Defect annealing in 4H-SiC

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Characterization Techniques

Detection and characterization of electrically active defects:

- *Deep Level Transient Spectroscopy*: concentration, energy level (enthalpy) and capture cross section of electrically active defects.
- *Capacitance-Voltage Characterization:* free charge carrier distribution.
- *Electron Beam Induced Current:* spatial distribution and recombination strength of extended defects.

Characterization of the device:

Current-Voltage Characterization: behavior of dark current in presence of defects.

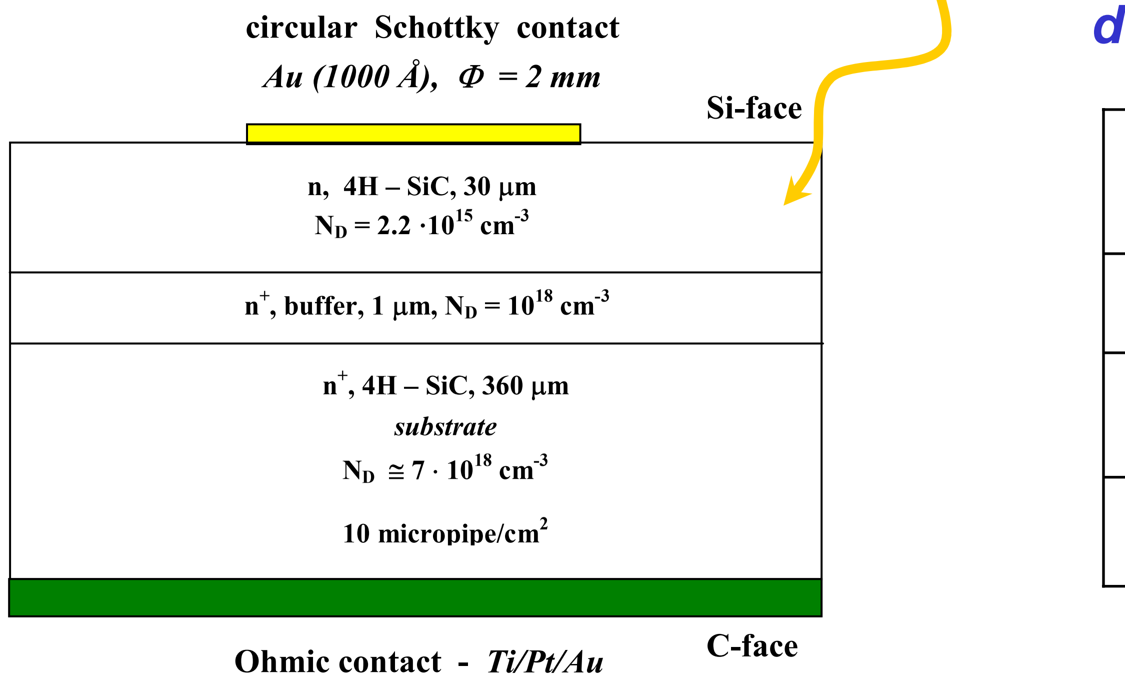
- *Charge Collection Efficiency:* effect of the defects on sample performance as a charged particle detector.

Applications

- Defective State analyses to predict trapping effects.
- Spatial distribution of major recombining centers.
- Annealing and recovery of free charge carriers at low temperature.
- Irradiation effects (radiation hardness).
- Analysis of irradiation-induced compensation effects.
- CCE analysis as a function of irradiation and annealing temperature.

Material

- **n 4H-SiC** epilayer grown by CVD: $N_D=2.2\times10^{15}cm^{-3}$, 30μm thick
- Au Schottky contact, ϕ=2mm, 1000Å thick

