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Pulsed neutron imaging using resonance transmission spectroscopy

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ABSTRACT

We are developing the energy-selective neutron radiography and tomography technique by using the pulsed neutron source and the time-of-flight (TOF) spectroscopy. Neutron resonance absorption spectroscopy with computer tomography, N-RAS/CT, can non-destructively give the tomographic image indicating material information such as nuclide, density and temperature inside the object. The primary N-RAS/CT was performed by detecting prompt γ-rays emitted from nuclei absorbing neutrons as a function of neutron TOF. In this case, position dependent data need to be obtained by scanning the object with a moving slit. On the other hand, in this paper, we propose a new N-RAS/CT method using neutron transmission spectroscopy combined with 2-dimensional position sensitive neutron detector (2d-PSND), which is applicable to TOF measurement. The greatest feature of this method is shorter measurement time than the previous one because 2d-PSND can obtain spatial information at once. For this reason, we carried out the new N-RAS/CT experiment to examine its feasibility at the pulsed neutron facility based on the small accelerator.

1. Introduction

The energy-selective neutron imaging is a new neutron imaging technique. An advantage of this method is that it can give various images with different contrast and material information by analyzing neutron energy. As one of the energy-selective neutron imaging, there is a method using the pulsed neutron source and the neutron time-of-flight (TOF) spectroscopy. We are developing Bragg-edge transmission spectroscopic radiography [1,2] and neutron resonance absorption spectroscopy with computer tomography (N-RAS/CT) [3,4] at pulsed neutron facilities in Japan.

Resonance absorption cross-section in the energy range of epithermal neutrons has various characteristics. For example, resonance energy depends on resonance nuclide, and Doppler broadening of resonance width depends on nuclear dynamics such as lattice vibration. For this reason, neutron resonance absorption spectroscopy with computer tomography, N-RAS/CT, can non-destructively give the tomographic image indicating the distribution of resonance nuclide and temperature, which is deduced from nuclear dynamics inside the material.

We developed N-RAS/CT by utilizing the pulsed spallation neutron facility KENS at High Energy Accelerator Research Organization (KEK) in Japan. DOG which was the first neutron resonance absorption spectrometer could give the resonance absorption neutron spectrum by detecting prompt γ-rays emitted from nuclei absorbing neutrons as a function of neutron TOF. In this case, spatial information must be obtained by scanning the object with a moving slit. Additionally, resonance peak intensity depending on resonance nuclide density needs to be normalized by using the standard sample with known density for obtaining density information of resonance nuclide. For overcoming these complex problems, in this paper, we propose a new N-RAS/CT method, neutron transmission spectroscopy combined with 2-dimensional position sensitive neutron detector (2d-PSND). For this reason, we carried out the experiment of neutron transmission spectroscopy to examine the feasibility of this technique at the pulsed neutron facility based on the small accelerator.

2. Experimental

We carried out the experiment to examine the feasibility of the pulsed neutron tomography using the resonance transmission spectroscopy by utilizing 45 MeV electron linear accelerator at Hokkaido University in Japan. In this facility, pulsed neutrons were generated by photo-nuclear reaction caused by bremsstrahlung of pulsed electrons. The neutron yield of Hokkaido LINAC is about 10^{12} n/s while that of KENS is about 10^{14} n/s. In this experiment, the pulse width of the pulsed electron beam was 3 μs, and its repetition rate was 50 Hz. Neutrons moderated by light-water were used. Pulsed neutrons were transported through the evacuated beam tube to the sample. The neutron flight path length from the neutron source to the sample was 13.41 m.

Fig. 1 shows the schematic layout of the experimental setup. The sample cell was a double cylinder (20 mm outer diameter,

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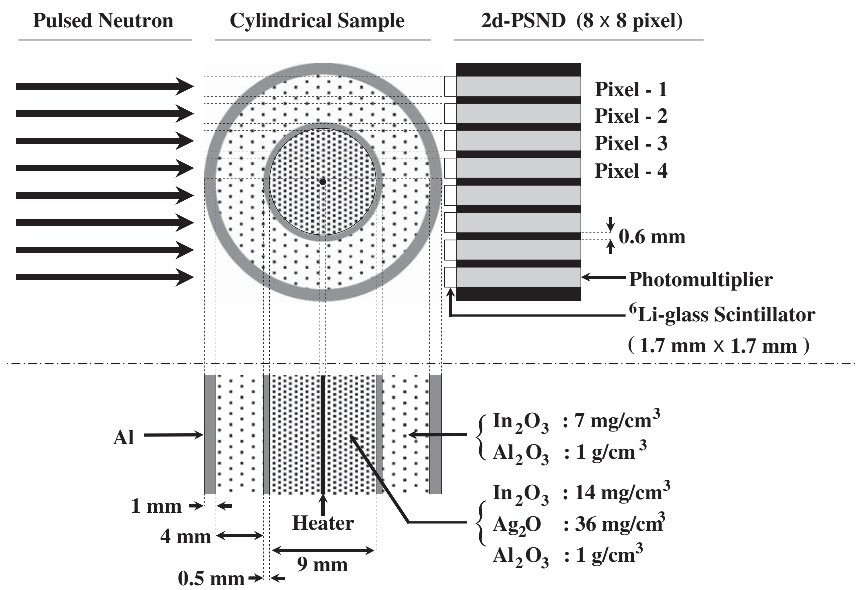

Fig. 1. Schematic layout of the experimental setup of the pulsed neutron transmission spectroscopic radiography.

