The ability to create NTD silicon technology in the IRT-T reactor in a horizontal experimental channel with one-side access

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Abstract. The article shows the ability of creation of neutron transmutation doping (NTD) of monocrystalline silicon technology in the reactor's channel, which has a one-side access. In the article a distribution of thermal neutron flux through the length of channel and it's radius, neutron spectrum were obtained which confirmed that horizontal experimental channel HEC-1 is suitable for NTD.

1. Introduction

On the reactor IRT-T [1] of the Tomsk Polytechnic University the great attention among other radiation technologies is given to the neutron transmutation doping of the silicon (NTD). This technology was created in 1985 [2]. It realized on the horizontal experimental channel of the reactor HEC-4. Since then, it has continuously improved [3-5] from the point of view of quality and productivity of NTD. The main criteria of quality of NTD silicon are:

a) the dispersion of specific electric resistance (s.e.r.) on the ends of silicon ingots;
b) the deviation of the obtained values of s.e.r. from a given value;
c) the lifetime of minority charge carriers.

These indicators of the quality of the existing technology at reactor IRT-T are following:

a) the dispersion of s.e.r. on the ends of silicon ingots is not exceeds 2-4 %;
b) the deviation of s.e.r. from the given value, typically is less than 7%;
c) the lifetime of minority charge carriers, typically is 600-800 microseconds even when doping of silicon on low-resistivity values of s.e.r. (40-60 Ω·cm).

These quality indicators correspond to the best foreign analogs. The proof of this is the constant offers from domestic and foreign companies for cooperation. As for doping productivity, the possibilities of the reactor IRT-T are still realized no more than for 20% for different reasons. However, at the present time 4-5 tons of NTD silicon are produced on the reactor IRT-T per the year. As an example, China uses 20 tons of this material in a year at requirement of 40 tons.

One of opportunities of increase of doping productivity is as follows. On the IRT-T reactor there are two tangent experimental channels of big diameter (150 mm) – HEC-4 and HEC-1. However, the doping is realized only on channel – HEC-4. In this channel the axial uniformity of a doping is achieved due to the reciprocating movement of the containers with ingots through entire irradiation zone. Both the forward and reverse directions, the containers are moved so that they are completely left an irradiation zone. Therefore, at each such movement from one extreme position to another all elementary volumes of containers are irradiated with the same neutron fluence at any distribution of the neutron field along an axis of the channel. The length of HEC-4 channel has allowed to move containers with such amplitude, and the HEC-1 channel has limited length. In one of extreme positions it is impossible to completely remove containers out of irradiation zone limits. Therefore, so far HEC-1 is not used for the production of NTD silicon. This was not necessary, since all orders for a doping were covered by irradiation in HEC-4 channel.

Currently, there is a need to considerably increase of volume of NTD silicon. In this regard, for the tangent channels of the reactor limited on the one side, we have developed a method of irradiation [6] at which the axial uniformity of a doping is achieved. Its essence is illustrated in Fig. 1.

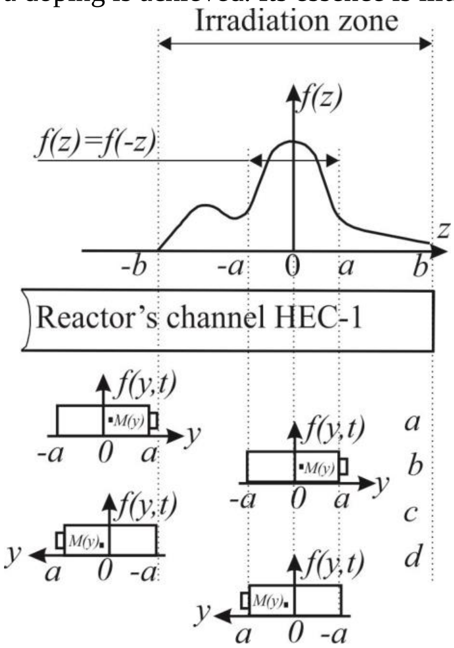

Figure 1. Position of container when using the channel with one-side access.

