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A New Thermal Neutron Reflectometer for Free Surface at KENS - ARISA -

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Abstract

A new neutron reflectometer (ARISA) with vertical scattering-plane geometry for studying free surface was installed at a thermal neutron port viewing an ambient-temperature water moderator at KENS. ARISA is a unique reflectomer using thermal neutrons at a pulsed spallation neutron source as well as the first neutron reflectometer with vertical scattering-plane geometry in Japan. An inner iron collimator with two beam holes and a neutron beam-line shield were installed to minimize high-energy neutrons directly coming from the neutron-target due to the shield loss produced by beam holes themselves. The inner collimator makes two independent downward beam holes with different angles, 0° - 0.47° and 1.4°. The neutron beam-line shield has function of an additional beam-shutter as well. The designed specifications for the covered range of neutron momentum transfer, q_z, in the vertical direction are 0.008 $Å^{-1}$ - 0.61 $Å^{-1}$ and 0.008 $Å^{-1}$ - 2.8 $Å^{-1}$ for liquid and solid samples, respectively, using the neutrons with 0.5 Å – 4 Å wavelengths.

1. Introduction

It has been well accepted that neutron reflectivity (NR) measurement is a powerful technique for studying surface and interface structures because of its high spatial resolution. There have been a few reflectometers in Japan: PORE [1] at the pulsed spallation neutron source of KENS, LTAS [2] of JAERI, and MINE [3] of ISSP, the University of Tokyo, at the JRR-3M reactor of JAERI. However, all the domestic reflectometers have horizontal scattering-plane geometry, so that they are not suitable for liquid samples since those samples can not be tilted. Thus, the authors mainly composed of polymer researchers applied for the grant of the Japanese Ministry of Education, Science and Culture, and the two-years grant (No. 11355037) was approved for the period of 1999-2000 to construct the first reflectometer with vertical scattering-plane geometry in Japan. Generally, the reflectometer at a pulsed spallation neutron source, i.e., using the neutrons with a wide band of wavelength, λ, is suitable for liquid samples, because it can cover wide range of the neutron momentum transfer, q_z ($=4\pi\sin\theta/\lambda$), in the vertical direction at one incident angle, θ. The new reflectometer named ARISA (Advanced Reflectometer for Interface and Surface Analysis) was constructed at the KENS spallation neutron source. ARISA is also a unique reflectometer using thermal neutrons compared with the other reflectometers at pulsed spallation neutron sources. The construction of ARISA was completed at the end of October in 2000, and the commissioning has been just started. Here, the conceptual design of ARISA is described in details.

