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Estimation of Induced Radioactivity of Silicon Carbide by Neutron Irradiation

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1. Introduction

Silicon carbide (SiC) single crystal has been a substrate material for high power and high frequency electronic devices because of its excellent thermal and electrical properties compared with silicon. Neutron transmutation doping (NTD) of semiconductors is an important method for applications that require high dopant homogeneity, for example in electric power devices [1]. When the SiC is irradiated by neutrons, Si, C and impurities become radioactive nuclides by neutron capture reaction (n,γ) and several threshold reactions such as (n,p), (n,np), (n,α) and (n,2p). Radiations emitted from these radioactive nuclides constantly damage to the SiC until they have been completely decayed. In order for operators to handle the irradiated SiC, residual radioactivity of the SiC should be evaluated in terms of safety. In this study, the time variation of induced radioactivity of radionuclides in SiC during and after neutron irradiation is calculated by using the Monte Carlo simulation for safety and quality management study.

2. Methods and Results

2.1 Monte Carlo code

A Monte Carlo particle transport simulation code PHITS (Particle and Heavy Ion Transport code System) version 3.02 was used for calculating the radioactivity of radionuclides in SiC during and after neutron irradiation. PHITS is developed under collaboration between JAEA, RIST, KEK and several other institutes. It can deal with the transport of all particles over wide energy ranges, using several nuclear reaction models and nuclear data libraries [2]. The DCHAIN program linked to PHITS was used to calculate the time variation of induced radioactivity during irradiation and cooling. Input of DCHAIN containing various conditions for the calculation was generated by using t-dchain tally in the input of PHITS.

2.2 Conditions for simulation

Neutrons in NTD1 irradiation hole of HANARO research reactor were considered as a source term for the PHITS calculations. Energy spectrum of neutrons in the NTD1 irradiation hole was calculated by using MCNP code. The MCNP equilibrium model (burned core model for 96 operation cycle) was employed for a whole core representation of the HANARO. Neutrons were assumed to be uniformly distributed on the surface of a vertical channel with a radius of 10.125 cm as the NTD1 irradiation hole. A sample for neutron irradiation was modeled as 5-inch cylindrical single crystal SiC with a volume of 3.8×10^3 cm^3. Aluminum, boron, iron and titanium that are major impurities in the SiC wafer were considered [3]. Concentration of each impurity was conservatively assumed as 10 ppm. For the t-dchain tally, the current of neutron beam was set corresponding to the neutron flux of 4.33×10^{13} $n/cm^2\cdot sec$ in SiC. Neutron irradiation time was set to 24 hours, and the radioactivity of each nuclide was calculated by the hour during irradiation. The residual radioactivity was calculated until 10 days later after irradiation. And the radioactivity of main radionuclides which are produced by activation of impurity elements of SiC was calculated for 1 days after irradiation.

2.3 Results of simulation

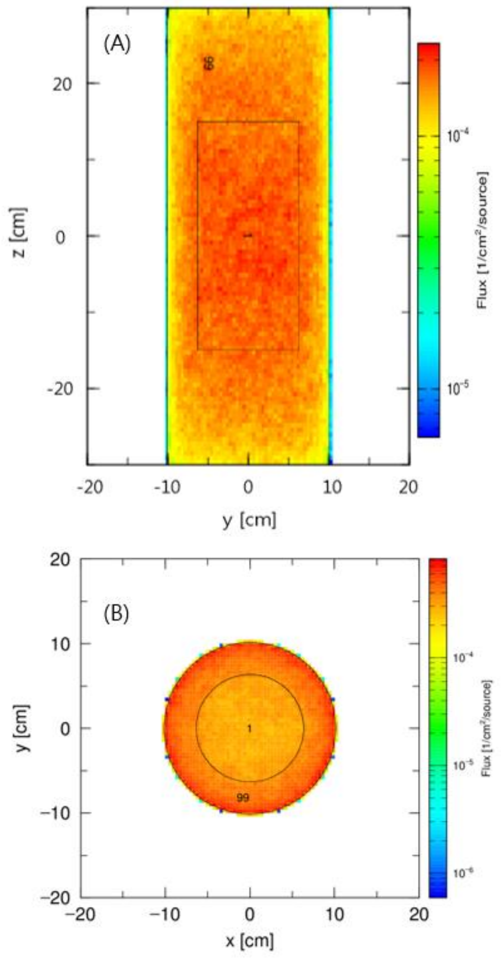

Fig. 1. The tracks of neutrons irradiated onto the SiC viewed in (A) y-z plane and (B) x-y plane (plotted by ANGEL 4.50).

Fig. 1 shows the tracks of neutrons entering into the SiC viewed in y-z and x-y plane. In this figure, the red area means the region of higher neutron flux. Neutrons irradiated on the SiC is easily confirmed through the distribution of red colors.