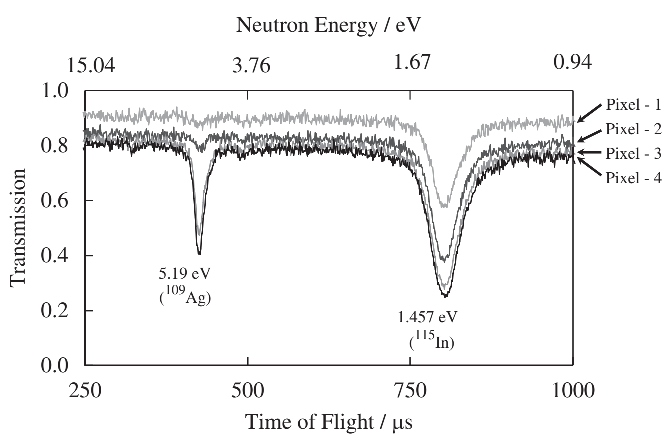

Fig. 2. Neutron transmission time-of-flight spectra using neutron transmission spectroscopy with 2-dimensional position sensitive neutron detector; Pixels 1–4 correspond to those of Fig. 1.

100 mm height) made of Al. This Al cylinder was fulfilled with different powders in each area. The inner area (9 mm diameter) was fulfilled with In_2O_3 of 14 mg/cm^3 (including ^{115}In of 6×10^{19} cm^{-3}), Ag_2O of 36 mg/cm^3 (including ^{109}Ag of 9×10^{19} cm^{-3}) and Al_2O_3 of 1 g/cm^3. On the other hand, the outer area (from 10 to 18 mm diameter) was fulfilled with In_2O_3 of 7 mg/cm^3 (including ^{115}In of 3×10^{19} cm^{-3}) and Al_2O_3 of 1 g/cm^3. Moreover, a thin Nichrome heater (0.5 mm diameter) heated to 478 K was installed at the center of the cylinder. 64 (8×8) pixel ^{6}Li-glass scintillation counter [1] produced by Japan Neutron Optics (J-NOP) was used as 2d-PSND which can obtain spatial information at once. The spatial resolution of this imaging detector is 2.3 mm, and its time of resolution is 1 µs.

Fig. 2 shows neutron transmission TOF spectra $Tr(tof)$ at each pixel position. These spectra were calculated by TOF spectrum data of the incident and transmitted beam, using the relation of

$$Tr(tof) = I(tof)/I_0(tof) \tag{1}$$

where $I(tof)$ is the TOF spectrum of the transmitted beam, and $I_0(tof)$ is that of the incident beam. The resonance absorption dips of ^{109}Ag and ^{115}In clearly appeared at 5.19 and 1.457 eV.

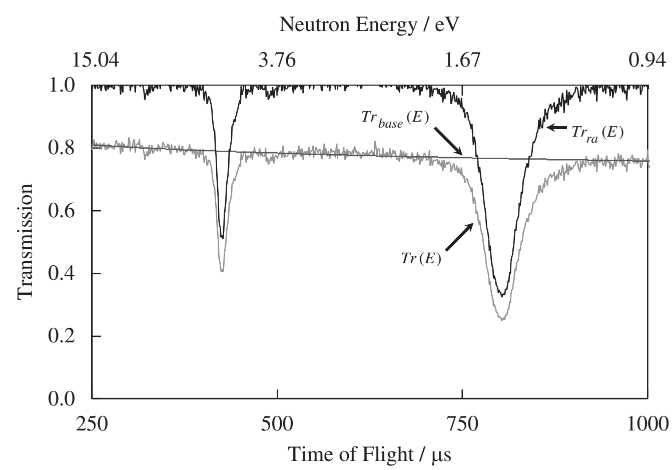

Fig. 3. Neutron transmission spectrum $Tr(E)$ of Pixel 4, its potential scattering and $1/v$ absorption component $Tr_{base}(E)$, and resonance absorption component $Tr_{ra}(E)$ extracted by using the relation of Eq. (7).

However, these transmission spectra indicate total cross-section information which includes potential scattering, $1/v$ absorption and resonance absorption at each pixel position. Therefore, we must consider the extraction method of the resonance transmission spectrum for evaluating the exact characteristics of individual resonance nuclides.

3. Extraction of resonance transmission spectrum

The extraction method of the resonance transmission spectrum is explained by using Fig. 3. In the measurement of neutron transmission spectroscopy in the epithermal neutron range, components of total cross-section mainly consist of potential scattering, $1/v$ absorption and resonance absorption. If we measured a material made from single nuclide, the neutron transmission spectrum depending on neutron energy E was represented by

$$Tr(E) = \exp(-\sigma_{tot}(E)\rho_d) \tag{2}$$