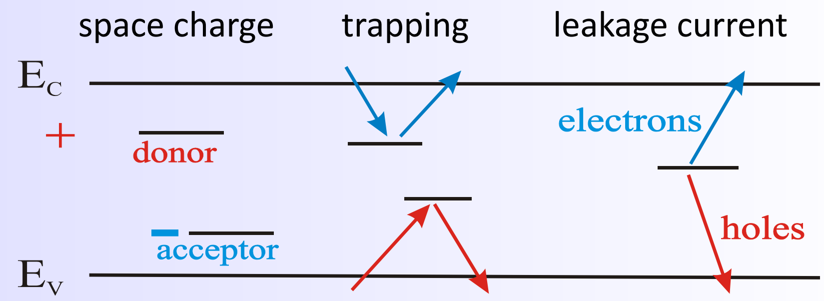
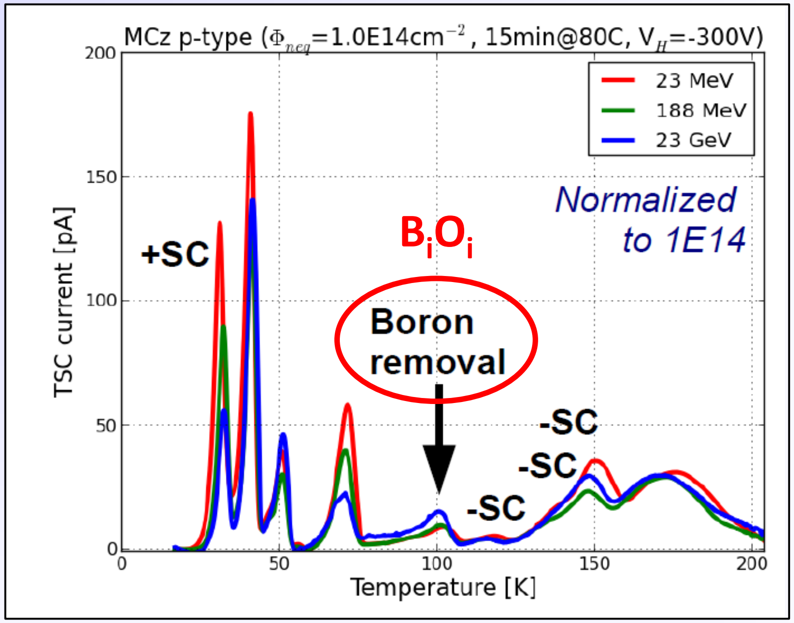
Defect Characterization

- **Aim of defect studies:**
  - Identify defects responsible for Trapping, Leakage Current, Change of N_{eff}, Change of E-Field
  - Understand if this knowledge can be used to mitigate radiation damage (e.g. defect engineering)
  - Deliver input for device simulations to predict detector performance under various conditions



- **Method:** Defect Analysis performed with various tools inside RD50:
  - **C-DLTS** (Capacitance Deep Level Transient Spectroscopy)
  - **TSC** (Thermally Stimulated Currents)
  - **PITS** (Photo Induced Transient Spectroscopy)
  - **FTIR** (Fourier Transform Infrared Spectroscopy)
  - **EPR** (Electron Paramagnetic Resonance)
  - **TCT** (Transient Current Technique)
  - **CV/IV** (Capacitance/Current-Voltage Measurement)
  - **MW-PC** (Microwave Probed Photo Conductivity)
  - *PC, RL, I-DLTS, TEM,… and simulation*

  - RD50: several hundred samples irradiated with protons, neutrons, electrons and ^{60}Co-γ

