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A two-dimensional scintillation-based neutron detector with wavelength-shifting fibers and incorporating an interpolation method

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ABSTRACT

A two-dimensional scintillation-based neutron detector with wavelength-shifting (WLS) fibers was developed that incorporated a novel data interpolation method. The interpolation method, which was developed for a photon-counting detector, produced an effective pixel size smaller than the physical pitch of the WLS fibers in the array. The WLS-fibers array was constructed by placing fibers at a regular pitch of 2.5 mm in both the x and y directions. The two crossed fiber arrays were sandwiched with two scintillator screens. Detectors with half- and quarter-pitch calculation logics exhibited spatial resolutions of 2.7 ± 0.1 and 2.5 ± 0.1 mm, respectively, for the full width at half maximum (for a 1-mm beam width). The corresponding effective pixel sizes were 1.25 and 0.625 mm. The measured spatial resolutions were approximately 1.3-fold better than that with the standard-pitch calculation logic. The presented results demonstrate the feasibility of using the developed interpolation method with a collimated neutron beam.

1. Introduction

Two-dimensional scintillation-based neutron detectors have been used extensively in many neutron-scattering instruments at the neutron facilities [1–3]. The detector specifications required for such instruments are influenced by the design of the beam lines. A single-crystal neutron diffractometer requires a high spatial resolution, a small pixel size, and a large neutron-sensitive area per module.

The scintillation-based neutron detector using wavelength-shifting (WLS) fiber technology adds great flexibility to detector parameters such as the pixel size and the coverage area. Conventional WLS-fiber-type scintillation-based neutron detectors have adopted x–y crossed WLS-fibers arrays, where each array is constructed from small-diameter fibers packed adjacent to each other to produce small pixels [4–6]. Such a WLS-fibers detector head is also advantageous in increasing the light collection efficiency. However, this approach is not economically efficient when constructing a large-area detector due to the large numbers of fibers and electronics channels required.

In order to address these problems we previously proposed the WLS-fiber-type detector employing a median point calculation (MPC) method [7,8]. The detector head covers a large area with the WLS fibers placed at a regular pitch whilst ensuring that the pixels are sufficiently small (equal to half the pitch of the WLS fibers), with the MPC method developed for the detector operating in photon-counting mode. With this interpolation method the detector required a less number of photomultiplier tubes and the associated electronics boards. This fact gives a considerable impact to decrease a detector manufacturing cost, particularly to our neutron scattering instruments where several tens of detector modules are required to cover a large scattering solid angle around the sample.

A purpose of the present study was to measure the position sensitivity of a WLS-fiber-type scintillation-based neutron detector implemented with this novel MPC method. The new MPC programs calculate the pixel size down to quarter of the WLS fiber pitch, and were tested with a high-spatial-resolution prototype detector constructed with a fiber pitch of 2.5 mm. The detector performance—including its spatial resolution and position linearity—was evaluated using a collimated pulsed neutron beam.

2. Description of the detector system with the MPC method

2.1. High-spatial-resolution detector

Fig. 1 shows schematic views of the neutron-detecting head. The WLS fibers are placed at a regular pitch of 2.5 mm in the x and y directions, and the crossed WLS-fibers arrays are in direct

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contact with each other. WLS fibers with a diameter of 1 mm were purchased from Saint-Gobain K.K. Two ZnS/$^{10}B_2O_3$ ceramic scintillator screens sandwich the crossed WLS-fibers arrays. Scintillator screens with thicknesses of 0.2 and 0.4 mm are placed upstream and downstream of the WLS-fibers arrays, respectively. The thicknesses of the scintillator screens were chosen in order to maximize the detection efficiency of the detector for thermal neutrons [9]. The detector comprises 256 fibers (128 in each of the 2 layers) and electronics channels that can accommodate a neutron-sensitive scintillator with an area of 320 mm × 320 mm. Four 64-channel multianode PMTs (H8804) purchased from Hamamatsu were used in the test detector. The scintillator screens that have sizes of 120 mm × 120 mm are implemented to the prototype detector for test. Detector electronics including the amplifier cards, and encoder electronics similar those in the SENJU detector [9] were used for performance testing.

