Prediction of the macroscopic "reverse annealing" using microscopic defect concentrations

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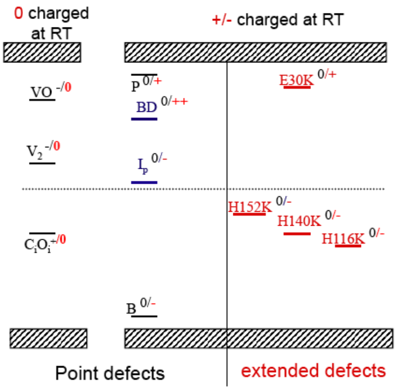
Motivation - defect engineering

Aim: Passivation of defects with impact on sensor properties

→ knowledge about defects needed



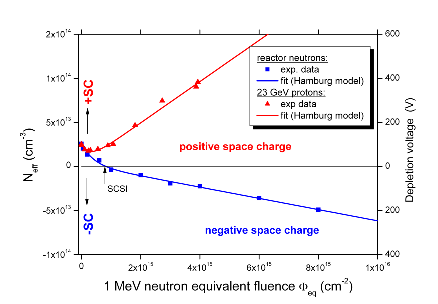
I. Pintilie, NSS, Dresden, 2008

Impact on N_{eff}:

- defects charged at RT have impact
- 0 charged defects do not contribute
- acceptors contribute with (-) to SC
- donors contribute with (+) to SC

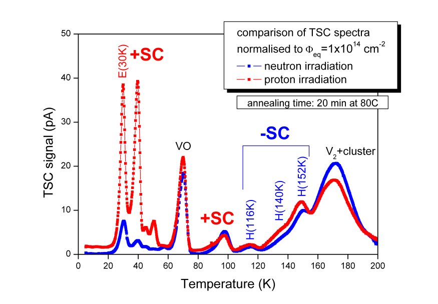
Influence of detected defects on N_{eff}

delopment of N_{eff} for EPI-DO after neutron and proton irradiation



I. Pintilie, et al., to be published.

TSC results after neutron and proton irradiation



- SCSI after neutrons but not after protons
- donor generation enhanced after proton irradiation
- microscopic defects explain macroscopic effect at low Φ_{eq}

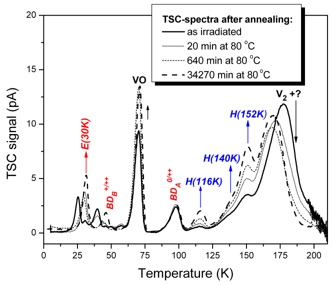
Previous results

$$\Phi_{eq} = 5 \times 10^{13}\ \mathrm{cm}^{-2}$$ neutrons

$$\Phi_{eq} = 2 \times 10^{14}\ \mathrm{cm}^{-2}$$ protons

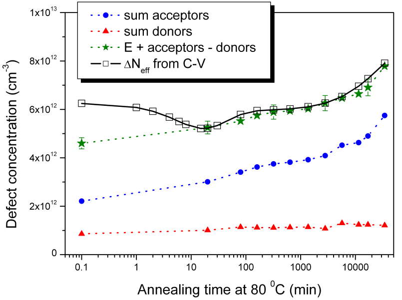
Isothermal annealing $\Phi_{eq} = 5 \times 10^{13}$ n/cm^2 (1MeV)

TSC-results (EPI-DO)



I. Pintilie, et al., to be published.

comparison to ΔN_{eff}



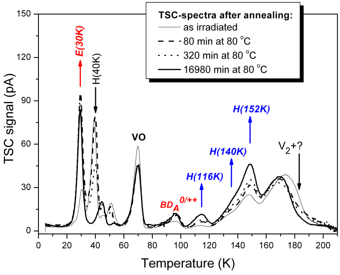
I. Pintilie, et al., to be published.

- acceptor generation dominates
- reverse annealing can be explained by deep acceptor traps

microscopic results predict macroscopic findings!

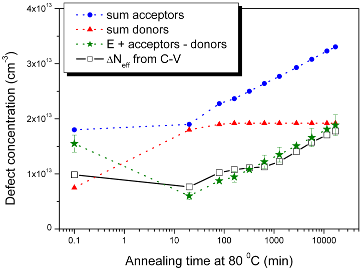
Isothermal annealing $\Phi_{eq} = 2 \times 10^{14} cm^{-2}$ (23 GeV p)

TSC-results (EPI-DO)



I. Pintilie, et al., to be published.

comparison to ΔN_{eff}



I. Pintilie, et al., to be published.

- donor generation enhanced relative to acceptor traps
- donor generation partly compensates acceptors

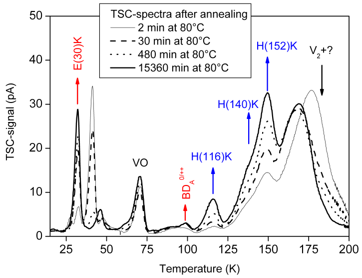
real breakthrough in understanding radiation damage

