SEMICONDUCTOR DETECTORS FOR MEASUREMENT OF THE NEUTRON FLUX IN WIDE ENERGY RANGE


Semiconductor silicon detectors with $^{235}$U converters and plastic converters and neutron dosimeters with p-i-n structure were used for measurement of the neutron flux in wide energy range from thermal to fast neutrons.

Registered by a Si-detector fission fragment from $^{233}$U nuclei after the fission process caused by a capture of a neutron have energy (about 70 MeV) and therefore signals from fission fragments may be separated with good reliability from other ones, caused by $\gamma$-rays and $\alpha$-particles. These advantages of Si-$^{235}$U sensors are useful for their use in BNCT methods.

Semiconductor detectors with area 1cm² with $^{235}$U converter allowed to measure neutron flux in energy range from thermal to epithermal neutrons. The detector efficiency was $5.5 \times 10^{-4}$ imp/n for thermal neutrons and $1.82 \times 10^{-5} \text{ imp/n-cm}^2$ for average neutron energy 10.4 KeV.

The possibility of fast neutron dosimeters made on p-i-n diodes base have been shown earlier(1). The principle of detection is based on the creation of radiation defects in semiconductors under influence of fast neutrons, which change the electrical parameters (the diode voltage drop increase for the fixed current). It is known that the minimum energy of neutron to displace atoms in silicon crystals (Si) is equal to ~ 200 eV. Because of that there were all reasons to test the worked out by us the p-i-n diodes under irradiation in the epithermal neutron range. At the beginning of investigation our international 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 the monoenergetic neutrons in energy range from 90 keV to 900 keV obtained in work (2). As evidenced from these data, that, in spite of the complicated view of the Kerma damage dependence, a good coincidence between the experimental results and theoretical calculation of Kerma by Monte Karlo method was obtained.

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² The Netherlands Energy Research Foundation, ECN.
³ GSF, Institute of Radiation Protection, Germany.
Presence of some hollow in the neutron energy range from 100 eV to 300 eV partly makes difficulties to use the p-i-n diodes as a tissue-equivalent sensors in practically used range of epithermal neutrons. There is an doubtless interest exists to test the offered by us semiconductor sensors intended for measurements of summery tissue dose from the extremely implicated spectrum of High Flux Reactor channel HBII, which was used in BNCT (3).

From these data, the fast neutrons (>10 keV) make considerable and undesirable contribution the damage Kerma. The questions arise whether our tests are correct. In our work (4) it was shown that p-i-n diodes which were calibrated to the known energy can be used to determine the tissue dose, received from neutron of unknown energy. Proceeding from this fact we were able to determine the sensitivity of our sensors under energy of 24 keV (channel HB 12). Average sensitivity was $1.4 \text{ mV/cGy}$. Being calibrated in channel HB 12, sensors were irradiated in channel HB11. Our sensors give the tissue dose of neutrons as much as $(276 \pm 16) \text{ cGy/h}$.

According to the HB11 channel technical characteristics in this channel besides neutrons the $\gamma$ - irradiation presents as well with the intensity of 120 cGy/h.

As the coefficient of discrimination for our neutron sensors in relation to the $\gamma$- irradiation is $-10^3$ (1), then the determined above tissue dose entirely relates to the neutron spectrum of channel HB 11.

Proceeding from the HB11 technical characteristics one may appreciate the share of fast and epithermal neutrons into tissue Kerma. The contribution of dose due to neutrons with energy of $E > 10 \text{ keV}$ in the total dose is about 60%.

To measure the neutron flux the silicon barrier-surface detectors with an attached $^{235}\text{U}$ converter has been used. The converter as $^{235}\text{U}$ oxide-protoxide being enriched up to $99.92\%$ with the thickness of 150 $\mu$m, mass 1 mg and $\alpha$- activity of 81 Bq was fabricated on AL- sublayer. The intensity of thermal neutron flux at the channel HB7 was determined by activation of Au target with diameter 1 cm $(5.8636.10^6 \text{ n/cm}^2 \text{s})$.

Fig. 1 The fission fragment spectrum obtained with the semiconductor detector under the thermal neutron irradiation at the horizontal channel HB7 with Bi filter.

The summary impulse number from 90 to 1024 channels is equal 1936982 $\text{imp/10 min}$.
N=3,23\times10^3\text{imp/cm}^2\text{s}. The detector sensitivity: K=3,23\times10^3/5,8636\times10^6=5,5\times10^4\text{imp/n}.

Measurements at HB11 channel (Neff=10.4\text{ keV}) were carrying out. The diaphragm with diameter 15mm decreases the beam flux in 100 times. However, in the thermal neutron range, the installed diaphragm suppresses the thermal neutron flux much more then in 100 times. Under this circumstances one may neglects with the thermal neutrons contribution into the detector response.

We have used detector N7 with the attached $^{235}\text{U}$ converter. Spectrum of fission fragments and alpha - particles under irradiation of detector by the neutron beam HB 11 without filter are given in Figure 2.

![Spectrum of fission fragments under irradiation of detector by the neutron beam HB11.](image)

One may see that $\alpha$ - radiation of $^{235}\text{U}$ converter gives the impulses in the range of 42-90 channels and gives ~ 1110 imp per 10 min, while the fission fragments give 3610 imp/10 min in range of 90-1024 channels. Since the peak of $\alpha$- particles is placed in low energy part of spectrum we may ignore their contribution in the common number of impulses, taking into account the impulses in range of 90-1024 channels. The sensitivity of detector: $K = 1,82\times10^5 \text{ imp}/\text{n}$.

Thus, we can come to the conclusion that the contribution into the detector signal from the thermal neutron is negligible. We confirm that the elaborated by us the semiconductor detectors with converter has got the linear dependence of the signal value as a function of intensity of thermal and epithermal neutron fluxes. Such semiconductor detectors can be applied for measuring the intensity of thermal and epithermal neutrons under the condition that the neutron beams have to be collimated. These detectors may be used for the purposes of BNCT in the on-line mode.

Surface - barrier detectors with thickness 800 $\text{um}$ and sensitive area 24 $\text{cm}^2$ were used as proton-recoil neutron spectrometer for measurement of fast neutron flux with energy till 10 MeV. As the converter PMMA - plastic plate with depth 1.5 mm was used. Spectrum of recoil protons from a hydrogenous radiator bombarded with
neutrons in range 5MeV -10 MeV was obtained at various bias. It was shown that efficiency of the detector increased at high bias (400V). Calculated efficiency this detector with converter is equal to $3.19 \times 10^3$ imp/n.

These semiconductor detectors with different converters may be used for measurement of neutron flux in wide energy range in the on-line mode.

**Conclusions**

A use of p-i-n diodes made on the base of high purity silicon for registration of thermal and epithermal neutrons with the coefficient of γ-ray discrimination $10^3$ is demonstrated. A good agreement of experimental data with theoretical calculation of the damage Kerma for silicon has been shown.

It is shown that p-i-n diodes may serve as tissue-equivalent dosimeters in the neutron energy range from 300 eV to 30 keV.

The tissue neutron dose rate for the spectrum of HB11 channel of the HF reactor amounts about 276 cGy/h, where the fast neutron part is nearly 60%.

The possibility of neutron flux monitoring by means of silicon surface-barrier detectors with $^{255}$U converter at the detector sensitivity for thermal neutrons $5.5 \times 10^4$ imp/n and for epithermal neutrons (HB11 neutron spectrum) $1.82 \times 10^5$ imp/n is shown.

**References**


