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Boron Thin Film for Neutron Monitor of KAERI-NDP System

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1. Introduction

The atomic concentrations for elements in the near-surface region can be measured by NDP (Neutron Depth Profiling) technique [1]. When light elements such as Lithium, beryllium, boron and sodium undergo neutron absorption reactions with a positive Q-value, they emit charged particles and recoil atoms.

The new KAERI-NDP system for ICT materials is being constructed at the end of CG1 (Cold neutron Guide1) as shown in Fig. 1. For the precise quantification of the atomic concentration, the neutron beam incident on the sample should be monitored during the irradiation. To quantify the neutron flux at the sample position, gold activation foil has been used based on $^{197}Au(n,\gamma)^{198}Au$ reaction [2]. However, this activation method is not appropriate for monitoring fluctuations of neutron beams in real time.

In this study, ^{10}B included standard materials that were evaluated for the in-situ neutron flux monitoring for the accurate investigation of the atomic concentration by NDP. In this study, ^{10}B included standard sample was prepared, as an thin film by using RF sputtering, and its property for in-situ neutron flux monitor, for the accurate investigation of the atomic concentration by NDP, was evaluated by MCNP (Monte Carlo N-Particle) transport code.

Fig. 1. A schematic diagram and picture of the KAERI-NDP system

2. In-situ neutron flux monitoring system

2.1. $^{10}B(n,\alpha)^7Li$ reaction for neutron flux monitoring

The particle-producing reaction rate per unit volume at depth *x* in the sample is determined by the equation as follows:

$$R(x) = \int_0^\infty C(x) \cdot f \cdot \sigma(E) \cdot \phi(E) dE \quad (1)$$

where, *C(x)* is the concentration of interested isotope at depth *x*, *f* is the fractional yield, *σ(E)* is the microscopic cross-section for charged particle production for neutrons with energy *E*, *Φ(E)* is the differential neutron flux, respectively.

Boron is selected as the target element for the in-situ neutron flux monitoring due to the high neutron cross-section of ^{10}B. The neutron flux can be estimated by measuring the $\alpha(^4He)$ particle which is produced by $^{10}B(n,\alpha)^7Li$ reaction. When ^{10}B absorbs a neutron, it undergoes the following nuclear reactions:

$$^{10}B + n \rightarrow \; ^7Li + \; ^4He(1471.64 \;\; keV)$$
$$^7Li^* \;\rightarrow\; ^7Li(839.56 \;\; keV) + \gamma(477.80 \;\; keV)$$
$$^{10}B + n \rightarrow \; ^7Li^* \; (1013.10 \;\; keV) \\ + \; ^4He(1775.87 \;\; keV)$$

The atomic density of the ^{10}B in the sample is known, then the neutron flux can be determined by measuring the alpha particles.

2.2. The depletion rate of ^{10}B by cold neutron

One of the important requirement for neutron monitors is the lifespan of the monitor. Count rate of the α particle depends on the neutron flux as follows

$$K = N \times \sigma \times \emptyset \times r \times a \quad (2)$$

where, *K* is count rate, *N* is the atomic density of the ^{10}B in the samples, σ is neutron cross-section, Φ is total neutron flux, r is reaction rate for α (1471.64 keV, 93.7 %) and *a* is the detection efficiency of the detector, respectively. A residual amount of ^{10}B as a function of the time (t) can be written by,

$$N_{RB}(t_n) = (N_0 + \textstyle\sum_{t=1}^{n-1} N_n)(1 - \sigma \times \emptyset \times r) \quad (3)$$

where, N_0 is the initial amount of ^{10}B, N_{RB} is a residual amount of ^{10}B, Using the equation (3) count rate of the alpha particles and depletion rate of ^{10}B are represented as shown in Fig. 2. In this calculation, the neutron energy, neutron cross-section and neutron flux were assumed to be 2 meV, 13666.8 barn and 10^7 n/cm^{2}s, respectively.

The count rate was decreased with only 0.04 % of differ for a 1000 year due to the change of the ^{10}B amounts in the samples. These results demonstrate that the ^{10}B is a suitable element as a cold neutron flux monitor.