New Results

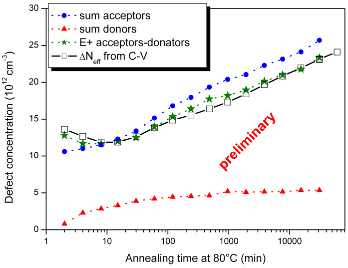
$$\Phi_{eq} = 2 \times 10^{14}\ \mathrm{cm}^{-2}$$ neutrons

Isothermal annealing 2 × 10^{14} n/cm²

TSC-results (EPI-ST)



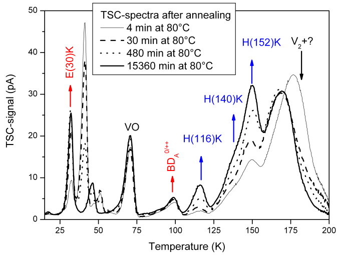
comparison to ΔN_{eff}



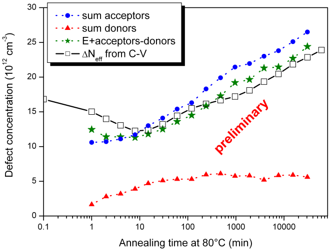
- short term annealing well described
- microscopic results predict macroscopic findings!

Isothermal annealing 2 × 10^{14} n/cm^2

TSC-results (EPI-DO)



comparison to ΔN_{eff}



- short term annealing deviates → still not fully understood
- reverse annealing explained by microscopic defects at this fluence

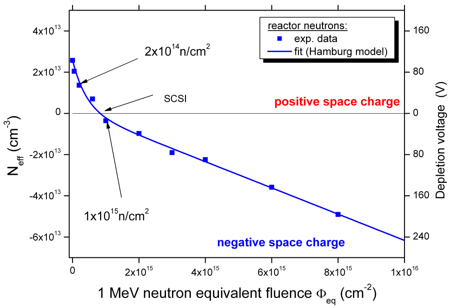
Increase of irradiation to

$$\Phi_{eq} = 1 \times 10^{15}\ \mathrm{cm}^{-2}\ \text{neutrons}$$

increase of the fluence to 1×10^{15} n/cm^2

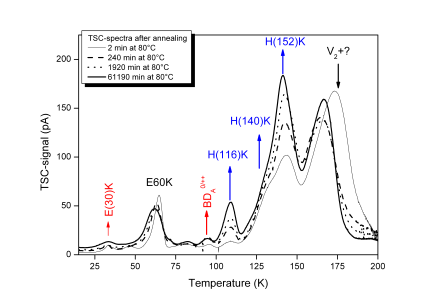
- type inversion between $\Phi_{eq} = 2 \times 10^{14}$ cm^2 and $\Phi_{eq} = 1 \times 10^{15}$ cm^2
- field distribution inside the diode?
  $\rightarrow$ double junction effect

development of N_{eff} for EPI-DO

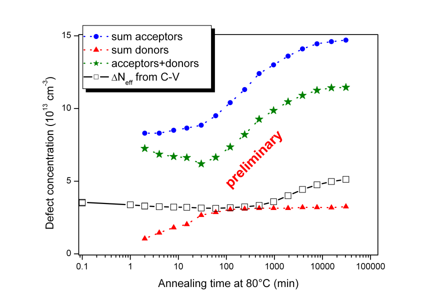


Isothermal annealing for 1×10^{15} n/cm^2

TSC-results for EPI-DO (400V)



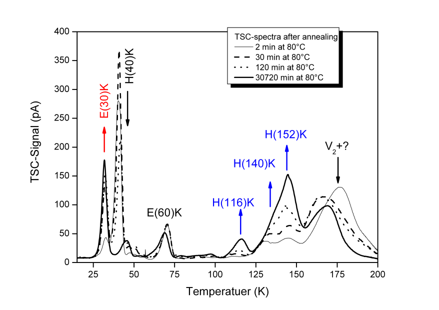
comparison to ΔN_{eff}



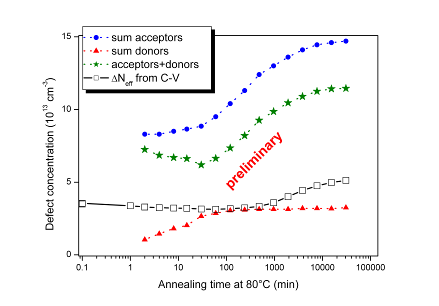
- obtained concentration of acceptors very high!
- evaluation very difficult due to high electrical field and double junction effect
- still more work needed!

Isothermal annealing for 1 × 10^{15} n/cm^2

TSC-results for EPI-DO (100V)



comparison to ΔN_{eff}



- obtained concentration of acceptors very high!
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- still more work needed!

summary

- real breakthrough in understanding radiation damage
- microscopic defects explain macroscopic findings for non-type-inverted diodes
- still some open questions for type-inverted diodes

outlook

- improve evaluation for highly irradiated sensors
- annealing study of $\Phi_{eq} = 1 \times 10^{15}$ cm^{-2} protons