Nuclear Data for Science and Technology (1988 MITO), 1053-1055, Copyright © 1988 JAERI.

Si-PKA SPECTRA IN A Si-SSD BOMBARDED BY 14MeV NEUTRONS

K. Yageta, S. Iwasaki, and K. Sugiyama
Department of Nuclear Engineering, Tohoku University
Aramaki-Aza-Aoba, Sendai 980, Japan

Abstract: Angle integrated primary knock-on atom spectra of silicon in a Si-SSD were first measured at the incident neutron energy of 14.8MeV. In the case of charged particle emmission reactions, such as (n,p) and (n,α), etc., the spectrum was sum of the PKA's and these charged particles, because there was no way to seperate each contribution. Resultant spectrum was compared with a simple model calculation which was used in the conventional damage analysis, using a nuclear data, ENDF/B-IV. The spectrum was almost reproduced if the penetration effect of the energetic light charged particles through the detector was included.

(primary knock-on atom spectrum, silicon, 14MeV neutron, model calculation, damage analysis)

Introduction

Recently it is pointed out that the reliable energy and angular distributions of the primary knock-on atoms (PKA's) are very important nuclear data in the field of the fusion neutron radiation damage study from the aspect of the elementary damage processes, especially in the microscopic simulation calculation[1]. In spite of this demand, there have been no experimental data for the PKA's because of its difficulty of measurement due to their extremely short range in a target materials. However, in a specital case, the short range problem would be easily resolved if we choose a target material which can be used as a radiation detector simultaneously.

In this study, an atempt to measure the PKA's spectra for silicon was made using a method in which a silicon detector was used as a sample, too. The silicon detector was bombarded by 14MeV neutrons and resulting pulse height spectra have been measured in order to compare with calculated ones using a code developed in this study for the PKA's and charged particles (CP's) with a evaluated neutron nuclear data library, ENDF/B-IV.

Experiment

The employed Si-SSD was a surface barrier type one of 100-mm^2 active area and its depletion layer of 300μm at maximum bias voltage of 100V. The energy resolution of the detector was about 15keV. This detector (PKA-SSD) was put in a small thin SUS vacuum chamber of cylindirical shape. Neutron target side flat surface of the chamber was replaced by niobium thin plate, and the inside of the lateral surface of the chamber was covered by molybdenum foil. These high Z materials were used for preventing the incidence of the energetic CP's to the SSD from the wall mateials.

A neutron beam of 14MeV was produced by the T+d reaction on a titanium-tritium target of about 1mg/cm^2 bombarding a deuteron beam of 300keV from the Cockcroft-Walton type accelerator. The associated α particles were detected by another surface barrier SSD (α-SSD) which was mounted at 25 cm from the target in a 165 deg. direction. The SSD was covered by a thin aluminum foil which stop the back-scattered deuterons from the target. The PKA-SSD was positioned at 6cm from the target inside the neutron cone around 15deg. corresponding to the α's. The coincidence signals between the two timing pulses from the detectors opened gate for the pulse height signals from the PKA-SSD. This coincidence technique remarkably reduced background level in the low pulse height range, mainly due to beta, gamma and x-rays emitted from surrouding materials.

The experimental layout and block diagram of the electronics are shown in Fig. 1. The typical two spectra are compared in Fig. 2 , which were obatained with and without the coincidence, respectively. The ordinate of the spectra was calibrated by α-particles from Am-242.