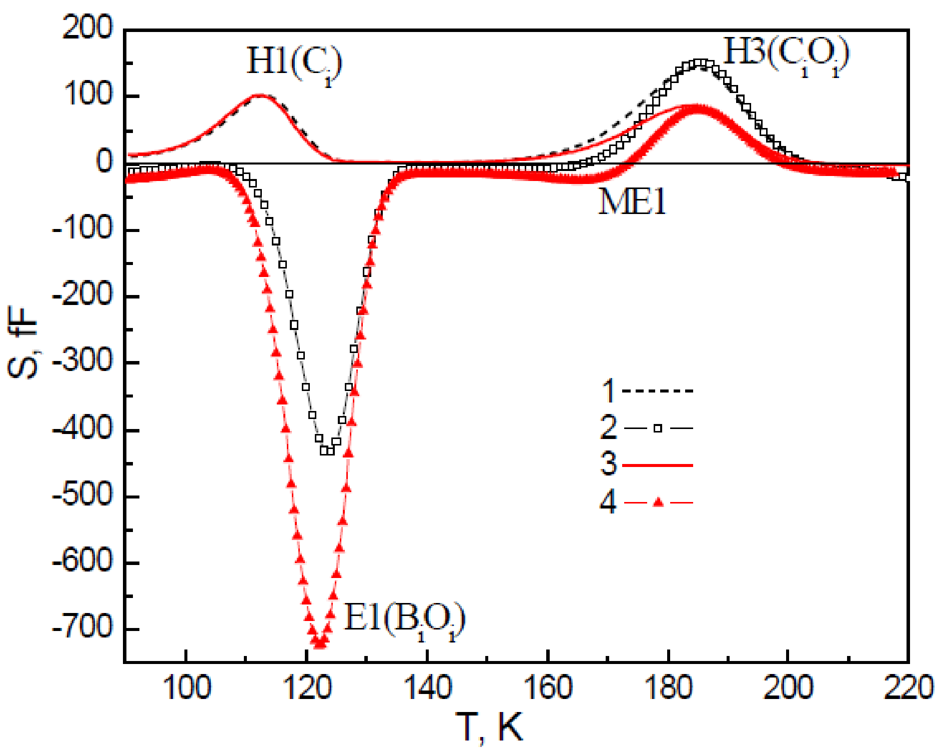


Example: TSC measurement on defects produced by 23 MeV, 188 MeV and 23 GeV protons

[Elena Donegani et al, UniHH, Trento Meeting, 2017]

Boron related defects

- **Leonid Makarenko (Minsk)**
  - **Defect spectroscopy on p-type sensors (DLTS)**
  - **BiOi measured … data analyses ongoing**



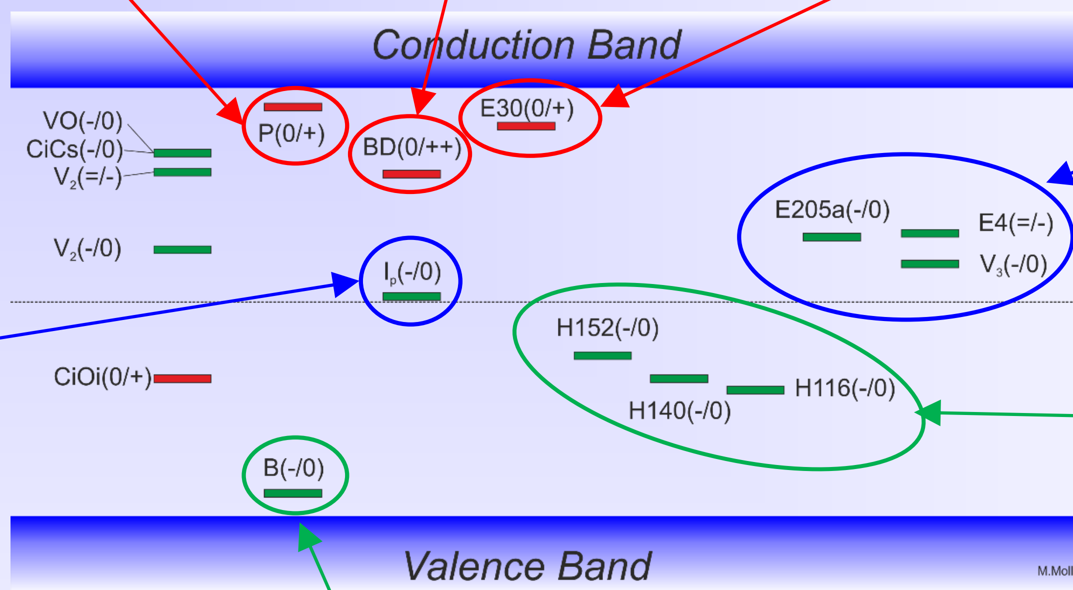
Summary on defects with strong impact on device performance after irradiation

- **Some identified defects**

Phosphorus: shallow dopant (positive charge)

positive charge (higher introduction after proton than after neutron irradiation, oxygen dependent)

positive charge (higher introduction after proton irradiation than after neutron irradiation)



Leakage current: V_3

leakage current & neg. charge

current after γ irrad, V_2O (?)