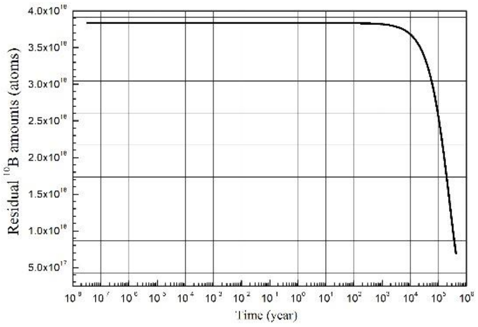

Fig. 2. Changing of residual amounts of ^{10}B and α count rate by $^{10}B(n,\alpha)^{7}Li$ reaction

2.3. Performance of the neutron monitor

As a design criterion for the in-situ neutron monitor, the target value of NTR (neutron transmission rate) was set to 90 % and a target α count rate was set to 1 cps. For the high NTR, the boron sample can be prepared on the Si substrate as a thin film by RF sputtering. Before the synthesis of the boron sample, the NTR and α count rate were evaluated by using MCNP transport code. MCNP model of the neutron monitor is shown in Fig.3. The two values of total neutron flux in a cell 300, as define the cell 310 to vacuum and boron, were compared to calculate the NTR.

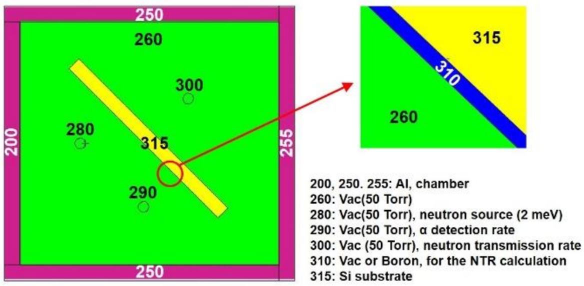

Fig.3. Schematic diagram of neutron flux model

The pressure of the vacuum was defined to 50 Torr based on the SRIM (Stopping and Range of Ions in Matter) results. The path length of the α (1471.64 keV) particle, from $^{10}B(n,\alpha)^{7}Li$ reaction, is increased from 70 to 120 mm as decreasing the pressure of atmosphere from 760 to 50 Torr. These results demonstrate that the distance of 120 mm is enough to measure the α particles under the 50 Torr of vacuum.

Total flux of neutron in the cell 300 and α particle flux in the cell 290 were calculated. As the results, the NTR was estimated to 92.48 % for the 1 μm of the B. Therefore, the in-situ neutron flux monitoring, with this sample, is possible during the irradiation. Figure 4.(a) shows the distribution of the α particle flux. The α particles were not detected at the rear side of B film due to the Si substrate. The ranges of α particles with energy of 1471.64 and 1775.87 keV in boron film are 3.87 and 5.07 μm, respectively. In order to obtain 1 cps for α particles at the detector position (cell number 290), 2.51×10^{6} cm^2/s of neutron flux is required.

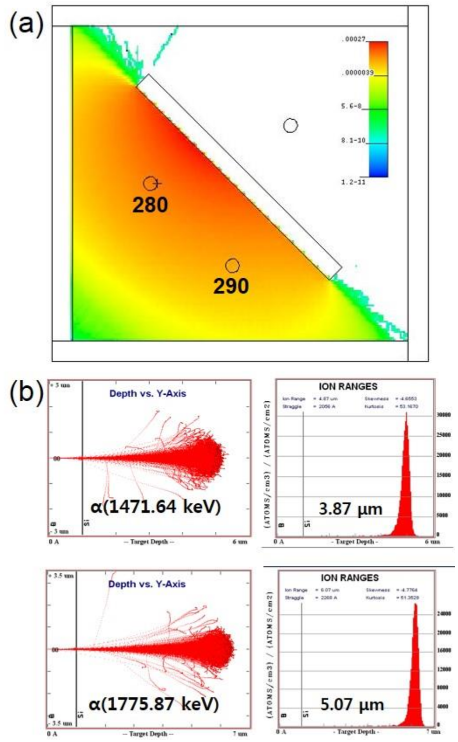

Fig.4. (a) α flux simulation results by MCNP and (b) SRIM simulation result

2.4. Performance of the neutron monitor for thermal and fast neutron from MC-50 cyclotron

For the experiment with neutron source, performance of the boron film neuron monitor was evaluated in the case of MC-50 cyclotron at KIRAMS (Korea Institute of Radiological Medical Sciences). A schematic diagram of the neutron source of MC-50 with $^{9}Be(p,n)^{9}B$ reaction is shown in Fig.5. Performance of the boron monitor can be improved by thermalize the fast neutrons of MC-50. The ratio of the thermal neutron to fast neutron can be increased by HDPE (High Density Poly Ethylene).

