GaN for ionizing radiation detectors

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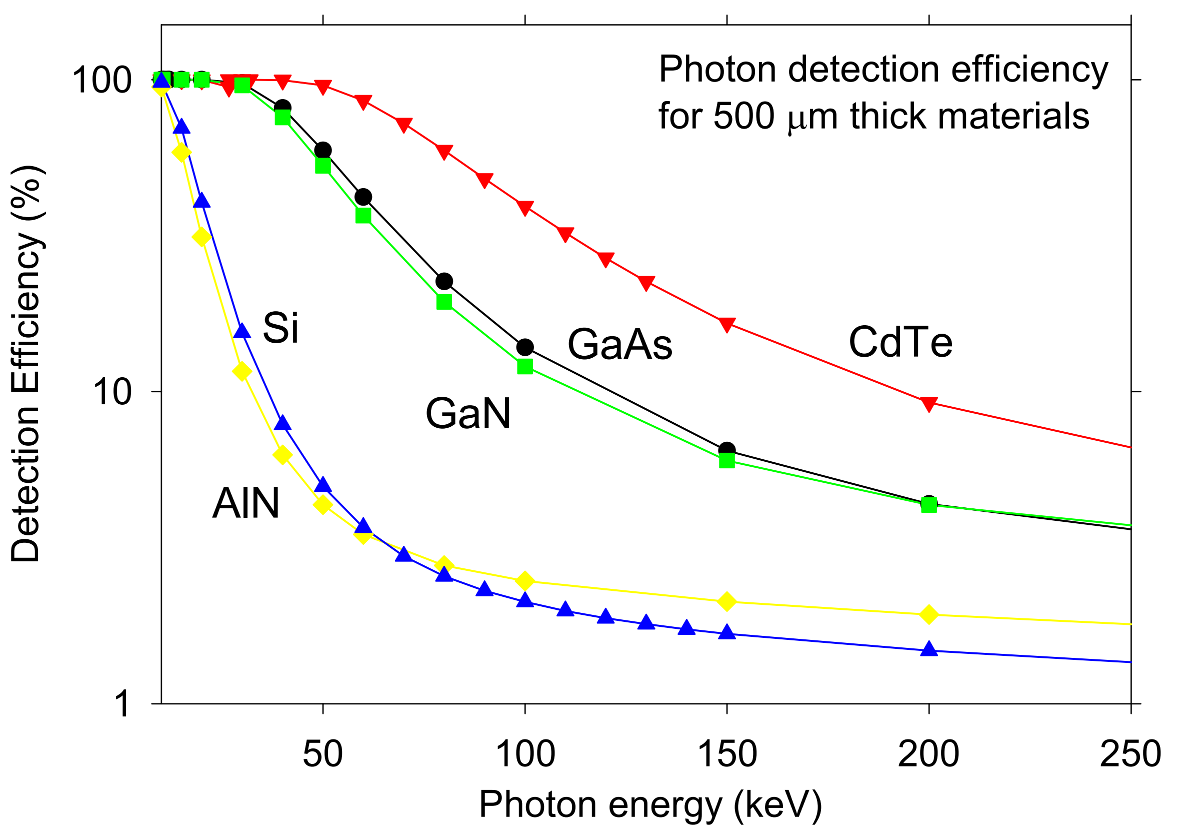
Introduction

- An initial characterisation has been made of epitaxial GaN detectors - a material of potential interest for X-ray imaging and charged particle detection
- SI epitaxial GaN of 2 μm thickness has been studied with alpha particles:

  $\Rightarrow$ good charge collection efficiency ; → a start of 0.45 mm high resisitivity GaN investigations.
- CV, luminescence and other analysis used to characterise the initial and irradiated samples

Photon Detection Efficiency for GaN

Atomic numbers of 31 and 7 provide good photoelectric absorption cross-sections:



Modelled using 'XCOM'

Juozas V.Vaitkus, RD50 3rd Workshop, 2003, CERN

Growth of epitaxial GaN

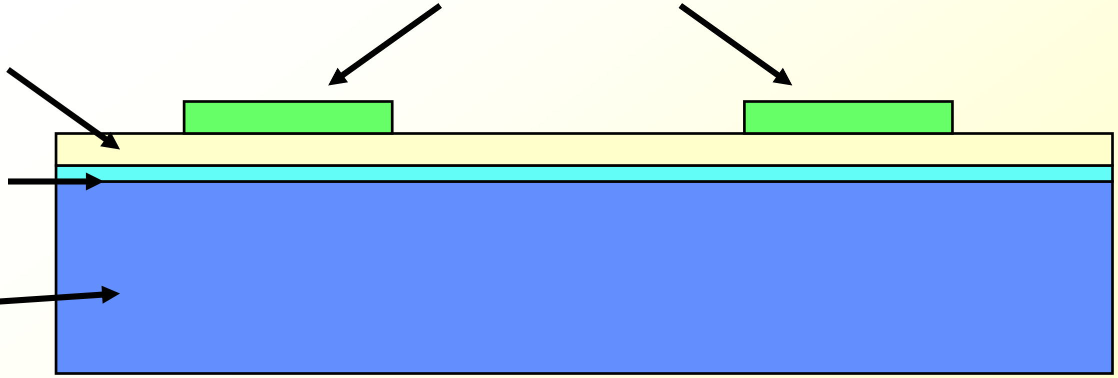
Thin epitaxial GaN layers are grown by metal organic chemical vapour deposition (MOCVD) - University of Tokushima, Japan

Growth process uses sapphire as a substrate, with an n-type conducting GaN buffer layer

High purity semi-insulating (SI) GaN layer is grown on top of the buffer layer

Typical SI GaN layer thickness is 2.5 μm

Mobility and carrier density can be optimised by varying growth temperature



Schottky contacts

high resistivity doped GaN (2.5μm)