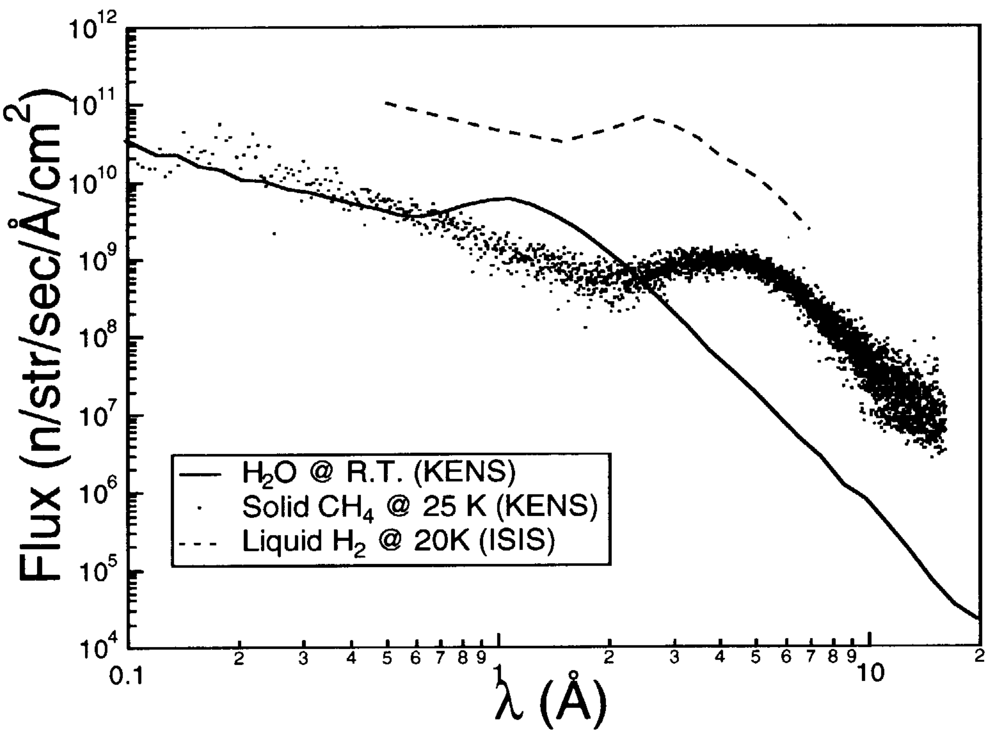

Fig. 1 Comparison of neutron spectra from different moderators. The spectra for KENS moderators were measured before the renewal of TMRA in the summer of 2000. [6]

2. Neutron Characteristics of KENS Moderators

Fig. 1 compares the neutron spectra of an ambient-temperature water [4] and a solid methane (at 25 K) moderators of KENS as a function of λ, together with the data for a liquid hydrogen (at 20 K) moderator of ISIS. [5] It should be noted that the neutron flux from the solid methane moderator has been recovered after the renewal of target-moderator-reflector assembly (TMRA) of KENS, [6] and the intensity should become higher now. The spectrum of the water moderator exhibits a peak at λ around 1 Å. For the reflectometer, such as ARISA, with vertical scattering-plane geometry, the incident angle of neutrons is generally limited due to the geometrical constraints of a beam hole since liquid samples can not be tilted. Thus, the thermal neutrons with shorter λ's are suitable to realize the measurement at higher q_z. On ARISA, the neutrons with the wavelengths ranging 0.5 Å – 4 (8) Å around peak intensity from the ambient-temperature water moderator are used for measurement.

3. Collimator Design

Fig. 2 shows a side-view of the neutron beam line before the first slit of the ARISA reflectometer. The biological shield of KENS covers 4 m from the center of a target station in the horizontal direction. Generally, opening a beam hole in a biological shield makes shield loss, so that high-energy neutrons coming directly from a neutron target contribute to the increase of background level. Thus, an inner collimator and a neutron beam-line shield were installed on ARISA to reduce the high-energy neutron background as much as possible. The iron collimator with 2.1 m long was inserted into an evacuated aluminum beam-duct inside the biological shield. The inner collimator makes two independent downward-beam holes with different angles, 0° - 0.47° and 1.4°. The angle of 1.4° is fixed by the geometrical constraints of the beam hole opened inside the biological shield, and the smaller angle was determined by considering q_z coverage at different incident angles, θ, of neutrons. Fig. 3 shows the q_z coverage at θ=0.15°, 0.47° and 1.40° when the neutrons with 0.5 Å – 4 Å wave-

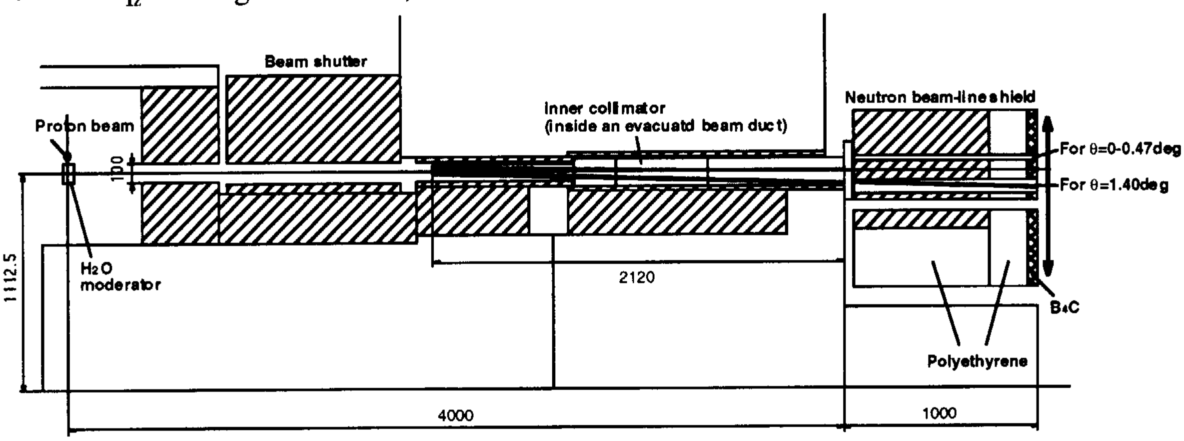

Fig. 2 A side-view of the beam line before the first slit of the ARISA reflectometer.