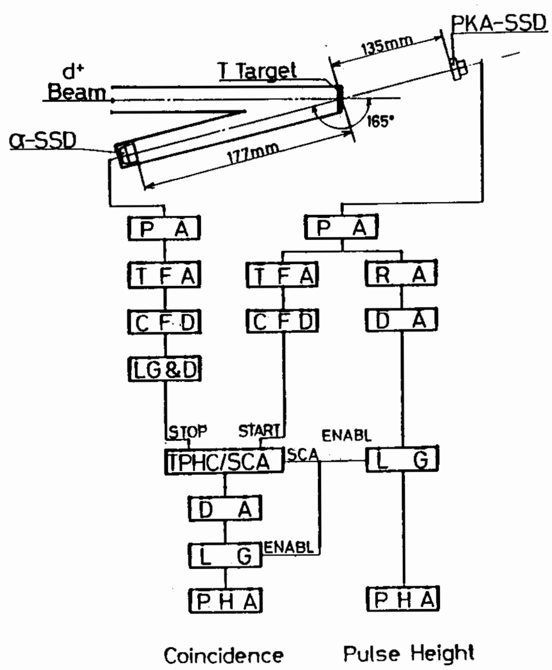

Fig. 1 Experimental set up for Si-PKA's spectra measurement and its block diagram of the electronics

Calculational Model

In Table 1, we listed the partial cross sections of the natural silicon given in ENDF/B-IV at 14.8MeV. In order to estimate the spectra by calculation, all light charged particle (CP's) as well as the PKA's should be taken into account, because the light particles from the reactions such as (n,p) and (n,α), etc., are emitted at the same time with the PKA's , and the obtained spectra in the SSD should be a sum of the corresponding two contributions. We are now developing a spectial code, 'PKACP' for the calculation of the CP's and PKA's spectra in the SSD. In the primary stage of the code development, we adopted a simple models for the PKA's used in the analysis codes of the radiation damage which had been developed by many authors[2,3,4,5].

For elastic and two-body discrete-level scattering, the recoil energy could be calculated accurately using the kinematics. The (n,p) and (n,α) reactions to the discrete levels were treated in the same fashon.

As for the continuum reactions, such as (n,n'_c),$(n,p_c)$and (n,α_c), only the information on the spectra of the emitted particle were given and the angular distribution of the emission were assumed to be isotropic in the laboratory system. In the present model, we calculated the recoil spectrum according to the pseudo-level concept in the laboratory system.

In the calculational model for the three-body reactions such as (n,2n), (n,np), and (n,nα), almost the same procedure with the two-body cases were adopted, because only the spectrum data on the firstly emitting neutrons were given and no information on the energy spectra and angular distributions of the secondarily emitting particles or no kinamatical descriptions for the two particles emission was not given in the file. Therefore there is no way to calculate the PKA's and CP's spectra realistically. Thus the recoil effects of the secondarily emitting particles, n, p and α were estimated to be small and neglected in the code. Because the p- and α-spectra were needed to calculate their own spctra, the first neutron spectra data were used in place of the charged paricles'.

In the present model calculation, (n,d) and (n,γ) reactions were also neglected, because on the former one, the cross section was rather small compared with others and the even the spectrum data was not given in the file and the later one didnot appreciably contribute the recoil effect. The effects of secondary emitting

Table 1 List of the partial cross sections at 14.8MeV given in the ENDF/B-IV file.

reaction	cross section (barns)
(n,n)	0.735
(n,n')	0.449
(n,p)	0.221
(n,α)	0.155
(n,γ)*	0.0005
(n,d)*	0.018
(n,2n)	0.053
(n,np)	0.160
(n,nα)	0.025

