Transactions of the Korean Nuclear Society Virtual Spring Meeting
July 9-10, 2020

Development of Analysis System for Micro-elements by using Neutron Absorption Reaction

Sang-hwa Lee[a], Byung-Gun Park[a], Young ku Jin[b], Dohyun Kim[a], Hyun woo Seo[b], Dong min Kim[b], Dong-jin Seo[a], Wan seok Oh[a]

[a] Korea Atomic Energy Research Institute, 989, Daedeok-daero, Daejeon, Korea.
[b] Department of Materials Science Engineering, Hongik University, 2639, Sejong-ro, Korea.
sanghwalee@kaeri.re.kr

1. Introduction

The atomic concentration of elements in material can be estimated by using neutron. When certain target elements undergo neutron absorption, they emit prompt gamma rays or energetic charged particles such as alpha, proton, heavy ions and etc. Neutron absorption reaction rate is theoretically determined by the number of target elements, nuclear cross-section, and the neutron flux as follows:

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

where, *C(x)* is the concentration of interested isotope at depth x, f is the fractional yield, $\sigma(E)$ is the microscopic cross-section for gamma ray of charged particle production of neutron energy E, and $\phi(E)$ is the differential neutron flux, respectively. Experimentally, this reaction rate can be determined by measuring the count rate of the gamma-ray or charged particles from the unstable isotope induced by the neutron absorption. The quantitative analysis methods from the reaction rate for gamma rays and charged particles are PGAA (Prompt Gamma-ray Activation Analysis) and NDP (Neutron Depth Profiling), respectively. The schematic diagram for PGAA and NDP are shown in Fig. 1.

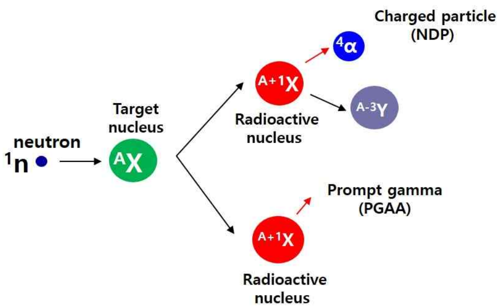

Fig. 1. A schematic diagram for NDP and PGAA

In the case of the charged particle measurement, the charged particles emitted from the isotopes that absorb neutrons, lose their energy by excitation, ionization, collision of nucleus colliding with atoms of host materials. The energy loss is determined by the stopping range of the charged particles. Because the amount of energy loss is directly related to the thickness penetrated by the particle, the measured energy spectrum can be converted to the thickness of the target material as shown in Fig. 2[1].That is why the quantitative analysis method using a charged particle detection called NDP.

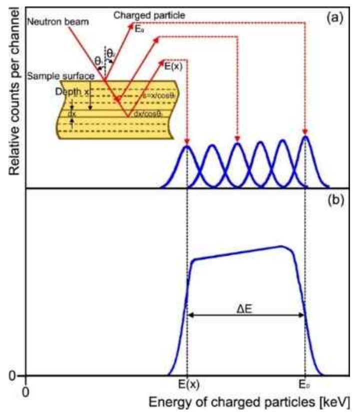

Fig. 2. A schematic diagram of energy distribution depending on depth *x* [1]

2. KAERI-NDP system

The 3rd generation KAERI (Korea Atomic Energy Research Institute)-NDP system has been constructed at the end of CG1 (Cold neutron Guide1) at HANARO (High-flux Advanced Neutron Application ReactOr) as shown in Fig. 3. The KAERI-NDP system has been improved to construct a target chamber, a charged particle detection system, and an in-situ neutron monitoring system dedicated to ICT material analysis. A sample stage and charged particle detectors were designed and built as shown in Fig. 4.

Fig. 3. Pictures of KAERI-NDP system

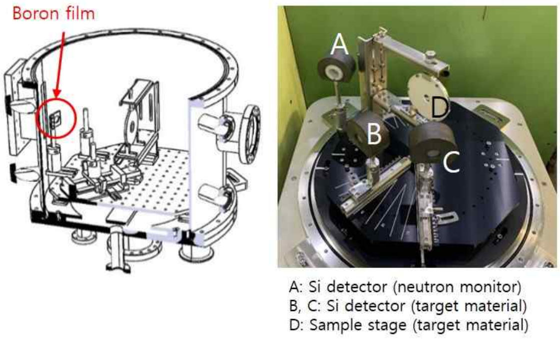

Fig. 4. The schematic diagram and picture of stage for KAERI-NDP system

For the measurement of the prompt gamma from the sample, the HPGe detector will be attached to the NDP system.

