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\cite{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:

\begin{itemize}
  \item to investigate the degradation of p-type Si based surface barrier and Si(Li) p-i-n detectors parameters during the long-term irradiation by a-particles,
  \item to study the type and concentration of the radiation defects formed under a-particles irradiation.
\end{itemize}

As-prepared detectors

Measurement conditions:
Detector 1: applied bias U=10V, active region width \textasciitilde 50 \textmu m (penetration depth of a-particles in Si \textasciitilde 30 \textmu m) reverse current at 10V \textasciitilde 0.3 \mu A
Detector 2: U=400V corresponding to full depletion reverse current at 400V \textasciitilde 7.5 \mu A

Resolution on as-prepared detectors:
Detector 1 FWHM \textasciitilde 70 keV
Detector 2 FWHM \textasciitilde 130 keV

Total FWHM is defined by:
\sigma = \sigma_F + \sigma_L + \alpha \tau + \sigma_R + \sigma_C
where
\sigma_F – Fano factor
\sigma_L – losses in radiation source and detector’s dead layer
\alpha = (1+\tau)^{1/2} – leakage current
\sigma_R= \tau/\tau_{RC}^{1/2} and \sigma_C= C/(\tau)^{1/2} feedback resistance and capacitance

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

Summary

- As a result of 8-weeks irradiation with a total dose of 6-8*10\textsuperscript{10} a-particles, it was established that increase of the reverse current is described by a linear function of fluence with the slopes D/\Delta \Phi = (1.5 - 2.7)*10\textsuperscript{-15} A/(cm\textsuperscript{2}).
- Degradation of the energy resolution of a-peaks is associated with an increase of the detector reverse current and could be described by \Delta D/\Delta \Phi = (4-5)*10\textsuperscript{-9} keV/\alpha.
- 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 a-particles until the fluence of a few 10\textsuperscript{10} a-particles.
- Two deep traps were revealed in irradiated Detector 1 by IDTS method. The concentration of the dominant Ev=0.55 eV traps at 3*10\textsuperscript{11} cm\textsuperscript{-3} is high enough to explain the observed increase of the reverse current.

Detectors description

- Detector 1 - surface barrier detector: p-Si, boron doping \textasciitilde 5*10\textsuperscript{12} cm\textsuperscript{-3} front surface – SiO\textsubscript{2} passivation layer (NAOS 2) + Al barrier contact rear surface – Pd ohmic contact
  Sensitive area \textasciitilde 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 a-particles
- Detector 2 - Si(Li) p-i-n detector produced by Pell,\textsubscript{s} method: p-Si, FZ, resistivity 4 KOhm*cm, carrier lifetime 800 \mu s,
  Sensitive area \textasciitilde 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 \mu s 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 a-particles containing 233U, 238Pu and 239Pu isotopes with almost equal activities.

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\textsuperscript{10} a-particles.
Detector 2 – of 6*10\textsuperscript{10} a-particles

Nearly linear increase of the reverse currents during irradiation up to:
Detector 1: \textasciitilde 0.7 \mu A, slope \Delta D/\Delta \Phi = 1.5*10\textsuperscript{-16} A/(cm\textsuperscript{2})
Detector 2: \textasciitilde 9.5 \mu A, slope \Delta D/\Delta \Phi = 2.7*10\textsuperscript{-16} A/(cm\textsuperscript{2})

Increased reverse currents have resulted in resolution deterioration.

Characterization of radiation defects in Detector 1 by current-DLTS

Two traps were revealed by IDTS:
Ev=0.39 eV - close to the previously observed in a-irradiated p-Si\cite{4} and ascribed to Cl-related radiation defect
Ev=0.56 eV - resembles the defect observed in a-irradiated p-Si\cite{4} and ascribed to unidentified radiation defect

References

\cite{1} T. Markwart, Journal of Materials Science: Materials in Electronics, 1, 1 (1990)

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