Ion Beam Induced Charge imaging of charge transport in bulk 4H-SiC and epitaxial GaN detectors

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Introduction

- An initial characterisation has been carried out using a high resolution nuclear microbeam to examine charge transport uniformity in bulk 4H-SiC and epitaxial GaN detectors

Bulk SiC:

- study of material uniformity due to micropipes and other defects
- investigation of trapping and relative charge drift lengths λ_e, λ_h of electrons and holes
- measurement of pulse timescales - evidence for slow detrapping of charge over microsecond - second timescales
- possible degradation of response after 10^{13} cm^{-2} pion irradiation

Epitaxial GaN:

- expect very good material uniformity in thin epitaxial GaN layers
- investigate charge collection efficiency vs temperature
- effects of radiation damage

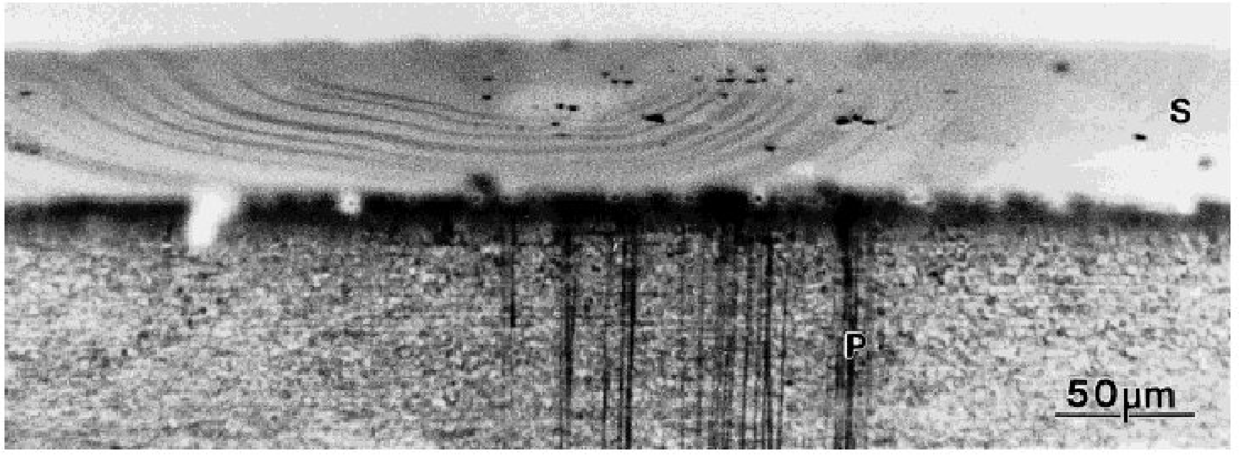
Properties of bulk 4H-SiC

SiC has been characterised for radiation detectors in both 4H and 6H polytypes, initially as semi-insulating bulk material, and increasingly as epitaxial layers.

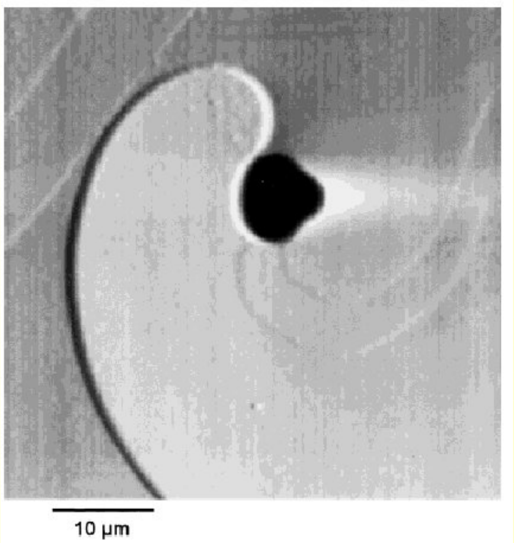
Intrinsic electron mobility is good, hole mobility is less good:

	6H-SiC	4H-SiC
μ_e (cm^2/Vs)	370	1000
μ_h (cm^2/Vs)	50	50-100
band gap (eV)	3.03	3.26
saturated v_e (cm/s)	2.4×10^6	2.2×10^6

Cree semi-insulating SiC is usually vanadium-doped at ~$10^{18}cm^3$



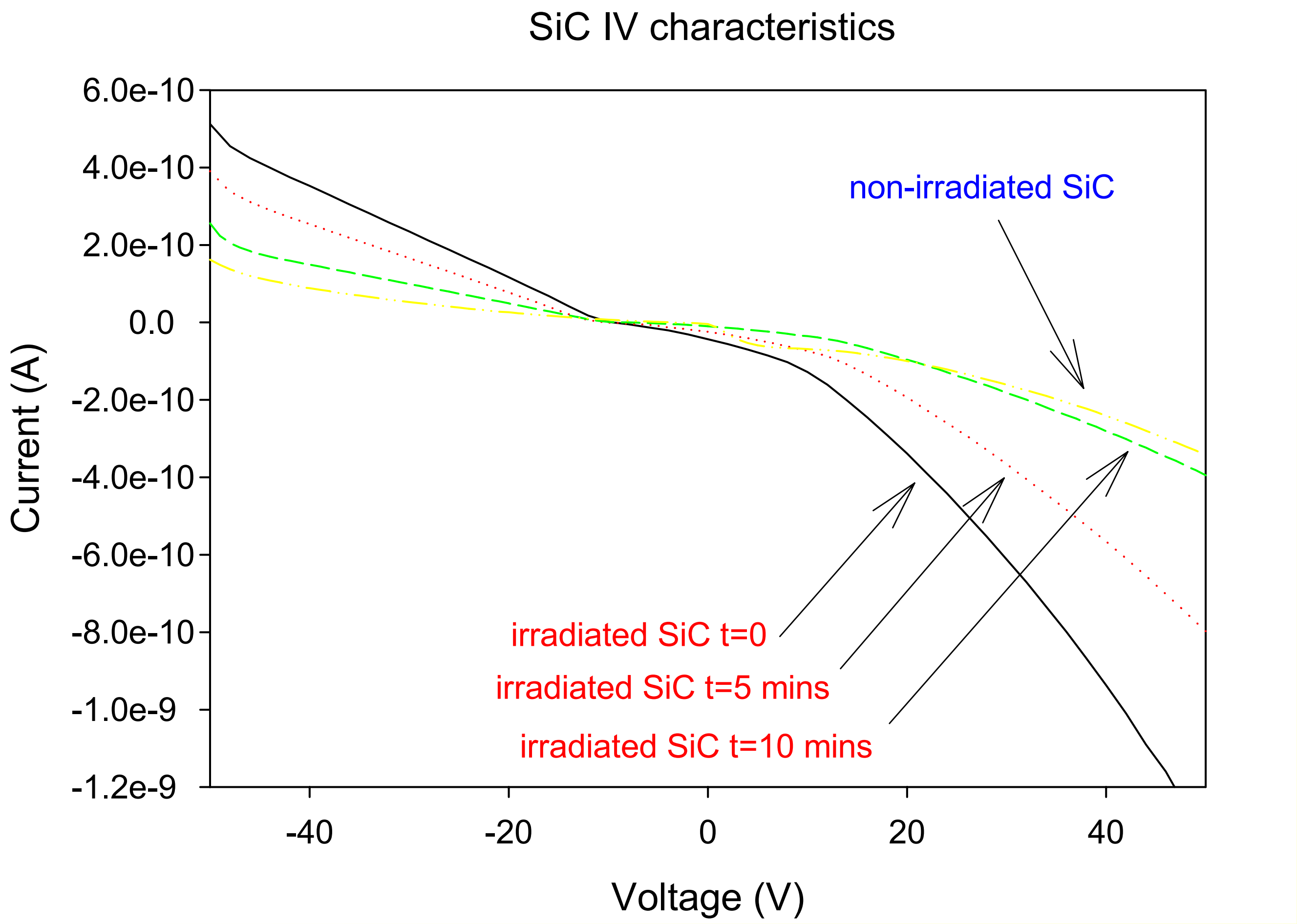
J. Heindl et al, Phys Stat Sol. A162 (1997) 251-162



IV properties of bulk SiC

IV data acquired with floating guard rings.

