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Epithermal neutron tomography using compact electron linear accelerator

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ABSTRACT

Neutron resonance absorption spectroscopy (N-RAS) with a pulsed neutron source can distinguish the dynamics of individual nuclides having resonance peaks on epithermal neutron region. The analyzed internal information of nuclide presence and its effective temperature can be reconstructed as distributions over the object cross-section using computed tomography (CT). Because some of the resonance absorption cross-sections have very large values, N-RAS could match the small neutron pulsed source by its high sensitivity. In this study, we have constructed a new instrument of N-RAS on a compact electron linac neutron source. Resonance absorption measurements and CT imaging with the instrument have succeeded for some kinds of nuclide.

1. Introduction

Generally, it is difficult to non-destructively analyze the distribution of particular isotopes in bulk objects using any of the existing techniques. Neutron resonance absorption spectroscopy (N-RAS) with a pulsed neutron source can distinguish the dynamics of individual nuclides with resonance peaks on the epithermal neutron region. The technique makes it possible to observe a motion of a particular nuclide by measuring the neutron resonance absorption spectrum. In the measured spectrum, the line-width of the peak caused the thermal motion of the particular nuclide. This ability makes N-RAS a unique material research technique of an individual observation of plural nuclide [1,2].

Moreover, N-RAS combined with computer tomography (CT), N-RAS/CT, can non-destructively show the tomogram, which reconstructs the distribution of resonance nuclides in bulk objects since neutrons have high penetration power [3,4]. As a result, N-RAS/CT can be used to investigate internal information of the objects in detail than neutron imaging using the steady neutron source such as a reactor. For applications, N-RAS/CT could be a new non-destructive analysis for atomic power research such as nuclide distributions in fuel elements or waste products.

One of the advantages of N-RAS is its higher sensitivity than the normal neutron scattering spectroscopy since the resonance absorption cross-section has a large value. Then it could be suitable for a small neutron source. The first N-RAS spectrometer was installed at the pulsed spallation neutron source facility KENS at High Energy Accelerator Research Organization (KEK) in Japan. The small neutron source at Hokkaido University 45 MeV electron linac facility is 1% intensity against KENS. In this study, we constructed a new N-RAS instrument at Hokkaido University source and checked the feasibility of the compact N-RAS/CT system.

2. Instrumental

The existing N-RAS spectrometer is counting prompt gamma rays emitted from nuclei-absorbing neutrons as a function of neutron flight time. The new spectrometer has the same arrangement. Fig. 1 shows the schematic drawing of its whole arrangement. The new spectrometer is set up at a light water moderator. The flight path length from the moderator to a sample is variable, but is normally 13.3 m.

The target–moderator–reflector assembly (TMRA) system for the instrument is constructed on a compact trolley, and consists of a Pb target, a graphite reflector and a water moderator. The linac electron port, the target and the moderator are placed linearly, and the neutron beam direction is perpendicular to the line. The neutron beam hole size has 100 mm width and 100 mm height on the TMRA. Inside the TMRA there is a thick Pb shield between the target and direction to the spectrometer to reduce the X-ray burst from the electron hit of the target. A vacuumed neutron beam flight path has two B_4C collimators, which can be used to control the size and the position of the neutron beam spot on the sample.

The sample absorbs neutrons with a resonance energy E_R and then emit the prompt gamma rays by (n, γ) reaction. Eighteen BaF_2 scintillation detectors installed on both sides of the sample detect the gamma rays and the events are recorded by time analyzers. The time analyzers have a time channel width of minimum 40 ns and the number of channels is 16,000.

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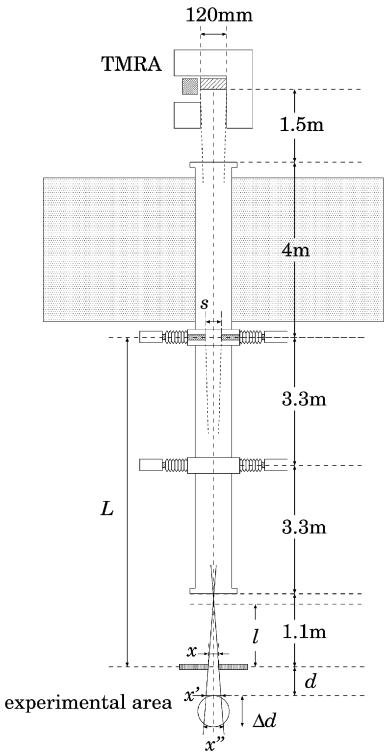

Fig. 1. Schematic diagram of the N-RAS beam line at Hokkaido University.