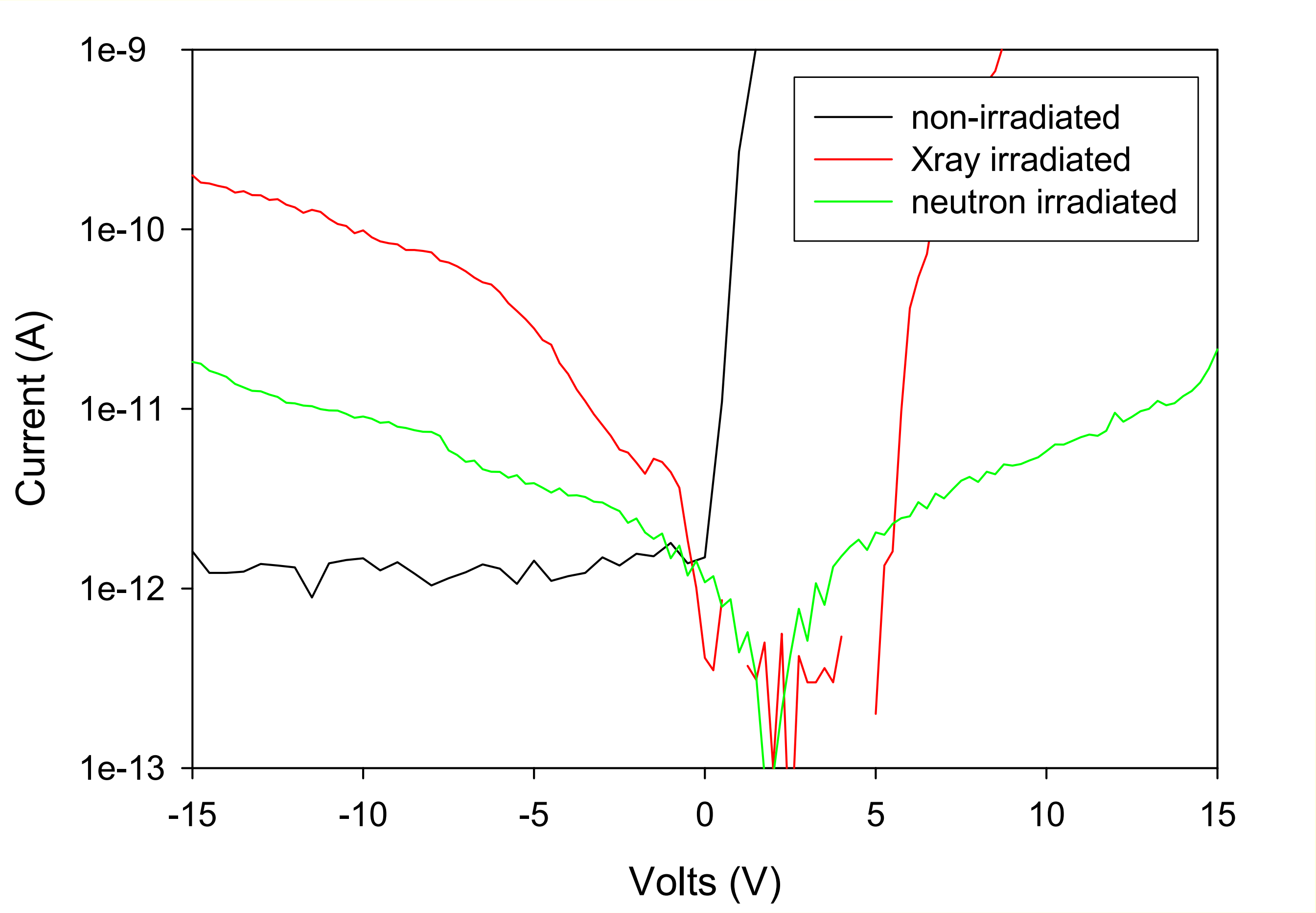
n-type undoped GaN (<1μm)

sapphire substrate

T. Wang et al, Applied Physics Letters ***76*** *(2000) 2220-2222*

IV characteristics

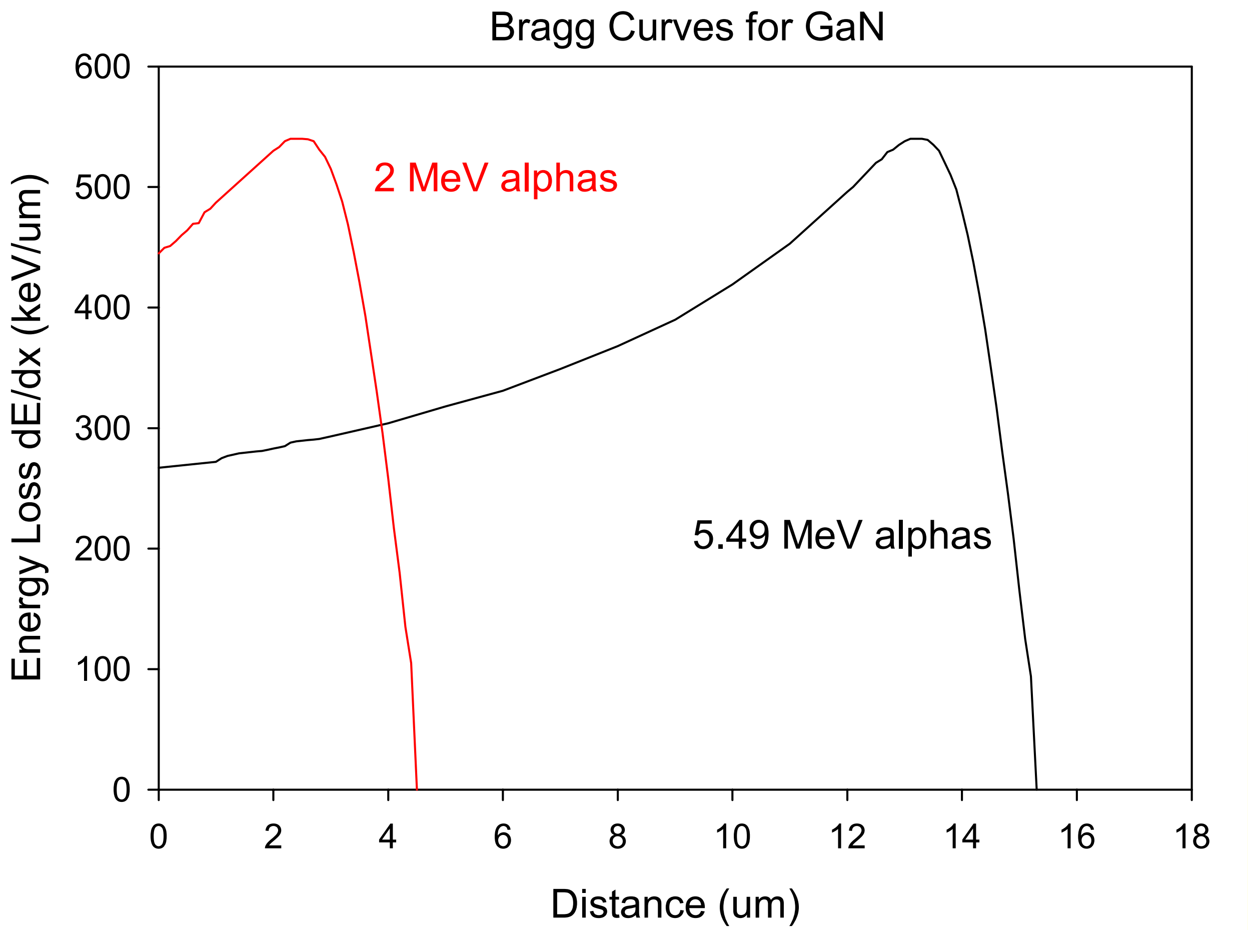
IV data on epitaxial device shows good diode characteristics from Schottky contact. Reverse-bias current ~10^{-12} A at -15V (J = 6×10^{-11} A/cm^2)