* neglected in the present model

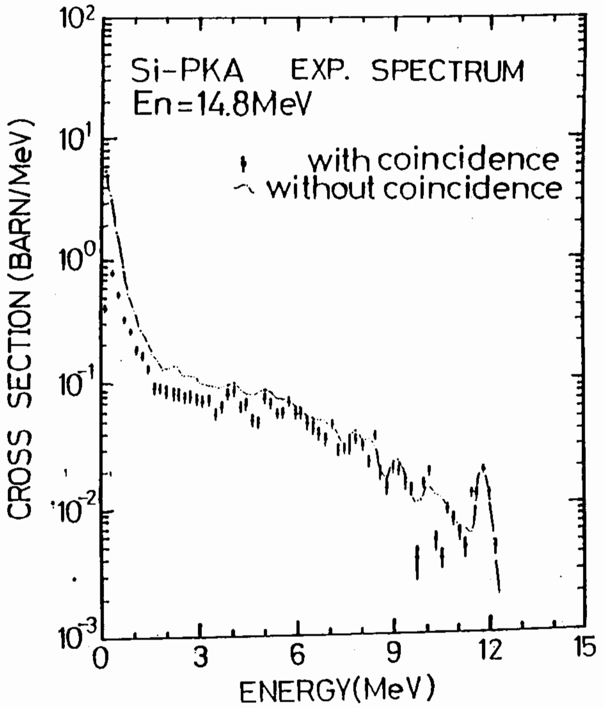

Fig. 2 Present experimental spectra ( ) with and with out the conincidence ( ) for silicon PKA's with charged particle's bombarded by 14MeV neutrons.

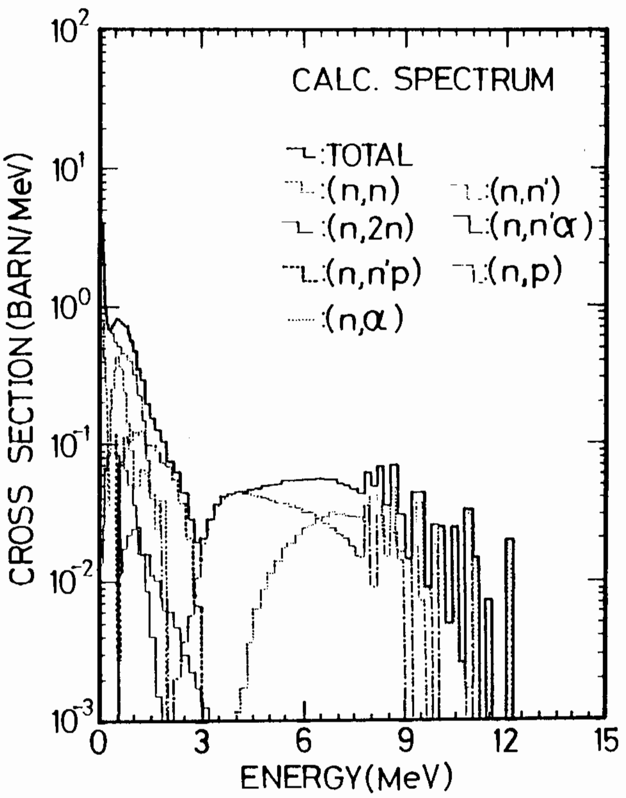

Fig. 3 Calculated spectra and its components for the silicon PKA's with charged particles bombaded by 14MeV neutrons.

photons' momenta were neglected implicitly.

The calculated spectra for the total and partial contributions given by the code version 1 is shown in Fig .3. In the figure, we can see the existence of the three distinctive regions; the high energy region above 6MeV, where there are many sharp line spectra which are the contribution of sum of the PKS's and charged particles from the (n,p) and (n,α) reactions for the discrete levels of the final nuclei; the medium energy region below 6MeV, where a plateau seemed to be due to the (n,p_c) (n,α_c) contiuum components; and the lowest energy region less than 3MeV, where the (n,n) and (n,n') are the main components and the three-body reactions also contribute. There is a clear valley between the later two energy regions.

In Figure 4, the calculational model (1) is compared with the experimental one with the coincidence. The calculation roughly reproduce the total trend of the experimental spectrum. In the high energy region, the line spectra of the protons and α's are almost reproduced with some exceptions due to inadequacy of the cross sections in the data file. In the low energy region, agreement is fairly good in the magnitude, but not so good in the shape.

