Silicon carbide: electronic levels associated to irradiation

A.Cavallini

INFM and Dipartimento di Fisica,
Universitá di Bologna, Italy

Research group

- **Prof. Anna Cavallini** — **HEAD of the Group**
- **Dr. Beatrice Fraboni** — **PhD, Researcher**
- **Dr. Laura Polenta** — **PhD, Post-Doc Researcher**
- **Mr. Antonio Castaldini** — **Technical Manager**

http://www.df.unibo.it/semiconductors

Collaborations activated in the framework of detectors study

- C.Canali, F.Nava (University of Modena and Reggio Emilia - Italy)
- P.Siffert (EURORAD – Strasbourg- France)
- F.Pirri, F.Giorgis (Politecnico di Torino – Italy)

Characterization techniques

Detection and characterization of electrically active defects

- *Deep Level Transient Spectroscopy*:concentration, energy level and capture cross section of electrically active defects
- *Photoconductivity*: energy level corresponding to transitions deep level-to band (useful in wide gap materials)

Analysis of electric field distribution across detectors

- *SP (Surface Potential):* measurement of electrostatic potential on the cleaved surface of the detector section
- *OBIC (Optical Beam Induced Current):* photoconductivity profiles across the detector

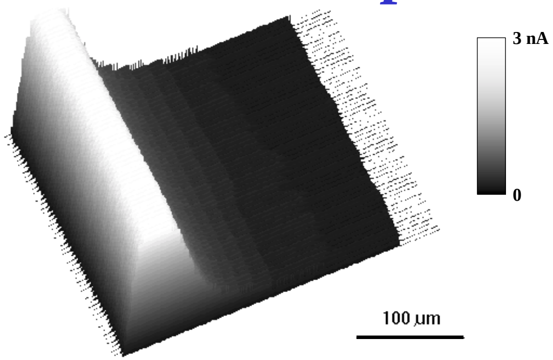
Applications

- Defective state analyses to predict trapping effects
- Electric field distribution to correlate with charge collection efficiency
- Analysis of compensation mechanisms acting in semiconductors
- Irradiation effects (radiation hardness)

