Applied Radiation and Isotopes 74 (2013) 70–77

Contents lists available at SciVerse ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

A new irradiation method with a neutron filter for silicon neutron transmutation doping at the Japan research reactor no. 3 (JRR-3)

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HIGHLIGHTS

- ► We studied a new silicon irradiation holder with a neutron filter made from B_4C.
- ► Designs of the holder were investigated by using the MVP code.
- ► Calculation method was validated by characteristic experiments in the JRR-3.
- ► The vertical uniformity was $\pm 3\%$ when using the new type holder.

ARTICLE INFO

Article history:
Received 26 July 2012
Received in revised form
1 January 2013
Accepted 2 January 2013
Available online 16 January 2013

Keywords:
NTD-Si
Neutron filter
Screening method
Vertical uniformity
JRR-3
MVP

ABSTRACT

We studied a new silicon irradiation holder with a neutron filter designed to make the vertical neutron flux profile uniform. Since an irradiation holder has to be made of a low activation material, we applied aluminum blended with B_4C as the holder material. Irradiation methods to achieve uniform flux with a filter are discussed using Monte-Carlo calculation code MVP. Validation of the use of the MVP code for the holder's analyses is also discussed via characteristic experiments.

1. Introduction

Neutron transmutation doping silicon (NTD-Si) (Lark-Horovitz, 1951; Tanenbaum and Mills, 1961) is an n-type doping method carried out by neutron irradiation. The reaction can be described as follows:

$$^{30}\mathrm{Si}(n,\gamma)^{31}\mathrm{Si}\rightarrow{}^{31}\mathrm{P}+\beta^{-}\quad (T_{1/2}=2.62\ \mathrm{h}).$$

This irradiation is carried out mainly in research reactors. The most distinctive feature of NTD-Si is its quite uniform doping. Uniform doping of the entire surface of a silicon ingot is necessary. As the uniformity of doping is higher, the breakdown voltage of the semiconductors is higher (Meese, 1982). Therefore, NTD-Si is used for insulated gate bipolar transistors (IGBTs) of high voltage. There is a growing demand for such IGBTs, because they are effective for energy saving and necessary for infrastructure such as electrical substation equipment and trains.

Most NTD-Si in Japan is produced in the Japan research reactor number 3 (JRR-3) at the Japan Atomic Energy Agency (JAEA). The silicon is cylindrical, with a diameter of 6 in. (15 cm) and a length of 70 cm, including a 10-cm dummy silicon part. The JRR-3 uses holders made from high-purity aluminum (1050) for silicon irradiation. Because the axial flux distribution possesses cosine distribution in the core, particular methods are necessary to achieve uniform irradiation (under $\pm 8.5\%$). There are two methods for making the flux distribution uniform. One method is the so-called reverse method that the JRR-3 has applied. This method is simple and easy to perform, but it requires two irradiation sessions for a silicon ingot to have uniform irradiation along the long axis direction, and a long cooling time of about 2 days is necessary in the interval between the first and second irradiations. In addition, there is low irradiation efficiency because of the

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0969-8043/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apradiso.2013.01.005

long irradiation time in this method, and the axial flux distribution is not efficient.

Another method for making the flux distribution uniform is the so-called filter method or screening method. NTD-Si production in the JRR-3 has already reached a ceiling, and it is impossible to increase production with the present irradiation method. Therefore, the screening method has been investigated in the JRR-3. The screening method has already been utilized in some research reactors, with nickel filters in FRM II (Li et al., 2009) of Germany and OSIRIS (Breant et al., 1980) of France, and stainless (SUS) filters in HANARO (Kim et al., 2006) of Korea. Those reactors apply the screening method to an irradiation pipe rather than to a holder. In the case of using the screening method in an irradiation pipe, the filter part is fixed on an irradiation pipe, in the pool and sufficiently far from the human operator to avoid radiation exposure. With this system, nickel and SUS are activated easily. The JRR-3 has not been able to apply the screening method to an irradiation pipe, because it would require a lengthy and costly remodeling of the facility. We investigated applying the screening method to a holder instead of to an irradiation pipe. Currently, no research reactor applies the screening method to a holder. In this paper, we call a holder that includes a filter a new type holder and a holder that doesn't apply the screening method a normal holder. The main restrictions for the new type holder are the mechanical design and the filter material.

