Development of Cold Neutron Depth Profiling System at HANARO

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1. Introduction

The depth profiles of intentional or intrinsic constituents of a sample provide valuable information for the characterization of materials. A number of analytical techniques for depth profiling have been developed. Neutron Depth Profiling (NDP) system which was developed by Ziegler et al.[1] is one of the leading analytical techniques. In NDP, a thermal or cold neutron beam passes through a material and interacts with certain isotopes that are known to emit monoenergetic-charged particle remaining a recoil nucleus after neutron absorption. The depth is obtained from the energy loss of those charged particles escaping surface of substrate material.

For various applications of NDP technique, the Cold Neutron Depth Profiling System (CN-NDP) was developed at a neutron guide CG1 installed at the HANARO cold neutron source. In this study the design features of the cold neutron beam and target chamber for the CN-NDP system are given. Also, some experiments for the performance tests of the CN-NDP system are described.

2. Cold Neutron Depth Profiling System (CN-NDP)

A Cold Neutron Activation Station (CONAS) has been constructed at the Korea Atomic Energy Research Institute (KAERI) [2]. At the CONAS, the CN-NDP system is developed at the end of the CG1 neutron guide for various applications of NDP technique. The CN-NDP system utilizes cold neutrons transported along the CG1 neutron guide from the HANARO cold neutron source and consists of a neutron beam collimator, vacuum chamber, beam dumper, and charged particle detectors along with their associated data processing nuclear electronics. Conceptual drawing and picture of the CN-NDP system is shown in Figure 1.

A cold neutron beam is collimated through a 16.5 mm thick borated rubber sheet with a 20 mm-diameter aperture. The neutron flux at the sample position was measured by gold wire activation. The true integrated neutron flux was estimated to be 1.84×10^8 n/cm^{2}s. The average neutron wavelength is about 5 Å, was calculated by a McStas Monte Carlo code. The cold neutron beam passes through a thin(3 mm) aluminum window and hits a sample in the vacuum chamber.

The diameter of the vacuum chamber is 60 cm. The vacuum chamber is composed of a body made of stainless steel and an aluminum top cover. The vacuum chamber has various vacuum ports for a turbo

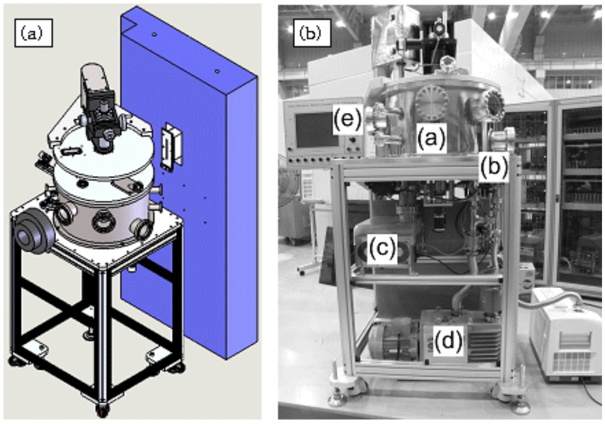

Fig. 1. Conceptual design of the CN-NDP system(a) and its picture(b). (a) : vacuum chamber, (b) : supporting table, (c) : Turbo molecular pump, (d) : Rotary pump, (e) controller.

molecular pump and mechanical pump, electrical and vacuum gauge feedthroughs. Samples are mounted on a 4-axes(x, y, z and rotation) positioner which includes a set of stepping motors. Two charged particle detectors are mounted on the two rotating brackets, which are coupled with the stepping motors located beneath the bottom of the chamber. Sample positioner and rotating brackets for detectors allow the detector to be positioned at any angle with respect to the sample without opening the vacuum chamber. All positioning devices are controlled by a personal computer. The electronics for the CN-NDP system consist of various NIM-standard modules for the charged particle pulse-height analysis. The residual energy of the charged particle is measured by an ion-implanted silicon detector.

3. CN-NDP experiments

Prompt charged particle measurements were carried out at the CN-NDP system using NIST Standard Reference Materials(SRM-2137 and SRM-93a)[3,4]. SRM-2137(boron implanted silicon wafer) and SRM-93a(borosilicate glass) include boron in silicon medium. When ^{10}B absorbs a neutron, it undergoes the following nuclear reaction:

$$\begin{aligned} &^{10}B + n \rightarrow {}^{7}Li^{*} + {}^{4}He(1472.4\,keV)\ (93.7\%) \\ &^{7}Li^{*} \rightarrow {}^{7}Li(840\,keV) + \gamma(478\,keV) \\ &^{10}B + n \rightarrow {}^{7}Li(1013\,keV) + {}^{4}He(1776.7\,keV)\ (6.3\%) \end{aligned} \tag{1}$$

The cross-sectional area of the incoming cold neutron beam is ~3.15 cm^2, while the active area of the Si ion-implanted detector is 150 mm^2. The detector was situated 11 cm from the sample in the normal direction of the sample surface. The detector resolution was calculated to be σ_E=25 keV using 5,486 keV alpha peak of the ^{241}Am standard source. The vacuum chamber is under vacuum(~10^{-5} mbar) and the sample surface plane is oriented 45° with respect to the incident beam.