Some degradation in IV behaviour is observed in irradiated devices

Bragg curves in GaN

Alpha particle range is much greater than 2 μm active thickness of GaN layer:



Energy deposited by alpha particles in 2 mm of GaN estimated from Bragg curves (SRIM):

2 MeV alpha: 949 keV

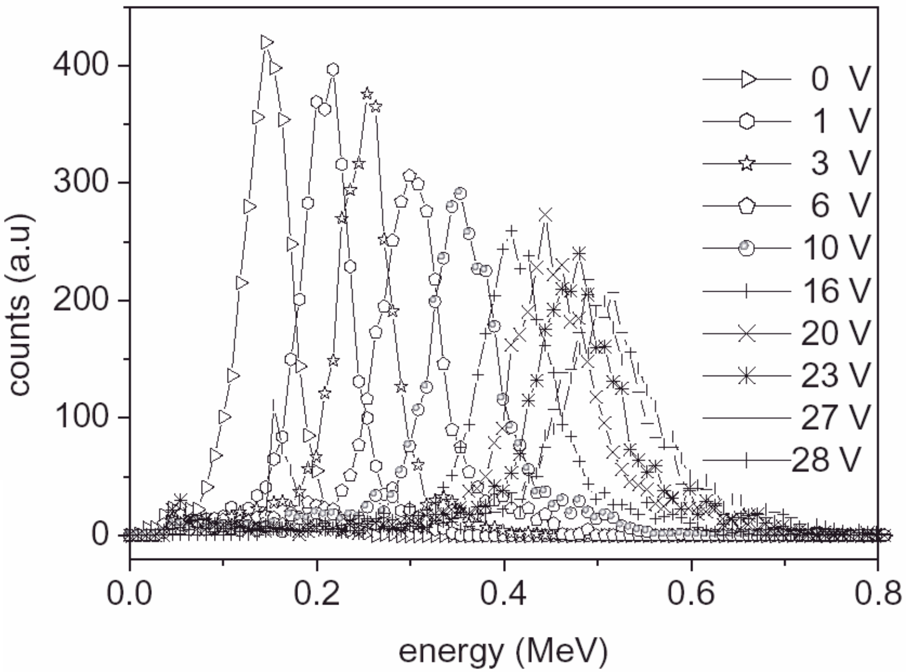
5.49 MeV alpha: 553 keV

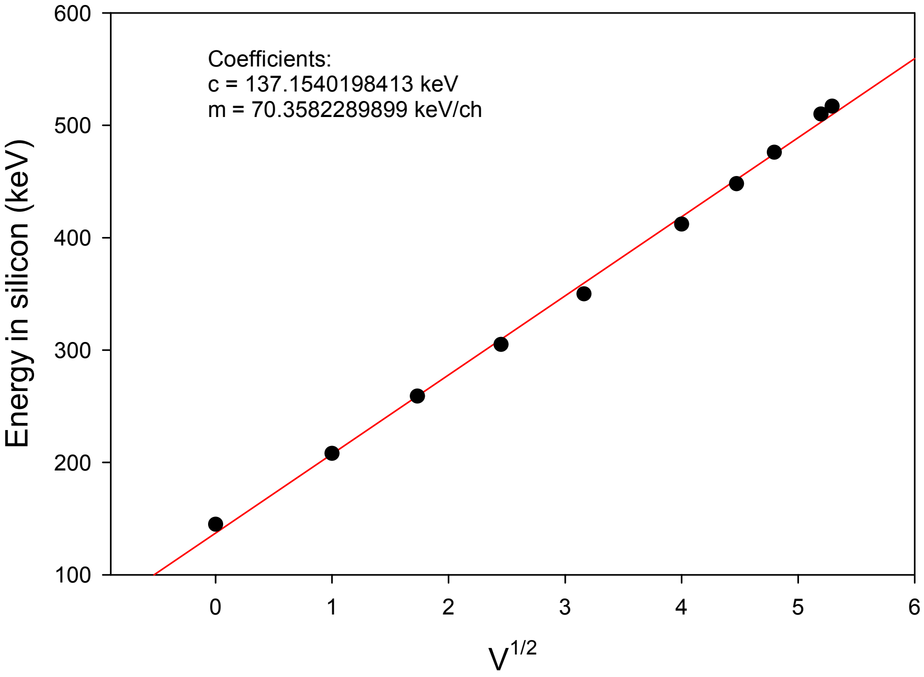
Alpha particle spectra

Room temperature alpha particle spectra:

⇒ systematic increase in measured energy as a function of bias voltage, as field strength increases

⇒ no evidence for charge trapping in this thin material





Plotting alpha peak centroid vs $V^{1/2}$:

⇒extrapolate to deposited energy in 2 μm of 553 keV

⇒ shows full charge extraction from layer at V=35V

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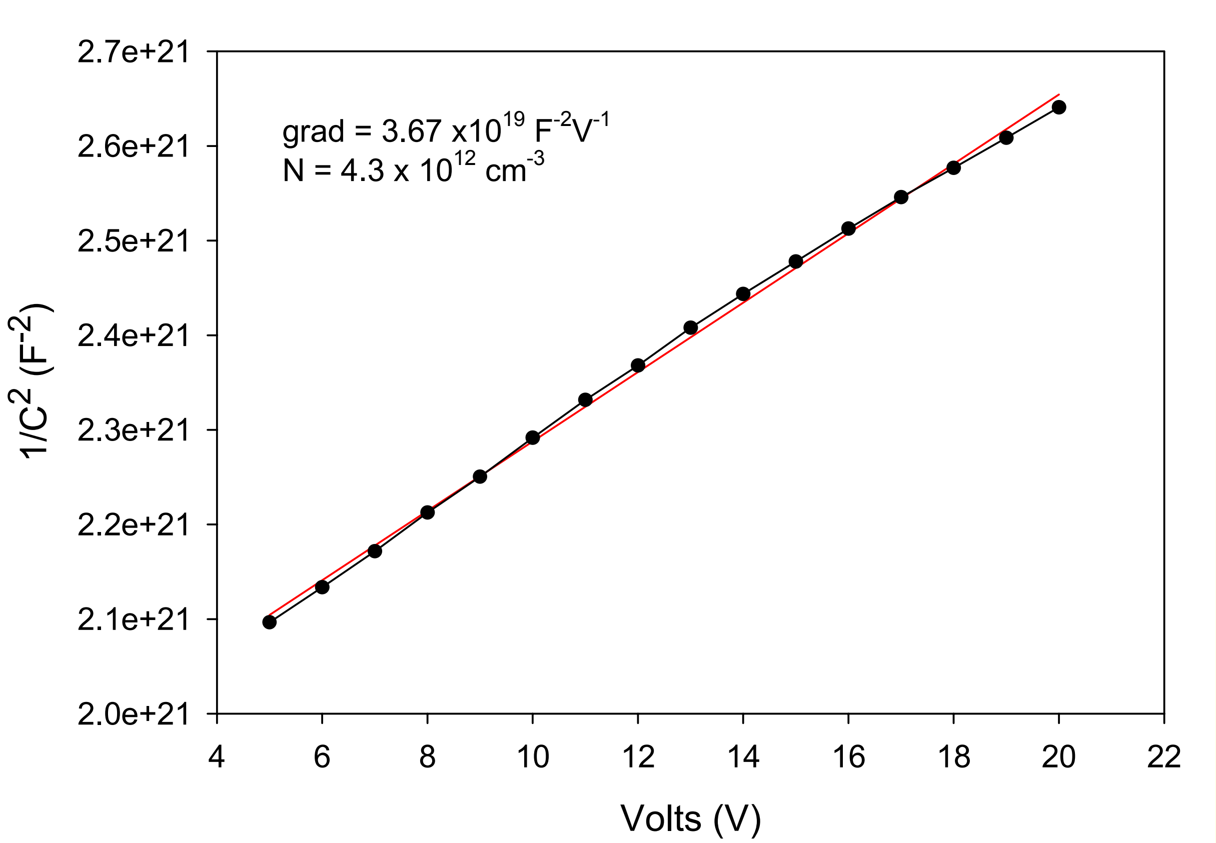
CV analysis of GaN

