Silicon Carbide Electronics for the Venus Entry Probe

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The Silicon Carbide Advantage

- Brief introduction to the use of silicon carbide
- Newcastle's achievements
- Silicon carbide sensors for extreme environments
  - Radiation detection
  - Gas detection

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Silicon Carbide Properties

Key electronic properties of Si, GaAs, and 4H-SiC

Property	Silicon	GaAs	4H-SiC
Band gap, E_g (eV)	1.12	1.5	3.26
Electron mobility, μ_n (cm^2/Vs)	1400	9200	800
Hole mobility, μ_p (cm^2/Vs)	450	400	140
Intrinsic carrier concentration, n_i (cm^{-3}) at 300 K	$1.5x10^{10}$	$2.1x10^{6}$	$5x10^{-9}$
Critical breakdown electric field, E_{crit} (MV/cm)	0.25	0.3	2.2
Thermal conductivity, Θ (W/cm•K)	1.5	0.5	3.0-3.8

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Large band gap allows operation at temperatures up to 900^{o}C

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Low intrinsic carrier concentration gives a low dark current in radiation detectors

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Allows low loss power electronic devices,
which gives longer battery life

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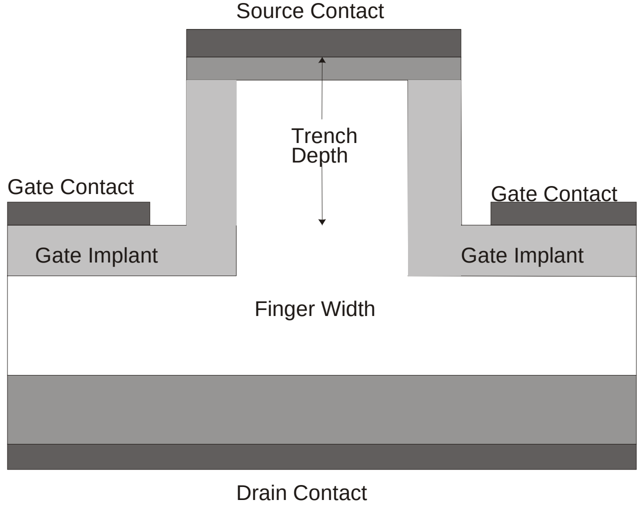
Silicon Carbide Research at Newcastle

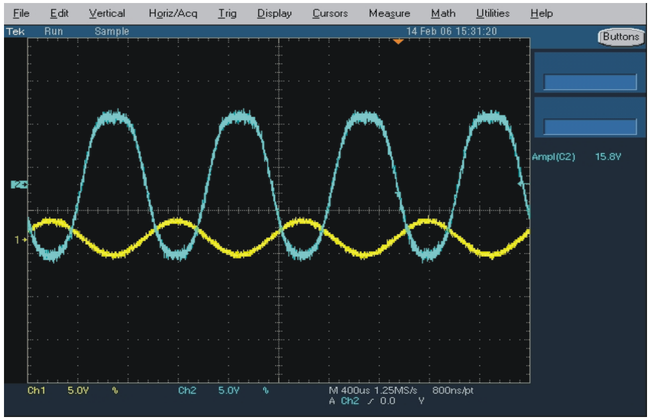
- Vertical Power Junction Field Effect Transistors