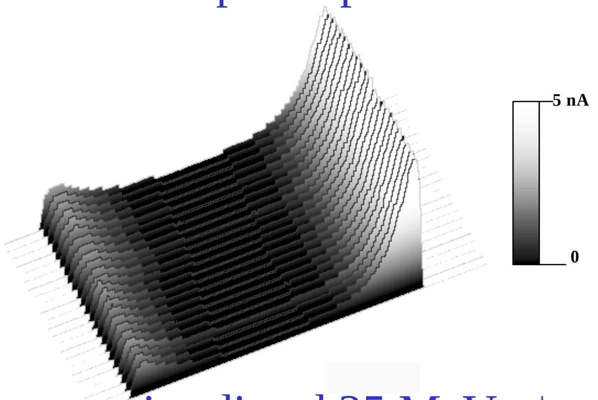
Electric field distribution

Silicon p-i-n detectors

OBIC maps



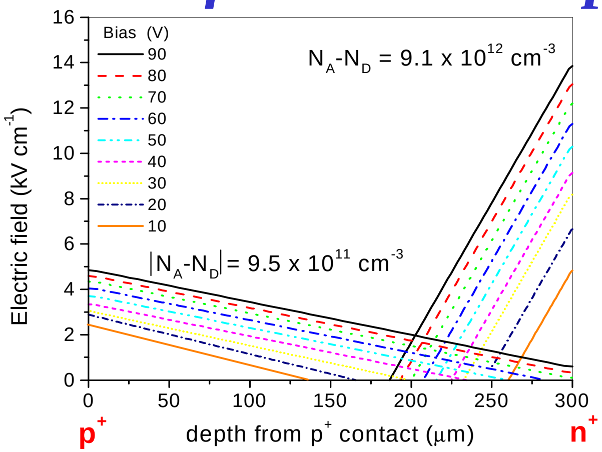
not exposed p^+-n-n^+



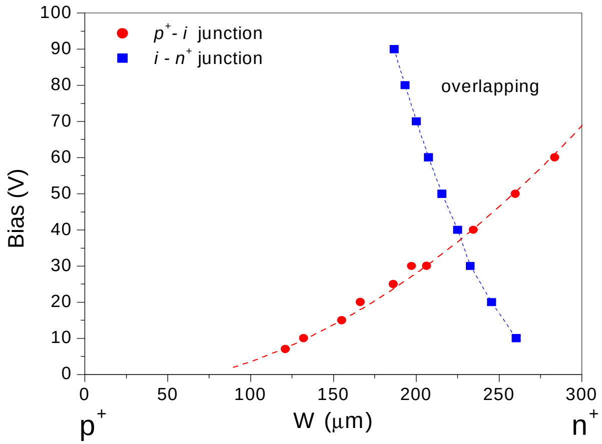
proton-irradiated 25 MeV p^+-p-n^+

$\phi_p = 8.3 \times 10^{13}$ p/cm^2

Surface Potential profiles



Electric field evolution after irradiation (double junction effects).



Active region evolution with bias.

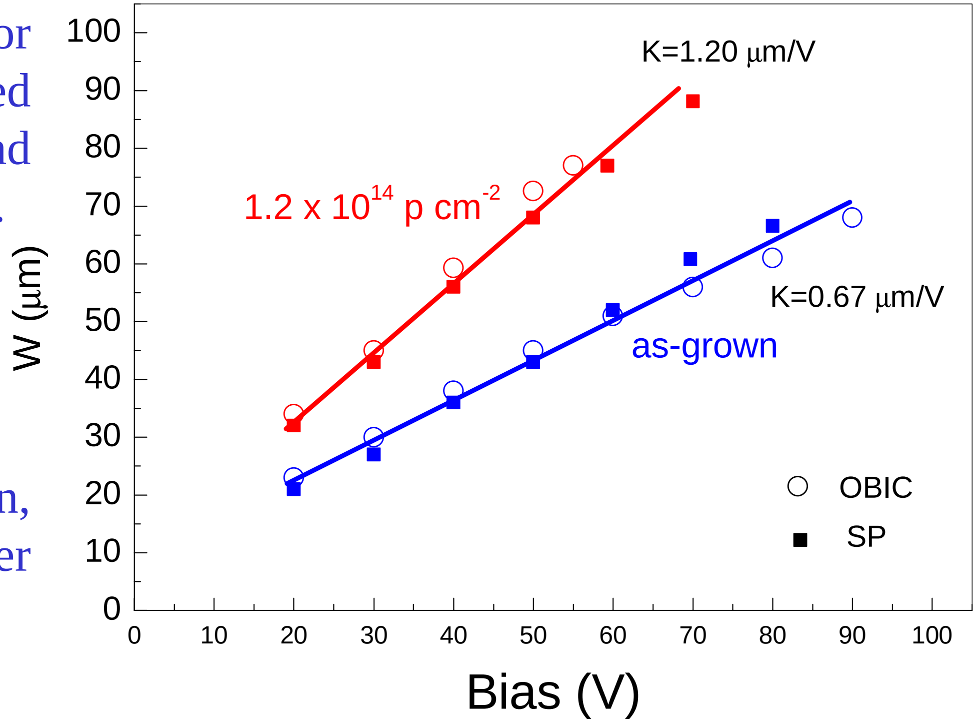
[A.Castaldini, A. Cavallini, L. Polenta, C. Canali, and F. Nava, **J. Appl. Phys. 92,** 2013 (2002)]
[A.Castaldini, A.Cavallini, L.Polenta, F.Nava and C.Canali, **Nucl.Instrum & Meth. A 476** (2002) 550]

Electric field distribution

SI GaAs detectors

Surface Potential and OBIC results

Evidence of a Mott barrier like behavior due to the electric field enhanced neutralization of donors (EL2 and irradiation induced donor-like defects).