Generally ohmic: $\rho = 5.5 \times 10^{10}\ \Omega$cm (non-irrad), $\rho = 2.4 \times 10^{10}\ \Omega$cm (irrad)



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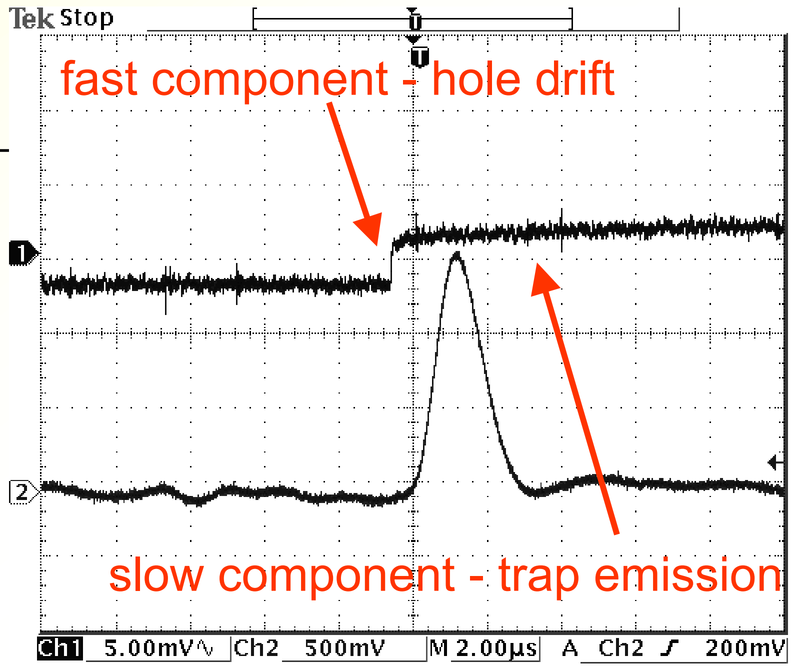
Alpha particle pulses

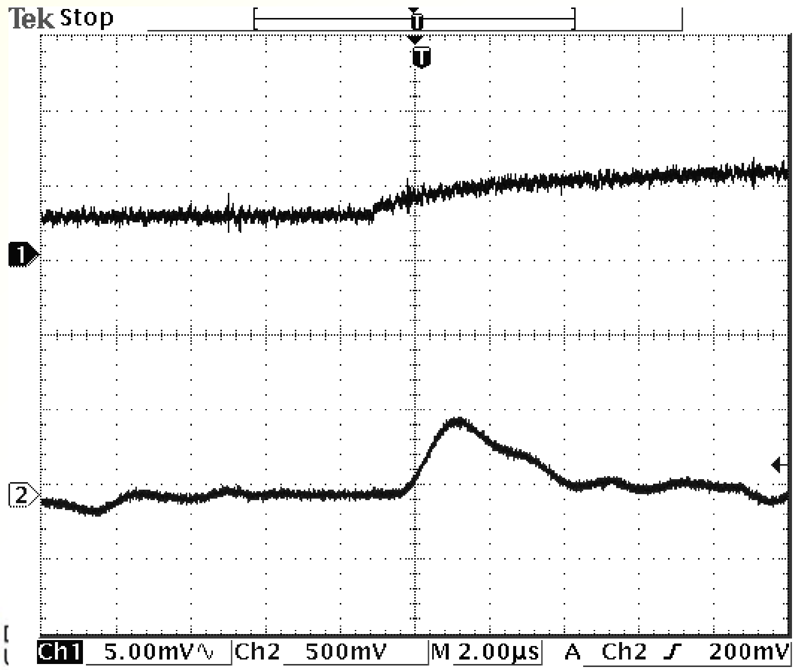
Alpha particle irradiation of the anode - sensitive to hole transport through the bulk

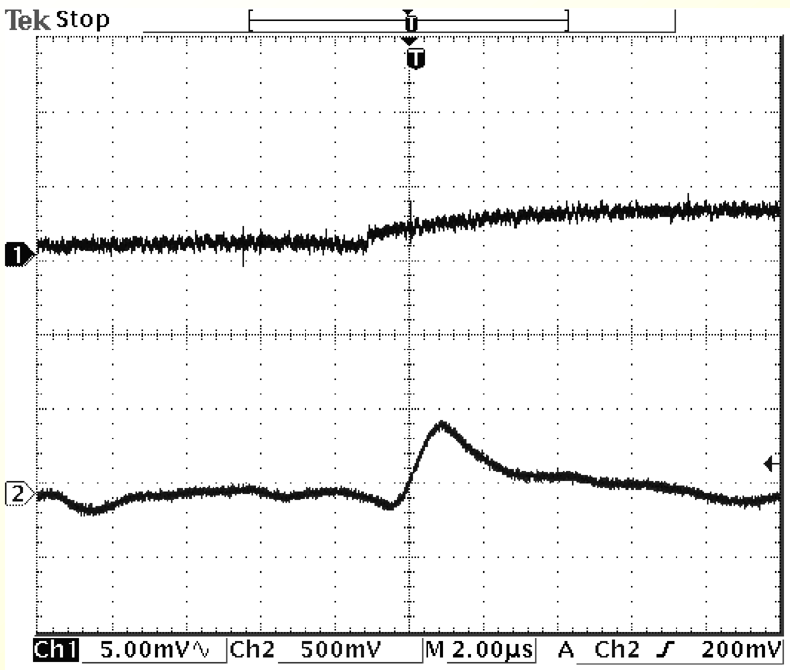
Preamplifier pulse shapes show fast and slow components - several microseconds duration

Pulse shapes vary at fixed bias - position dependent?

Cathode irradiation shows no electron transport over short (< ms) time-scales







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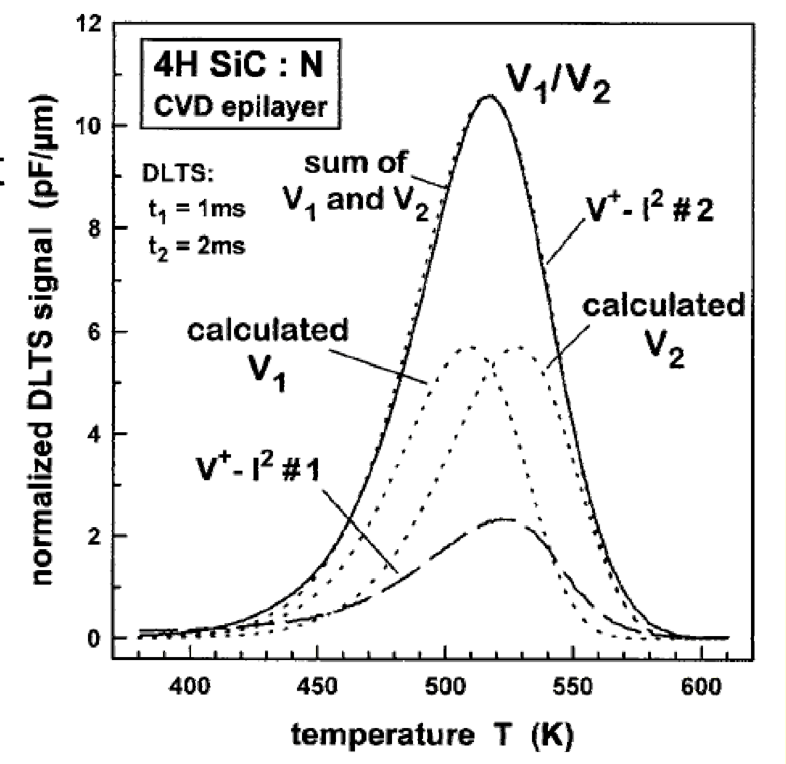
Trapping model in bulk SiC

