Degradation of Si-based detectors parameters under the alpha-particle irradiation

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Motivation

Semiconductor detectors are widely used in nuclear physics and high energy physics experiments. They possess unique characteristics for solving various experimental tasks – thin entrance window, good temporal and energy resolution. However, the application of semiconductor detectors could be limited by their ultimate radiation resistance.

Radiation defects in silicon are known to be electrically and recombination active. An increase of radiation defects concentration leads to significant degradation of the working parameters of semiconductor detectors. Thus, the investigation of radiation defects properties in order to enhance the radiation hardness of semiconductor detectors is an important task for successful implementation of a number of nuclear physics experiments.

Goal of the work

Some previous experiments [1] suggest higher radiation resistance of p-type Si as compared to n-type Si, which is widely applied in detector production. Thus, in this work we planned

- to investigate the degradation of p-type Si based surface barrier and Si(Li) p-i-n detectors parameters during the long-termed irradiation by α-particles,
- to study the type and concentration of the radiation defects formed under α-particles irradiation.

Detectors description

- Detector 1 - surface barrier detector: p-Si, boron doping ~ $5*10^{12}$ cm^{-3}

front surface – SiO_2 passivation layer (NAOS [2]) + Al barrier contact

rear surface – Pd ohmic contact

Sensitive area - Ø 7.5 mm, thickness 0.7 mm

Due to limited active region depth, suited for detection of particle with small penetration depth, such as α-particles

- Detector 2 - Si(Li) p-i-n detector produced by Pell,s method:

p-Si, FZ, resistivity 4 kOhm*cm, carrier lifetime 800 μs,

Sensitive area - Ø 13.5 mm, thickness 4.3 mm.

Suited for detection of particles with high penetration depth

- The spectrometric channel consists of BUI-3K amplifier with shaping time of 1-4 μs and a 4000-channel 12-bit CAMAC ADC type 161.31 (produced by PNPI) with resolution of 1.7 keV/channel.
- Irradiation was performed at room temperature in vacuum by reference spectrometric source of α-particles containing 233U, 238Pu and 239Pu isotopes with almost equal activities.

As-prepared detectors

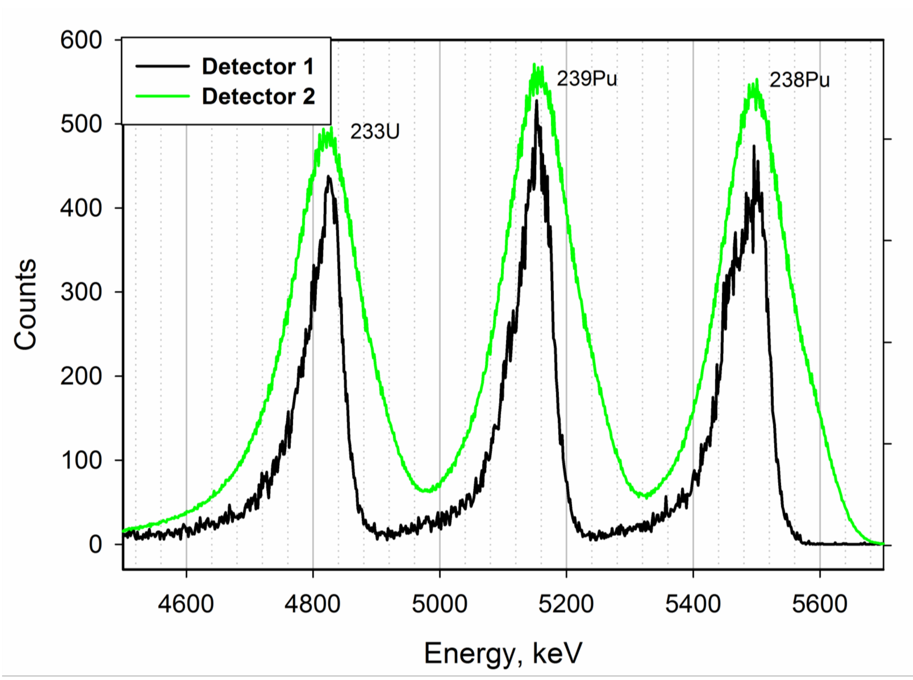
Measurement conditions:

Detector 1: applied bias Ub=10V, active region width ~50 μm (penetration depth of α-particles in Si ~30 μm)

reverse current at 10V Ir=0.3 μA

Detector 2: Ub=400V corresponding to full depletion

reverse current at 400V Ir=7.5 μA



Resolution on as-prepared detectors:

Detector 1 FWHM ~ 70 keV

Detector 2 FWHM ~ 130 keV

Total FWHM is defined by: $\sigma=\sigma_F^2+\sigma_s^2+\sigma_I^2+\sigma_R^2+\sigma_C^2$ where

σ_F – Fano factor

σ_s – losses in radiation source and detector's dead layer

$\sigma_I \sim (\tau I)^{1/2}$ leakage current

$\sigma_R \sim (\tau/Rc)^{1/2}$ and $\sigma_R \sim C/(\tau)^{1/2}$ feedback resistance and capacitance

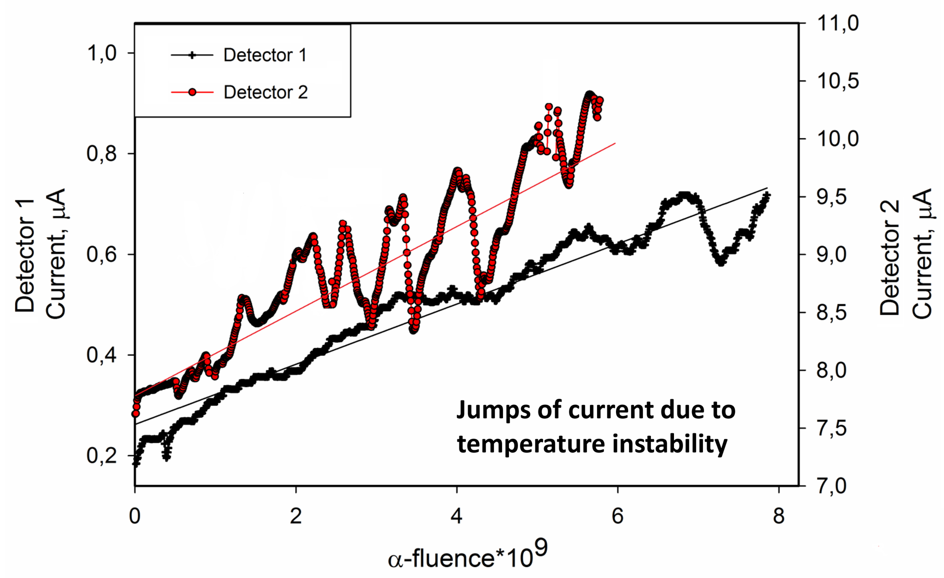
In our case the main contribution to the energy resolution is determined by σ_I, i.e. by the reverse current of the detector.

Irradiated detectors

Detectors were irradiated during 8 weeks at room temperature in vacuum with counting rate of 2200-2400 cps up to a total dose:

Detector 1 - of $8*10^9$ α-particles

Detector 2 - of $6*10^9$ α-particles



Nearly linear increase of the reverse currents during irradiation up to:

Detector 1: Ir=0.7 μA, slope $\Delta I/\Delta\Phi \sim 1.5*10^{-16}$ A/(cm²α)

Detector 2: Ir=9.5 μA, slope slope $\Delta I/\Delta\Phi \sim 2.7*10^{-16}$ A/(cm²α)

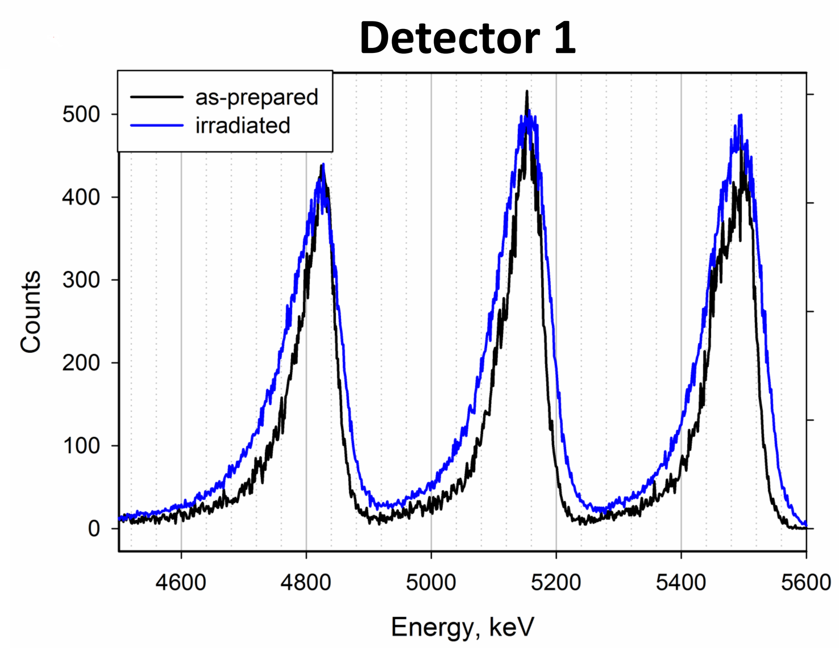
Increased reverse currents have resulted in resolution deterioration.

