SEMICONDUCTOR DOSIMETERS FOR SELECTIVE DETERMINATION OF THE COMPONENTS IN MIXED GAMMA AND NEUTRON FIELDS

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INTRODUCTION

In order to estimate doses received by people in a case of nuclear accident it is important to have convenient sensors of mixed radiations and to discriminate heavy particles from ionizing radiation, becouse their biological effects are different. Semiconductor devices are widely used for such purposes. In comparison with traditional sensors (ionization chambers, Geiger-Muller counters,TLD and track detectors), semiconductor dosimeters have certain advantages because of their high sensitivity, small sizes and weights and simple readout. They can work in both passive and active modes, can store information for a long time, and can operate in count integrating mode. They register different kinds of radiation over wide ranges of doses and energies and are useful for accident and for routine dosimetry as well.

Possible use of semiconductor devices for dosimetry were described previously (for instance,MOS transistor for gamma (1,2) and PIN diode for neurton (3,4) - irradiation).New gamma and neutron sensors have been produced in our Institute and their main dosimetric parameters have been published in (5,6).

The purpose of this work was to describe all functional opportunites of PIN and MOSFET dosimeters, designed in our Institute.

PRINCIPLES OF SEMICONDUCTOR DOSIMETERS AND EXPERIMENTS.

The non-ionizing loss induced by neutrons in the bulk of silicon structures generates atomic displacements leading to defects in the crystal. These act as generation-recombination centers. PIN structures have relatively small sensitivity to gamma-rays , which produce few displacements, so they can be used for neutron radiation measurement only. Extensive studies have been performed on the effects of neutrons on the behaviour of PIN structures. The variation of forward voltage under fixed current shows a simple dose dependence by the equation:

$$\Delta U_f = U_f - U_0 = kD \qquad (1)$$

where U_0 and U_f are the initial bias and the bias after irradiation, respectively; D is the neutron dose. Sensitivity k has a complicated dose dependence on minority carrier lifetime τ_0 , resistivity ρ and diode geometry and can be expressed as:

$$k = dU/dD = k_\tau \tau_0 \, f(d/L) \qquad (2)$$

were k_τ is the damage constant, d is the base thickness and L is the diffusion length.

The known PIN diodes for dosimetry (4) were made from p- and n-Si ($\rho \sim 10 \div 100\ \Omega$ cm) and have been studied at a high level of injection, where damage constant depends on lifetime only. The authors found a value of k = 100 mV/Gy and dose dependence was linear up to 12 Gy.

We have studied (both theoretically and experimentally) PIN diodes on the high-resistivity base under intermediate injection level (6). In this case one can vary three parameters (d, L, ρ) to achive the best neutron sensitivity.

Thus for PIN diodes on the base of n-type silicon we have received a higher sensitivity over a wider dose range in comparison with a case of high level of injection (for $\rho \sim 1k\Omega$ cm, d=0,12÷0.3cm, k=0.1÷1.0 V/Gy, dose range from 0.1 Gy to 100 Gy; for $\rho \sim 40k\Omega$ cm, d=0.5cm, k=5V/Gy, dose range (0.005 ÷3.0)Gy).

The discrimination coefficient to gamma irradiation in mixed field is ~1000.

An accuracy of neutron dose determination depends on a temperature instability coefficient (TIC). For PIN diodes on the base of high resistivity silicon TIC is smaller and decreases with neutron dose in contrary with diodes on the low-resistivity base.

PIN sensors described above have been tested in count integrating mode under ^{137} Cs and ^{139} Ce gamma irradiation and had readout cut-off ~40 keV. Lower limit for gamma dose rate was 0,7 msv/h. Radiation defects created by fast neutrons do not effect significally on count characteristics up to neutron dose 10 Gy.

Proposed PIN diodes may be usful to measure the gamma dose rate and the accident fast neutron dose at the same time.

The mechanism of radiation sensitivity of MOS structures have been studied in details by many authors (1,2). A positive charge is stored in the gate oxide and the radiation-induced charge on the Si-SiO$_2$ interface appears under ionizing radiation. This leads to the threshold voltage shift, ΔU_t, for MOSFET or flat-band shift, ΔU_{FB}, for MOS capacitors. The built- in charge in the oxide and, therefore the value ΔU_t, depends on the concentration of hole traps, their space and energy distribution and the gate bias during irradiation. This dose dependence can be expressed:

$$\Delta U_t = (\Delta U_t) \max [1 - \exp (- \beta D_\gamma)], \qquad (3)$$

where sensitivity β depends on the oxide structure and is proportional to $N_t d^2_{ox}$, d_{ox} is the oxide thickness, N_t is the trap concentration. In order to get higher sensitivity one must increase d_{ox}.

Our previous measurements have been extended to n-channel MOSFET sensors on the base of p-Si substrate with resistivity 10 Ω·cm and oxide thickness 1 μm.

MOSFETs channel lengths have been varied from 10 to 50 μm.The dosimetric sensitivity to ^{137} Cs gamma irradiation was 150 mv/Gy in a passive mode and did not depend on channel length up to 40 μm; For standard radiotechnical transistor with 0.1μm oxide thickness β is three orders of magnitude less.In an active mode (with the positive gate bias V_g) the sensitivity is higher and varies as $\beta \sim V_g^{2/3}$.

Irradiation temperature (-60°÷60°C) does not effect on the sensitivity both in passive and active modes.

Studies of MOSFETs irradiated at the high dose rate (with pulse gamma rays source) has showed that sensitivity was practically independed on the dose rate up to 10 Gy/s.

Temperature instability coefficient depends on readout current. We have found experementally thermostability current 43 μA, when TIC=0.

A coefficient of discrimination to neutrons in mixed radiation field is ~100 and strongly depends on dosimeter encapsulation (7).

For dose measurement applications it is important to know the fading of devices.

Changes of voltage shifts with time for our MOSFET sensor are ~15% in two months storage, while the main change takes place during the first hour after irradiation (as in the case of PIN diodes).

The MOSFET dosimeters described above have been tested on the 3-d block of Tchernobyl atomic pover station after accident and have shown good agreement with results for standard TLD dosimeters (see table).

Gamma ray dose (rad)		
MOSFET dosimeters	Termoluminiscence dosimeters	Place of exposition
599	450±30	roof
365	370±20	roof
253	247±15	roof(Pb-3mm)
247	320±30	bulding, point 12
300	320±30	bulding, point 12
318	320±30	bulding, point 12
897	900	roof
394	353±13	bulding, point 12

Our next step was to combine PIN diode and MOS transistor in one sensor. For this purpose p-channel MOSFET with thick gate oxide and high resistivity base have been taken. Source-base and/or drain-base give P-N diodes with a linear response, changes in their current-voltage curves under irradiation could be used to measure neutron dose. Influence of gamma ray and neutron irradiation on dosimetric characteristics of such p-MOSFET has been investigated. The sensitivi to ^{137}Cs gamma rays was 100 mV/Gy , to fast neutrons of nuclear reactor ~ 30 mV/Gy. The last value may be increaced by using MOSFET with a thicker base.

CONCLUSION

Silicon dosimeters described above were developed for reliable selective determination of gamma and neutron radiation at accident , routine measurements and medical application:

1. PIN diodes on high resistivity base for fast neutron dose measurement, n-MOSFET transistors for gamma dosimetry.
2. PIN diodes to measure gamma dose rate in routine dosimetry and accident fast neutron dose at the same time.
3. Accident dosimeter for mixed radiation fields, using PIN diode together with MOSFET transistor.

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