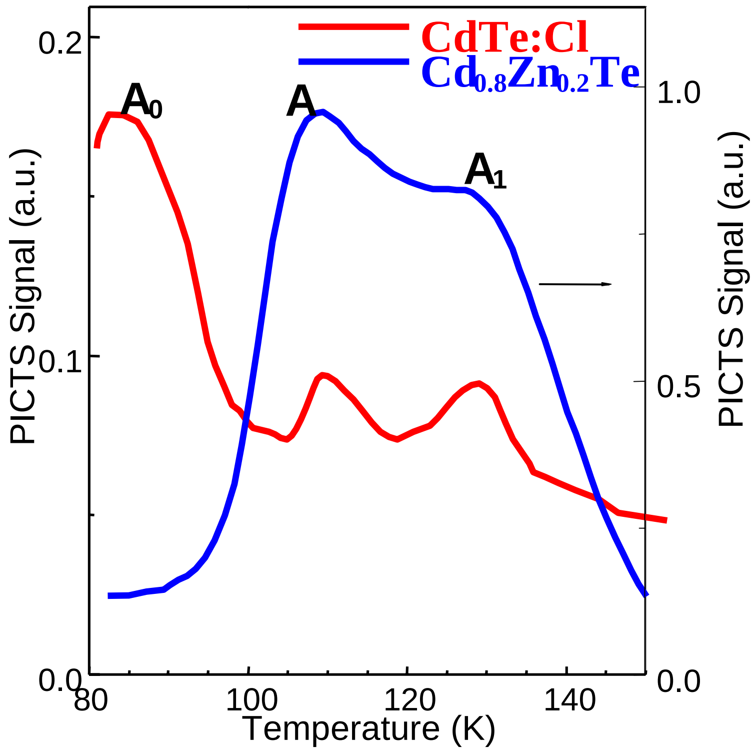


Linear evolution of depletion region, depletion rate increases after irradiation.

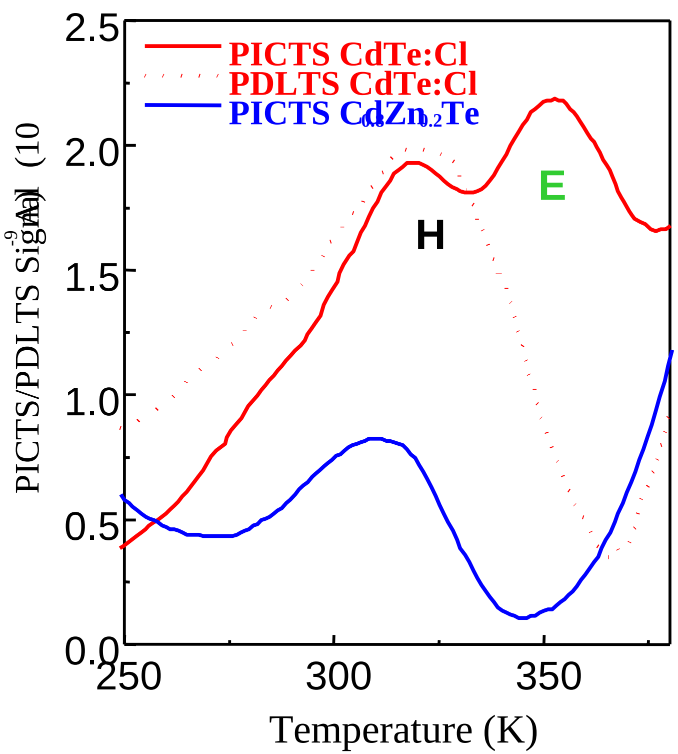
[A.Castaldini, A.Cavallini, L.Polenta, C.Canali and F.Nava, **Nucl. Instr. & Meth. in Phys. Res.A.** 426(1999), 192]
[A.Castaldini, A.Cavallini, L.Polenta, C.Canali, C.del Papa, F.Nava, **Phys.Rev. B56** (1997) 9201]
[ACastaldini, A. Cavallini, L. Polenta, C. Canali, and F. Nava ***IEEE SIMC-X*** (1999) p.153-157]