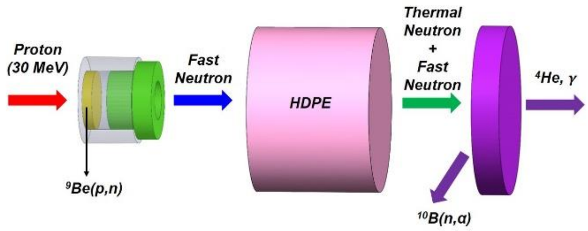

Fig.5. A schematic diagram of thermal neutron generation process from the proton

To find the optimized thickness of the HDPE, the thermal neutron flux (10 meV to 10 eV) per a proton ($/pcm^2s$) and fast neutron flux (0.1 to 100 MeV) were calculated by increasing the thickness of HDPE. The ratio of the thermal to fast neutron was increased as increasing the thickness of HDPE, while absolute thermal neutron flux having the highest value at the 6 cm of the HDPE thickness as shown in Fig.6.

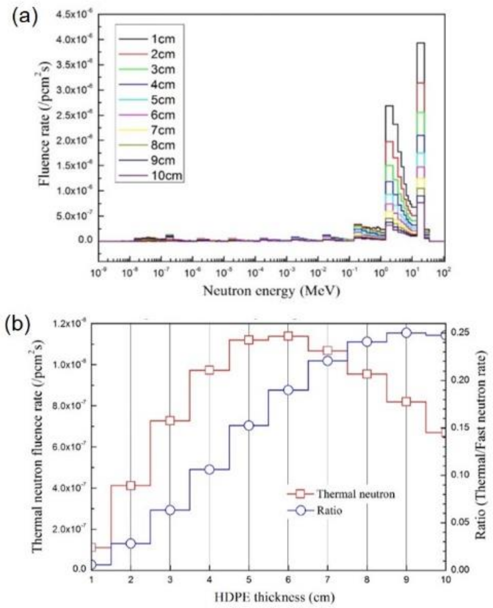

Fig.6. (a) changing of the total neutron flux and (b) comparison of thermal and fast neutron flux depending on HDPE thickness

Count rate of alpha particle was calculated by using the MCNP code. In the calculation, the proton flux of MC-50 was assumed to be 5.37×10^{8} cm^2/s [3]. Total count rate of alpha particle was calculated to be 5.9×10^{-3} cpm (counts per min) as shown in Fig.7.

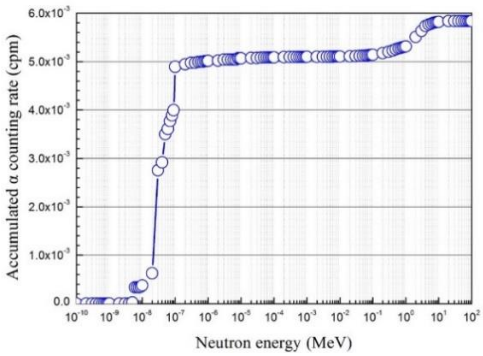

Fig.7. Accumulated α count rates depending on neutron energy at MC-50 cyclotron

3. Conclusions

To evaluate the probability of the B film on the Si substrate as an in-situ neutron flux monitor, the NTR and α count rate were evaluated by MCNP. The NTR for the 1 μm of boron on the Si was 92.48 %, while $2.51\text{x}10^{6}$ cm^2/s of neutron flux is required at least for the 1 cps of α count rate. The neutron flux, from the $^{9}Be(p,n)^{9}B$ reaction using proton source at MC-50, is not enough for the measurement of α particles due to the rack of total neutron flux. For the acceptable and accurate evaluation of the boron film as a neutron flux monitor, the experiment for the NTR and α count rate should be operated at HANARO.

Acknowledgement

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