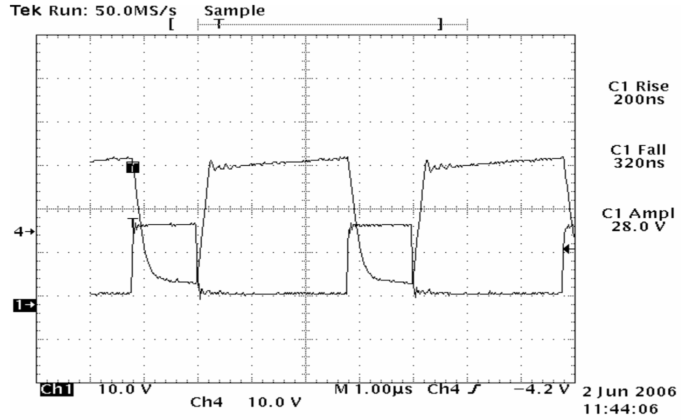


Transistor technology for operation at temperatures above 400ºC

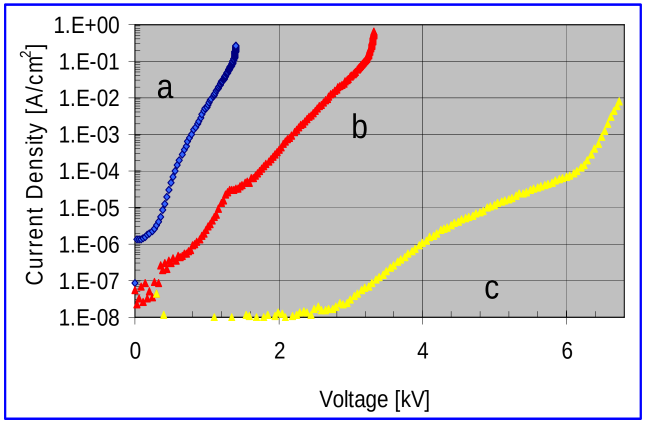
Demonstration of amplifier and power electronic circuits running in air

Power handling >250A cm^{-2} with > 1000V blocking



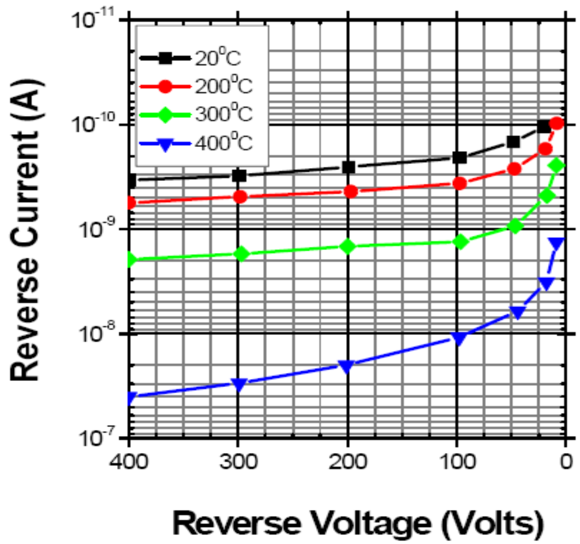


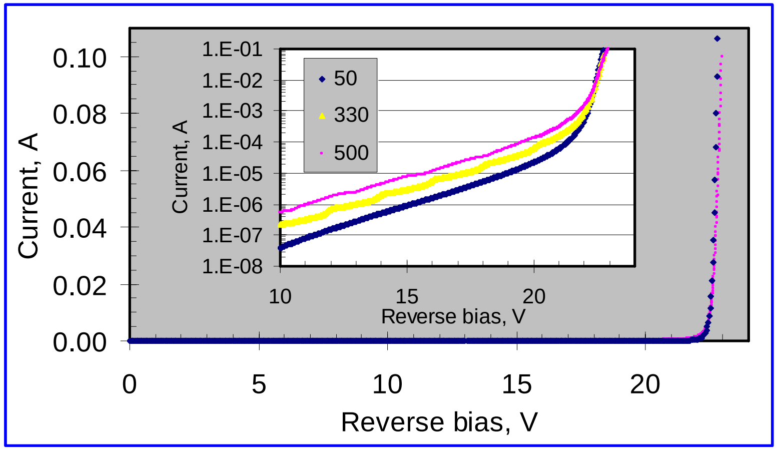
Silicon Carbide Diodes



Variety of diodes, with breakdown voltages upto 6.8kV, running at temperatures to 500^{o}C