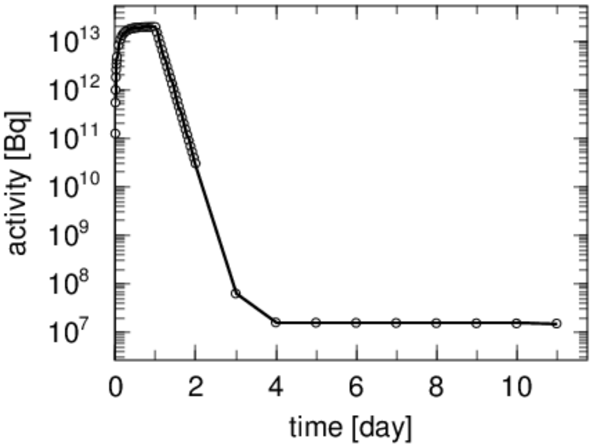

Fig. 2. Time variation of neutron induced total activity of SiC during and after neutron irradiation of 1 day (plotted by ANGEL 4.50).

The time variation of neutron induced total activity of SiC during and after neutron irradiation is showed in fig. 2. Total radioactivity increases until the end of neutron irradiation, and it continues to decrease constantly for 2 days. Most of the induced radioactivity is come from the ^{30}Si(n,γ)^{31}Si reaction. Half-life of the ^{31}Si is relatively short (2.62 hours), and thus cooling time of 2-3 days is enough for sufficient decay of the ^{31}S. Since the concentration of impurity elements of the SiC is very low, radioactivity of impurity elements are about 1 % of the total radioactivity. To minimize redundant activations and to study the radiation damage of SiC by NTD, however, the radioactivity of impurities should be estimated.

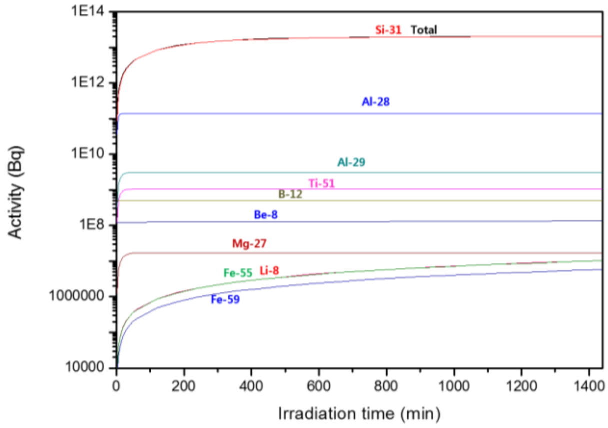

Fig. 3. Time variation of activity of neutron induced radionuclides in SiC during neutron irradiation of 1 day.

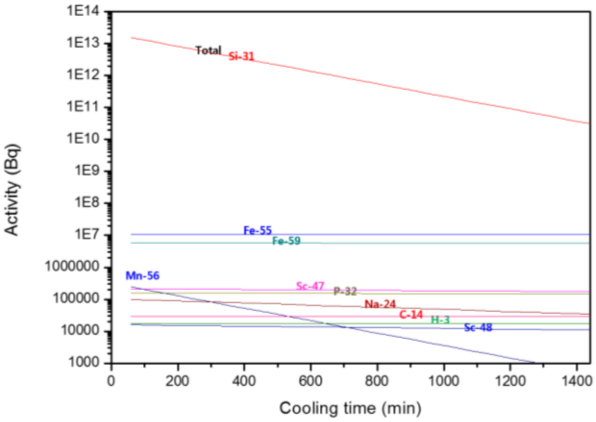

Fig. 4. Time variation of radioactivity of neutron induced radionuclides in SiC after neutron irradiation of 1 day.

The time variations of radioactivity of neutron induced radionuclides in SiC during and after neutron irradiation are showed in fig. 3 and fig. 4, respectively. During the neutron irradiation, ^{28}Al, ^{29}Al, ^{51}Ti, ^{12}B, ^{8}Be, ^{27}Mg, ^{8}Li, ^{55}Fe and ^{59}Fe are main radionuclides which are produced by activation of impurity elements of SiC. ^{28}Al has dominant radioactivity because of large neutron capture cross-section of ^{27}Al. After the neutron irradiation, the radionuclides with short half-life are early decayed and radionuclides with relatively long half-life such as the ^{55}Fe and ^{59}Fe become the main residual radionuclides.

3. Conclusions

The time variation of induced radioactivity of radionuclides in SiC during and after neutron irradiation was calculated by using the PHITS and DCHAIN program for safety and quality management study. As a result, total radioactivity of SiC sufficiently decay away in 2 or 3 days because the main radionuclide ^{31}Si has a relatively short half-life of 2.62 hours. The main radionuclides activated from impurities are also estimated to control the unintended effect and study the radiation damage to SiC by NTD. These results will be used as the basis for future study.

Acknowledgements

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