lengths are used. The shape of the beam hole for the smaller angle, ≤ 0.47°, was designed to extract the horizontal beam as well. The position of the two beam holes in the inner collimator was designed to minimize the shield loss produced by the beam holes themselves. Fig. 4 shows the path-length inside iron shield for high-energy neutrons emitting from a bottom part of a proton beam impinging the neutron target as a function of the height from floor level at the position just before the first slit. In the figure the height of 1112.5 mm is corresponding to the center of the water moderator. The path-length for the bare beam hole without the inner collimator exhibits a wide dip of shield loss as shown by the broken line, and the shortest path-length becomes 0.2 m at worst. The introduction of the inner collimator reduces shield loss significantly, and separating the positions of the two beam holes in the inner collimator makes the shield-loss dip narrower as shown by the solid line in the figure. However, it should be noted that large separation of the two beam holes needs large translation in the vertical direction of a sample stage or a detector causing the difficulty in keeping their mechanical accuracy. The two narrow shield-loss dips at the height around 930 mm and 1000 mm are produced by the beam holes with the angles of 0° - 0.47° and 1.4°, respectively.

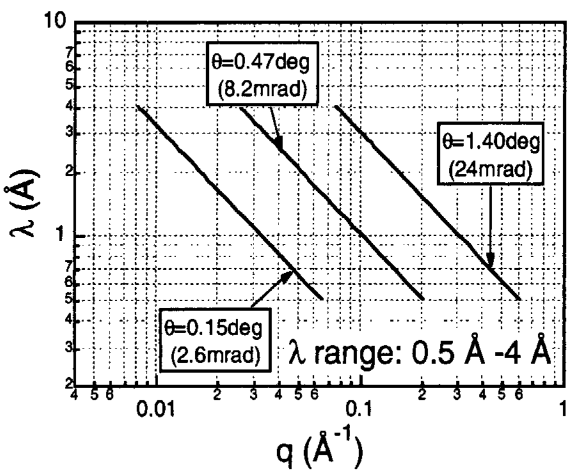

Fig. 3 The designed q_z coverage at the incident angles of 0.15°, 0.47° and 1.40° when the neutrons with 0.5 Å – 4 Å wavelengths are used.

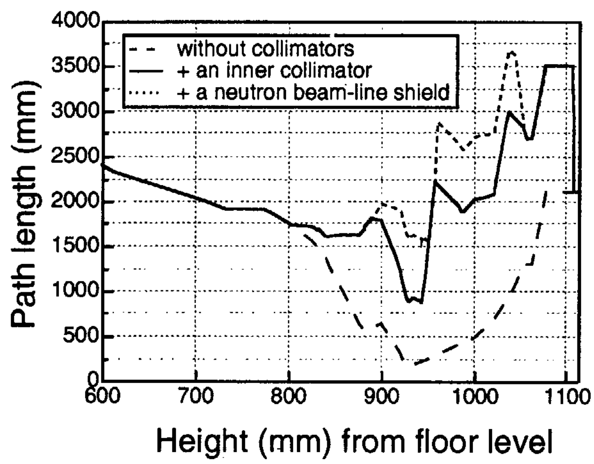

Fig. 4 The path-length inside iron shield for high-energy neutrons emitting from a bottom part of a proton beam as a function of the height from a floor level at the position just before the first slit of ARISA.

On the other hand, the neutron beam-line shield with 0.7m-long stainless steel collimators was installed just outside biological shield. This neutron beam-line shield has function of an additional beam-shutter, and the shutter section can be precisely replaced with the other collimator sections corresponding to each beam hole of the inner collimator by computer control. As shown by the dotted line in Fig. 4 the shield loss is further reduced by installing the neutron beam-line shield, and the path-length inside iron shield for the high-energy neutrons was designed to be kept above 1.5 m.