3. In-situ neutron monitor

To improve an analysis uncertainty of the KAERI-NDP system, it is required to identify fluctuations of the neutron beam during irradiation and measurement. For monitoring the neutron beam, in-situ neutron monitor made of boron thin film was designed. The neutron flux can be estimated by measuring the emission rate of the α-particles from the $^{10}B(n,\alpha)^{7}Li$ reactions.

To determine the thickness of the thin film monitor, the transmission ratio of neutron and the count rate of α-particles from the $^{10}B(n, \alpha)^{7}Li$ reaction were calculated by MCNP (Monte Carlo N-Particle) transport code. In the simulation, the target chamber, the thin film monitor was modeled as actual dimension. The MCNP model is shown in figure 5. The 1 μm thick boron thin film was located behind the neutron inlet port at an angle 45 degree to the surface normal. The energy and flux of the neutron beam were considered as 2 meV and 10^7 n/cm^{2}s, respectively.

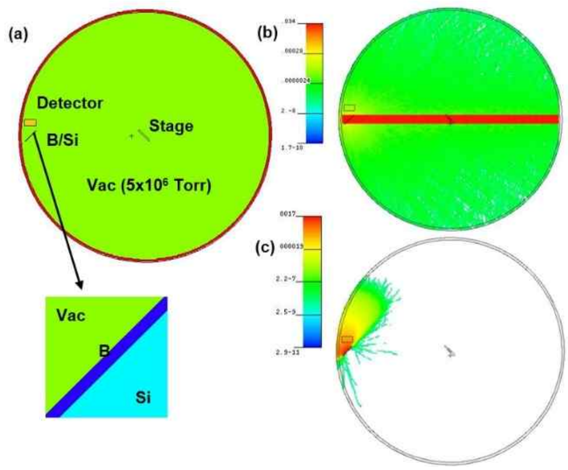

Fig. 5. (a) A model of target chamber on top view (b) neutron transmission ratio (91.1 %), (c) count rate of α particles (4.15 cps)

As the results, the optimized thickness of the boron thin film was determined to be 1.4 μm. The neutron transmission ratio and count rate of α-particles were estimated to be 91.1 % and 4.15 cps, respectively.

To apply the in-situ neutron monitor for the KAERI-NDP system, boron thin film on the Si substrate was prepared by RF sputtering as shown Fig. 6. To make elaborate samples, the surface of the samples was analyzed by using AFM (Atomic Force Microscope) as changing the sputtering conditions, which are the Ar partial pressure, RF power, and heating temperature. The difference in peak to peak and RMS value of B film are 4 nm and 200 pm, respectively as shown in Fig. 7.

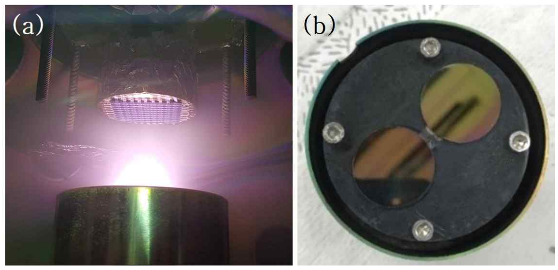

Fig. 6. The pictures of (a) RF sputtering and (b)B film on the Si substrate

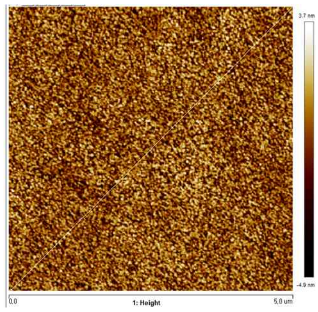

Fig. 7. AFM image of B thin film

4. Conclusions

The 3rd generation KAERI-NDP system has been constructed at the end of CG1 at HANARO for the quantitative analysis of micro elements by measuring the prompt gamma rays or energetic charged particles, which were emitted from the target materials by neutron absorption reaction. In this system, B thin film included as a in-situ neutron flux monitor, which is made by RF sputtering as following the recipe calculated by MCNP code. The prompt gamma spectrum measurement system will be attached.

Reference
[1] B. G. Park, Ph. D. thesis (2013).