Study of the development of defects in Si PIN diodes exposed to 23 GeV/c protons

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Introduce:

- The Si PIN diodes were irradiated with 23 GeV/c protons at doses ranging from 0,5 to 43Gy
- The 23GeV/c protons produce typical crystallographic defects
- Defects are classified by their energy levels in the forbidden band from the conduction band
- Use DLTS method to measure the energy traps of the defects

Manufacture of type S2 PIN diodes:

- Resistivity ranging from 0.7 to 2Ohm.m
- Bulk material is FZ thus containing a low amount of oxygen atoms less then 10E15 cm^{-3}
- Oxygen atoms increase the radiation hardness
- The thickness: 2.5 mm
- Ion implantation is done with phosphorus and boron, at a total fluence of 10E16 cm^{-3}
- Anneal at 900C for 20 minutes
- The standard deviation of initial voltage determined at the current of 25mA was reduced to 1%

Yuzhen:

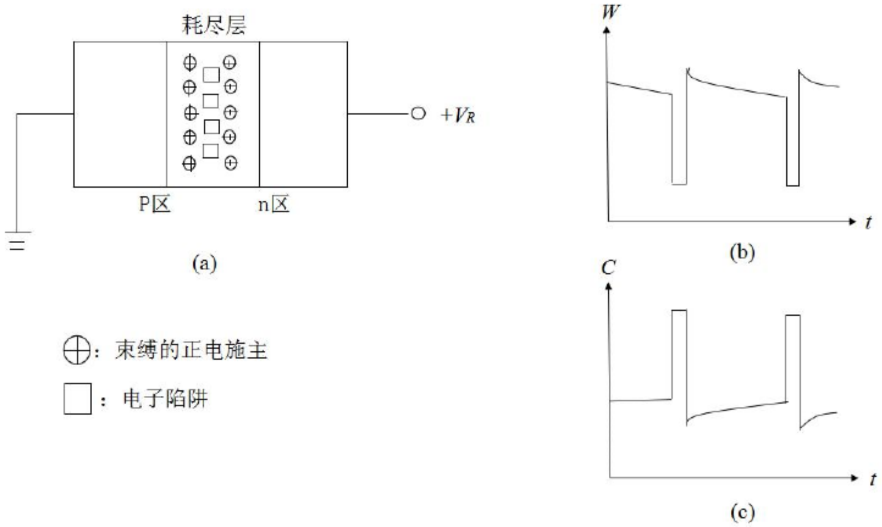
Can you introduce the working principle of DLTS?
And what is FZ-materials?

Float-zone silicon is very pure silicon obtained by vertical zone melting. The concentrations of light impurities, such as carbon and oxygen, are extremely low.

Principle of DLTS:

The deep level transient spectrometer (DLTS) is used to determine the deep level trap center level and concentration by testing the junction capacitance transients.

- Apply reverse bias V_R on the PN junction
- Assuming a depletion layer thickness of W, the junction capacitance: $C = \frac{\varepsilon A}{W}$
- Assuming that the thickness of the depletion layer is W, the junction capacitance is applied with a positive pulse voltage V_p, which is reduced.
- After the pulse, the depletion layer gradually becomes wider
- If there is a trap center, the electrons trapped in the trap center cannot be released immediately
- W is bigger than the original. The larger W, the greater the defect concentration



Experimental:

- 23 GeV/c protons irradiation
- Prior to irradiation exposure, the PIN were measured in 25mA with pluse of 40ms
- The duration of pulse is chosen on purpose so as to avoid heating the measured diode
- The error of voltage is not exceed 1mV

Results and conclusion:

- Time window was 0.02-2.06ms
- The time period was from 5 to 60ms and pulse duration was 900 µs
- The dose range from 0.5 to 43Gy

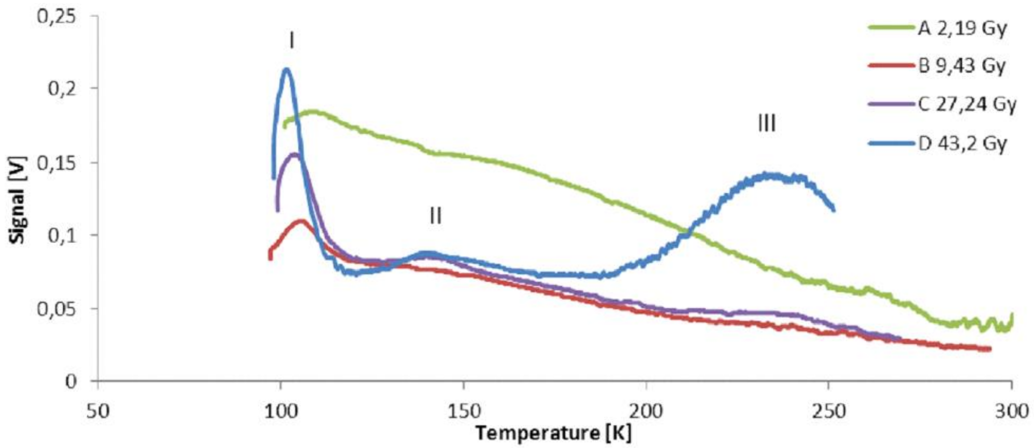


Table 1. Results of energy traps E_c in Si PIN diode irradiated by high energy protons.