Reverse annealing (negative charge)

Boron: shallow dopant (negative charge)

A table with levels and cross sections is given in the spare slides.

- **Trapping: Indications that E205a and H152K are important** (further work needed)
- Converging on consistent set of defects observed after p, π, n, γ and e irradiation.
- Defect introduction rates are depending on particle type and particle energy and (for some) on material!

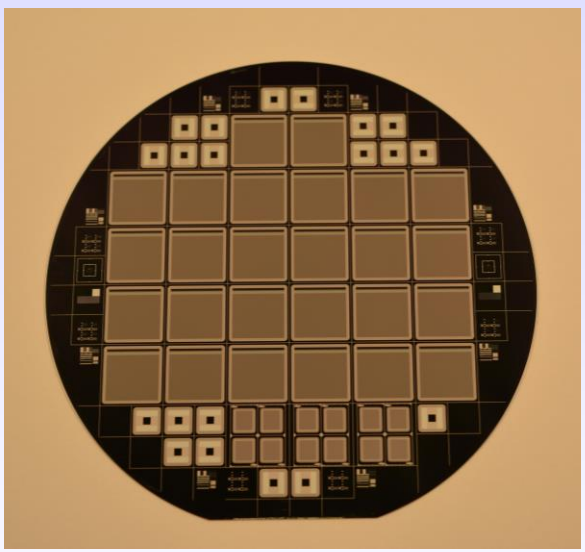
Summary on defects with strong impact on device performance after irradiation

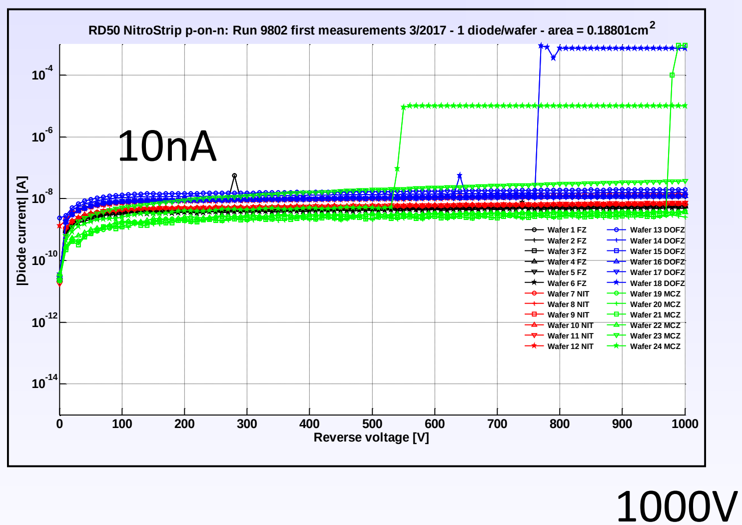
- **Most important defects** *[for details and references see JAP 117, 164503, 2015]*