Compensation mechanisms

II-VI detectors



A_0= Centre A, shallow acceptor (CdTe only)

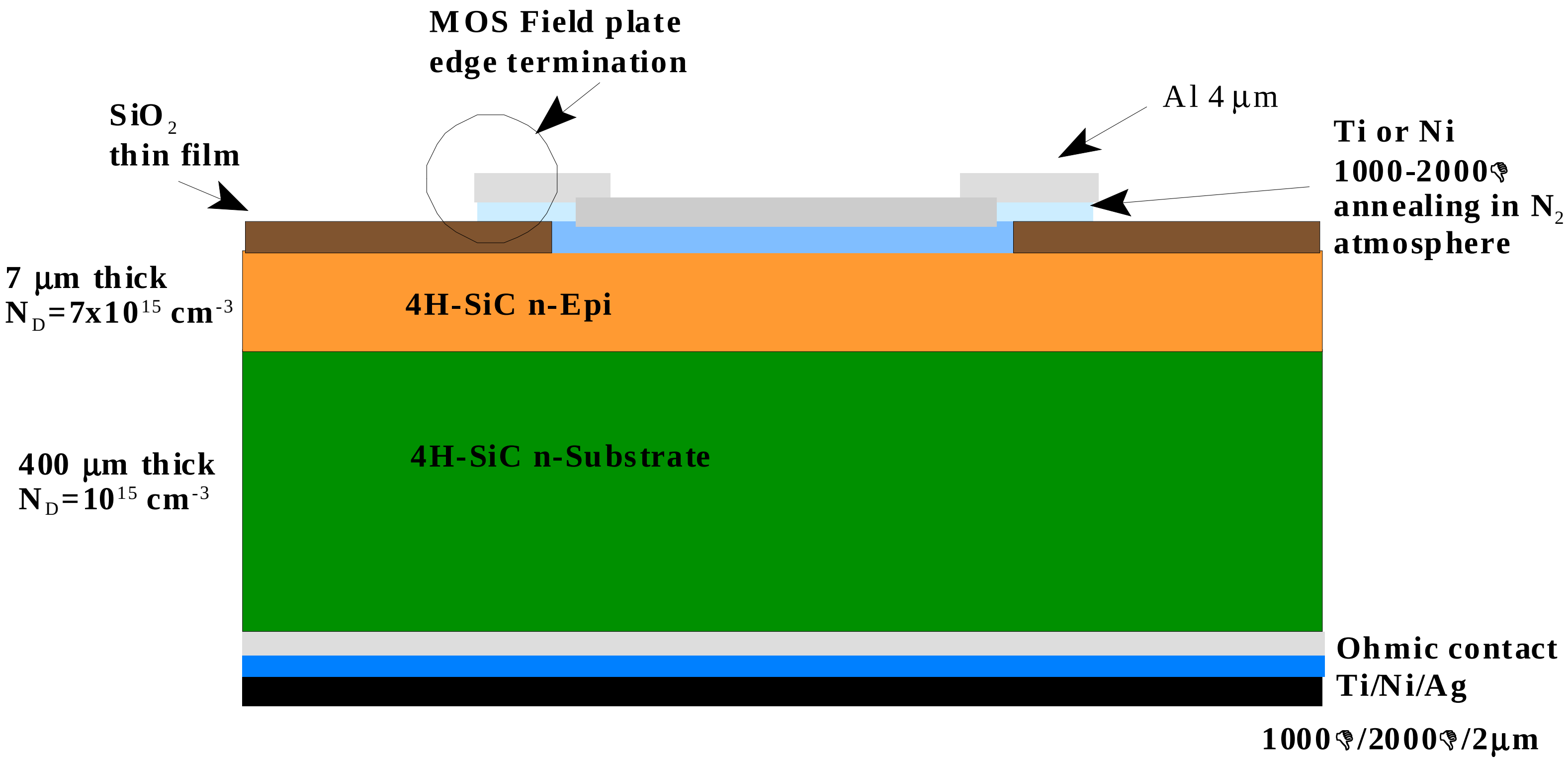


H=deep acceptor E = deep donor (CdZnTe only)