The nett impurity concentration N_D is calculated from room temperature CV measurements using

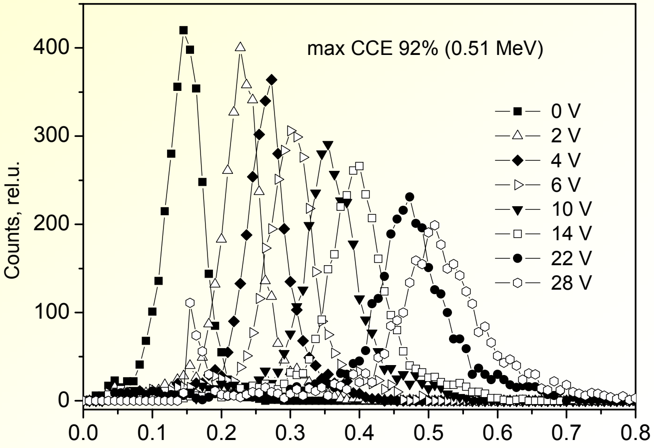
$$N_D = \frac{2}{q\varepsilon_0\varepsilon_R A^2 \, d\left(1/C^2\right)/dV}$$

For 1.5 mm diameter contact pads, $\boldsymbol{N_D}$ **= 1x10^{13} cm^{-3}** - good quality material

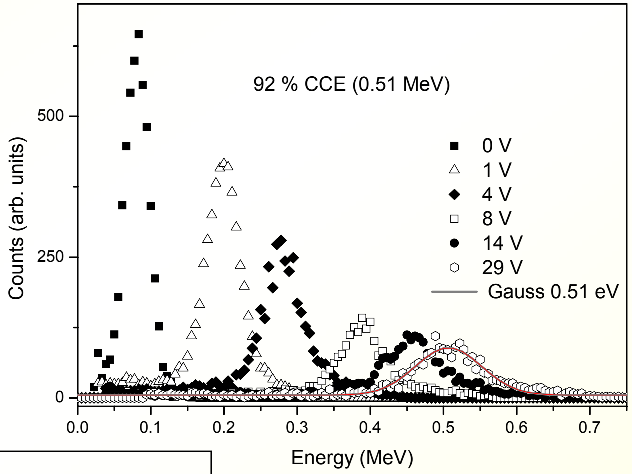


Alpha particle response

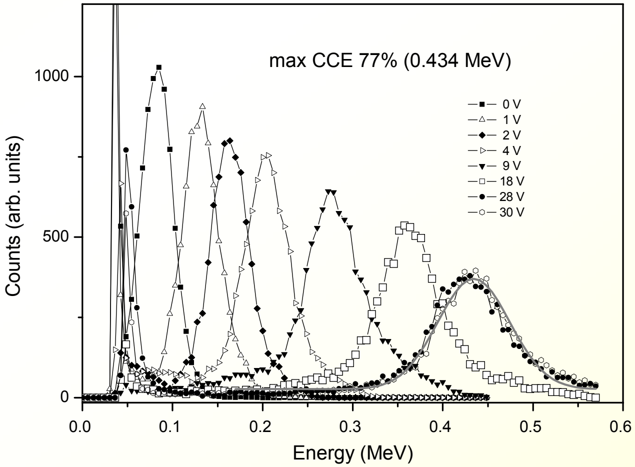
2 devices were irradiated to investigate radiation hardness - with 600 MRad X-rays and $5x10^{14}$ cm^{-2} neutrons:



Nonirradiated SI-GaN



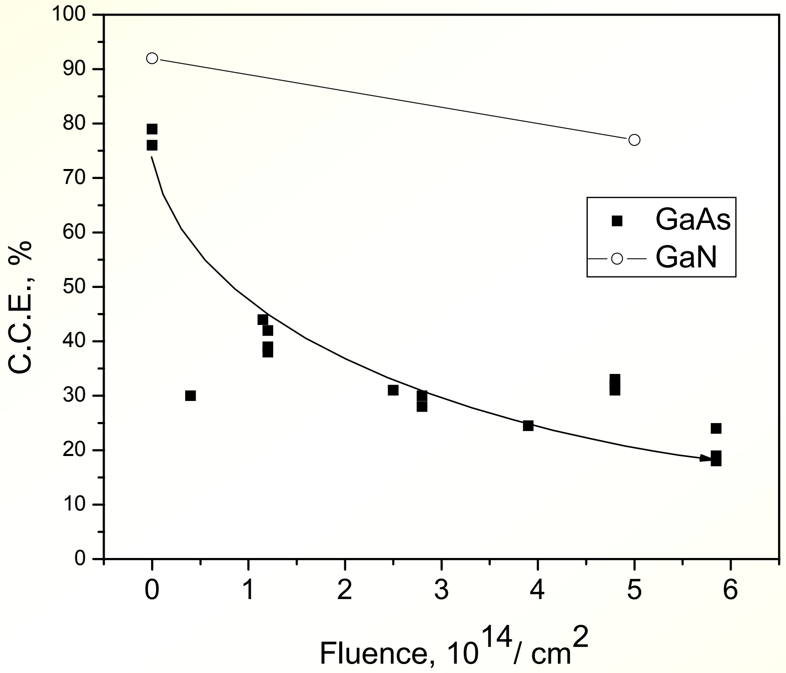
SI-GaN Irradiated by X-rays, 10 keV, 600 Mrad



SI-GaN irradiated by neutrons, >100 keV, up to the fluence of $5\cdot10^{14}cm^{-2}$.