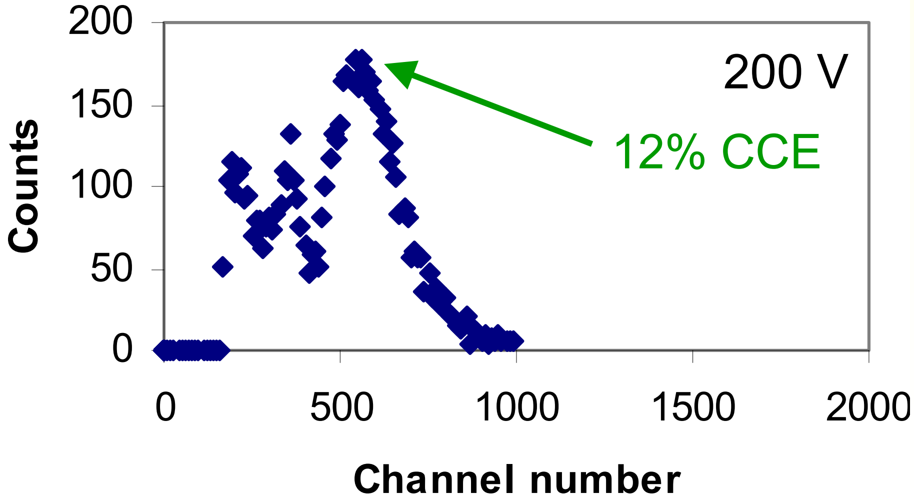
- Deep traps are known in V-doped SiC - eg. DLTS studies of V-doped 4H-SiC epi layers (T. Dalibor et al, Phys Stat Sol **A162** 1997 199-225)
- 2 overlapping V states observed - acceptor levels at room temperature at energy *Ec - (880 to 970)* meV
- What is the origin of microsecond hole signals - is it just low mobility?
  - Assume 200V over 100 μm
    $\Rightarrow$ E = 2×10^4 V/cm
  - With $\mu_h \sim 50$ cm^2/Vs $\Rightarrow$ v = 10^6 cm/s
    $\Rightarrow \Delta t$ = 10 ns drift time

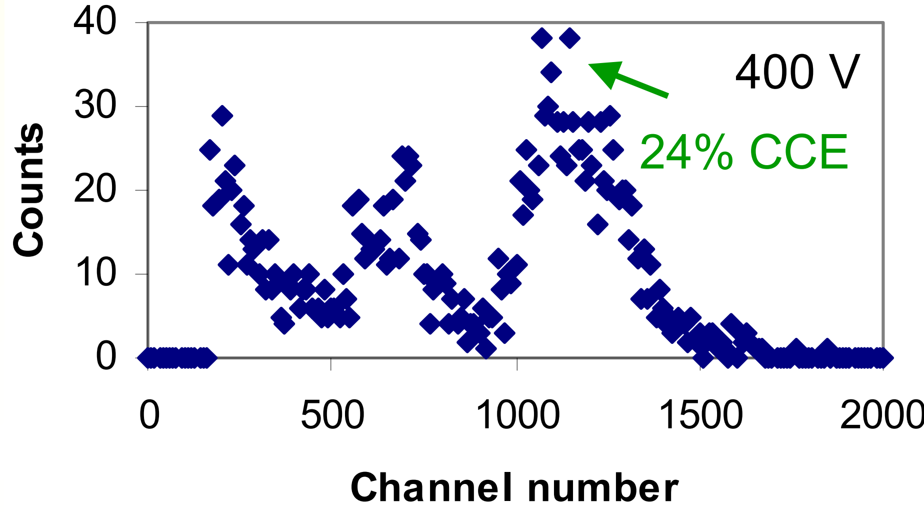
  Most likely due to trapping followed by re-emission of charge

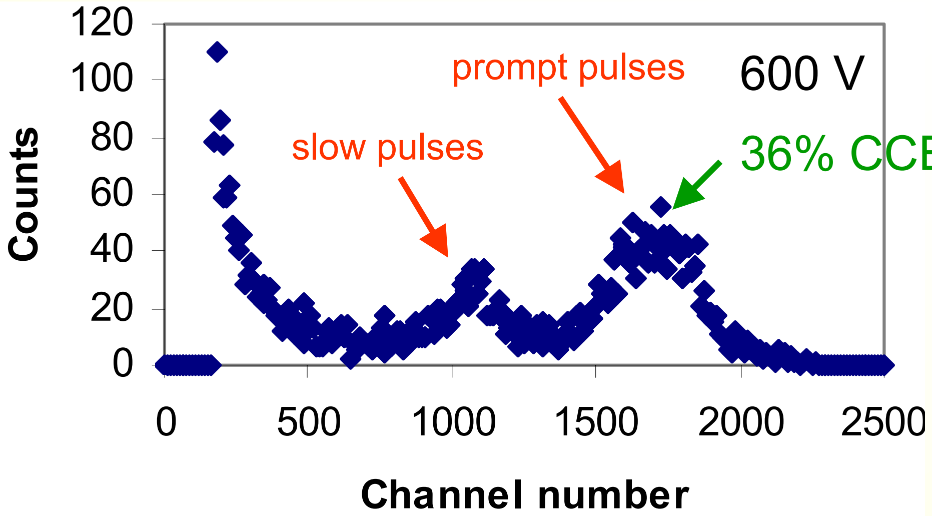
  Temperature-dependent pulse shape analysis is need for further confirmation