Delicate balance between shallow and deep donors and acceptors

Irradiation effects, defect detection

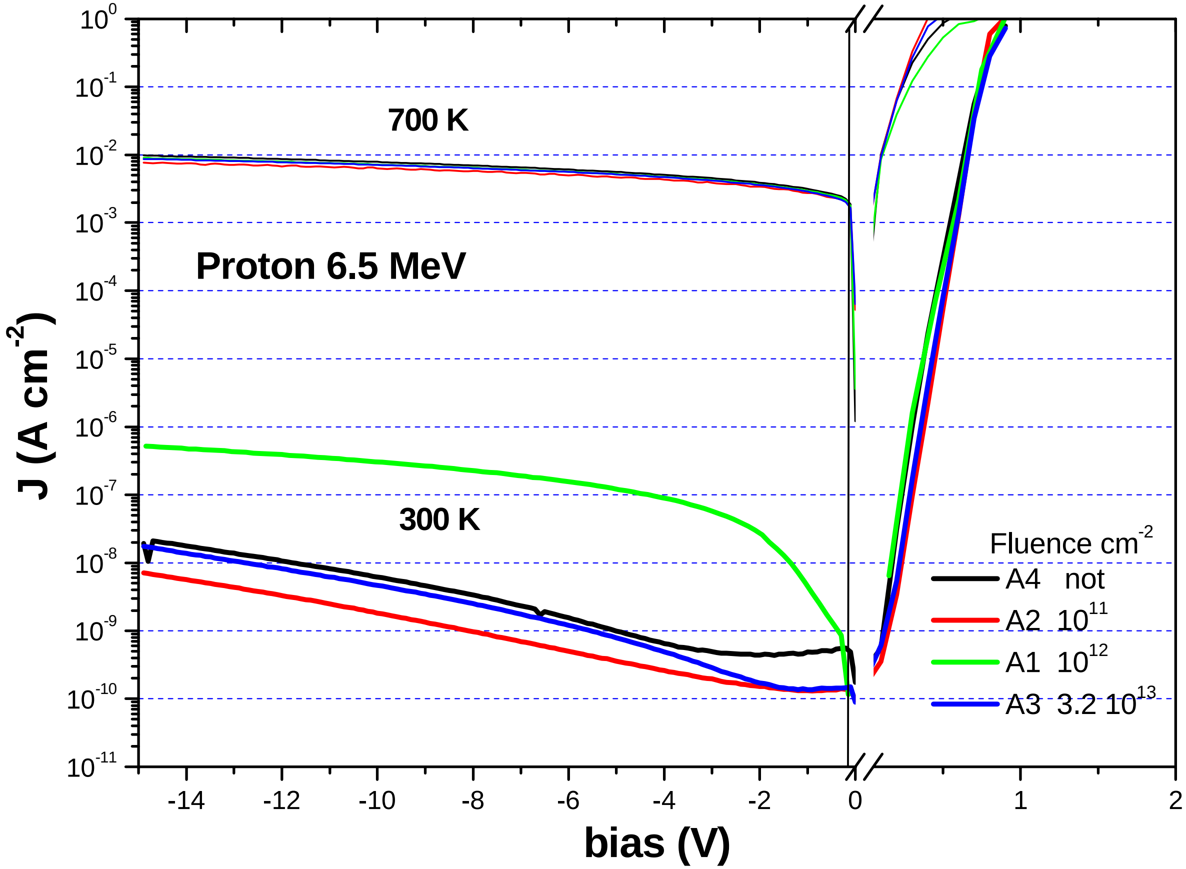
4H-SiC detectors



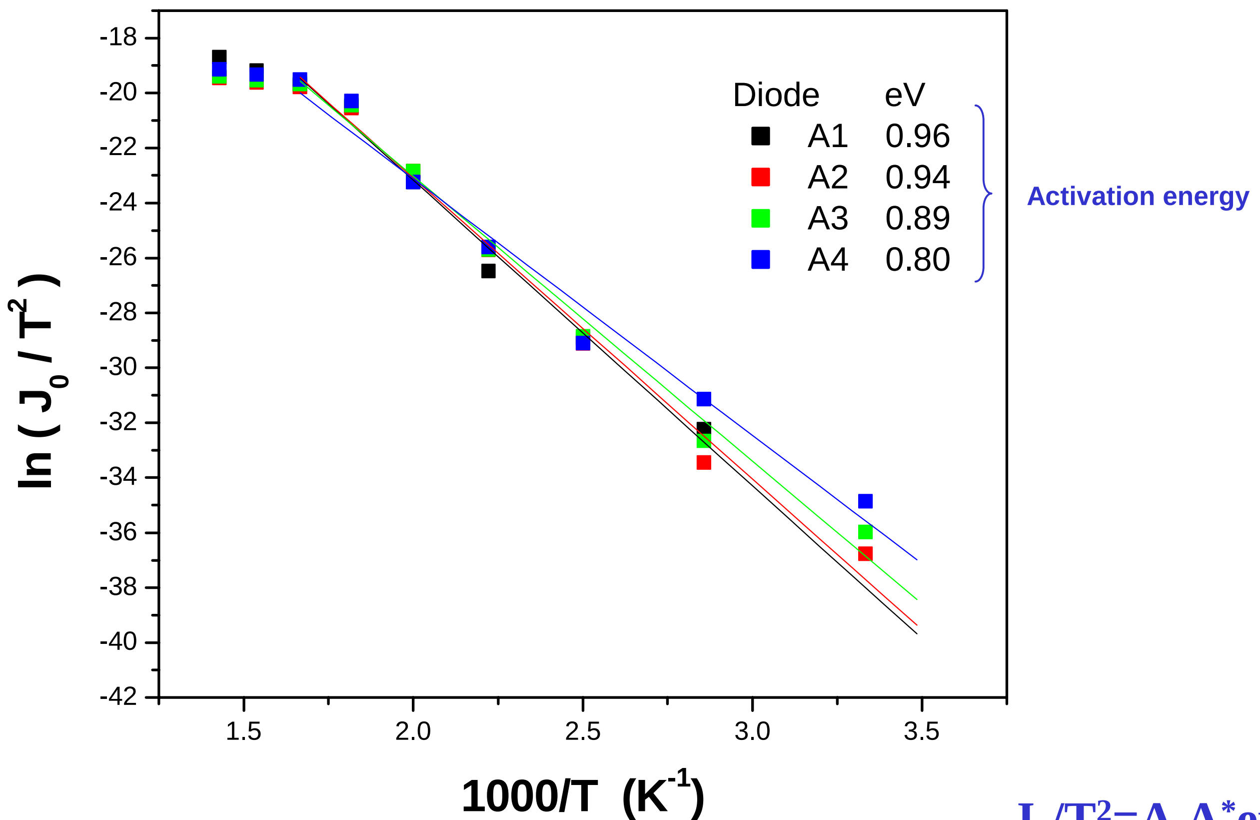
Irradiation characteristics

Diode	ion	Energy (MeV)	Fluence (cm^{-2})	Schottky
A1	proton	6.5	10^{12}	Ti + 400 C°
A2	proton	6.5	10^{11}	Ti + 400 C°
A3	proton	6.5	$3.2\ 10^{13}$	Ti + 400 C°
A4	not	-	-	Ti + 400 C°
A5	not	-	-	Ti + 400 C°
C1	proton	6.5	$3.2\ 10^{13}$	Ni
C2	alfa	12	$3.2\ 10^{13}$	Ni
C3	proton	6.5	$6.4\ 10^{13}$	Ni
C4	alfa	12	$6.4\ 10^{13}$	Ni