Alpha particle response of irradiated devices

Comparison of GaAs and GaN irradiated by neutrons:



GaAs from: Bates, R.L., Da Via C., D'Auria S., O'Shea V., Raine C., Smith K.M. and RD8 collaboration. The effects of radiation on gallium arsenide radiation detectors. Nuclear Instruments and Methods in Physics Research Section A, 21997; 395:54-59

Photoconductive Decay measurements

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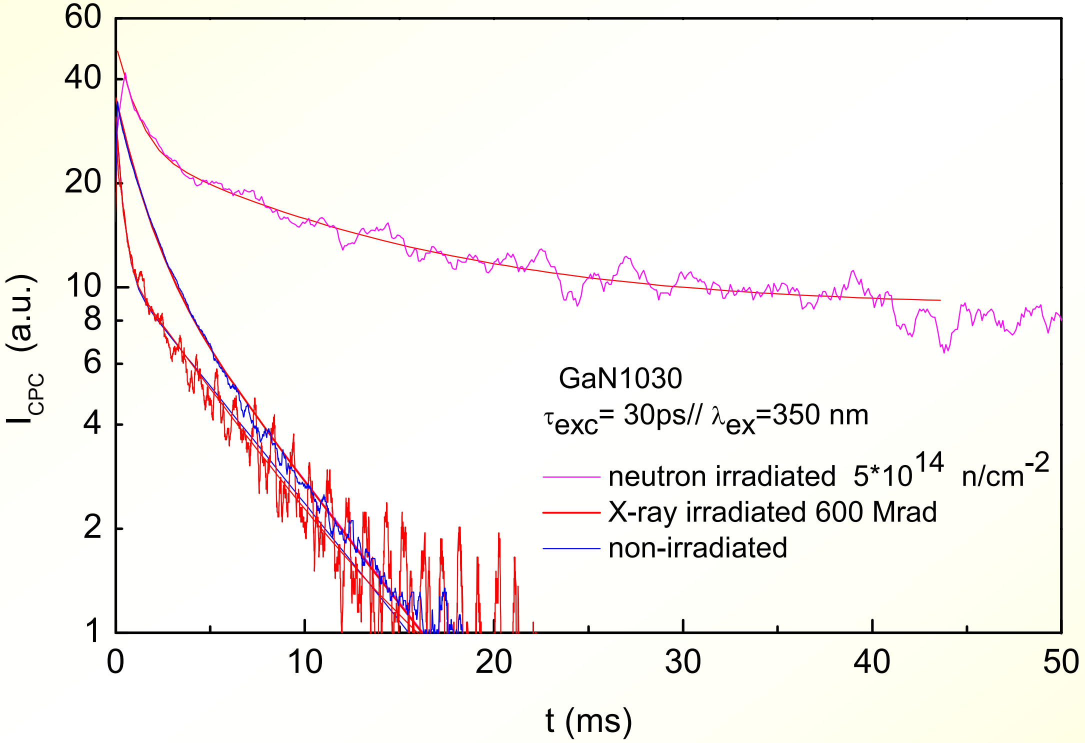


Ion Beam Induced Charge (IBIC) measurements

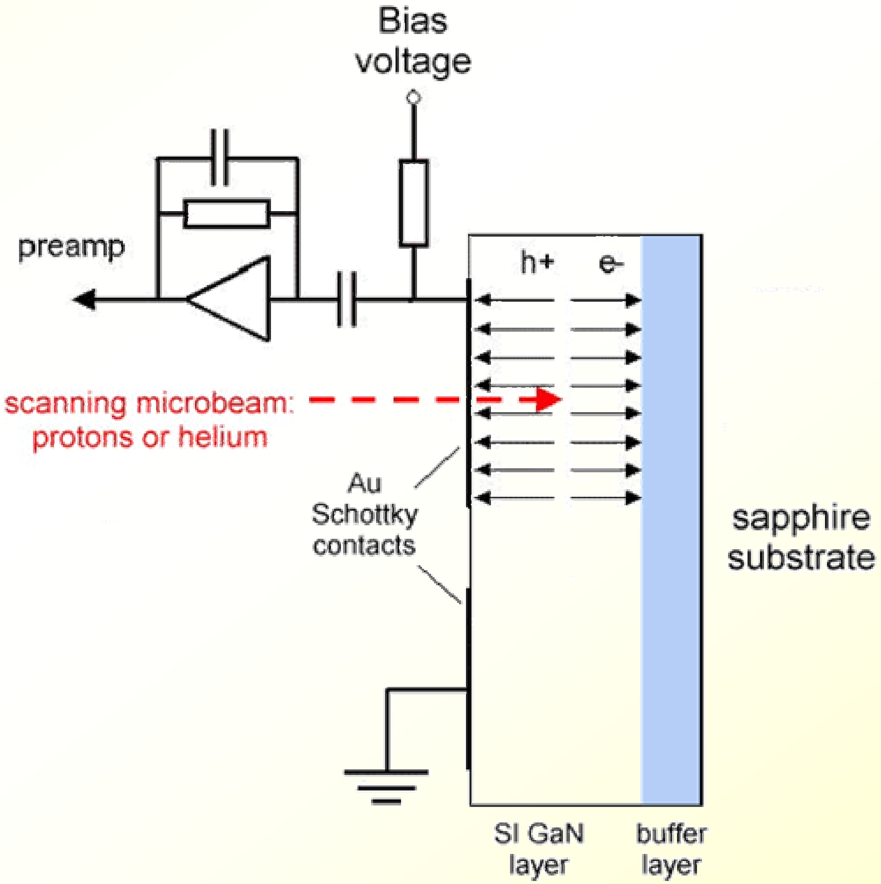
Surrey facility

Ion Beam Induced Charge (IBIC) data provides:

- high spatial resolution imaging of charge signal uniformity
- single event detection
  (~1 kHz event rate on sample)
- true bulk measurement

Ion beam is incident orthogonal to one of the electrodes:

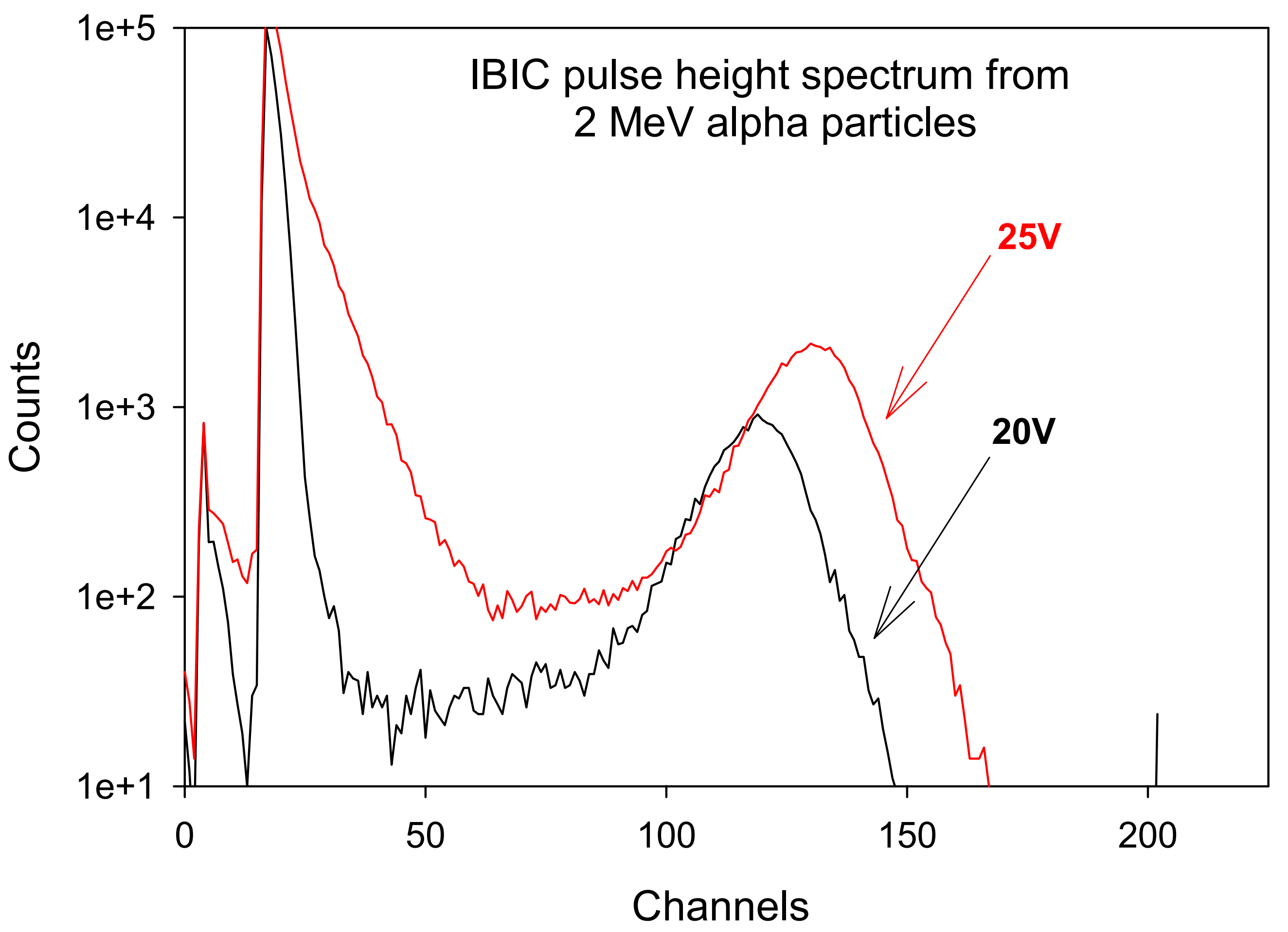
- charge drift through the SI GaN layer to the conducting buffer layer
- alpha beam cannot pass through silver DAG