The energy spectra for the SRM-93a and SRM-2137 are shown in Figure 2. In the spectrum, 1 channel corresponds to 1 keV. The step-wise energy spectrum of the SRM-93a can be inferred from the relation between the thickness of the sample and range of the alpha particle. The thickness of the SRM-93a is 6.3 mm, which is longer than the ranges of alpha particles emitted from ^{10}B.

In the spectrum of the SRM-2137, the alpha continua starting at 1472.1 keV and 1776.2 keV can be seen well-resolved. The gamma component of the beam is seen in the lower-energy side of the background. Therefore the two expected lithium peaks are indistinguishable from the background radiation and electronic noise. The background can be subtracted from the raw data by using the leading and trailing edges of the two alpha peaks. The detail of the alpha peaks of the SRM-2137 is shown in Figure 3. The counts under the 1472.1 keV and 1776.2 keV peaks can be expressed 94.3% and 5.7% of the total counts as a percent, which is close to the actual value 93.7% and 6.3% as shown in Equation (1).

A depth profiling calculation of the SRM-2137 was performed using the 1472.1 keV alpha peak. A depth versus concentration profile of ^{10}B was determined by using the conversion method in Ref. [5]. Without consideration of energy broadening effect in the conversion process, total dose of ^{10}B was determined 7.74×10^{14} atoms/cm^2 which is 23.4% less than actual implanted dose.

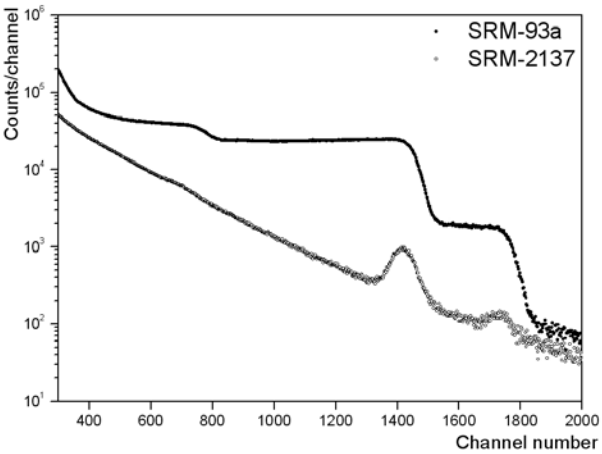

Fig. 2. Charged particle energy spectra of SRM-93a and SRM-2137 samples obtained with a silicon ion-implanted detector.

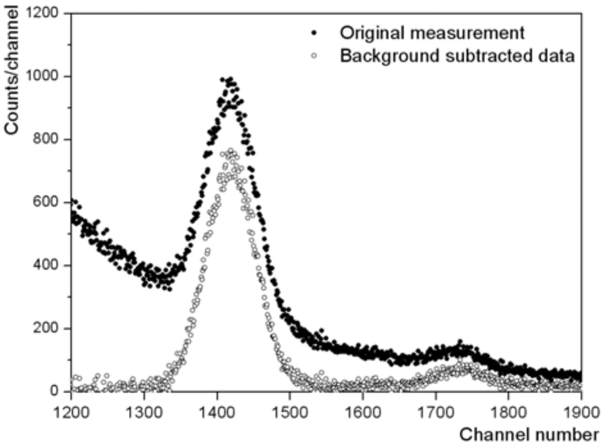

Fig. 3. Alpha-particle spectrum expanded of the SRM-2137.

4. Conclusion

The Cold Neutron Depth Profiling system has been developed for various applications of NDP technique. All equipment of the system has been designed and built. The Cold Neutron Activation Station has been constructed and the main components of the CN-NDP system have been installed in the CONAS. The charged particle energy spectra of the NIST SRM samples were measured and the boron profile in SRM-2137 was calculated as a test for the performance of the CN-NDP system. In the future, the CN-NDP system will be optimized to improve the depth resolution.

ACKNOWLEDGEMENTS

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