In contrast, in the middle energy region,

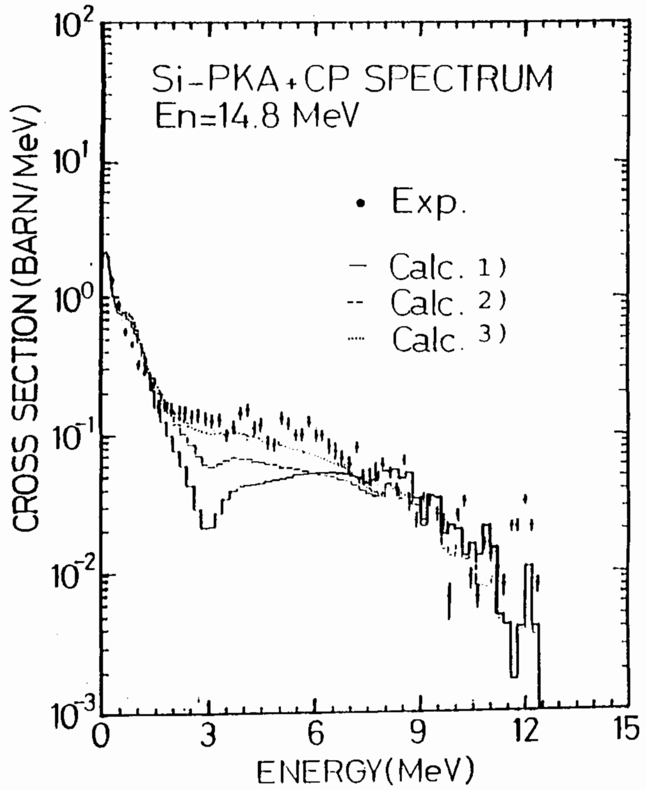

Fig. 4 Comparison of the present expeirmental spectrum and calculated spectra by the code of the first version :(1); the second version which includs the effect of the CP penetrations:(2); and the third version which includes the contribution of the CP's from the backside dead layer in addition to the (2):(3).

there is large discrepancy between two spectra. The energetic CP's would penetrated through the depletion layer and deposited the small portion of their original energies in the sensitive layer. Therefore the contribution of these CP's moved down from the normal pulse height region and built up in the lower energy side. This effect was included in the second version of the code of which results is curve (2) in Fig. 4. The magnitude of the discrete lines of the high energy region decreased and the gap of (1) in the middle energy was compensated by a half.

The rest of the gap between the calculation and experiment was considered to be the contribution of the charged particles coming from the rear side dead layer of the detector. In the third version of the calculational model, this effect was included assuming that the dead layer thickness was equal to the range of the highest energy protons, 700μm. The gap is almost compensated by this model. Some broad peak structure between 4 and 6Mev in the experimental spectrum seems to be mainly the contribution of the neglected (n,d) reaction, considering the Q-values.

Summary

Using the method that a solid state silicon detector was used as detector and target simultaneously, the PKA's spectrum could be measured as the mixed one with charged particles. The measured spectrum was compared with that of the calculated one using a code which was developed in the present study. The calculation globally reproduced the experimental data. The penetration effect of the energetic charged particles in the SSD was rather important to reproduce the measured spectra.

It is necessary to provide more realistic nuclear informations, especially for two-body continuum and three-body reactions in the future nuclear data files if we hope to estimate the accurate energy and angular distributions of the PKA's in the simulation calculations for the damage study.

Measurement of the Si-PKA spectra with improved energy resolution in the extended enegy region down to less than 100keV using a total depletion type SSD is planed to compare the spectra with more realistic model calculation in datail.

The authors express their appreciation to Messrs. T. Mogami and K. Onodera for their help to the operation of the acclerator.

References

1. General Steering Group for Special Study on Energy Development (Nuclear Fusion)Ed.: Proc. of seminar on the elementary damage processes due to 14MeV neutrons and their simulation (in Japanese), Mar. 25, 1987, Monbusho (1987).
2. J.D. Jenkins: Nucl. Sci. Eng. 41, 158 (1970).
3. D.G. Doran: Nucl. Sci. Eng. 49, 130 (1972).
4. T.A.Gabriel et al.: Nucl. Sci. Eng., 61,p21 (1976).
5. R.E. MacFarlane et al.: Jour. Nucl. Mat., 122&123 1041 (1984).