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Semiconductor sensors for dosimetry of epithermal neutrons

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Abstract. Minimum energy of neutron to displace atoms in silicon crystals are equal to 200 eV. Due to this fact testing our *p-i-n* diodes under irradiation by the epithermal neutrons was carried out. The more advanced *p-i-n* diodes on the base of high purity silicon were used at present work, and, as a result, we have obtained considerably more sensitive sensors for more wide range of neutron doses. The sensitivity of sensors is 0.14 V/Gy for average neutron energy of 24 keV.

Keywords: dosimetry, semiconductor detectors, epithermal neutrons, silicon, converter.

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1. Introduction

The measurement of epithermal neutron flux is very significant task for Boron Neutron Capture Therapy (BNCT). In this paper semiconductor sensors were used for epithermal neutron flux measurement. These semiconductor sensors were produced by us. These are *p-i-n* diodes and semiconductor detectors with ²³⁵U converter.

Possibilities for application of fast neutron dosimeters using the *p-i-n* diodes as a base have been shown earlier [1]. The principle of detection is based on the creation of radiation defects in semiconductors under the influence of fast neutrons, which change the electrical parameters (a diode voltage drop increases for a fixed current). It is known that the minimum energy of neutron to displace atoms in silicon crystals is equal to ~ 200 eV. Due to this fact there were all reasons to test the *p-i-n* diodes prepared by us under irradiation in the epithermal neutron energy range.

2. Experimental results

At the beginning of investigation, our colleagues and we have made the detail analysis of all available dates, such

as the KERMA damage and the total KERMA for silicon [2]. The results of experimental verification for monoenergetic neutrons in the energy range from 90 to 900 keV were obtained in [2]. In spite of the complicated view of the KERMA damage dependence, as evident from these data, a proper coincidence between the experimental results and theoretical calculations of KERMA by Monte Karlo method was obtained. The presence of some hollow in the neutron energy range from 100 to 300 eV partly makes difficulties to use the *p-i-n* diodes as tissue-equivalent sensors in practically used energy range of epithermal neutrons. There is doubtless interest to test the offered by us semiconductor sensors intended for measurements of total tissue dose from the extremely complicated spectrum of Petten High Flux Reactor, which was used in BNCT [3]. From these data, the fast neutrons (>10keV) make a considerable and undesirable contribution to damage KERMA. In our work [4], it was shown that *p-i-n* diodes, which were calibrated with a known energy, could be used to determine tissue doses, received in the courses of irradiation by neutrons with an unknown energy. Proceeding from this fact, we were able to determine a sensitivity of our sensors under the energy of 24 keV (the channel HB12) and intensity of $1.23 \cdot 10^{12}$ n/m²·sec.

The changes of a direct voltage drop (ΔV) for *p-i-n* diodes under fixed current of 1mA (at irradiation time 85 min,

$E_n = 24$ keV, tissue KERMA $1\text{Gy} = 5 \cdot 10^{15}$ n/m²) were measured. The average changes of the direct voltage drop is $\Delta V = 0.175$ V and the received dose is $\Phi = 1.25$ Gy. The average sensitivity of sensors was $\Delta V/\Phi = 0.140$ V/Gy.

Dose dependences of ΔV were obtained by means of additional irradiation of the same diodes up to the total 16 hours. Dose dependencies are presented in Fig. 1 for the sensors of numbers 2n and 3n with the best and the worst sensitivities, respectively. As one can see from Fig. 1, the changes of a direct voltage drop are very good fits to linear dependence ΔV vs Φ in the range of used irradiation doses.

Mentioned sensors were calibrated in the channel HB12, and then irradiated in the channel HB11 for $1.8 \cdot 10^3$ sec. Our sensors give the average tissue dose of neutrons as much as $\Phi = (2.76 \pm 0.16)$ Gy per hour.

In this channel, besides neutrons, the gamma irradiation is presents, according to the HB11 channel technical characteristics, and gives the contribution to dose 1.2 Gy per hour. As the coefficient of discrimination for our neutron sensors in relation to the gamma irradiation is $\sim 10^3$ [2], then the determined above tissue dose entirely relates to the neutron spectrum of the channel HB 11. Proceeding from the HB11 technical characteristics one may appreciate the share of fast and epithermal neutrons into tissue KERMA. The epithermal neutron flux (0,414 eV-10 keV) is $3.3 \cdot 10^{12}$ n/m²sec. If we suppose that all neutrons in this spectrum possess the energy as much as 10 keV (KERMA = 10^{16} n/m²), then the dose will correspond to $\Phi = 1.2$ Gy per hour. Under assumption that both the average energy and flux of fast neutrons are 0.5MeV (KERMA = $5.6 \cdot 10^8$), and $4.7 \cdot 10^7$ n/cm²/s (>10keV) respectively, we obtained $\Phi = 1.6$ Gy. These appraisals of ours coincide with obtained by us results on the total dose $(1.6+1.2)=2.8$ Gy and confirm an undesirable contribution of fast neutrons (60%) in the total therapeutical dose.

The epithermal neutron flux at the HB11 channel was measured also by the silicon barrier-surface detectors with

an attached ²³⁵U converter. The converter as ²³⁵U oxide-protoxide being enriched up to 99.92 % with the thickness of $1.5 \cdot 10^{-4}$ m, mass 10^{-6} kg and alpha activity of 81 Bq was fabricated on Al- sublayer. We established that the detectors efficiency to epithermal neutrons the (HB11 neutron spectrum) is $1.82 \cdot 10^{-5}$ imp/n.

Conclusions

The use of *p-i-n* diodes made on the base of high purity silicon for registration of epithermal neutrons with the coefficient of gamma ray discrimination 10^3 is demonstrated. A good agreement of experimental data with theoretical calculations of the damage KERMA for silicon has been shown.

It is shown that *p-i-n* diodes can serve as tissue-equivalent dosimeters in the neutron energy range from 300 eV till 30 keV. The possibility of neutron flux monitoring by means of silicon detectors with ²³⁵U converter was shown.

References

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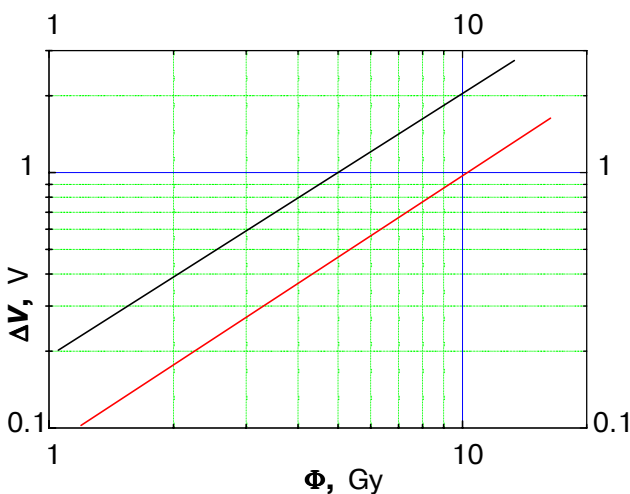


Fig. 1. Dose dependence as a function of change of voltage (ΔV) at *p-i-n* diodes with big (2n) and little (3n) sensitivity under irradiation of neutron with energy of 24 keV.