Alpha IBIC spectra from GaN

SRIM estimate of energy loss in 2 μm layer = 950 keV

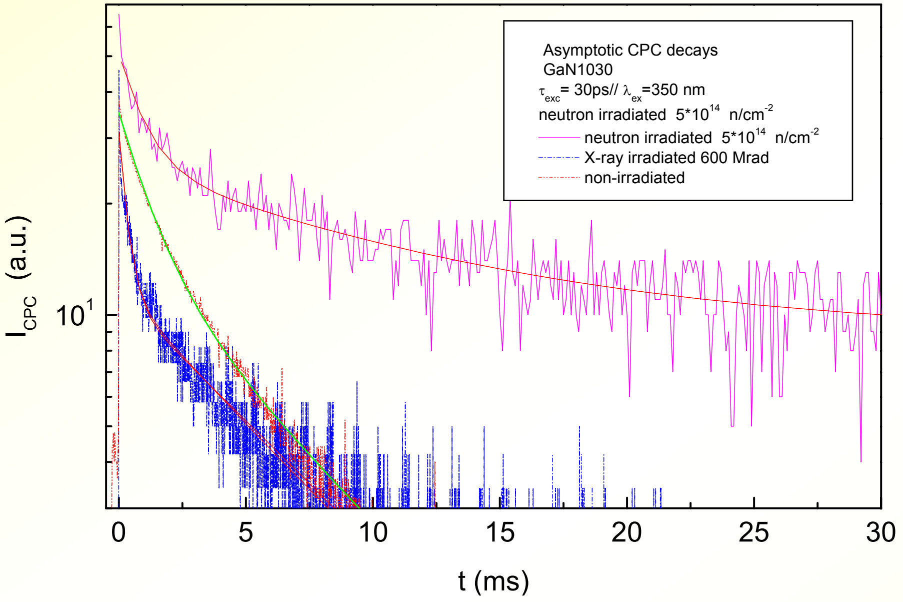
Saturation of peak centroid at V=25V

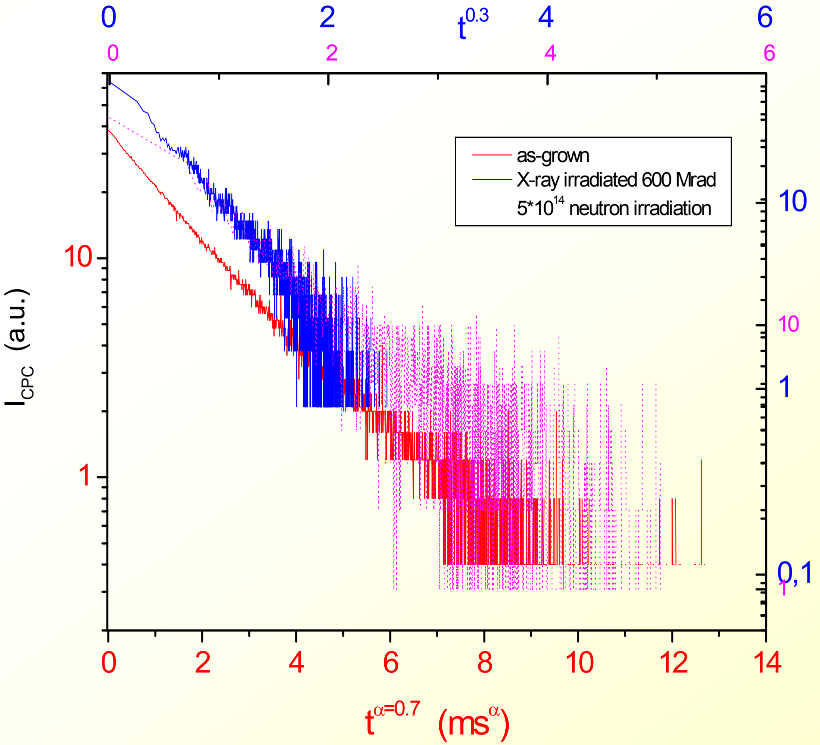


Photoconductivity decay measurements

Photoconductive decay time constants have been measured in the 3 samples

Neutron-irradiated sample shows higher intensity slow components





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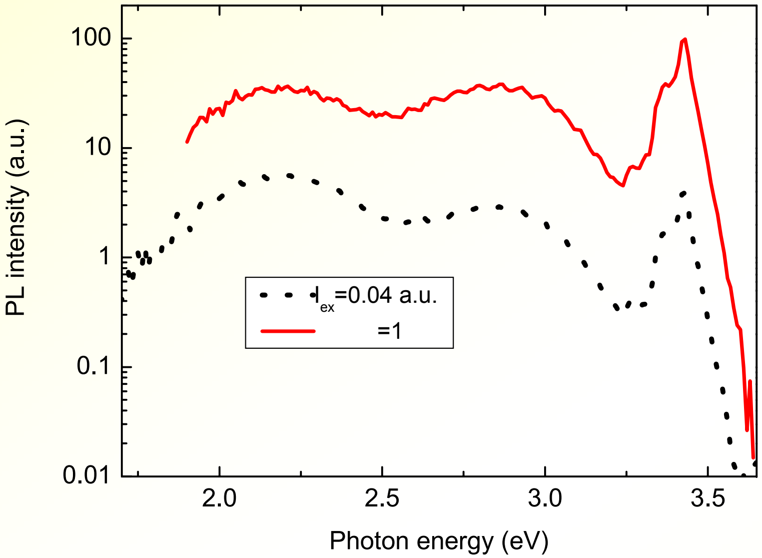
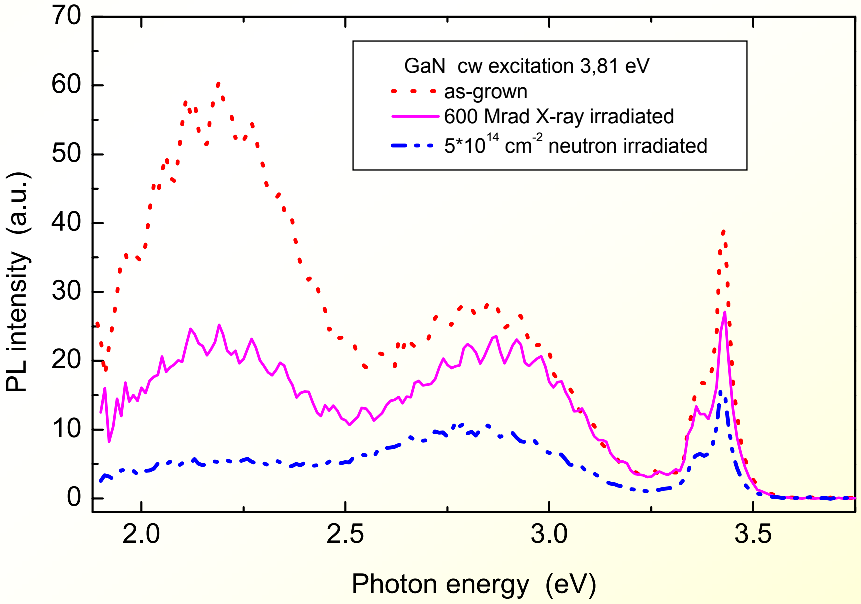
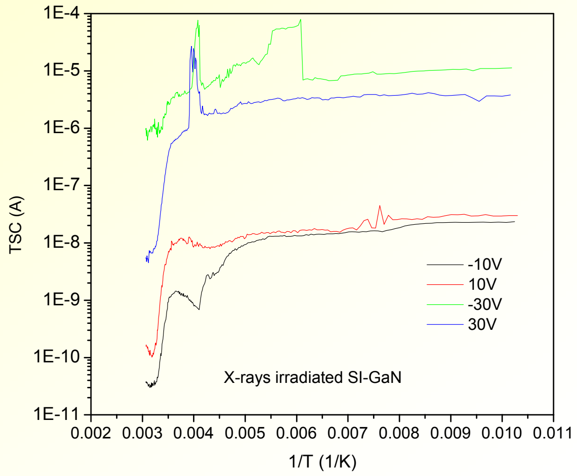
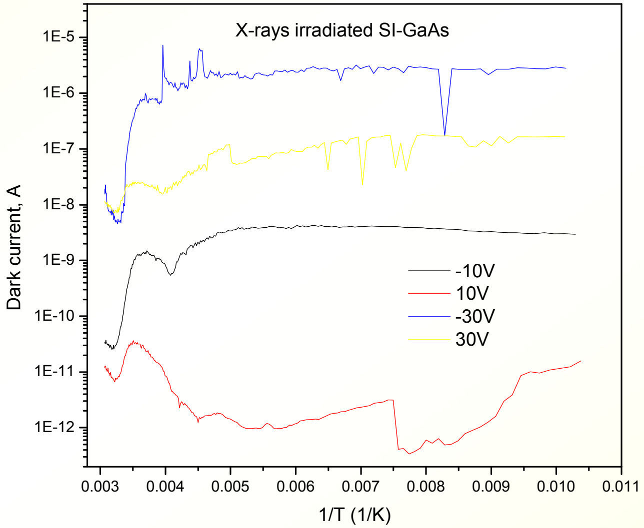
Photoluminescence spectra measurements