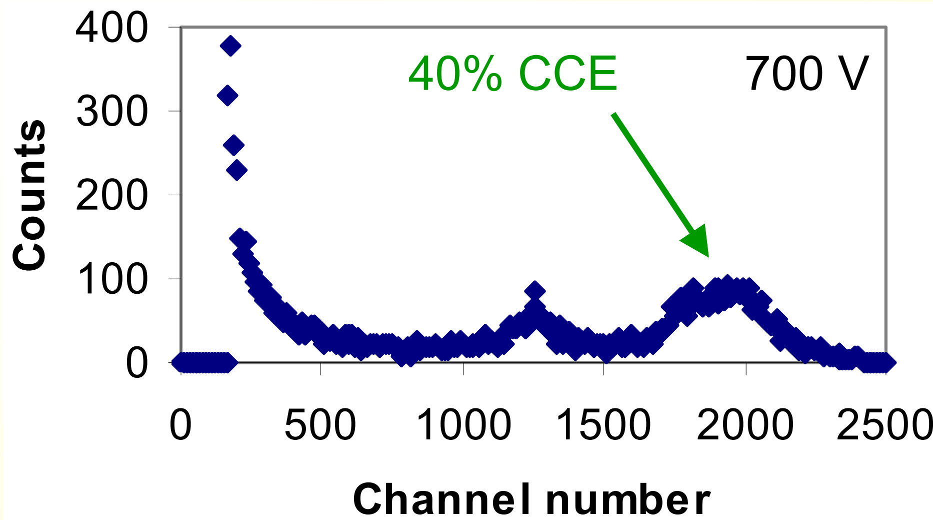


Alpha particle spectra from SiC



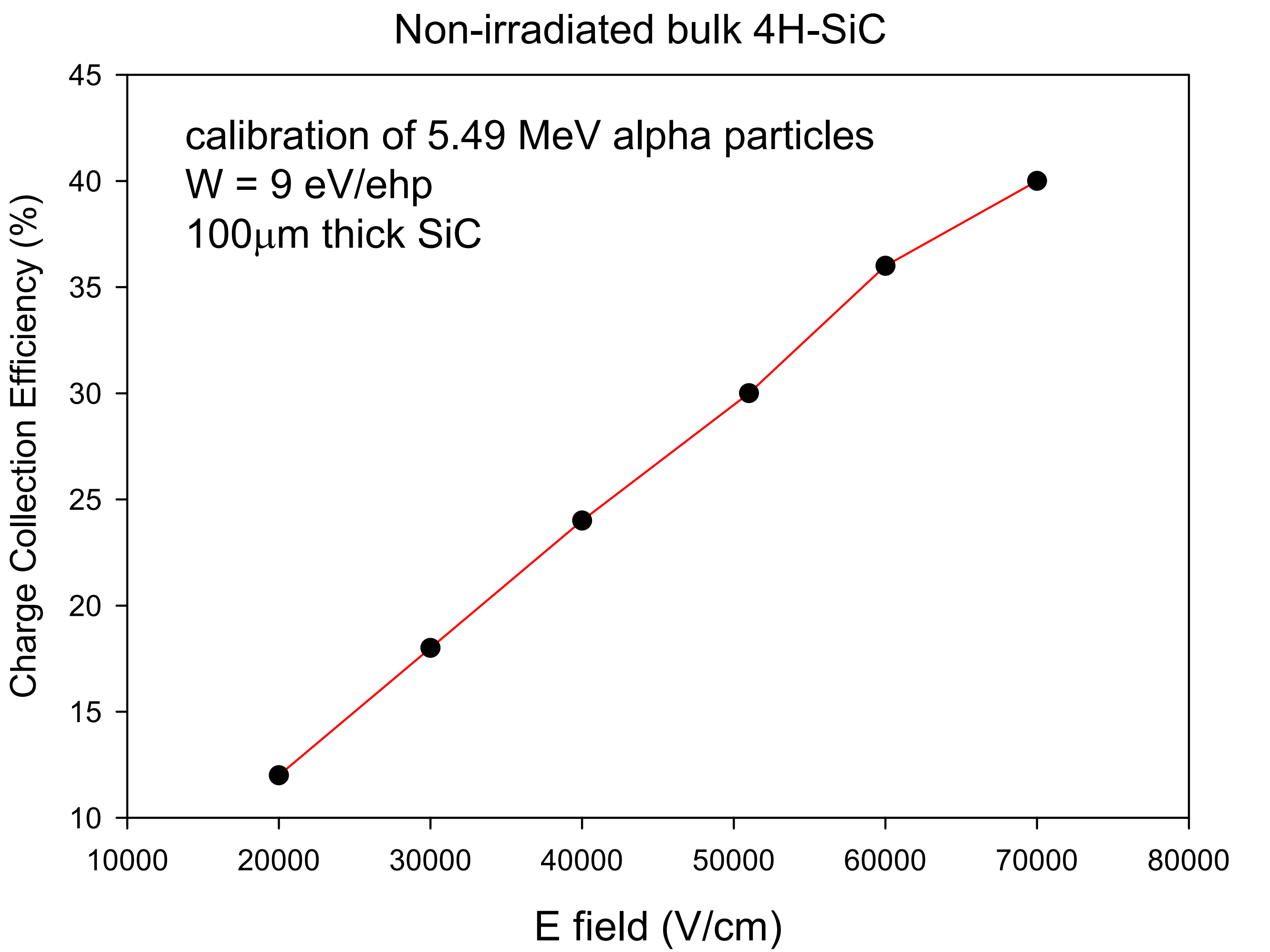






Summary of alpha CCE at Room Temperature

Hole drift lengths are increasing linearly with E-field - no saturation visible up to 7×10^4 V/cm (V=700 V). No electron transport observed



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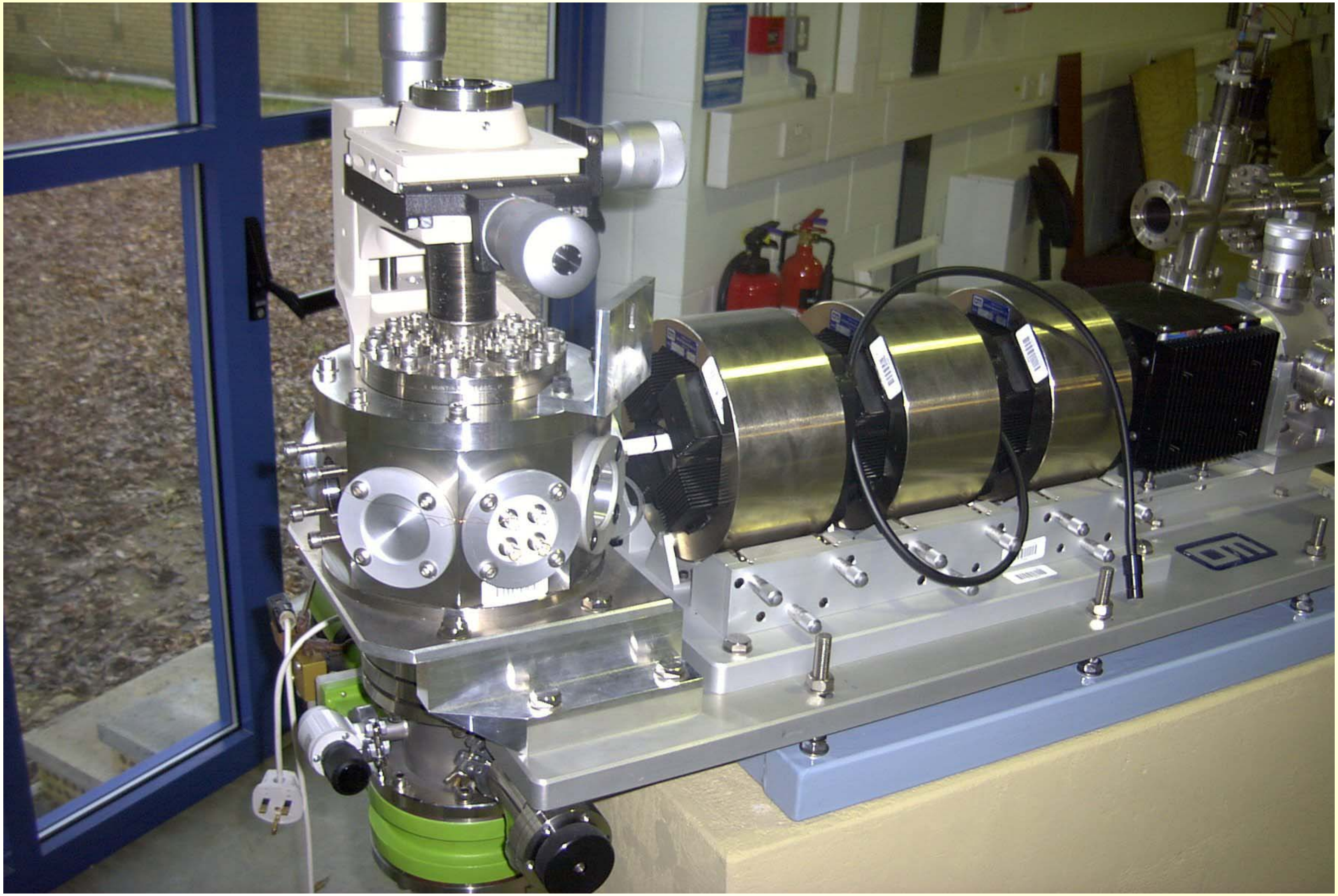
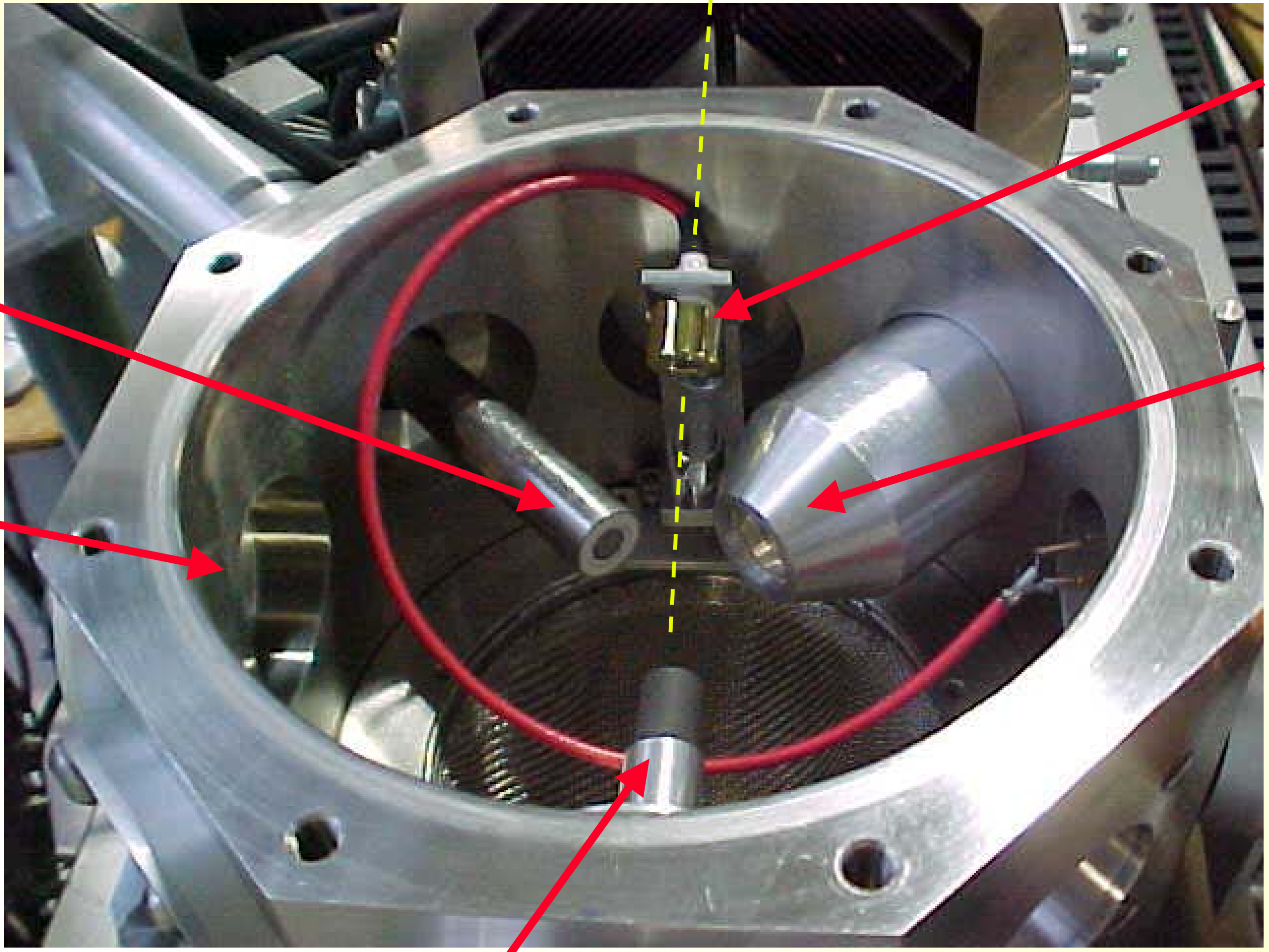
The Surrey Ion Beam Microprobe