A neutron incident on the detector is absorbed in the scintillator screen in the nuclear reaction of $^{10}B(n,\alpha)^7Li$. The generated secondary particles (alpha particle and ^7Li ion) deposit energy on the surrounding ZnS phosphor to generate scintillation light that has a peak emission wavelength of 450 nm. The ZnS scintillator emits about 100,000 photons per neutron absorption. There are two light decay components: a primary light with a time constant of 100 ns and the secondary of 70 μs. The amount of photons separate almost half within each component. Only those escaped from self-absorption in the scintillator are collected in the WLS fibers. The WLS fiber reemits the shifted secondary light that has a wavelength of 500 nm. These secondary lights propagate through the fiber to the PMTs that are connected at the end of each fiber. The detector is operated in photon-counting method to ensure high detection efficiency and temperature stability. Hence the detector electronics measure every single photoelectron, so the choice of PMTs rather than solid-state alternative such as silicon photomultiplier. The number of photoelectrons detected at each fiber is counted for 2 μs after the trigger signal opens the gate. A scintillation event is recorded as a neutron event only when the total number of detected photoelectrons exceeds a threshold level, which is typically set at six photoelectrons. The incident position is

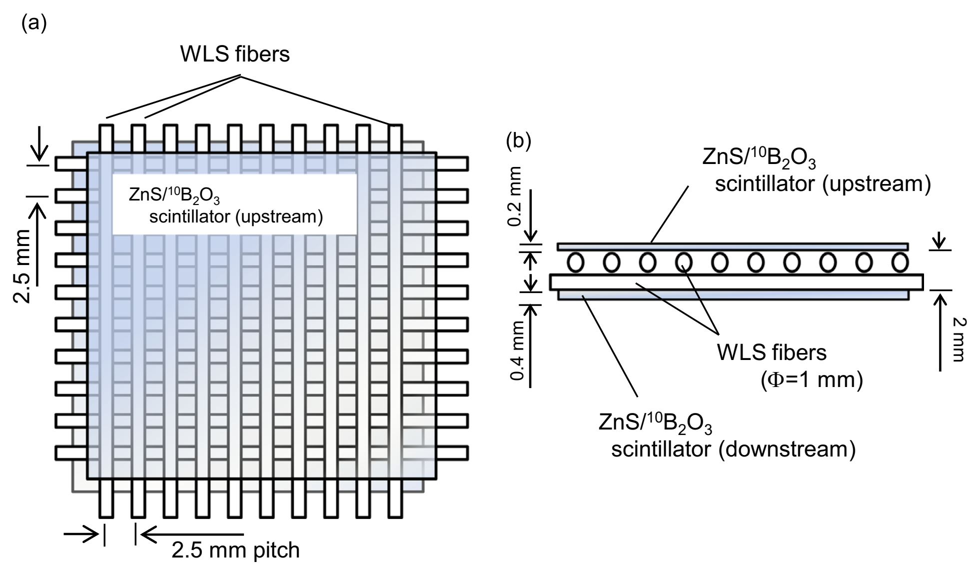

Fig. 1. Schematic views of the neutron-detecting head: (a) top view and (b) side view. Only ten fiber channels for each direction are shown.

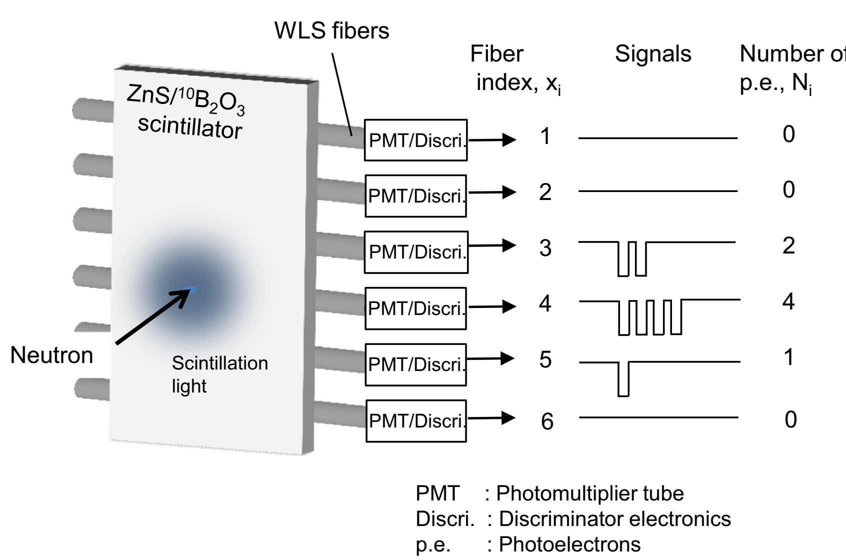

Fig. 2. Schematic diagram of the scintillator and wavelength-shifting (WLS) fiber detector (only the WLS-fibers array in the *x* direction is presented for simplicity). In this case the incident position of the neutron is calculated as ~3.9(=(3×2+4×4+5×1)/(2+4+1)) with the MPC method.