A novel energy resolved neutron imaging detector based on a time stamping optical camera with high spatial resolution at CSNS

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Introduction

The China Spallation Neutron Source (CSNS) operates in pulsed mode and has a high neutron flux. This provides opportunities for energy resolved neutron imaging by using the TOF (Time Of Flight) approach. An Energy resolved neutron imaging instrument (ERNI) is being built at the CSNS but significant challenges for the detector persist because it simultaneously requires a spatial resolution of less than 100 μm, as well as a microsecond-scale timing resolution.

This study constructs a prototype of an energy resolved neutron imaging detector based on the fast optical camera, TPX3Cam coupled with an image intensifier. To evaluate its performance, a series of proof of principle experiments were performed in the BL20 at the CSNS to measure the spatial resolution and the neutron wavelength spectrum, and perform neutron imaging with sliced wavelengths and Bragg edge imaging of the steel sample. A spatial resolution was improved for neutron imaging by using the centroiding algorithm, the timing resolution was on the microsecond scale and the measured wavelength spectrum was identical to that measured by a beam monitor. Any wavelengths can be selected for the neutron imaging of the given object, and the detector can be used for Bragg edge imaging. Several samples including a wrist watch, flower and battery were measured. The results show that our detector has good performances and can satisfy the requirements of ERNI for detectors at the CSNS.

Methods

A schematic diagram and setup of the energy resolved neutron imaging detector is shown in Fig. 1. At the CSNS, a pulsed neutron beam was produced by the spallation reaction, with a repetition frequency of 25 Hz. The signal T0 from the accelerator represents the time of generation of the pulsed neutron beam. It was used as the trigger for TPX3Cam and was recorded for the calculation of the TOF. The pulsed neutrons transmitted through the sample and the transmitted neutrons were converted into light through the scintillation screen. The Timepix3 chip of TPX3Cam had a high detection threshold, about 1000 photons per pixel hit according to the specification in the manual of TPX3Cam. Thus, an image intensifier was needed to enhance the scintillation light induced by the neutrons. The scintillation light was deflected into the optical lens by a reflective mirror, enhanced by the image intensifier, and finally reached the Timepix3 chip. The coordinates (x,y), TOA, and TOT of each fired pixel were measured simultaneously. The TOF was calculated according to T0 and TOA, and represented energy or wavelength of the neutron.

