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Energy Spectra of Gamma-rays and Electrons in the Silicon Carbide Irradiated with HANARO Neutrons

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1. Introduction

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 semiconductor is irradiated by neutrons, elements become radionuclides by neutron capture reaction and several threshold reactions. Radiations emitted from these radionuclides constantly damage to the semiconductor until they have been completely decayed. Radiation damage to material is generally evaluated in displacement per atom (DPA) unit. In order to calculate the DPA, radiation spectrum data with displacement cross section is required. In our previous study, the time variation of induced radioactivity of radionuclides in SiC (silicon carbide) after irradiation with HANARO neutrons was calculated by using the Monte Carlo simulation for safety and quality management study [2]. Based on the previous results, energy spectra of gamma-rays and electrons emitted from radionuclides are calculated to produce radiation source data for estimating the radiation damage to SiC.

2. Methods and Results

2.1 Monte Carlo simulation

A Monte Carlo particle transport simulation code PHITS (Particle and Heavy Ion Transport code System) version 3.02 was used for calculating energy spectra of gamma-rays and electrons in the SiC after neutron irradiation. PHITS can deal with the transport of all particles over wide energy ranges, using several nuclear reaction models and nuclear data libraries [3]. The radionuclides data of our previous study listed in Table I were used as a RI-source term for the PHITS calculation. These data show the time variation of radioactivity of radionuclides produced by activation of elements in SiC. The RI-source function in PHITS can be used by setting the e-type subsection to 28, and the alpha, beta (including Auger electrons), and gamma-rays of RI decay are generated by simply specifying the activity (in Bq) and name of the RIs [4]. In this function, the DECDC nuclear decay database (equivalent to ICRP107) is used to obtain the energy spectra [5]. The SiC sample was modeled as 5-inch cylindrical single crystal with a volume of 3.8×10^3 cm^3. Residual radionuclides were assumed to be uniformly distributed in the cylindrical model.

Table I: Activity of radionuclides in SiC after irradiation

RI	Activity [Bq]		
	1 hour	1 day	10 days
Si-31	1.52E+13	3.09E+10	1.62E-15
P-32	1.56E+05	1.49E+05	9.62E+04
C-14	2.86E+04	2.86E+04	2.86E+04
Fe-55	1.04E+07	1.04E+07	1.03E+07
Fe-59	5.80E+06	5.72E+06	4.97E+06
Sc-47	2.12E+05	1.74E+05	2.78E+04
Sc-48	1.58E+04	1.09E+04	3.55E+02
Na-24	9.97E+04	3.44E+04	1.57E+00
H-3	1.79E+04	1.79E+04	1.79E+04
Mn-54	6.60 E+03	6.58E+03	6.45E+03
Mn-56	2.40E+05	4.96E+02	null
Al-29	5.50E+06	null	null
Ti-51	7.67E+05	null	null
Mg-27	2.11E+05	null	null

T-track tally in PHITS can be used for calculating flux of particles in certain regions and visualizing particles trajectories by setting small mesh for tally region. Distributions of gamma-rays (photons) and electrons emitted from the irradiated SiC were visualized using T-track tally with setting the xyz mesh.

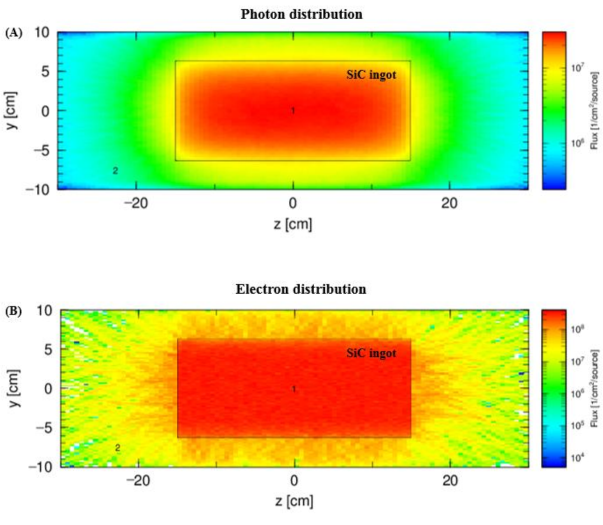

Fig. 1. Distribution of (A) gamma-rays and (B) electrons emitted from the irradiated SiC viewed in y-z plane (plotted by ANGEL 4.50).