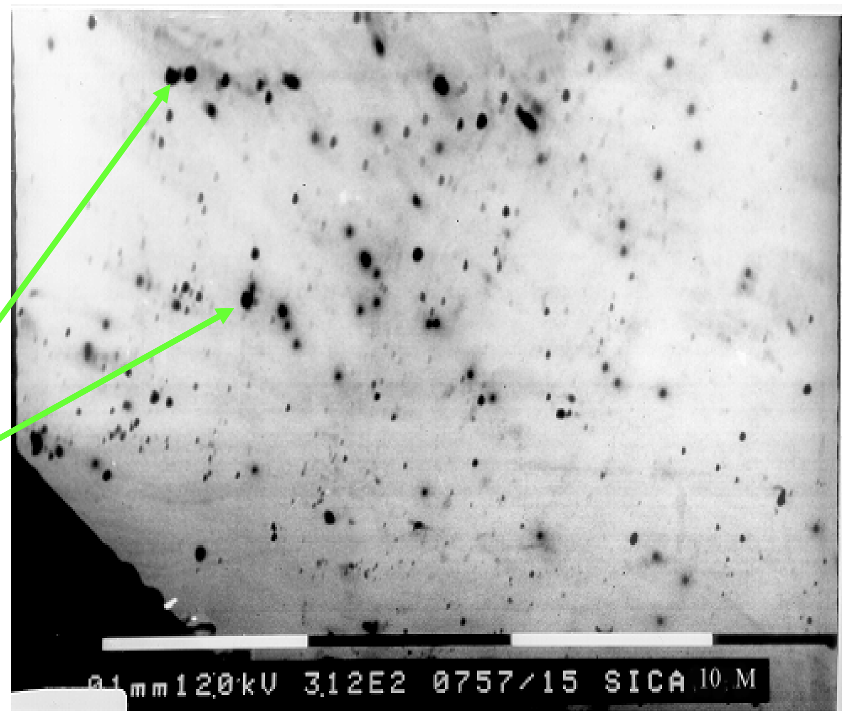


IRRADIATION:

8.6 MeV electrons at different doses/fluences

Dose	Fluence (cm^{-2})
2 Mrad	4.74×10^{13}
10 Mrad	2.37×10^{14}
40 Mrad	9.48×10^{14}

EBIC micrographs



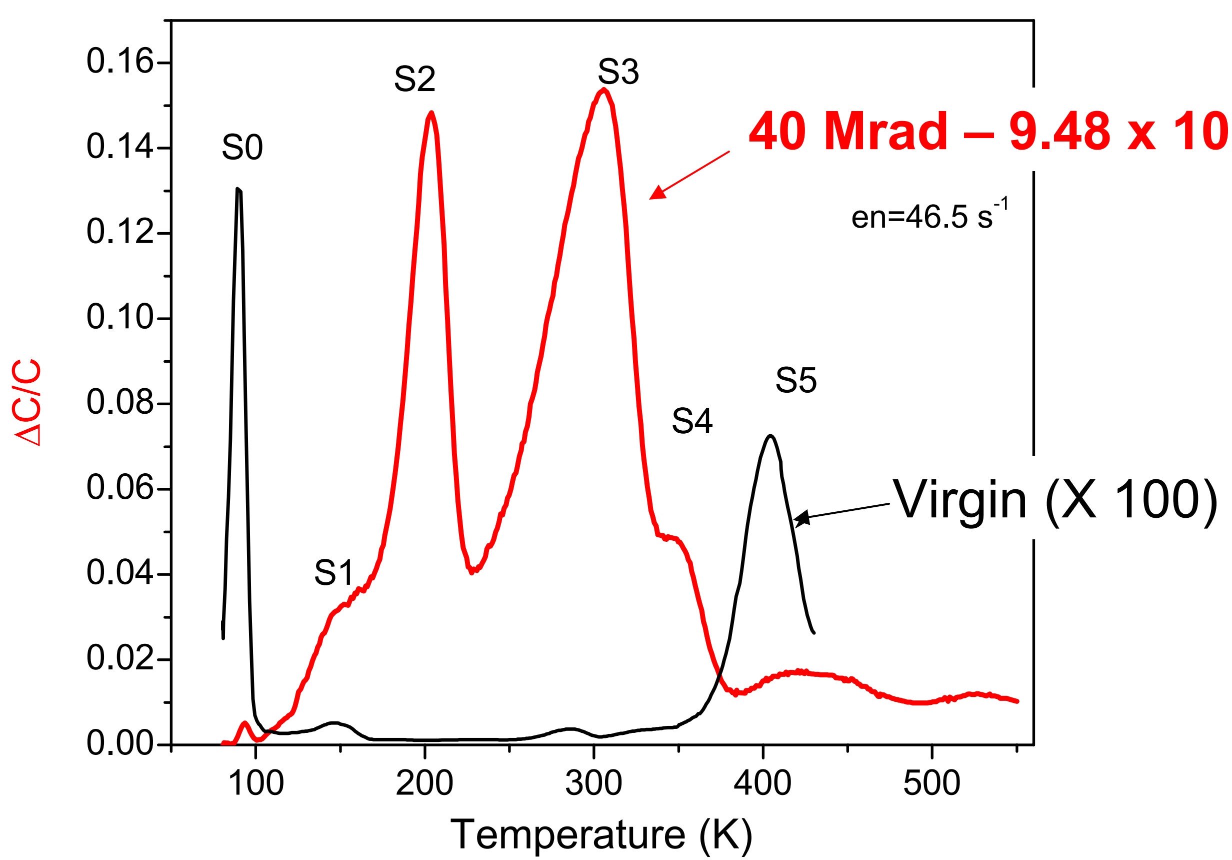
Dislocations appear as dark spots on the surface