2.5 MeV alpha particles, with event rates on the sample of 100 Hz - 1 kHz

The microbeam chamber



IBIC + IBIL measurements

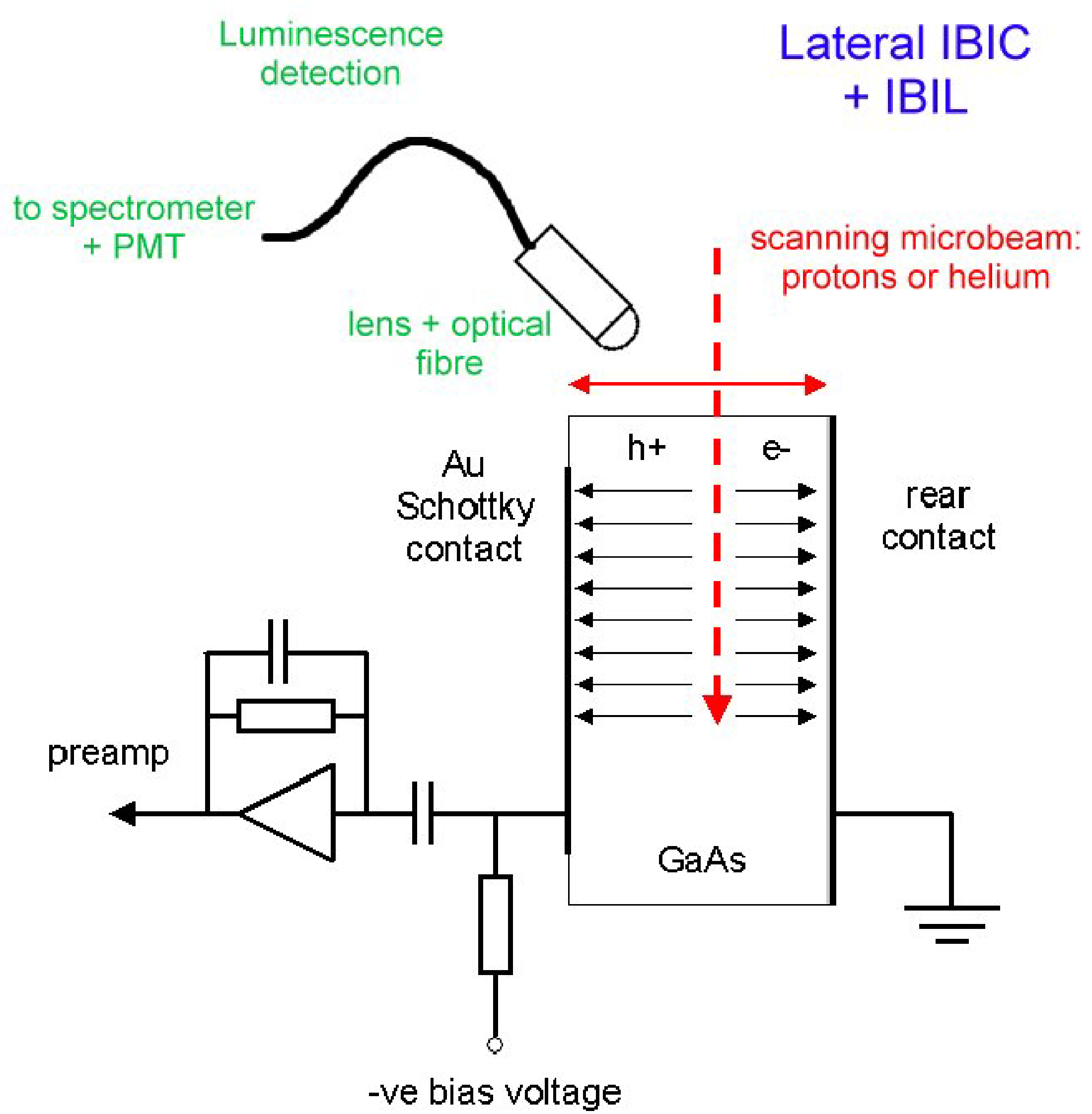
Charge (IBIC) and luminescence (IBIL) data can be acquired simultaneously:

- high spatial resolution
- single event detection (~1 kHz event rate on sample)
- true bulk measurement