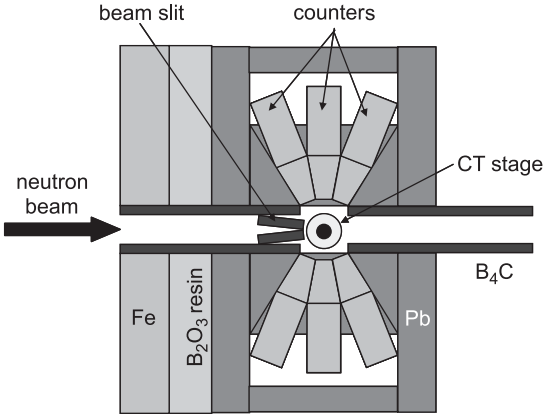

Fig. 2. Schematic diagram of the N-RAS spectrometer at Hokkaido University.

The absorbed neutron energy is determined from the neutron flight time between the moderator and the sample. The counter banks are shielded for neutrons and gamma rays by Fe, B and Pb as shown in Fig. 2. The whole spectrometer is equipped on a large turn table to adjust the alignment of CT measurement. The CT stage has two motions, one is the sample rotation and the other is neutron slit movement. The neutron slit can select the appropriate width from 0 to 3 mm. The slit is made by B_4C. All stage motions can control remotely.

3. Experimental

Ag, In, Nd, Sb, Sm and Ta were used as the sample elements having suitable resonance peaks. They were formed as the thin plates from their oxides and Al_2O_3 powder mixtures. The plate size was about $20 \times 20\,mm^2$. The temperature was controlled by a closed-cycle helium refrigerator.

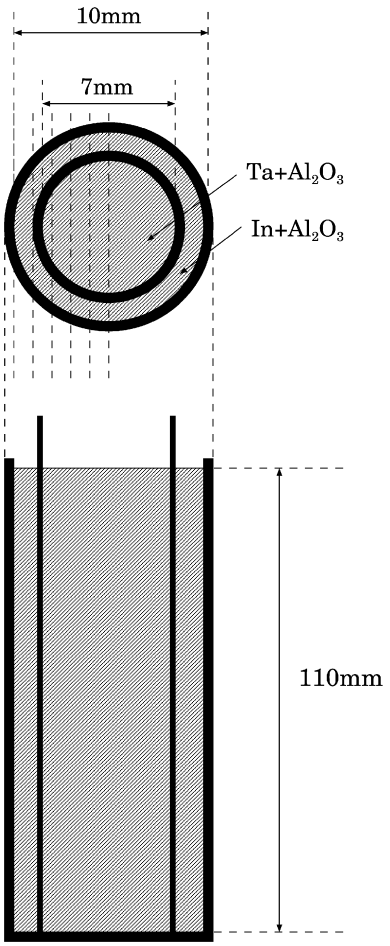

Fig. 3. Schematic diagram of the sample cell for tomography.

For CT measurement the sample objects had a cylindrical outer shape of 10 mm diameter and 100 mm height (Fig. 3). Inside the objects there were other small cylinders to make the nuclide distribution. We made some nuclide distribution patterns to check the tomogram reconstructions. The CT measurement was done by the step scan of the neutron slit, though the sample rotation was omitted because the sample had cylindrical symmetry. The slit scan step in this study was 1 mm.

Normal measurement times for powder samples were 1 or 2 h but for the CT measurement it took 5–10 h to take each partial spectrum.

4. Results and discussion

Fig. 4 shows an example of the measured N-RAS spectrum. The sample is Sm_2O_3, then there are plural resonance peaks which arise from the neutron absorptions by Sm. The background, which is considered to cause the X-ray burst from the target or air scattering around sample position, is rather high. But it is easy to subtract the background from the measured spectrum because it has no structure. Such smooth background implies that the spectrometer has the enough radiation shield as shown in Fig. 2.

For the spectral peak analysis the neutron pulse shapes for each energy have to be decided. Fig. 5 shows an example of temperature dependence of the number density of resonant absorbing atoms, N_d, analyzed with the use of integrated intensity of the 0.87 eV Sm resonance peak. The sample is common to the measurements, so N_d must have a single value. The time-of-flight