Dislocation density is about

10^5 cm^{-2}

EBIC contrast up to 40%

DLTS analysis – Irradiation induced deep levels

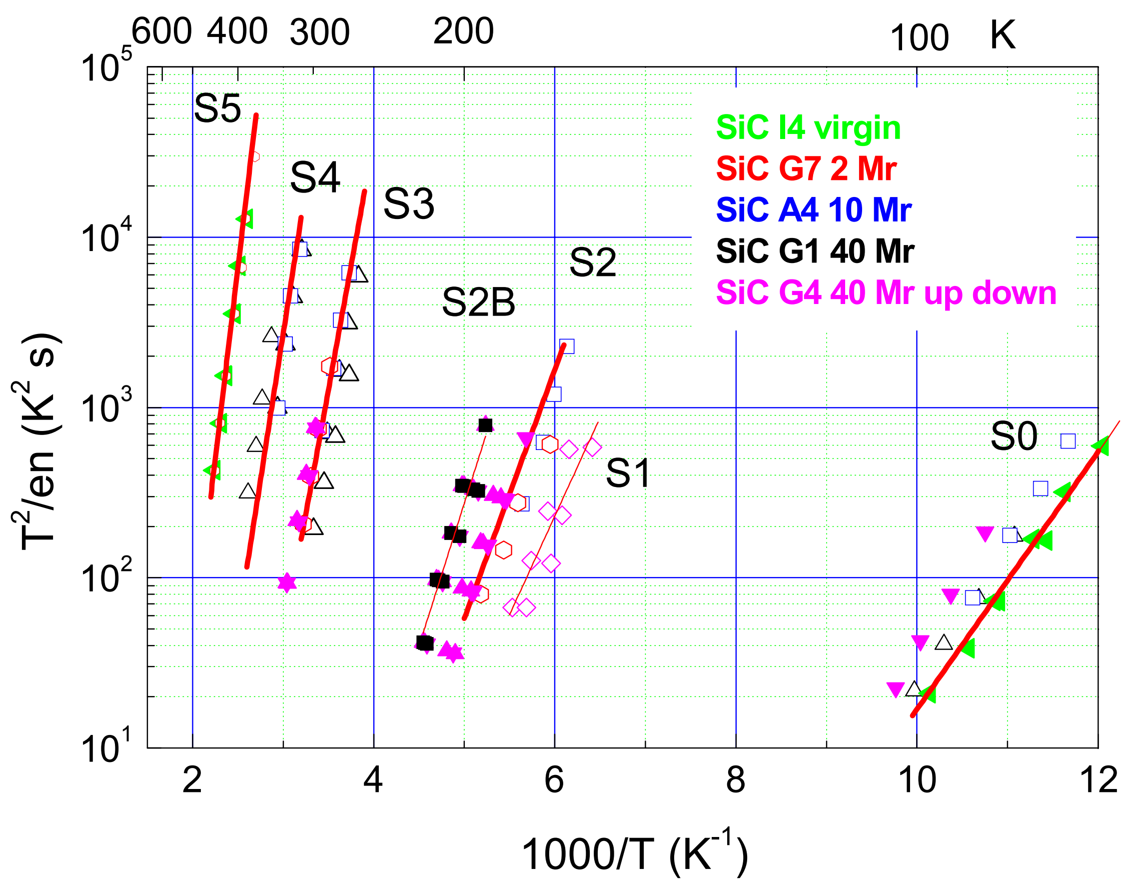


DLTS analysis – Trap parameters

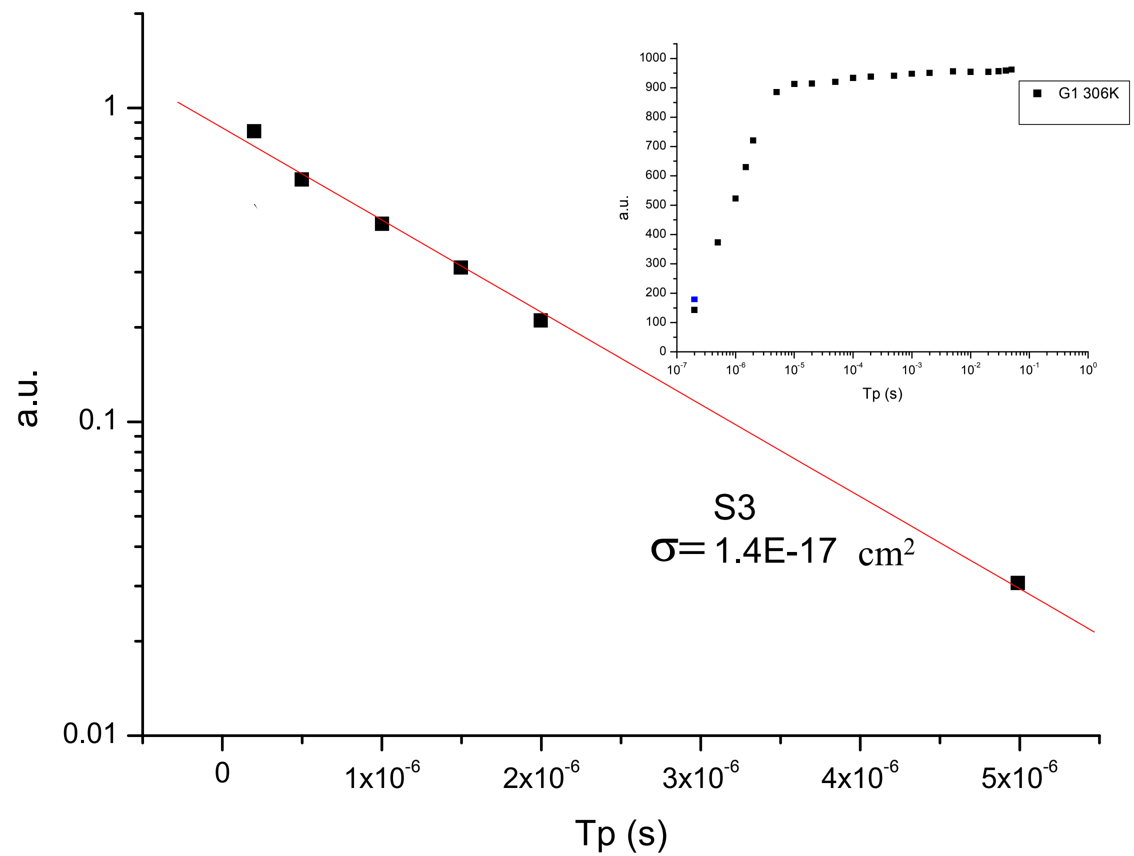
Trap level	Deep level enthalpy E_T (eV)	Concentration N_T (cm^{-3})	Capture cross section σ_{inter} (cm^2)	Introduction rate η (cm^{-1})
S0	E_c - 0.15	1.4 x 10^{13}	6.0 x 10^{-16}	0.02
S1	E_c - 0.23	5.5 x 10^{13}	9.3 x 10^{-16}	0.116
S2	E_c - 0.39	4.0 x 10^{14}	1.7 x 10^{-15}	0.84
S3*	E_c - 0.50 / 0.65	4.2 - 5.4 x 10^{14}	1.4 x 10^{-16} 1.7 x 10^{-14}	0.88
S4	E_c - 0.75	1.3 x 10^{14}	6.6 x 10^{-15}	0.27
S5	E_c - 0.89	4.6 x 10^{13}	7.2 x 10^{-15}	0.09