Dose [Gy]	Peak I [eV, type of traps]		Peak II [eV, type of traps]		Peak III [eV, type of traps]	
0.5–14	0.17± 0.03	0.170, VO [4] 0.163, $VO^{-/0}$ [5]				
25–43	0.17± 0.03	0.170, VO [4] 0.163, $VO^{-/0}$ [5]	0.23± 0.03	0.230, VO^{2-} [4] 0.229, $VO^{=/-}$ [5]	0.41± 0.04	0.420, $V_2^{-/0}$ [4] 0.421, V_2^{1-} + VP [5]

- The existence of the traps measured is reflected in the calibration curve for the measurement of high-energy protons

Kai:

The diodes were irradiated with high energy protons at doses up to 43 Gy, could you give a rough estimation that, how long will the doses up to this value if it is put into ATLAS detector with current or the future HL-LHC enviroment?

apparatus. The time window was 0.02–2.06 ms, the time period was from 5 to 60 ms and pulse duration was 900 μs. The diodes were irradiated with doses ranging from 0.5 to 43 Gy. Traps were

Dengfeng:

I have a small question on the Figure 2 in this paper:
Why the signals corresponding to 27.24 and 43.3 Gy are always larger than the signals corresponding to 9.43 Gy at high temperature(> 150 k)?

In general, the bigger irradiation doses, the more defects. And in fig.2, the height of the peak is positively correlated with the concentration of the defect. So in same temperature position, when 9.43, 27.24 and have pea. The signals corresponding to 27.24 and 43.3 Gy are always larger than the signals corresponding to 9.43 Gy.

Xin：

On figure 2, how to understand the peak of “III” from blue curve around 250K?

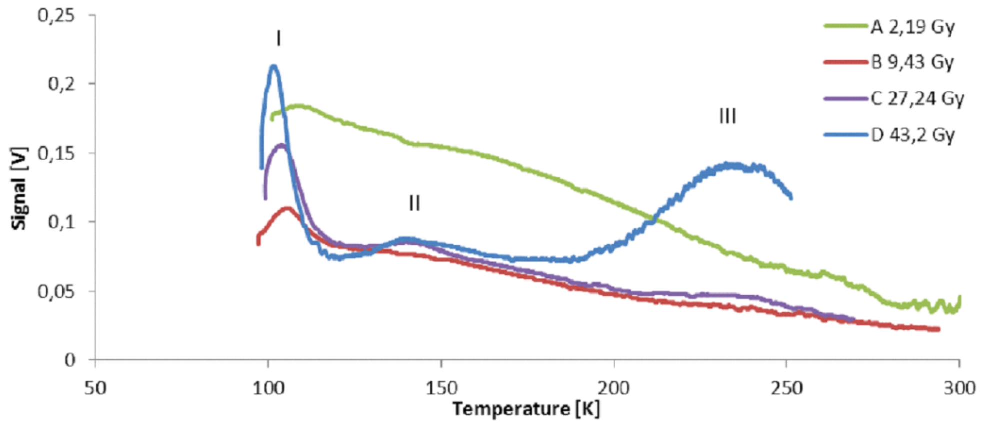
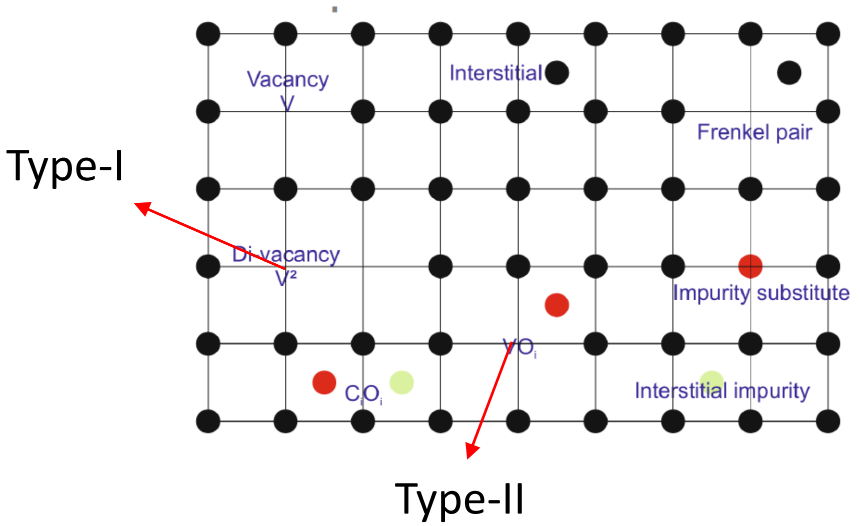


Figure 2. DLTS spectra for a PIN diode irradiated by high energy protons.

- Type I defects are di-vacancies caused by the interaction of vacancies among themselves
- Type II defects are oxygen vacancies with different charge states
- Type III defects are phosphorus vacancies

PIN: Boron doping. Boron leaves the original position. Donor Removal process (suppressed in O-rich material)



Ryuta:

In the Table 1, could you explain the notation of vacancies ?
(for example, VO: oxigen vacancy ? VO^{=} : ?? ...)

One more question is that does (so called) ″tri−vacancy″ included in above ?
if it is not the case, can the peak position exist within the range of Fig.2 (though the signal strength is not enough) ?

Sorry, I am not very understanding “$VO^{=/-}$”and “tri-vacancy”.

Table 1. Survey of electron traps identified in the n-base of proton irradiated diodes

Level	Bandgap position (eV)	Electron capture cross section (σ_n) (cm^2)	Identity
E1	E_C−0.163	1×10^{-14}	$VO^{-/0}$
E2	E_C−0.229	8×10^{-16}	$V_2^{=/-}$
E3	E_C−0.308	1×10^{-15}	VO-H
E4	E_C−0.421	1×10^{-15}	$V_2^{-/0}$
E5	E_C−0.457	3×10^{-16}	H-rel.

Only find this. The EC - 0.23 and EC - 0.43 eV levels are assigned to the doubly (=) and singly (-) negative charge state of V_2.