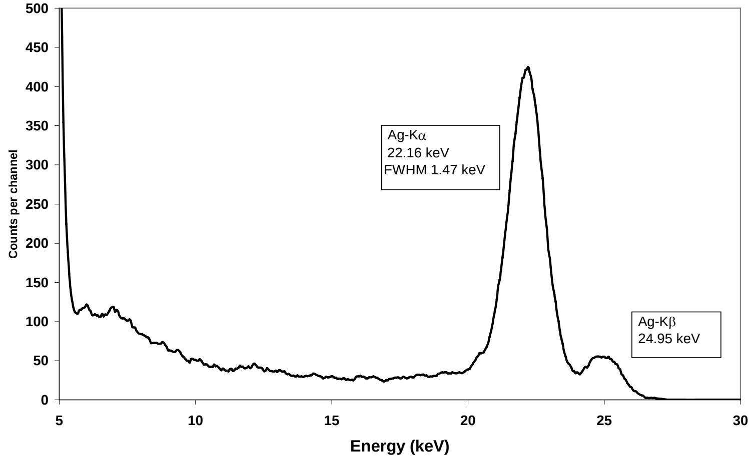
Microwave IMPATT diodes running in the 10GHz band

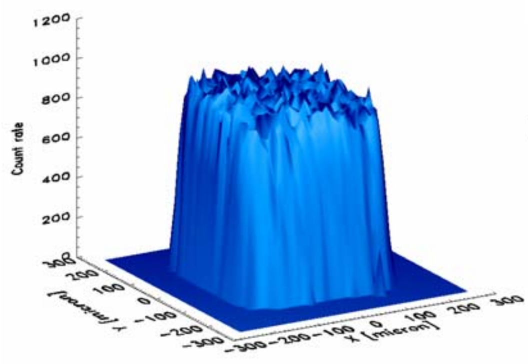




Radiation Detectors

- Based on Schottky diodes
- X-Ray spectroscopy at above room temperature





Silicon Carbide gas sensors

- Demonstration unit 5mm x 5mm comprising 100 test sensors in a package
- Total mass is under 25mg, with a power budget of below 10 micro Watts for a sensor array
- Analysis electronics - power budget expected to be close to 1mW
- No high voltages / moving parts

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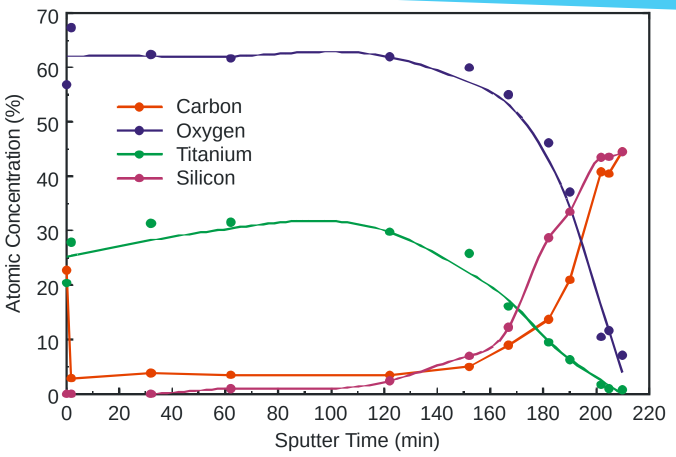
Silicon Carbide gas sensors

- Based on a MIS capacitor structure
- Evaluate the leakage current through the oxide at low bias levels (high reliability) and simple measurement circuit
- Results give identical characteristics to the more traditional capacitance techniques, but with more simple analysis
- Operable at temperatures above 150ºC, with millisecond response times