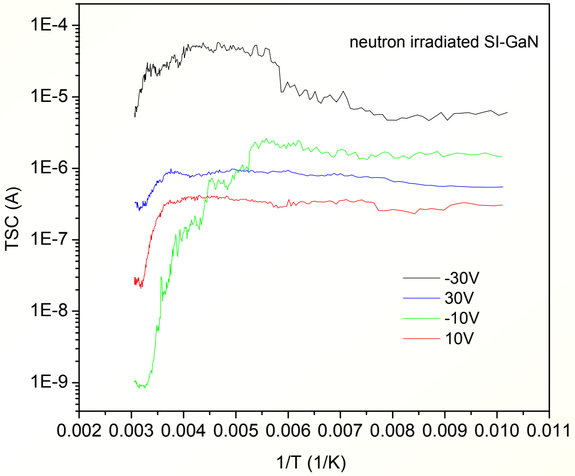




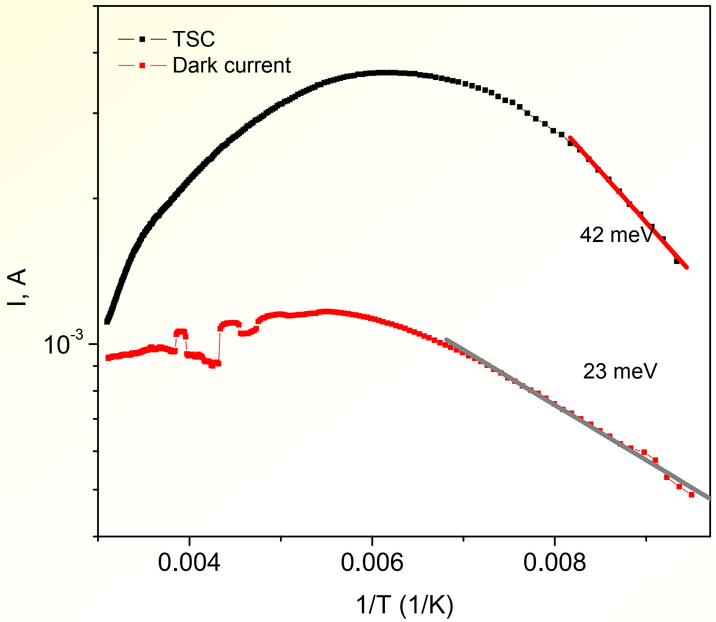
Thermally stimulated conductivity measurements, SI-GaN

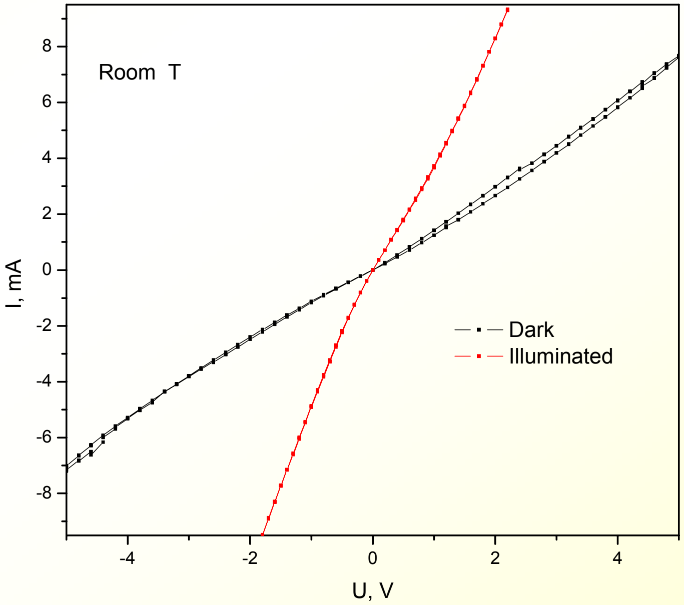




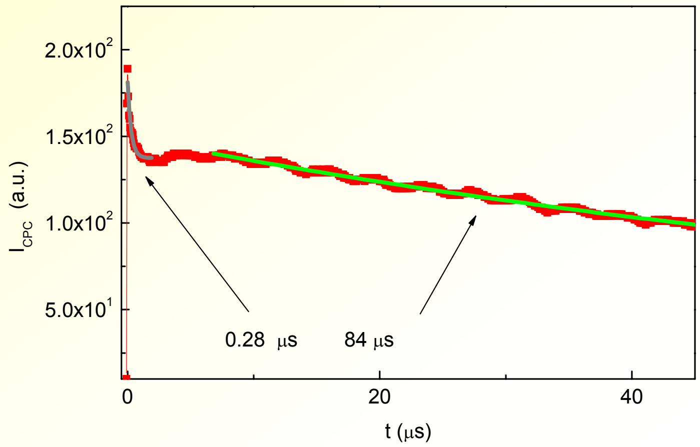


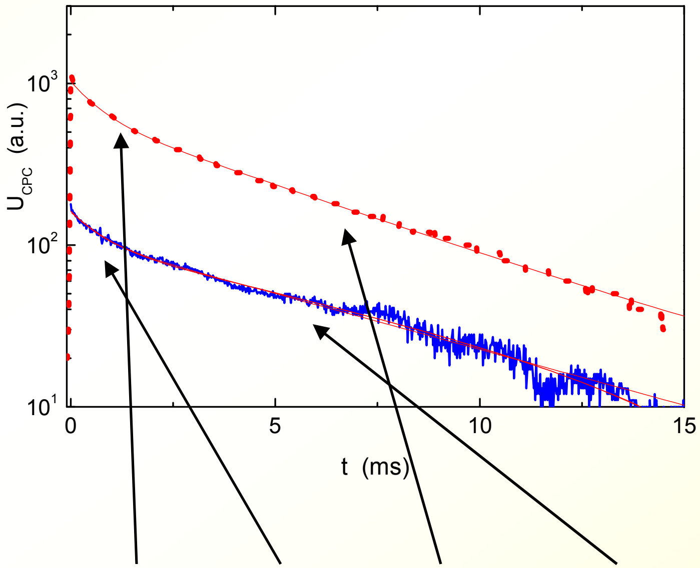
TSC and I-V measurements, HR-GaN



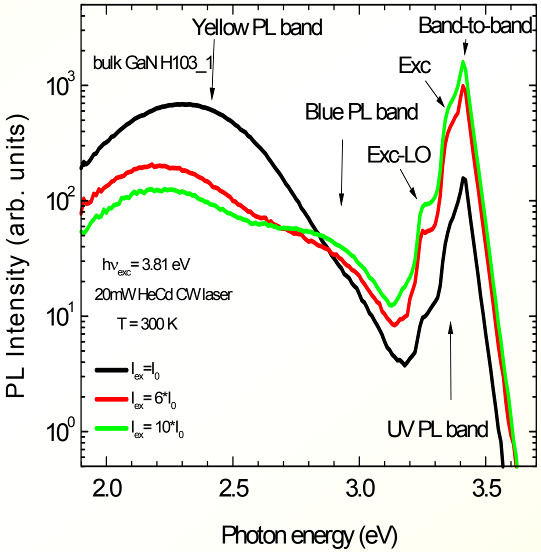


TSC and I-V measurements, HR-GaN





0.5µs 0.6 µs 6.2 µs 6.3 µs



Conclusions

We have carried out a preliminary characterisation of three epitaxial SI-GaN detectors:

- High purity SI GaN detector of 2 μm thickness shows good alpha particle response.

  Gold Schottky contacts show good diode behaviour - reverse bias leakage current is ~10^{-12} A at -15V (J = 6×10^{-11} A/cm^2)

  CV analysis gives a carrier concentration of 1×10^{13} cm^{-3}
- initial IBIC imaging shows excellent material uniformity and ~100% CCE in very thin layers
- Luminescence, lifetime and TSC shows the defect types
- further measurements are required with thicker epitaxial layers, whilst maintaining ~ 10^{13} cm^{-3} carrier concentration. What will show the thick one? – Next workshop!