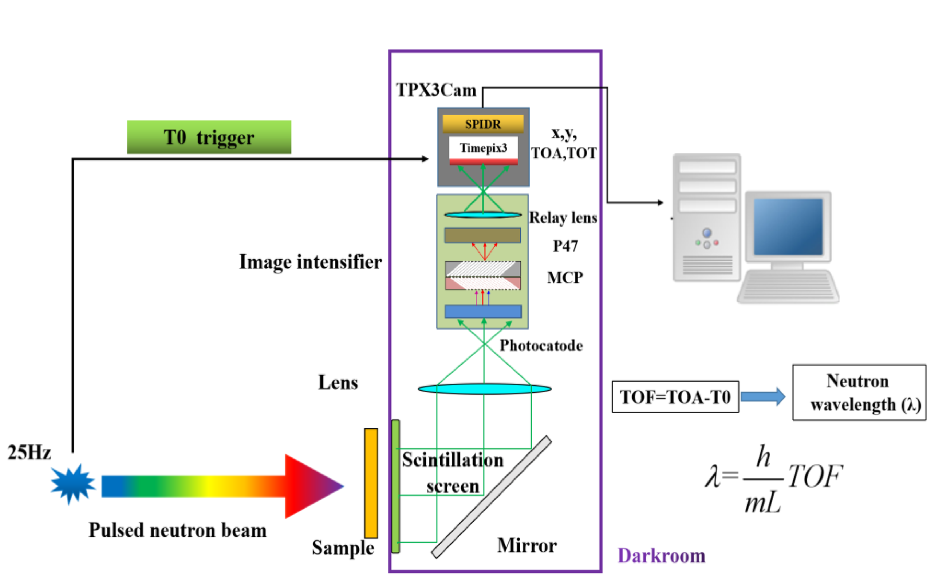


Figure 1 Schematic diagram of detector

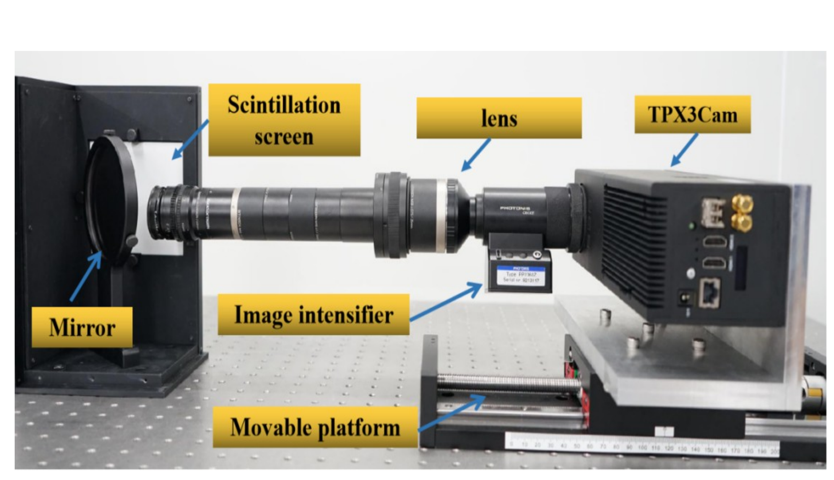


Figure 2 Setup of the detector

Results

To verify the capability of the detector in terms of timing resolution, the wavelength spectrum was firstly measured at the BL20 with a decoupled poisoned hydrogen moderator using the TOF approach. The results in Fig. 3 show that the spectral shape measured by the TPX3Cam detector was almost identical to that measured by the beam monitor. The spatial rsolution was measured using a siemens star test object and the result is shown in Fig.4 (left). The spatial resolution was improved from 84 μm o 57 μm by using the centroiding algorithm was measured(shown in Fig.4 (right)).

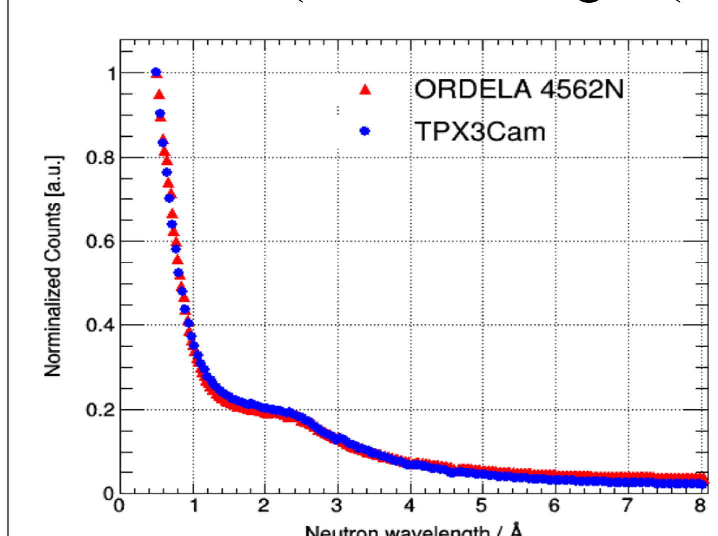


Figure 3 Neutron wavelength spectrum ovf CSNS BL20

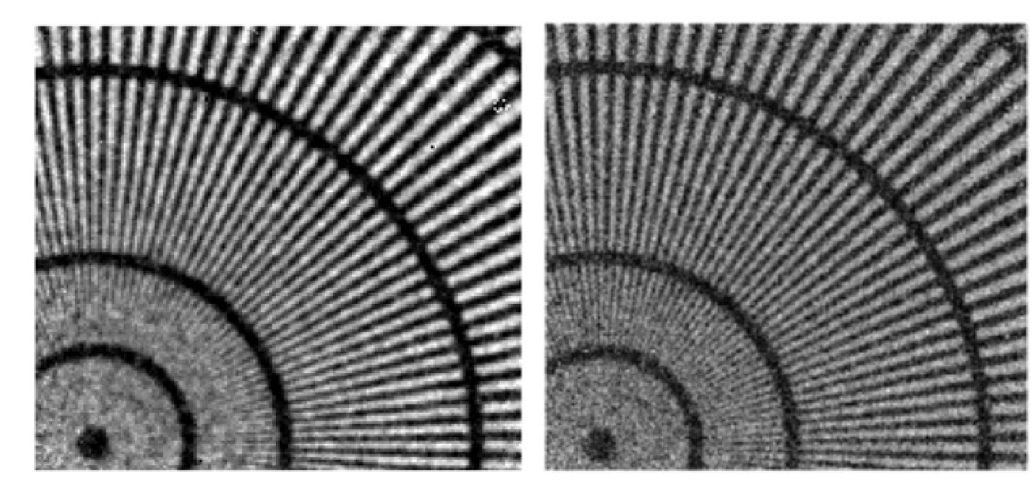


Figure 4 Neutron wavelength spectrum of CSNS BL20

Neutron imaging of the total and sliced wavelengths were carried out for a CSNS Cd object (shown in Fig.5). On the whole, the cross-section of neutrons through cadmium increased with the wavelength in the range of 0–4 Å. It was clear that the image contrast depended on the chosen neutron energy/wavelength, and gradually enhanced with the wavelength for the CSNS pattern object. In addition, the samples including steel and watch were measured (shown in Fig. 6 and 7).