Resolution of irradiated detectors:

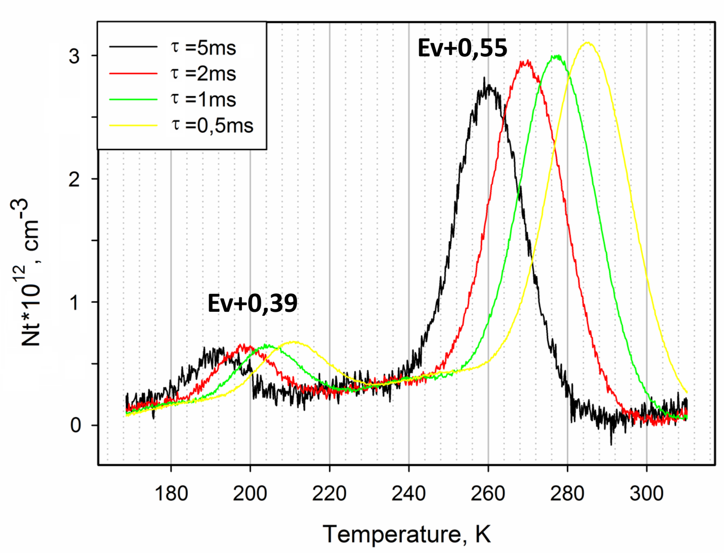
Detector 1: FWHM ~ 100 keV

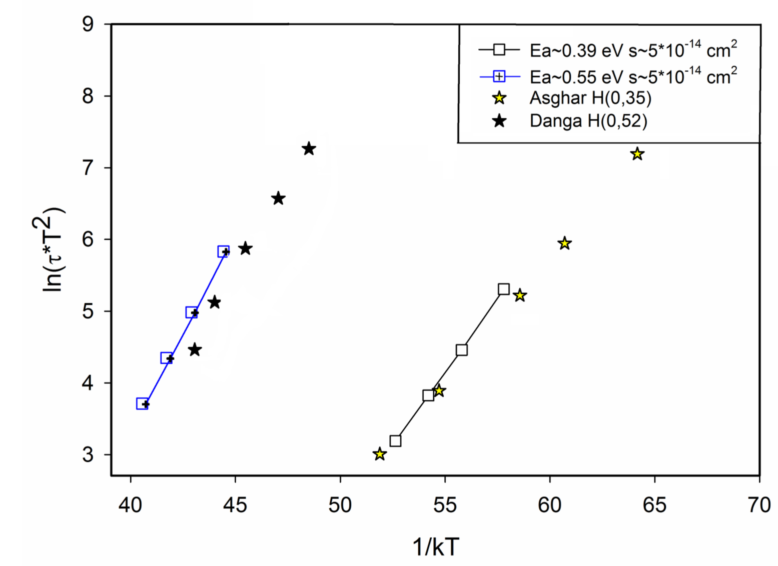
Detector 2: FWHM ~ 160 keV

Resolution has degraded!



Characterization of radiation defects in Detector 1 by current-DLTS





Two traps were revealed by iDLTS:

Ev+0.39 eV - close to the previously observed in α-irradiated p-Si [3] [4] and ascribed to Ci-related radiation defect

Ev+0.56 eV - resembles the defect observed in α-irradiated p-Si [4] [5] and ascribed to unidentified radiation defect

Summary

- As a result of 8-weeks irradiation with a total dose of 6-8*10⁹ α-particles, it was established that increase of the reverse current is described by a linear function of fluence with the slopes $\Delta I/\Delta\Phi = (1.5 - 2.7)*10^{-16}$ A/(cm²α).
- Degradation of the energy resolution of α-peaks is associated with increase of the detectorreverse current and could be described by $\Delta\sigma/\Delta\Phi = (4\text{-}5)*10^{-9}$ keV/α.
- It was established that a change in the energy resolution of the p-Si based detectors makes it possible to reliably separate the signals from α-particles until the fluence of a few 10^{10} α-particles.
- Two deep traps were revealed in irradiated Detector 1 by iDLTS method. The concentration of the dominant Ev+0,55 eV traps of $3*10^{13}$ cm^{-3} is high enough to explain the observed increase of the reverse current.

References

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