The first restriction comes from the existing pipe and holder. The filter length must be less than the present holder length (70 cm), and the filter thickness must be less than 0.4 cm. The second restriction comes from the filter's ability with regard to radiation exposure. The filter must be able to reduce neutron flux within 0.4 cm thickness. Since a human operator would have to be near to the new holder, materials that are activated easily, such as nickel and SUS, are not available.

The purpose of this study was to investigate the possibility of a new holder that does not have restrictions with regard to its mechanical design and filter material. The filter of the new holder

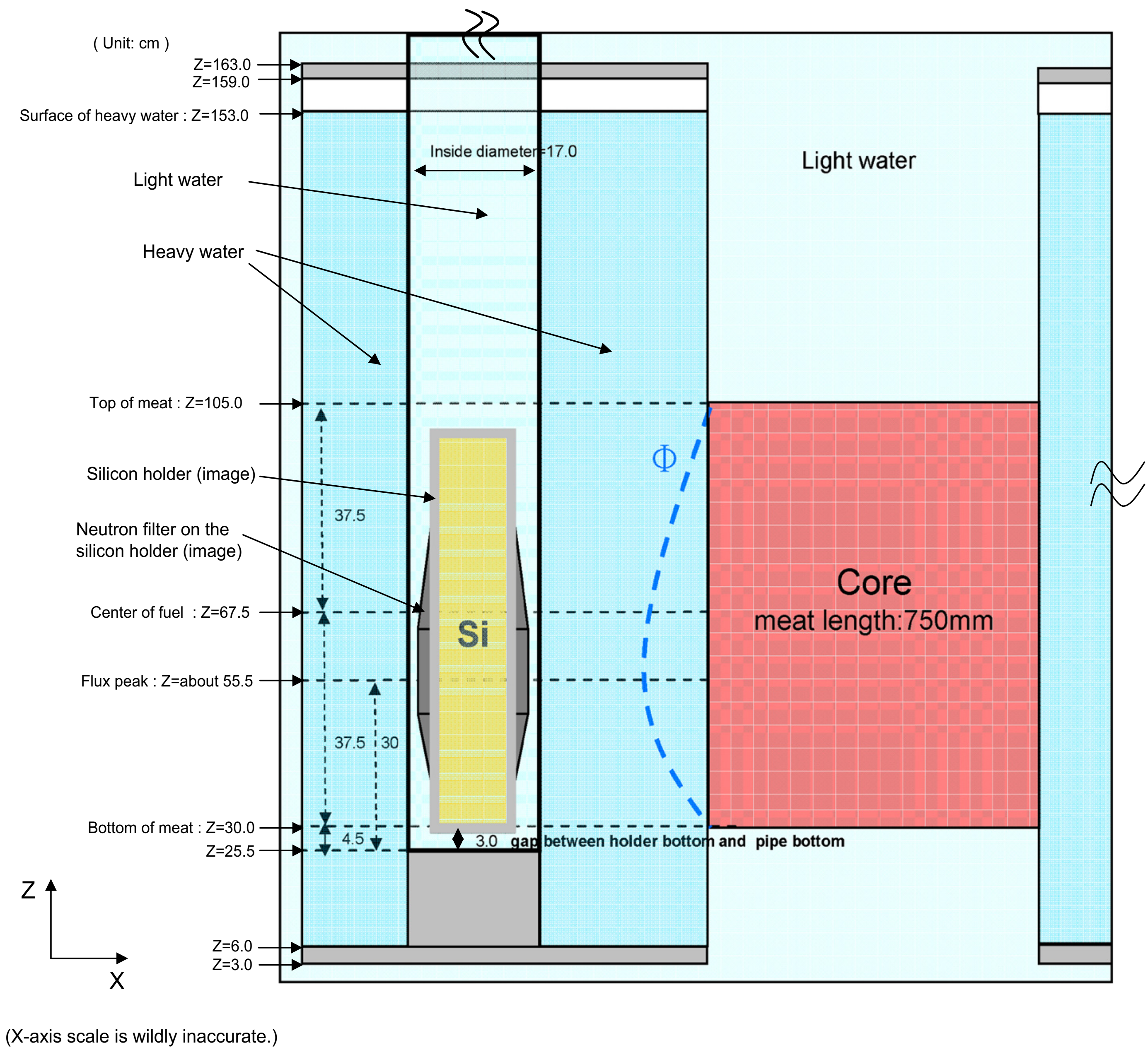

Fig. 1. Vertical section image of JRR-3.