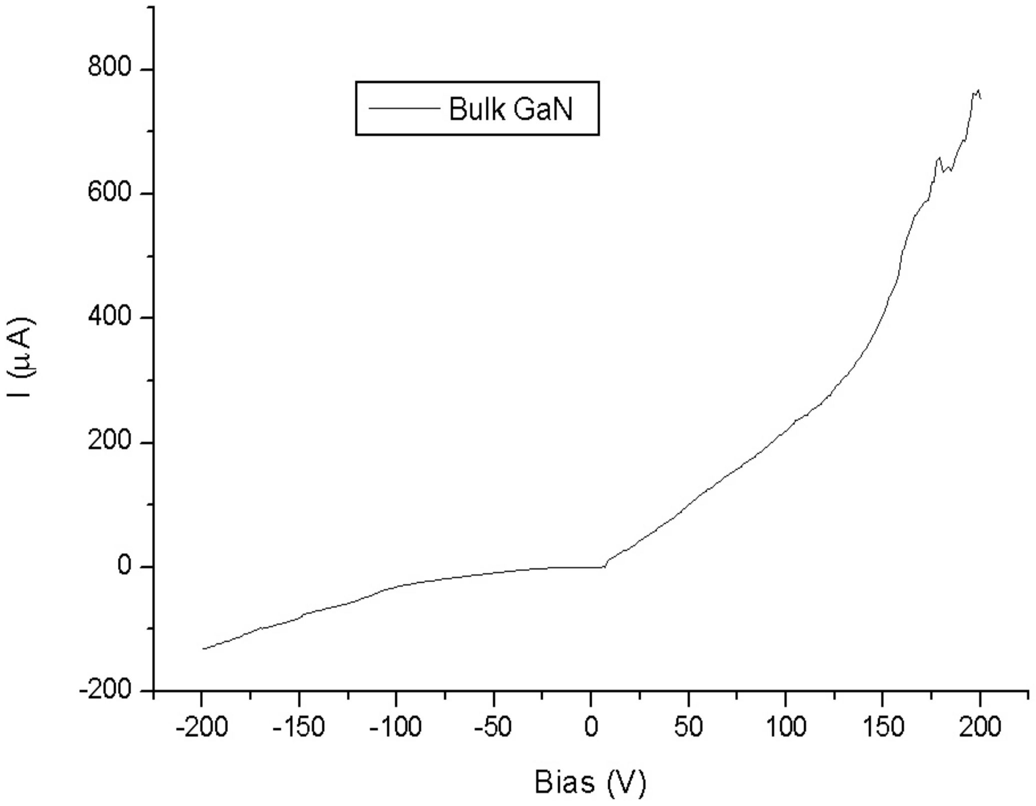
I-V's of SI epitaxial GaN



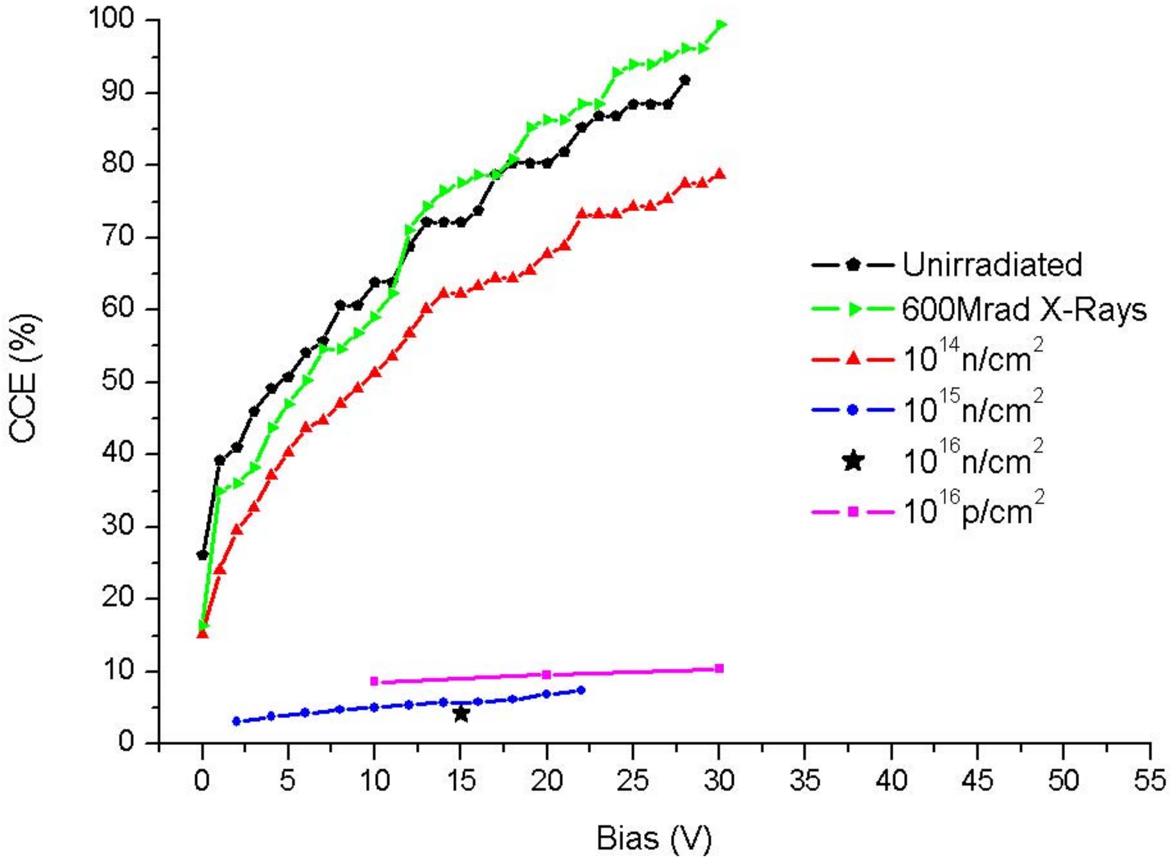


I-V characteristic of bulk GaN

Poor non-symmetric leakage values due to inhomogeneous crystal



CCE of SI epitaxial GaN



Analysis and Summary of GaN

- SI epitaxial GaN

  - Non-linear increase in leakage current with fluence

    has been observed in other widegap materials

  - CCE modification at high fluences

    ~5 % for 10^{16} cm^{-2} protons and neutrons

    could be improved by cooling?

- Bulk GaN

  - Diode fabricated. High leakage current. Could be explained by it's low resistivity + high density of defects

  - CCE measurements to come

Conclusions and Future Work

- Bulk SiC reasonably promising detector material

- Demonstrated potential of SI GaN for room temp ionising radiation detectors

- Fabricated bulk GaN devices. CCE measurements to be carried out

- Have 12μm epitaxial GaN. Device fabrication is ongoing

Background and Motivation

- Harsh environments present a severe challenge for designers of semiconductor devices and electronics