4. Instrument Design

Figs. 5 and 6 are a schematic layout and a photograph of ARISA reflectometer inside a blockhouse, respectively. The three separate parts of the reflectometer, i.e., the first slit, a sample stage and a detector, are precisely arranged on the beam line. Fine collimation in the vertical direction is provided by two computer-controlled slits with sintered B_4C blades before and after sample. The incident angle of neutrons is determined by the relative heights of the first and second slits in the beam divergent of each beam hole with 0° - 0.47° or 1.40° in the collimators. The beam size in the horizontal direction is 50 mm in maximum, and it is manually changeable by 10mm step. A laser beam can be guided through the same paths as the neutrons with different incident angles for the ease of sample alignment. A monitor with low counting efficiency will be introduced at the position of the first slit to monitor the incident flux of neutrons in the near future. The whole sample stage including the second and third slits is mounted on an active anti-vibration table of Newport Co. The translations in the vertical and horizontal directions and the rotations around two orthogonal axes in the horizontal plane are accurately computer-controlled for the sample table. A liquid trough with a movable barrier and a high-temperature cell up to about 200 °C are prepared as sample environment equipment. The detector is tilted according to the angles of the detected beam, and was designed to make the measurement with high incident angle, ~10°, possible for solid samples. Currently, a ^3He proportional counter is used for specular reflection measurement, and is shielded by B_4C resign to reduce background intensity. A position-sensitive detector can be mounted for off-specular scattering measurement in future. The instrument parameters of ARISA are summarized in Table I.

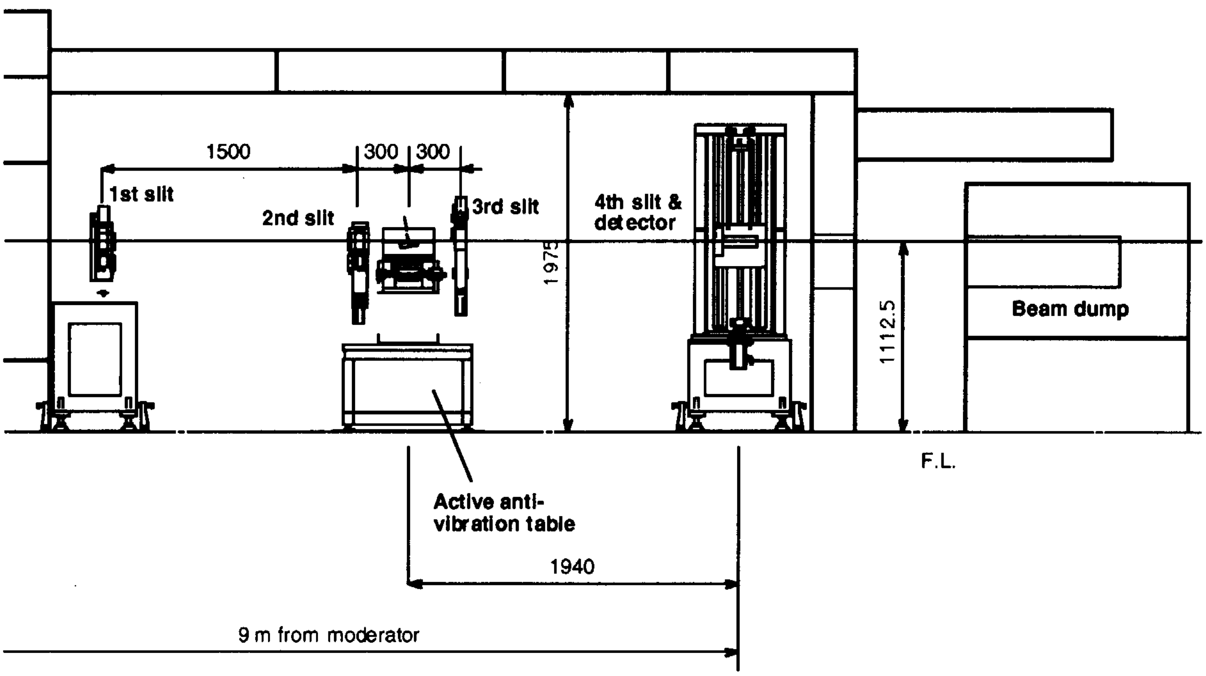

Fig. 5 A schematic layout of ARISA inside a blockhouse.