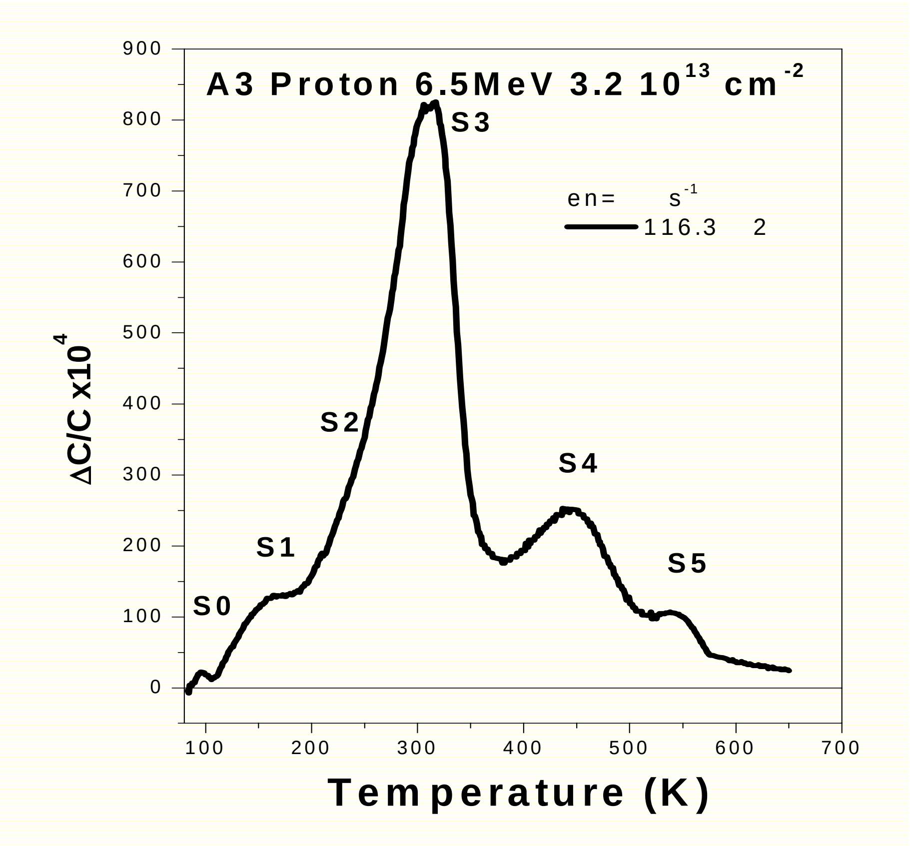
Current density for different fluences of proton irradiation
Ti contacts



Arrhenius plot of the reverse current at high temperature proton irradiated diodes



$$J_0/T^2 = A\,A^{*}\exp[-q(\phi_{bn}-V)/kT]$$


A3 Proton 6.5MeV 3.2 10^13 cm^-2
S0
S1
S2
S3
S4
S5
en= s^-1
116.3 2
ΔC/C x10^4
Temperature (K)
0
100
200
300
400
500
600
700
800
900

Concluding Remarks

- proton irradiation only slightly changes the electrical properties of 4H-SiC Schottky diodes

- we detected 2 deep levels in as-prepared devices

- proton irradiation induces 5 levels, the density of which increases with fluence

- these deep levels are reasonably related to impurity-intrinsic defect complexes