* S3 undergoes annealing at T~400-470K; the parameters after annealing are typical of the level known from the literature as Z1/Z2

DLTS analysis – Arrhenius Plot



DLTS analysis – Filling Kinetics



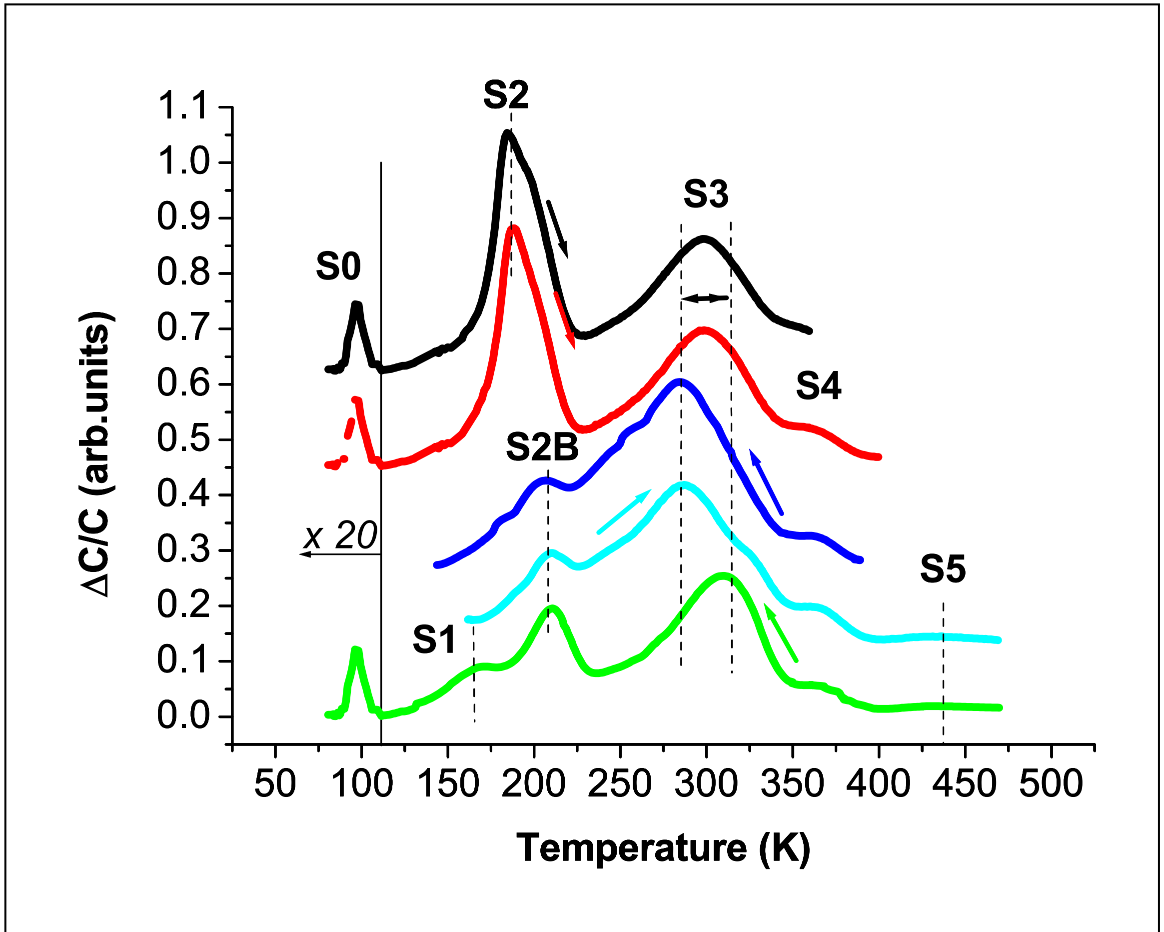
DLTS and annealing analysis

1. Run 80-360K *2. Run 80-400K* *3. Run 400-150K* *4. Run 160-470K* *5. Run 470-80K*

1st annealing stage

(360 – 400 K):

- very strong decrease of peak S2
- slight amplitude gain and temperature shift of S3
- S2B and S1 become resolved