At implementation of this method the neutron field previously is formed so that in an irradiation zone (-b ≤ z ≤ b) there is area on which the distribution of density of a flow of thermal neutrons f(z) along an axis of the channel (axis z) would be even function (f(z) = f (-z)), and define this area - a ≤ z ≤ a. The length of the container must not exceed the length of the selected section (2a). Then the container once or repeatedly reciprocatingly is moved on the channel of the reactor from a position *a* to *b* and back. The irradiation is stopped when the fluence of neutrons average on container volume becomes equal to a half of the required. Then the container is deployed that its ends in the channel are reversed, and similarly is irradiated, moving it from a position *c* to *d* and back. At the same time in one extreme situation (positions *a* and *c*) the container is located outside an irradiation zone, and in the other (positions *b* and *d*) - combine the center of the container with the middle of a section (z=0), on which f(z) = f(-z). The proof, that at such method of irradiation the axial uniformity of a doping is achieved, is provided in [6].

The main requirement to NTD silicon monocrystals is the high uniformity of distribution of s.e.r. on ingot volume. So, according to specifications 48-4-443-83, acting in Russia, the dispersion of s.e.r. at ends of an ingot shouldn't exceed 5%, and a deviation of average value of s.e.r. at each end from nominal value shouldn't exceed 10%. The strictest requirements are put in standards of Wacker firm: 5% and 7% respectively. Therefore when the performing of researches the main attention was paid to definition of conditions under which the uniform irradiation of silicon ingots is achieved by thermal neutrons. According to it spatial distribution of the field of thermal neutrons in HEC-1 channel was experimentally defined. According to the obtained distribution of thermal neutrons on HEC-1 channel the optimum mode of irradiation of silicon ingots was chosen: velocities of rotation and linear movement of ingots on the channel of the reactor, the amplitude of reciprocating movement of ingots.

2. Experiment technique

At the measurements of the neutron field in HEC-1 the method of activation detectors [7] was used. As activation detectors, a copper foils and a copper wire were applied, which were fixed on the special device and by means of a bar were moved to the reactor channel. The reference points put on a bar allowed to install the device in the channel of the reactor with a margin error not worse than 3 mm, i.e. each activation detector was installed in the defined point of the irradiation zone with a margin error mm ±3, and their relative position – with a margin error about 1 mm. The irradiation of activation detectors was carried out at a power of reactor is 20 kW within 30 minutes. After the endurance of the irradiated samples within 24 hours, from irradiated foils and a wire the interesting areas were excised, weighed them and dissolved in nitric acid. The measurements of activity of solutions were conducted in the same geometry on the installation γ-γ coincidence. At the same time errors of relative measurements didn't exceed 3%.

As a result of measurements of activity of a copper wire the relative distribution of density of a neutron flow along an axis of the channel was obtained (Fig. 2).

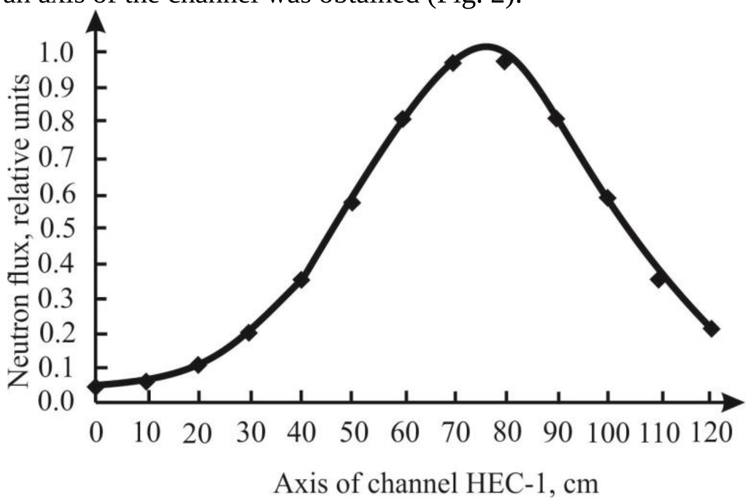

Figure 2. The distribution of the thermal neutron flux along axis of channel HEC-1.