Table I The instrument parameter of ARISA reflectometer

Beam port	H5 beam port at KENS
Moderator type	Ambient-temperature water
Scattering plane	Vertical
Moderator-sample	7.10 m
Sample-detector	1.94 m
Separation of the 1st - 2nd slits	1.50 m
Incident angle	≤0.47°, 1.40° (for liquid) ≤6.4° (for solid)
Wavelength band	0.5 Å – 4 (8) Å
q_z range	0.008 $Å^{-1}$ - 0.61 $Å^{-1}$ (for liquid) 0.008 $Å^{-1}$ – 2.8 $Å^{-1}$ (for solid)
Beam size at sample	Max 10 mm (height) × 50 mm (width)
Angular resolution	Δθ/θ≤7.5% (sample size: 50 mm)
Sample environment option	A LB trough with a movable barrier, a high-temperature cell (~200°C)

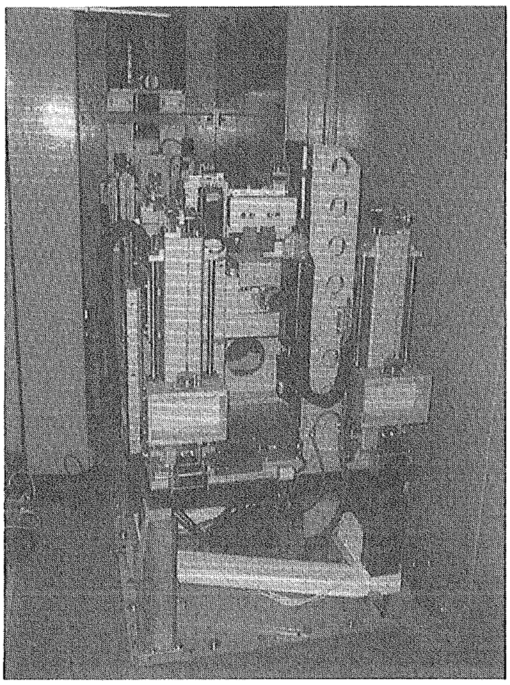

Fig 6 A photograph of the ARISA reflectometer inside a blockhouse viewing from the downstream of the sample stage.

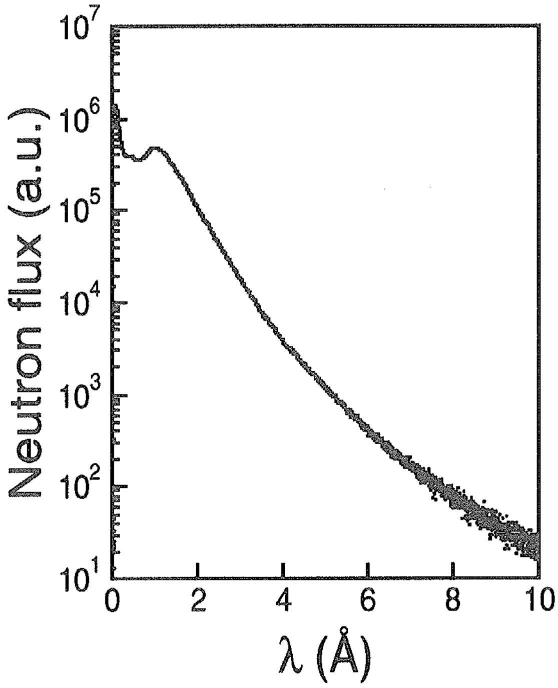

Fig 7 The neutron spectrum measured on ARISA just after the renewal of KENS target-moderator-reflector assembly in the summer of 2000.

5. The Neutron Spectrum Measured on ARISA

Fig. 7 shows the neutron spectrum measured on ARISA using a ^{3}He proportional counter as a function of λ, just after the renewal of KENS target-moderator-reflector assembly in the summer of 2000. The beam hole with the angle of 1.4° was used, and the sizes of the 1st and 2nd slit-openings were 1×20 mm^2 and 1×20 mm^2, respectively. The spectrum exhibits a peak at λ around 1 Å, and it is consistent with that obtained at the H9 port from an ambient-temperature water moderator.

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