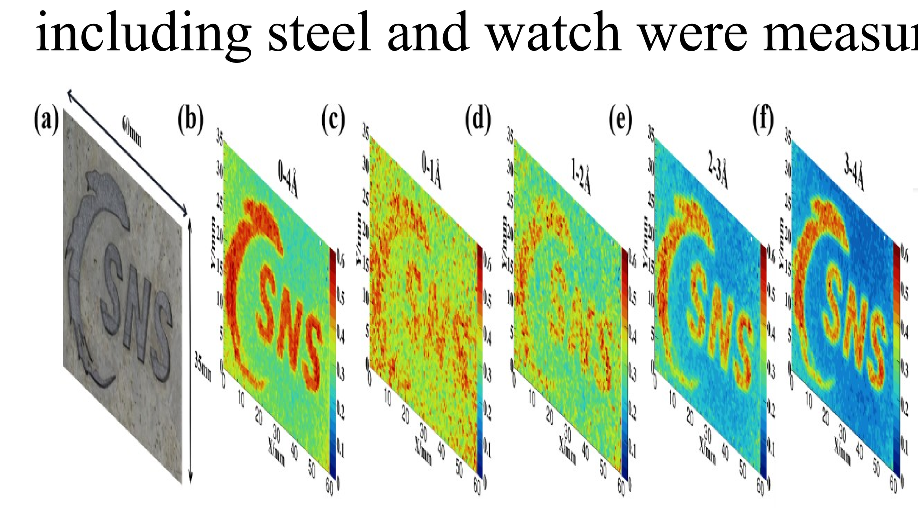


Figure 5 CSNS Cd object and neutron images

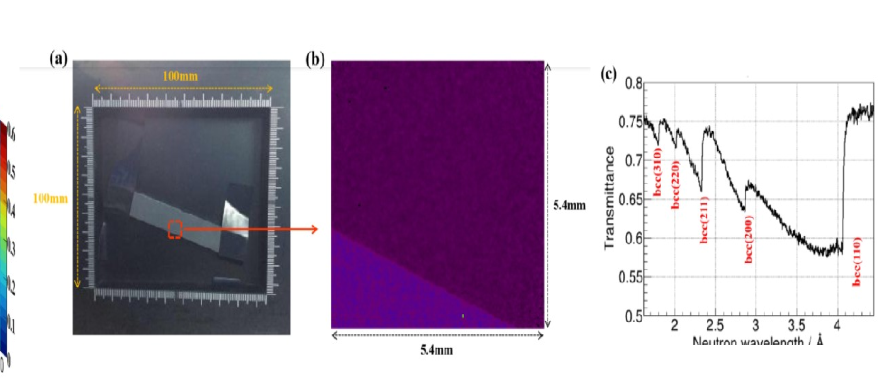
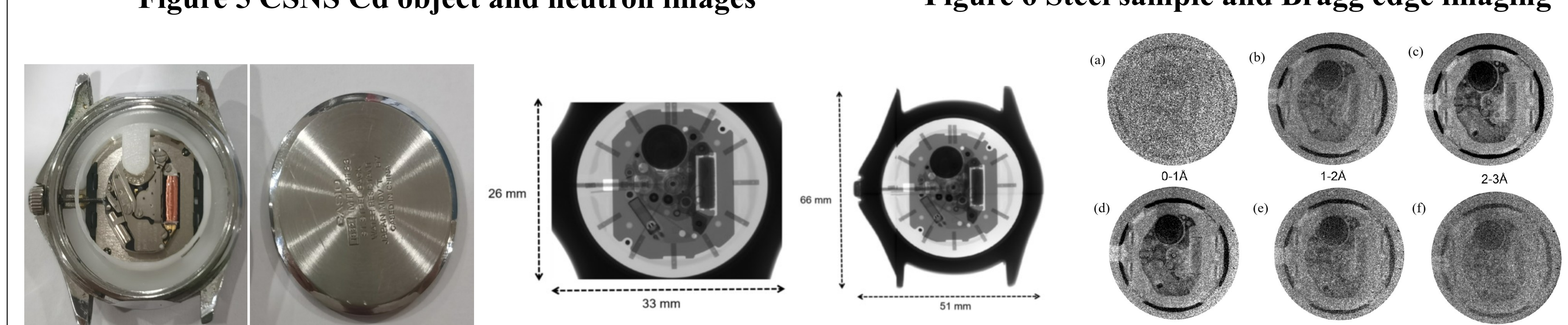


Figure 6 Steel sample and Bragg edge imaging



(a) A quartz wrist watch (b) X-ray images (c) Neutron images of different wavelengths

Figure 7 A quartz wrist watch and imaging results using X-ray and neutrons

Conclusions and outlook

This study constructed an energy resolved neutron imaging detector based on the TPX3Cam. The results verified the high timing resolution and spatial resolutions of this detector. It can be applied as an instrument detector for ERNI. In future work of the area, the experiments should be performed in the SANS (Small Angle Neutron Scattering Instrument) which has a better colliation ratio and higher flux than those of BL20, to further improve the spatial resolution neutron imaging.

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