Incident ion beam can be orthogonal or lateral:

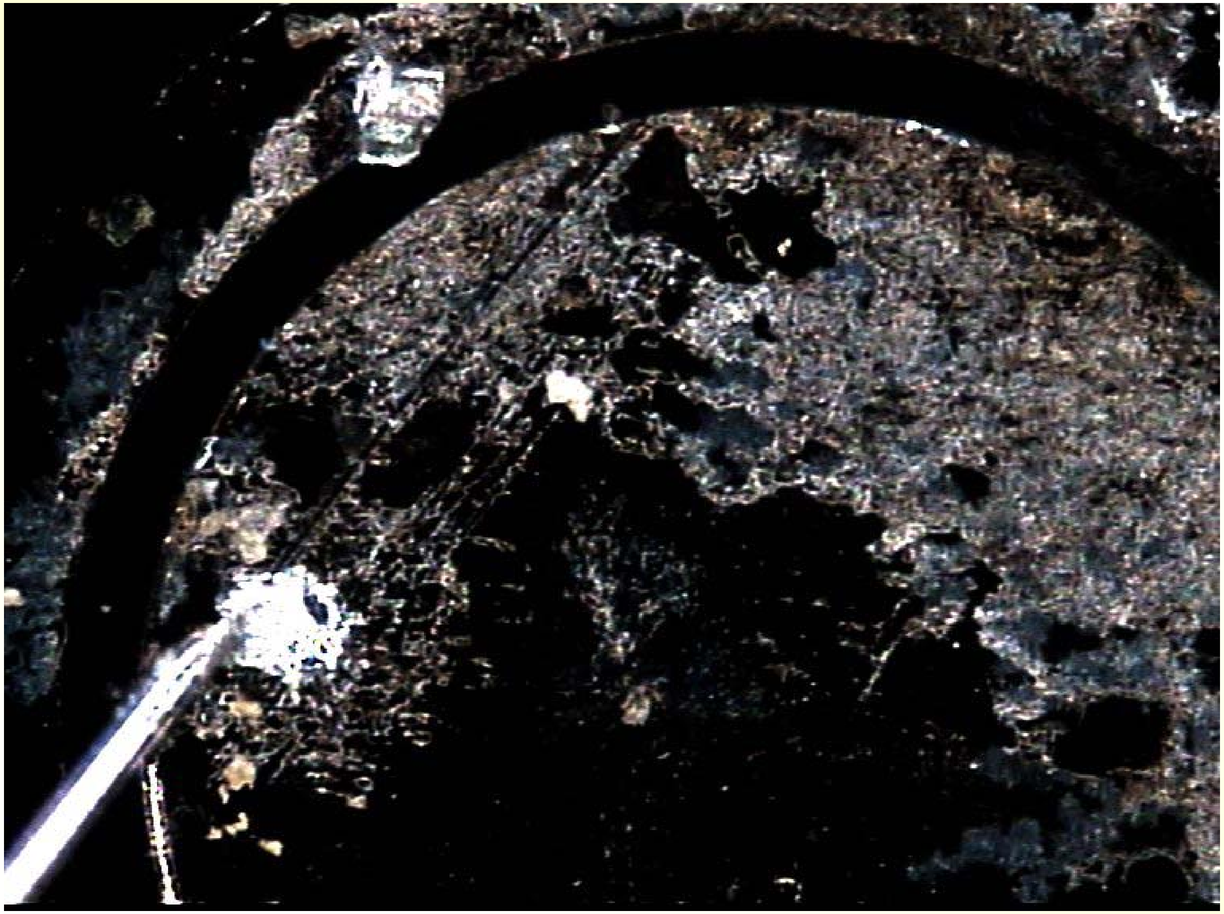
- orthogonal: for uniformity and single carrier CCE

- lateral: for electric field probing



Irradiated SiC contact

Photo of wire bond attached to circular pad. The central region of the contact shows considerable damage

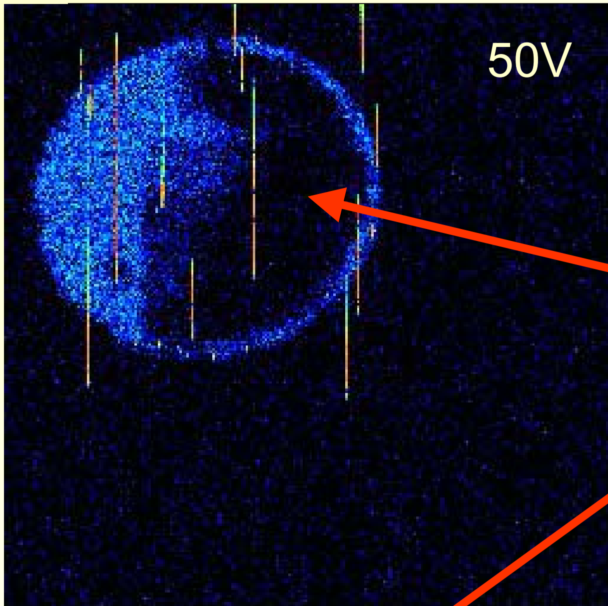


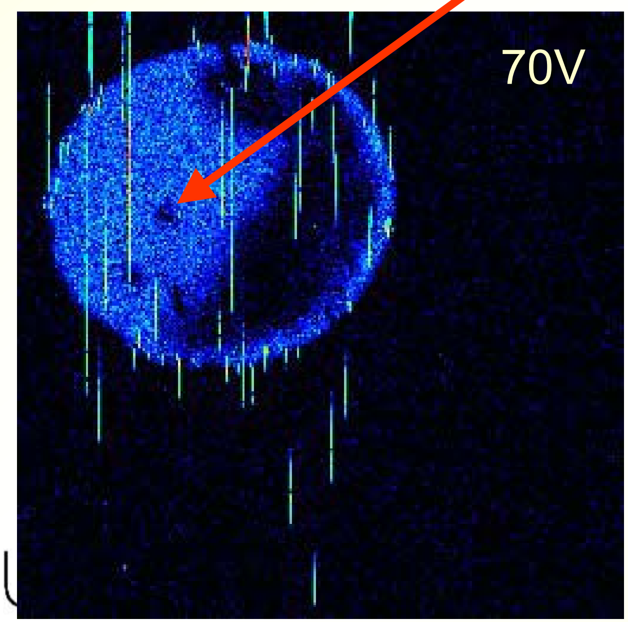
Front contact pad: titanium Schottky

Rear planar contact: nickel

The guard ring was floating in these measurements

2 MeV alpha particle IBIC - irradiated SiC





IBIC imaging of irradiated SiC pad:

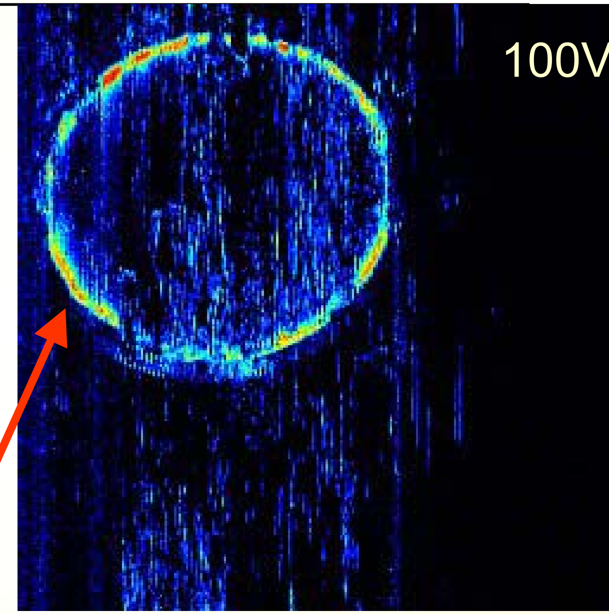
•non-uniform response under damaged contact