Fig. 1 shows the distribution of gamma-rays and electrons emitted from the irradiated SiC visualized using T-track tally with setting the xyz mesh. In this figure, emission of particles and their tracks are easily confirmed through the distribution of colors. The red area, which means the region of higher flux, shows that electrons more interact in SiC than gamma-rays. Using the T-track tally, volume flux and energy spectra of gamma-rays and electrons in the SiC at 1 hour, 1 day and 10 days after irradiation were calculated.

2.2 Energy spectra of Gamma-rays and electrons

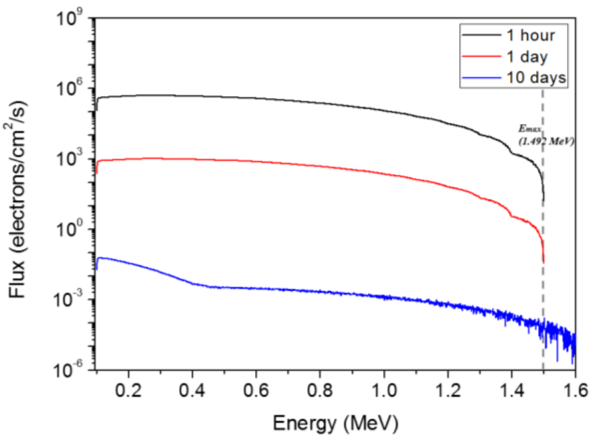

Fig. 2. Energy spectra of electrons in the SiC volume at 1 hour, 1 day and 10 days after neutron irradiation.

Fig.2 shows energy spectra of electrons in the SiC volume at 1 hour, 1 day and 10 days after neutron irradiation. At 1 hour and 1 day after irradiation, most of electrons are emitted from beta decay of ^{31}Si. Emitted electrons have a continuous kinetic energy spectrum, the energies range from 0 to the maximum available energy 1.492 MeV (beta-decay energy of ^{31}Si). Half-life of the ^{31}Si is relatively short (2.62 hours), thus cooling time of 2-3 days is enough for sufficient decay of the ^{31}S. At 10 days after irradiation, radionuclides with relatively long half-life such as ^{59}Fe, ^{32}P and ^{14}C become the main electron sources. The maximum energy of blue line spectrum becomes 1.711 MeV (beta-decay energy of ^{32}P), also low energy electrons are beginning to stand out. The electrons under 0.156 MeV emitted from ^{14}C also contribute to this trend.

Fig.3 shows energy spectra of gamma-rays in the SiC volume at 1 hour, 1 day and 10 days after neutron irradiation. ^{31}S emits strongest single gamma line of 1.266 MeV until 2-3 days for sufficient decay of it. At 1 hour after irradiation, high energy gamma lines emitted from short half-life radionuclides such as ^{28}Al, ^{56}Mn and ^{27}Mg are shown. At 10 days after irradiation, ^{59}Fe becomes the strongest gamma-ray emitter, the single gamma lines of 1.099 and 1.292 MeV emitted from ^{59}Fe are dominant gamma lines in the spectrum.

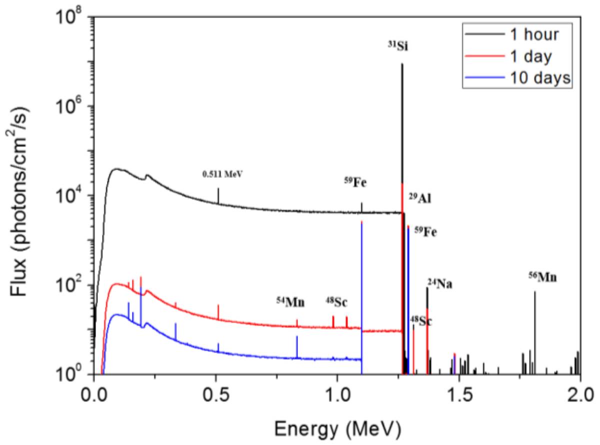

Fig. 3. Energy spectra of gamma-rays (photons) in the SiC volume at 1 hour, 1 day and 10 days after neutron irradiation.

3. Conclusions

The energy spectra of gamma-rays and electrons in the irradiated SiC are calculated by using the PHITS. Main emitters and flux data according to the cooling time are compiled from the spectra. These gamma-ray and electron source data in SiC will be used to determine the radiation damage with displacement cross section or DPA calculation code.

Acknowledgements

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