In this Figure, the system of coordinates is as follows. The point 0 corresponds to border a gate of HEC-1 channel – a tank with water. The length of the channel in a tank is equal to 120 cm. The maximum density of a flow of thermal neutrons in the channel ($1{,}95\cdot10^{13}cm^{-2}s^{-1}$) at the coordinate of 75 cm. Figure 2 shows that distribution of thermal neutron flux in the range of 30 cm – 120 cm is even function relative to the coordinate of 75 cm. It means that in HEC-1 the silicon doping by the method [6] developed by us is possible. According to this method the irradiation of silicon ingots with a total length up to 90 cm is possible. At the same time it is necessary that due to the rotation of ingots the high radial uniformity of a doping was achieved. For research of parameters of radial uniformity of a doping the device with 6 copper foils in the form of the disks established one after another through 20 cm was used. Seven rings of different radius were cut from each disk and their activities were measured. Thereby, the rotation of a disk was imitated. For this purpose previously each ring was weighed and dissolved in nitric acid, and the results of measurements of activity were normalized on weight and the square of rings. For imitation of reciprocating movement along an axis of the reactor channel of activity of six rings with identical radiuses were summarized. As a result the distribution of activity on the radius (Fig. 3) was obtained. Thus, the average distribution of a fluence of neutrons was estimated due to rotation and reciprocating movement on the radius of the channel of the reactor. This figure shows in the limits of measurement error (±2 of %), the activity of a copper disk was radially uniform.

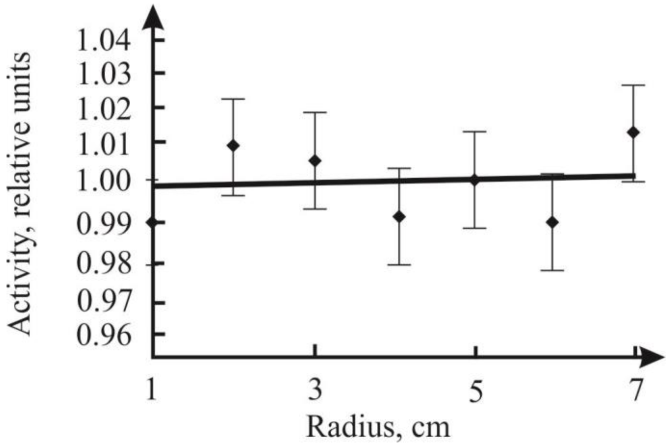

Figure 3. The neutron flux distribution through copper rings.

The neutron spectrum (Fig. 4) in HEC-1 was calculated with Monte-Carlo method.

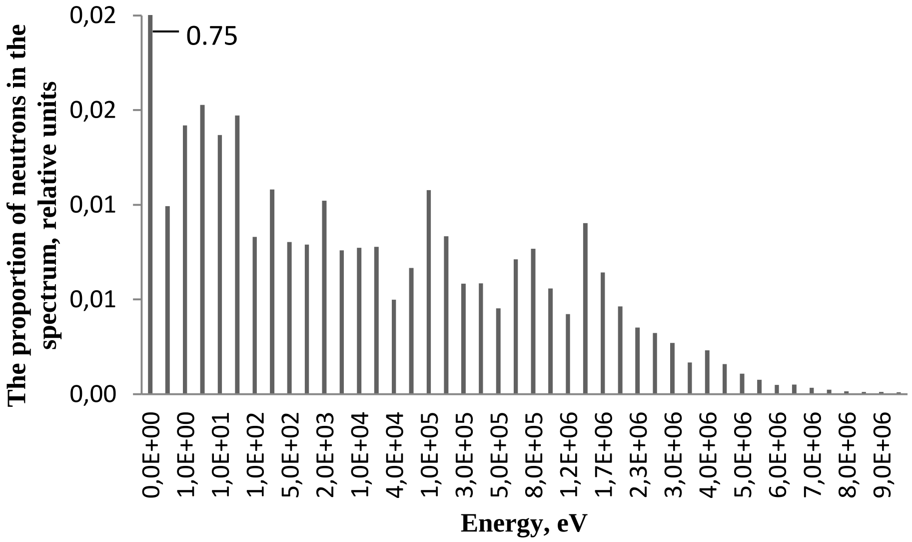

Figure 4. The spectrum of neutron flux in HEC-1.

3. Conclusion

Thus, the conducted measurements of neutron and physical parameters of the neutron field in HEC-1 lead to the conclusion that in HEC-1 channel the doping of silicon ingots up to 90 cm long with high axial and radial uniformity is possible.

Application of this method for moving containers is allows to create the NTD technology in the reactor's channel with one-side access. The resulting neutron spectrum, distribution of thermal neutron

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flux and deviation through channel's radius shows that the implementation of technology in the channel HEC-1 will allow to obtain the NTD silicon of high quality.

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