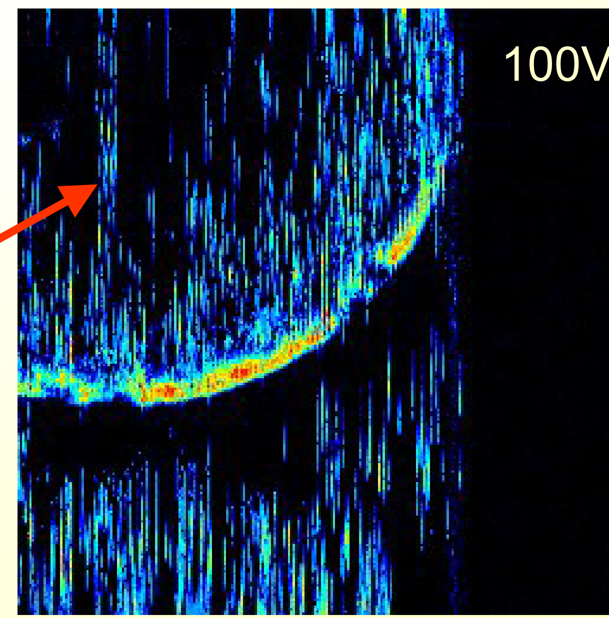
• smaller (~10-50μm) defects possibly due to micropipes

• field enhancement at contact edges boosts charge drift lengths

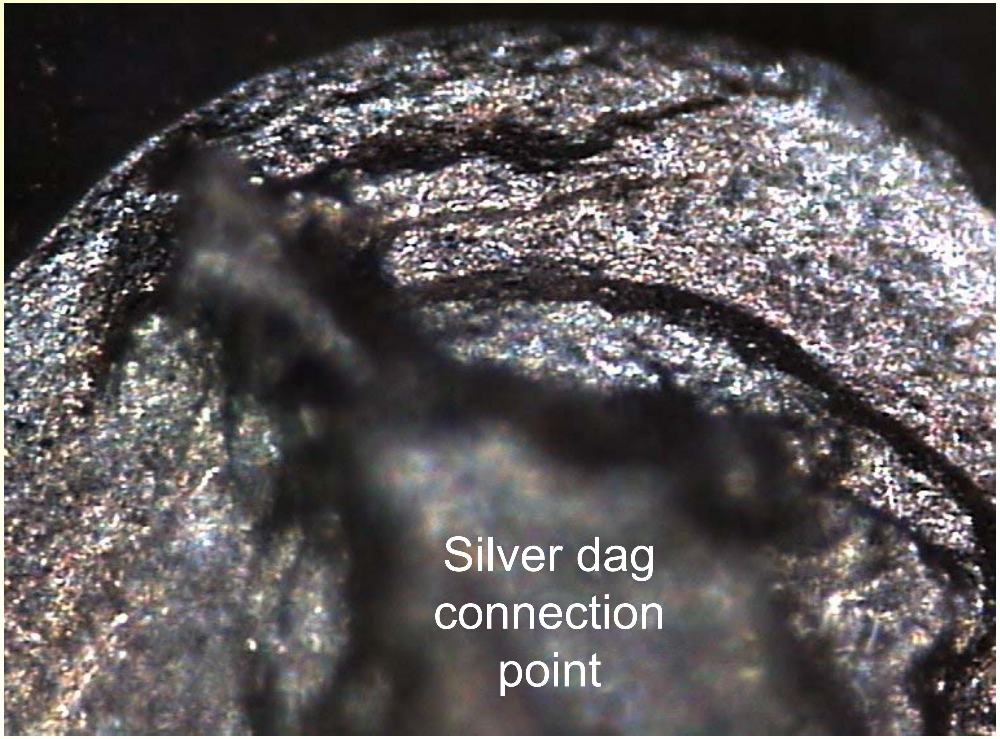
• slow emission of charge shows as vertical streaks