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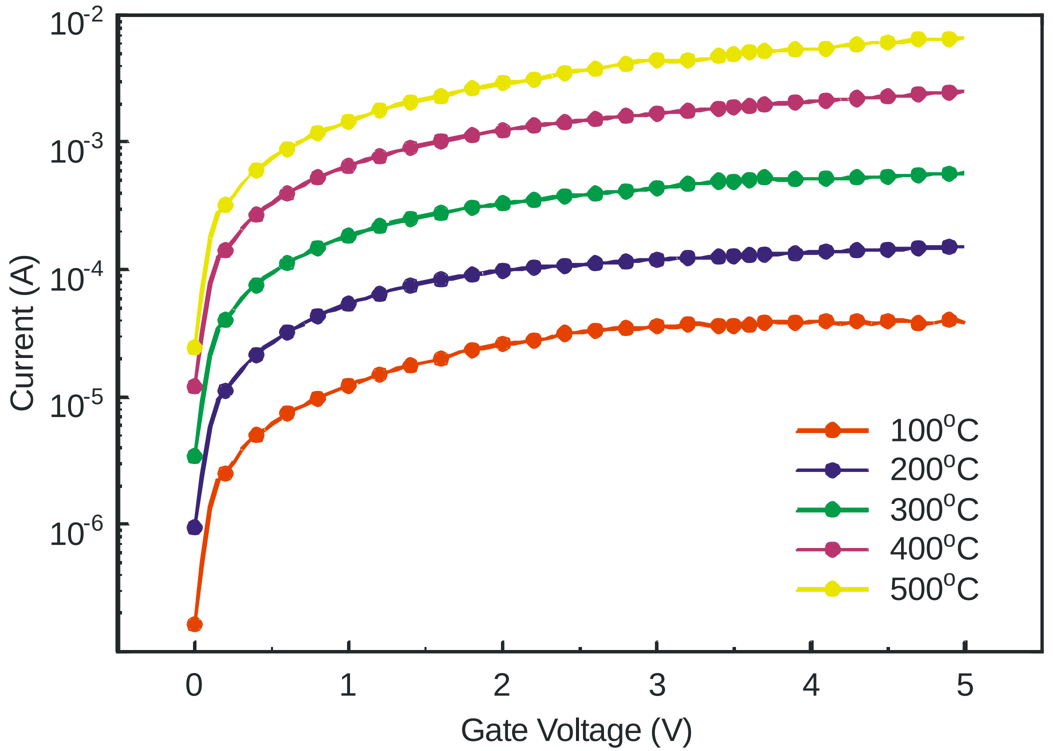
Current – Voltage Characteristics



- Variation in leakage current in pure nitrogen ambient. Sensor is stable to temperatures beyond 500ºC