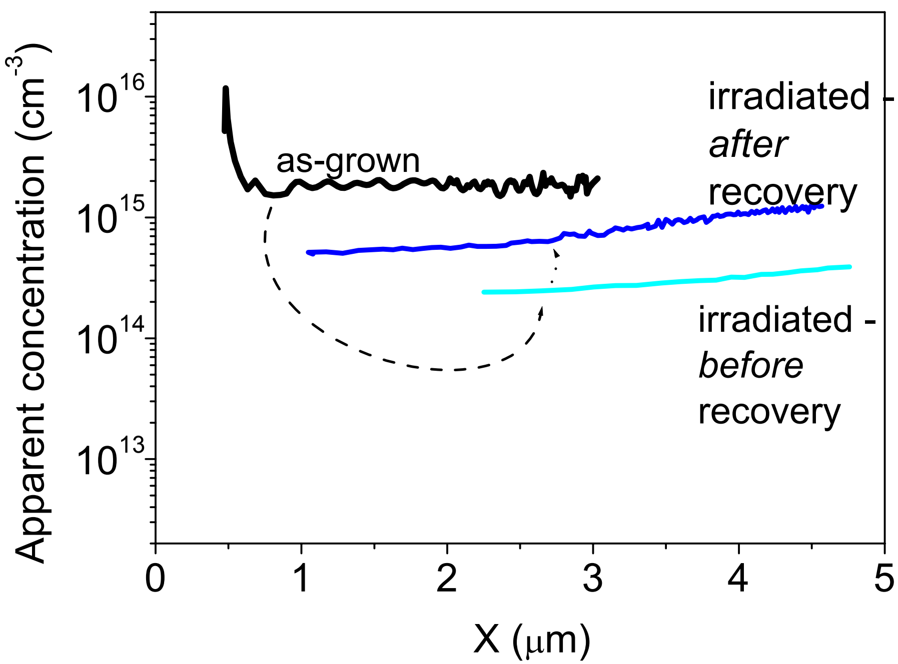
2nd annealing stage

(400 – 470 K) :

- blue shift of S3 activation energy
- sharpening of S3 peak

C-V analysis

- **Strong compensation** of free charge for $\Phi = 9.48 \times 10^{14}$ cm^{-2} (~1/10 of the as-grown value).
- Significant **free charge density increase after annealing of peak S2** at 360K-400K.



Post-recovery free charge increase

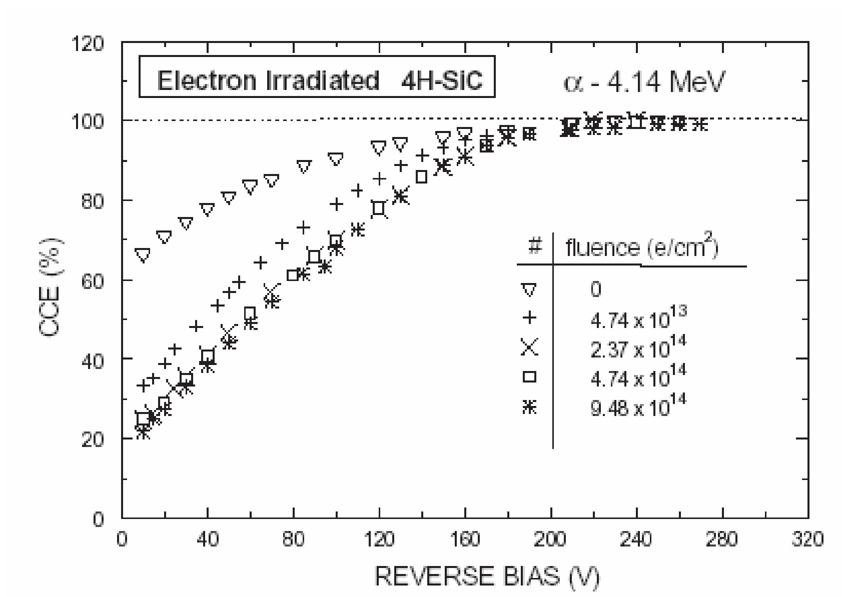
✓Possible explanation:
recombination and annihilation of the defect related to level S2