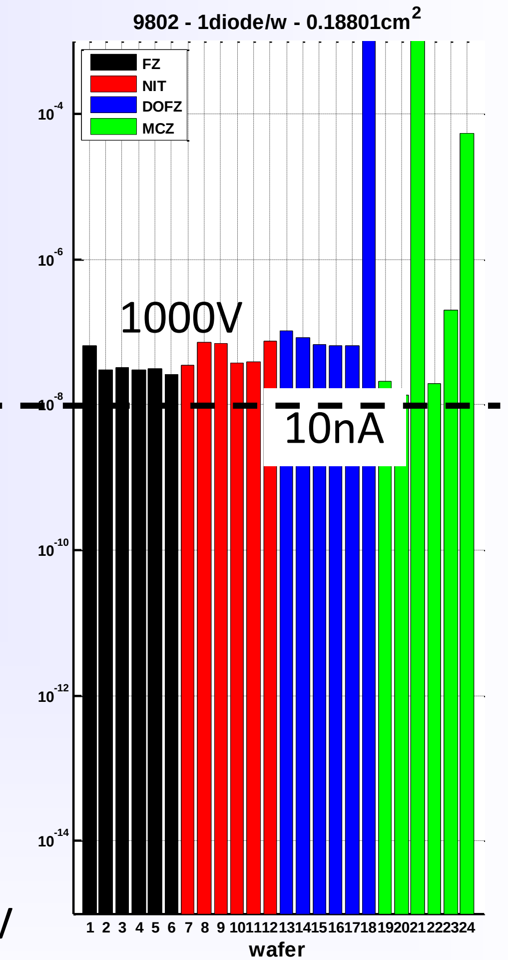
Defect	Assignment and particularities	Configuration	Energy levels (eV) cross section (cm^2)	Impact on electrical characteristics of Si diodes at room temperature (RT)
E(30K)	-Not identified extended defect -Donor in tupper part of the bandgap, strongly generated by irradiation with charged particles. [10,29] -Linear fluence dependence. [this work]	$E(30K)^{0/+}$	E_C-0.1 $\sigma_n = 2.3\times10^{-14}$	- Contributes in full concentration with positive space charge to N_{eff}
BD	*Thermal double donor (TDD2)* - point defect - Bistable donor existing in two configurations (A, B) in the upper part of the bandgap, strongly generated in Oxygen rich material. [24, 26, 27]	$BD_A^{0/++}$	E_C - 0.225 σ_n= 2.3 x 10^{-14}	- It contributes twice with its full concentration with positive space charge to N_{eff} , in both of the configurations
		$BD_B^{+/++}$	E_C - 0.15 σ_n= 2.7 x 10^{-12}	
I_p	- Not identified point defect - Suggestions: V_2O or a C related center. [22-24, 10] - Amphoteric defect generated via a second order process (quadratic fluence dependence), strongly generated in Oxygen lean material. [22-24, this work]	$I_p^{+/0}$	E_V + 0.23 σ_p= (0.5-9) x10^{-15}	- No impact
		$I_p^{0/-}$	E_C - 0.545 σ_n=1.7 x10^{-15} σ_p= 9 x 10^{-14}	- Contributes to both N_{eff} and LC
E_{75}	*Tri-vacancy (V_3)* - small cluster -Bistable defect existing in two configurations (FFC and PHR) with acceptor energy levels in the upper part of the bandgap. [10, 28, 30-33] -Linear fluence dependence. [this work]	FFC $V_3^{-/0}$	E_C - 0.075eV σ_n = 3.7x10^{-15}	- No impact
E4		PHR $V_3^{=/-}$	E_C - 0.359 σ_n = 2.15x10^{-15}	- No impact
E5		PHR $V_3^{-/0}$	E_C - 0.458 σ_n = 2.4x10^{-15} σ_p = 2.15x10^{-13}	- Contributes to Leakage Current
H(116K)	- Not identified extended defect - Acceptor in lower part of the bandgap. [10, 29] - Linear fluence dependence. [this work]	$H(116K)^{0/-}$	E_V + 0.33 σ_p=4 x 10^{-14}	Contribute in full concentration with negative space charge to Neff **Reverse annealing!**
H(140K)	- Not identified extended defect - Acceptor in the lower part of the bandgap. [10, 29] - Linear fluence dependence. [this work]	$H(140K)^{0/-}$	E_V + 0.36 σ_p=2.5 x 10^{-15}	
H(152K)	- Not identified extended defect - Acceptor in lower part of the bandgap. [10, 29] - Linear fluence dependence. [this work]	$H(152K)^{0/-}$	E_V + 0.42 σ_p=2.3 x 10^{-14}	

Nitrogen enriched Silicon

- **New defect and material engineering approach: Nitrogen enriched silicon**
  - Produced in collaboration with wafer foundry **TOPSIL, Denmark/Poland**
  - **4 materials used:**
    - Floating Zone (Standard, **Nitrogenated**, Oxygenated)
    - Magnetic Czochralski
  - Processing at CNM Barcelona Spain
  - Sensors ready in 4/2017 (in excellent quality)
    being distributed for radiation testing now







Workplan for 2017/2018 (1/2)

- **Defect and Material Characterization** *(Convener: Ioana Pintilie, Bucharest)*
  - Consolidate list of defects and their impact on sensor properties (Input to simulation group) including introduction rates & annealing for different type of irradiations and materials
  - **Extend work on p-type silicon including low resistivity material**
    - Understand boron removal in lower resistivity p-type silicon:
      Performance of MAPS, CMOS sensors, LGAD … adding new macroscopic measurements
    - Working group on **acceptor removal** formed!
  - Characterization of **Nitrogen enriched silicon** (starting project, wafers ready)