All data acquired with 0.5 μs shaping time





Epitaxial GaN detectors

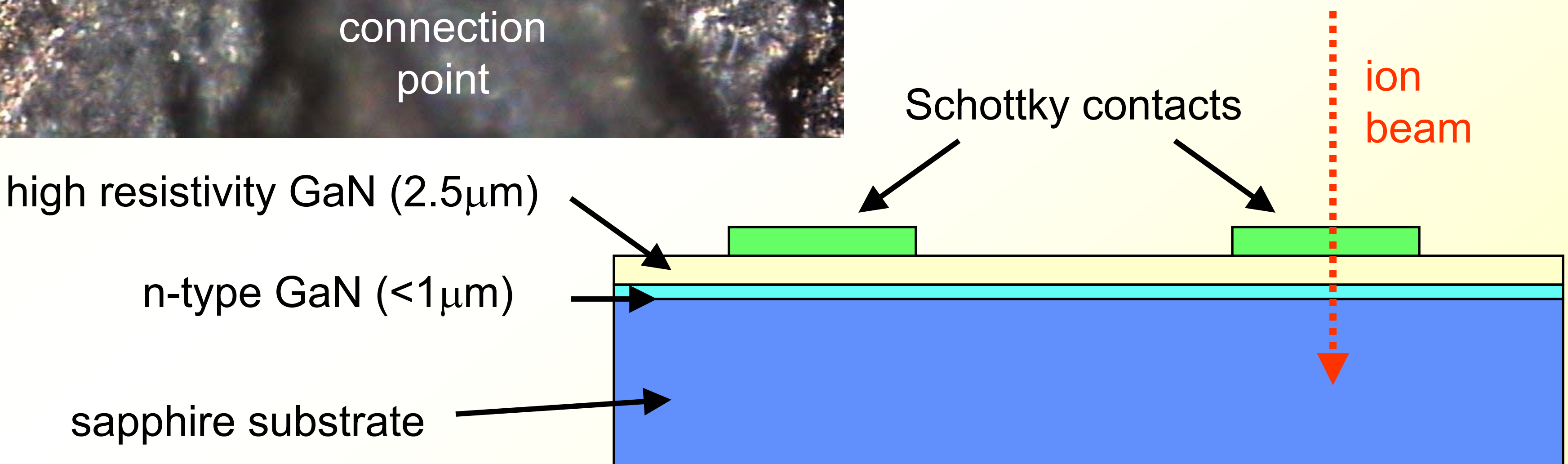


A GaN test structure was measured in the ion beam

High purity epitaxial material 2.5 μm thick

1 device was non-irradiated

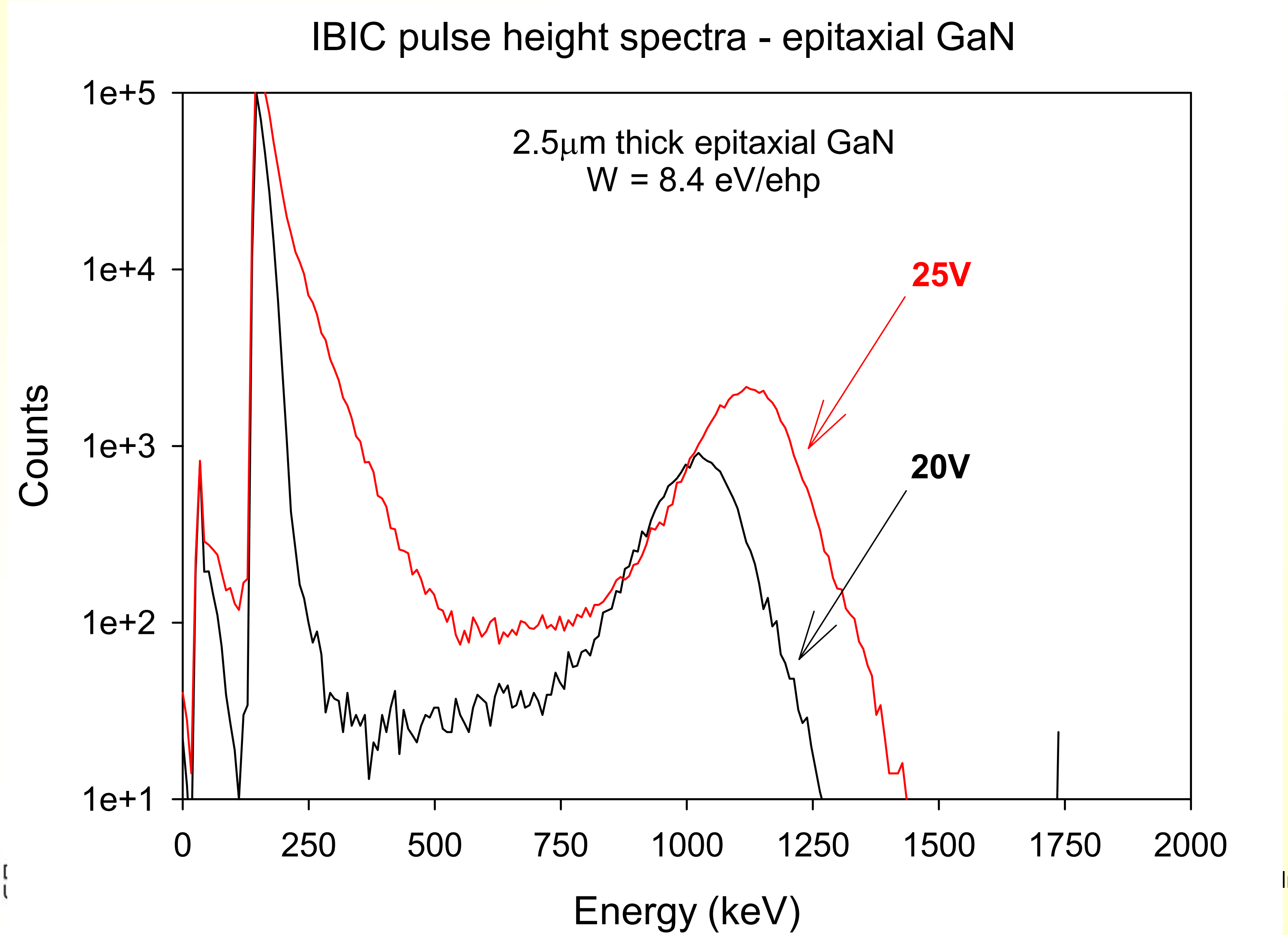
1 device had received 600 MRad of X-rays (not tested)



Alpha IBIC spectra from GaN

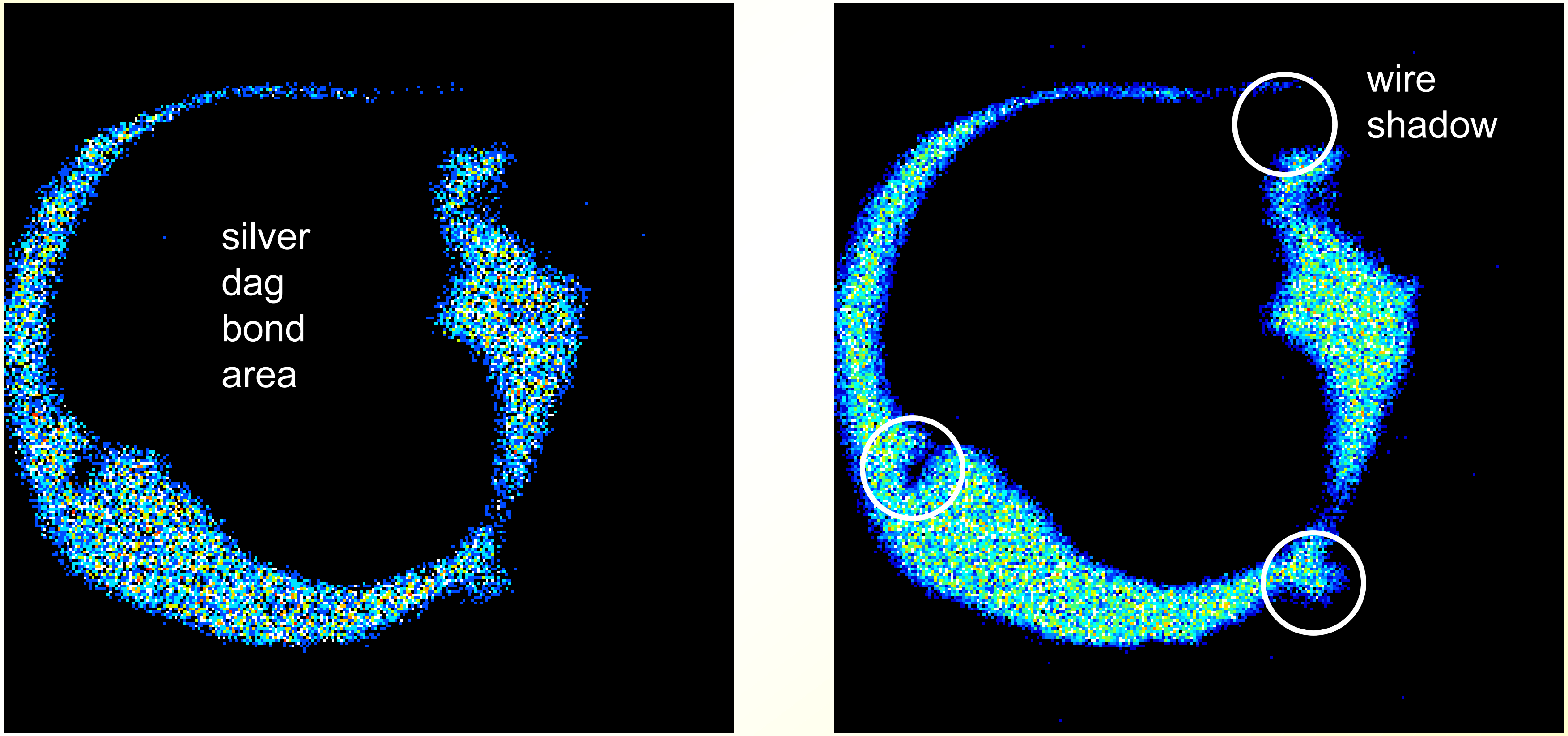
SRIM estimate of energy loss in 2.5 μm layer = 1150 keV

Measured energy at 25 V = 1120 keV (97%), at 20 V = 1020 keV (89%)



GaN IBIC images

- GaN IBIC images show charge transport only under contact pad
- Excellent uniformity of signal with no field enhancement at edges
- Contact is mainly obscured by silver dag bond wire



Conclusions

Bulk 4H-SiC:

- first measurements of 100 μm thick samples show significant trapping levels, with charge re-emission over millisecond timescales
- V-compensated material shows reasonable hole transport (λ_h ~ 50 μm) but strong trapping of electrons
- no significant degradation in performance with 10^{13} cm^3 pions
- IBIC images hampered by sample contact problems, and lack of guard ring connection
- more measurements are required with new sources of high resistivity, low compensation bulk SiC (eg. Okmetic)

Epitaxial GaN:

- initial IBIC imaging shows excellent material uniformity and ~100% CCE in very thin layers
- further measurements are required with thick epitaxial layers combined with $<10^{15}$ cm^{-3} net carrier concentration

Ion Beam imaging for RD-50

We plan the next SiC/GaN beam time for the Surrey Ion Beam in early July.

If you have SiC or GaN samples and would like to carry out collaborative measurements on this system please email me:

p.sellin@surrey.ac.uk

More details of the ion beam facility are on our website:

www.ph.surrey.ac.uk/cnrp/imaging

Optical microscopy of epitaxial SiC