CCE characterization

CCE vs. irradiation dose

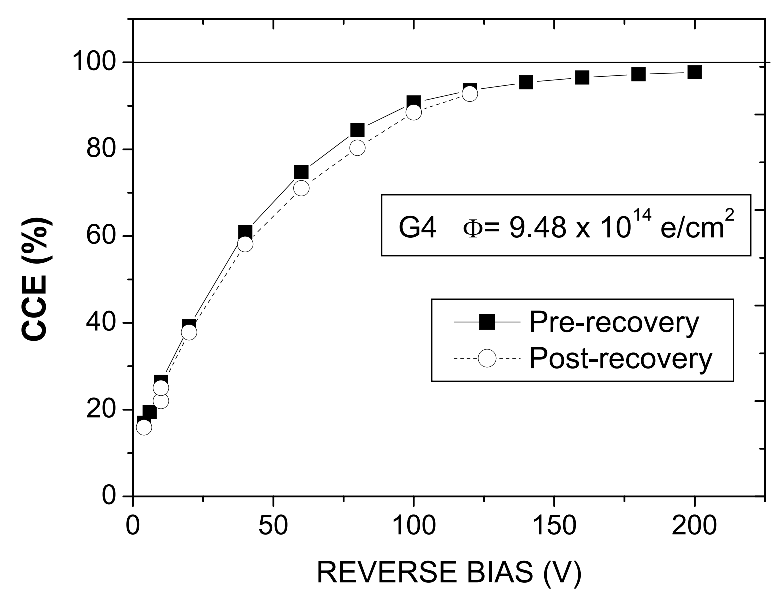
•In the diffusion regime (Bias<~160V) CCE is degraded by the introduction of traps.

•In the drift regime (Bias>~160V) CCE saturates to 100% for all irradiation doses.



CCE vs. annealing

•Low T annealing does not change the CCE of the detector.



Conclusions

- Electron irradiation
  - Introduction of at least 4 trap levels.
  - Strong compensation of free carrier density.

- 1st Annealing stage (360K-400K):
  - Disappearance of level S2 (Ec-0.39 eV).
  - Free carrier density increase (recovery).
  - Rearrangement of peak S3.

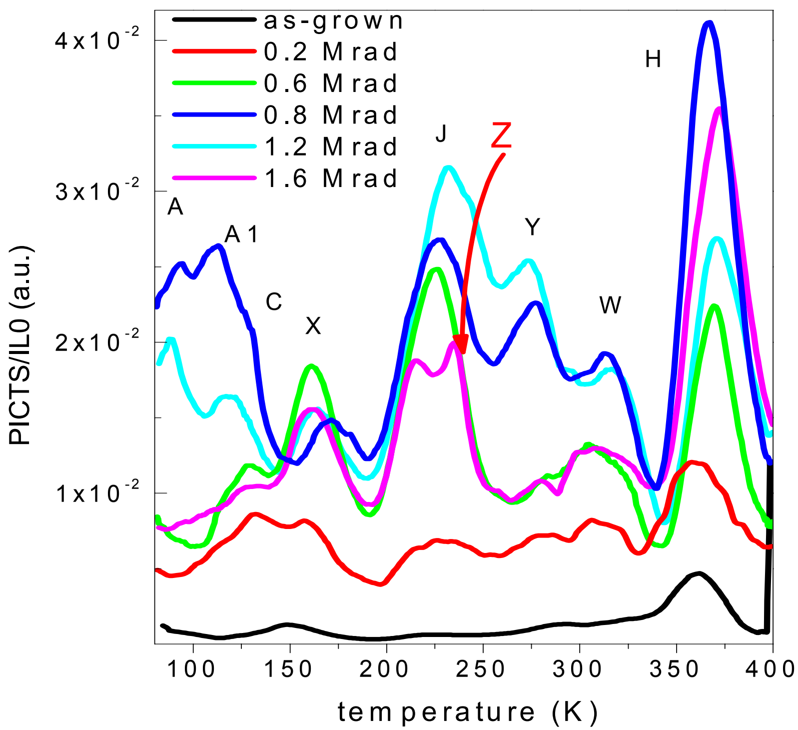
- 2nd Annealing stage (400K-470K):
  - Blue shift of S3 level energy; S3 parameters are those of Z1/Z2 level.

- Possible recovery cause: annihilation of the defect related to S2 during 1st annealing stage (360K-400K).