  e.g. electronics for use in space

  critical systems for nuclear reactors

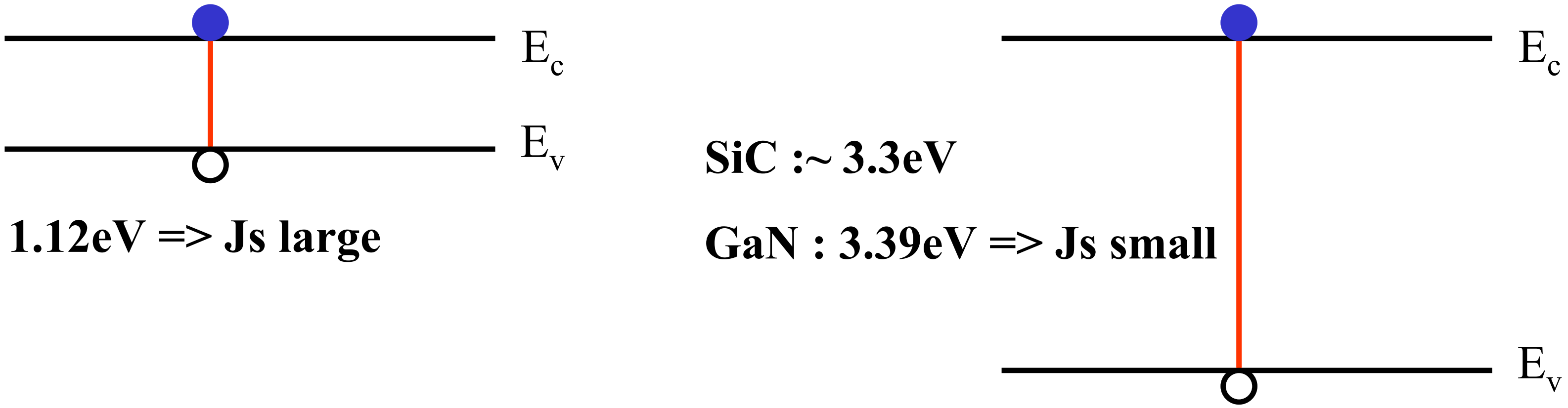
  position sensitive detectors for particle beams

- Radiation induced defects within s/c lead to

  - enhanced generation /recombination currents (J_s)
  - reduced charge collection signals
  - drift in the operating point

Wide Bandgap Materials

- Wide bandgap materials are often advertised as being radiation hard



Si : 1.12eV => Js large

SiC :~ 3.3eV

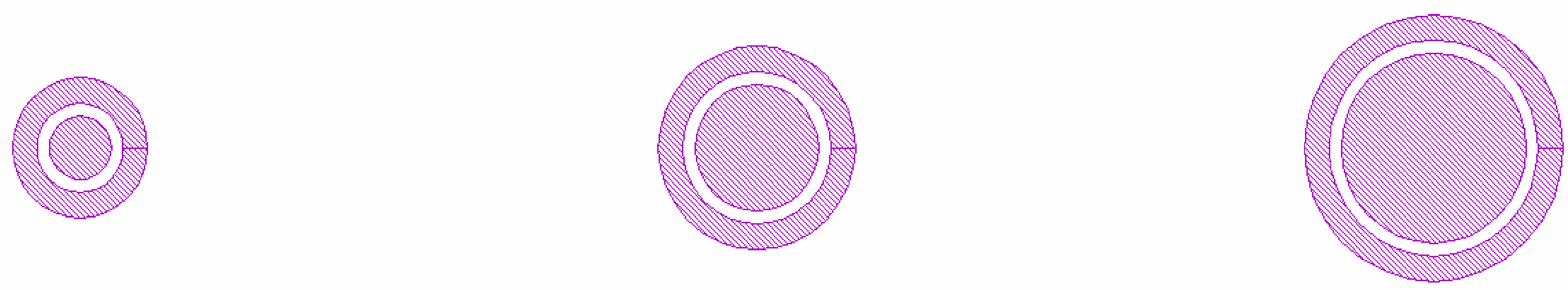
GaN : 3.39eV => Js small

- This arises because the large energy difference between any created defect levels and the conduction or valence band edges reduces the transition probabilities significantly. Hence any Js currents that are usually a problem with radiation damage are minimised

Fabrication (SiC)

➢ Pad/Guard ring structures fabricated on the 2 different SiC materials using photolithography techniques

- 100nm Ti Schottky front contact
- 100nm Ni ohmic back contact
- Si_3N_4 passivation of remaining free SiC surfaces (Okmetic SiC)



Pad Diameter 250-750µm

50µm between pad +GR

100µm thick GR

Fabrication (GaN)

- Pad/Guard ring structures for both the Bulk GaN and SI epitaxial GaN using photolithography
  - SI epitaxial GaN => 100nm Au Schottky contact
  - Bulk GaN => 80nm Pd for both front and back Schottky contacts