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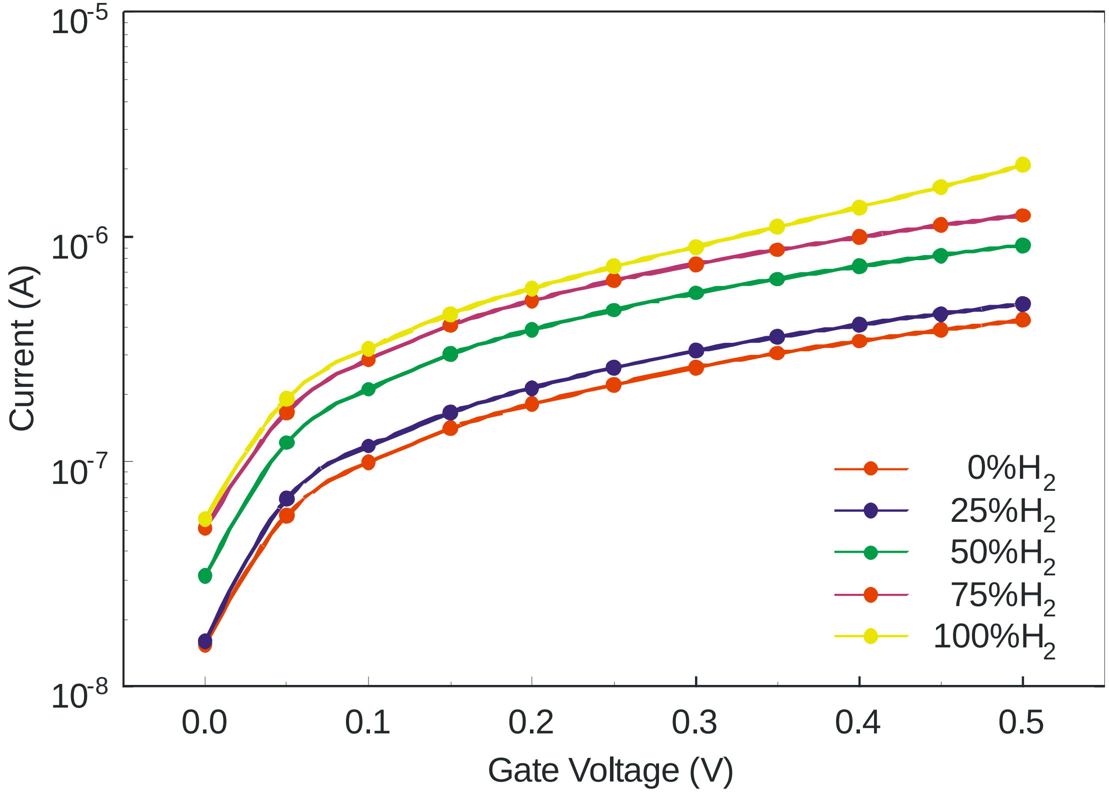
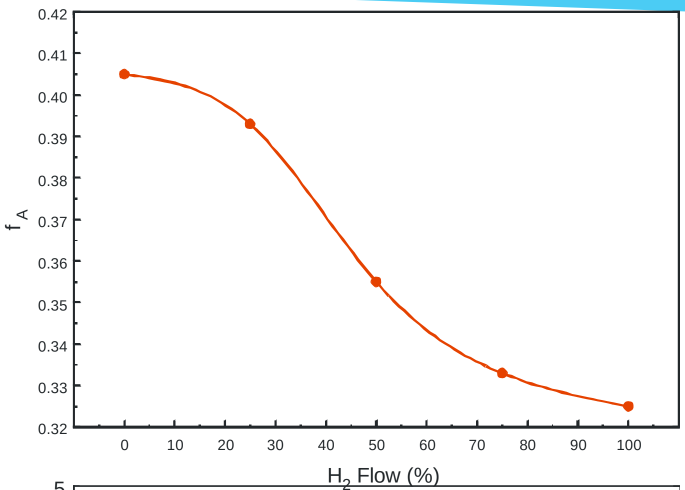
Hydrogen Sensitivity

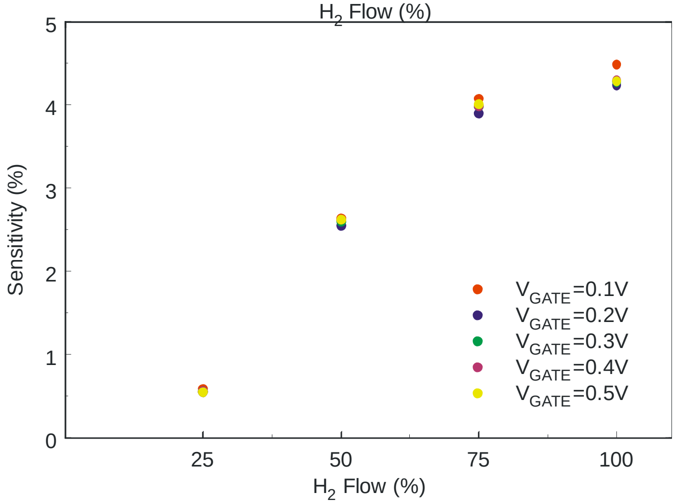


- Benchmark data for comparison to other groups. The gas concentrations are flow rates and 100% corresponds to under 100 ppm.