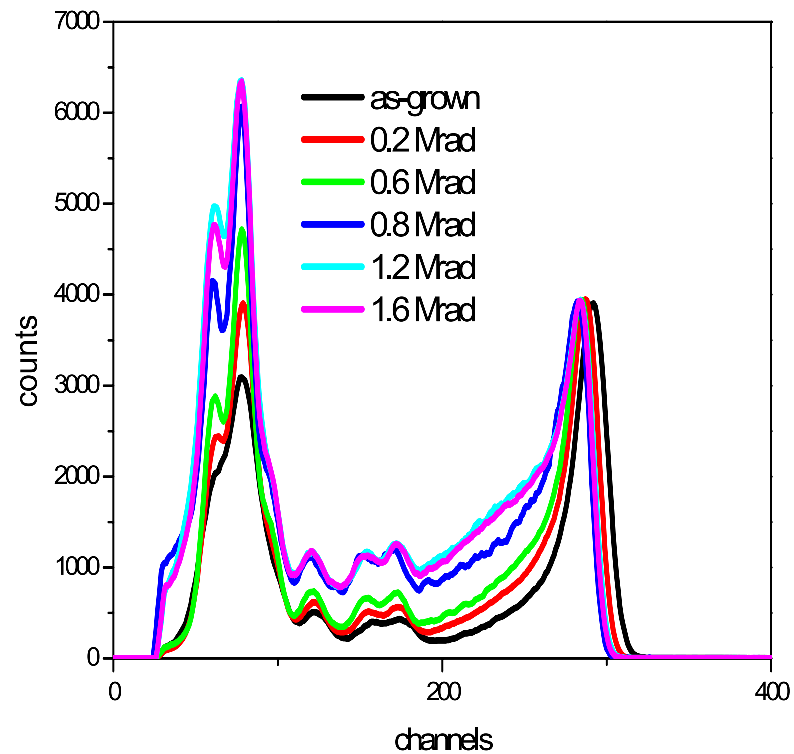
- Detector performance preserved up to $\Phi \sim 10^{15}$ cm^{-2}.
  - CCE saturates to 100% in drift regime and remains unchanged upon annealing.

9 MeV electron irradiation on CdZnTe

PICTS

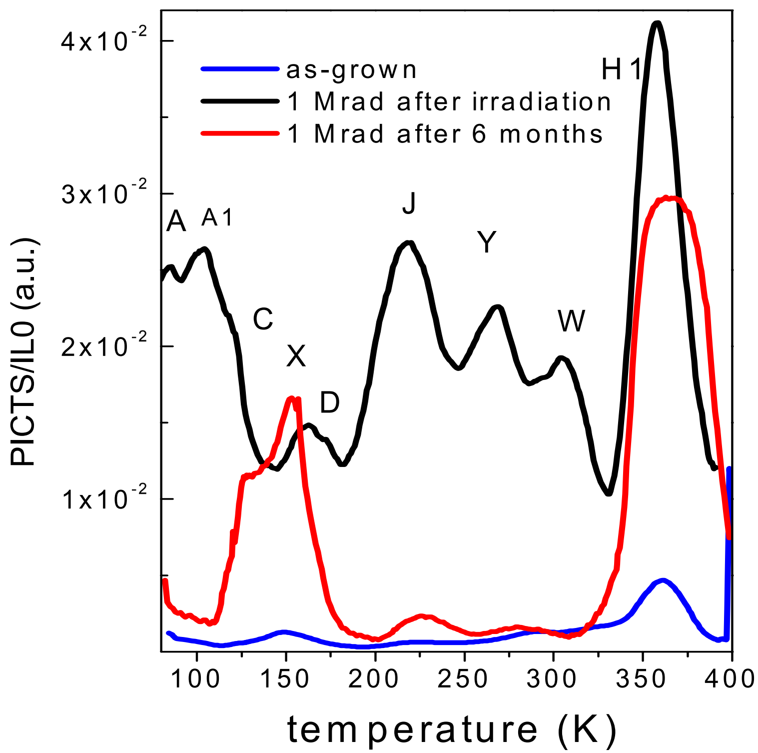


Gamma Spectroscopy



Time recovery of 9 MeV electron irradiated CdZnTe (6 months)

PICTS



Gamma Spectroscopy