Analysis

- Gas sensitivity is controlled by trap assisted conduction through the oxide
- Evaluate a barrier height and a trap density from the model.
- Only the barrier height is affected by exposure to the gas
- Sensitivity is not controlled by the voltage across the capacitor, unlike traditional measurement techniques
- No effect from the SiC/oxide interface – enhanced reliability





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Variation in Barrier Height with Gas

- Observe a change in barrier height with hydrogen (–ve), oxygen (+ve) indicating the charge dipole model is responsible

Gas Flow	Barrier Height (eV)
500 ppm of H_2, 0 ppm of O_2	0.34
0 ppm of H_2, 0 ppm of O_2	0.45
0 ppm of H_2, 450 ppm of O_2	0.54

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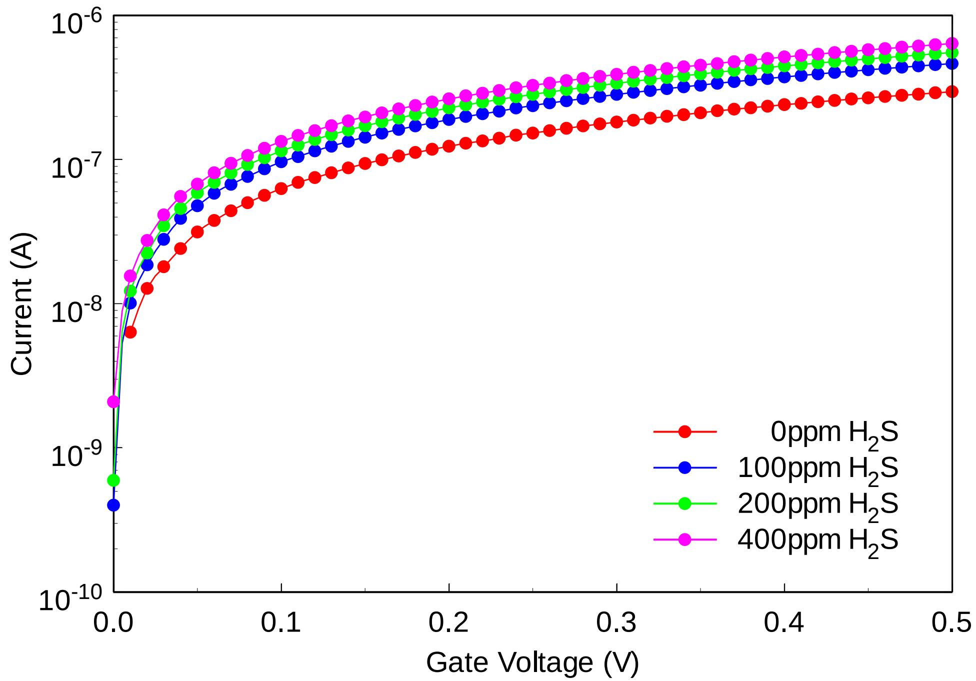
Sensitivity to Hydrogen Sulphide

- Sensor operating at 325°C
- Sensitivity is around 10 ppm in this configuration (enhancement expected!)
- Reduction in barrier height (hydrogen like) with gas exposure



Project status

- Sensor development has been funded through grants from the Royal Society and EPSRC
- Sensor fabrication is currently funded through EPSRC platform grant, and responsive mode projects
- Test facilities exist for 900ºC and a variety of gas mixtures (H_2, O_2, H_2S, SO_2)
- Looking for application specific funding to match the technology to the requirements of the end user

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Conclusions

- Silicon carbide will survive on the surface of Venus for many years
- A modest improvement in sensitivity will enable a sub ppm resolution (mostly in the detection electronics)
- Response time is expected to be in the millisecond range
- Microheaters for deployment in the upper portion of the atmosphere

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