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High-resolution neutron radiography with microchannel plates: Proof-of-principle experiments at PSI

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ABSTRACT

With the appearance of highly collimated and intense neutron beamlines, the resolution of radiographic experiments is often limited by the parameters of the neutron imaging detector. Neutron-sensitive microchannel plates (MCPs) proved to be very efficient for conversion of a thermal or cold neutron into an electron pulse of up to 10^6 electrons preserving location of the neutron absorption within ~15 μm. In this paper, we present the results of preliminary measurements performed with neutron-sensitive MCPs coupled with a Medipix2/Timepix active pixel sensor. A set of test objects was imaged at both thermal and cold neutron imaging beamlines of Paul Scherrer Institute. The spatial resolution of the detector operating at high counting rate mode was confirmed to be limited by the 55 μm pixel size of the Medipix2 readout. At the same time, event centroiding applied to the charge values measured with Timepix readout allowed individual neutron counting with spatial resolution on the scale of MCP pore spacing (11 μm in the present measurements). The ongoing improvement of the speed of the readout electronics should eliminate the low counting rate limitation of the latter high-resolution imaging.

1. Introduction

Neutron radiography has proven to be a very attractive technology for nondestructive testing of objects opaque or completely transparent to X-rays. Spatial resolution, detection efficiency and readout noise of the detection system are critical parameters defining the capabilities of a particular experiment. The existing high-resolution neutron imaging technologies rely on either neutron sensitive scintillators optically coupled to a CCD camera [1] or conversion of neutrons into electrons in special absorbers with subsequent detection by silicon-based sensors [2–4]. The recent experiments indicate that neutron counting detectors with microchannel plates (MCPs) can be very attractive alternative for neutron radiographic applications due to their ability to count neutrons with high spatial resolution of ~55 μm at counting rates exceeding $10^8\,cm^{-2}\,s^{-1}$ [5,6] and <15 μm at low counting rates [7,8]. At the same time the efficiency of neutron detection with MCPs has already been measured to exceed 40% for cold neutrons and ~16% for thermal neutrons for unoptimized structures [9]. Our detailed modeling predicts that efficiency of thermal neutron detection can be better than 60% [10]. The uniqueness of MCPs for neutron detection is their ability to efficiently convert a single neutron into 10^4–10^6 electrons preserving the location of neutron absorption within ~10–15 μm [8,10] as the process of electron amplification happens within a single pore of 6–10 μm in diameter. In this paper we present the results of neutron radiographic measurements of a detector, comprising a combination of neutron sensitive MCPs with the Medpix2 readout, which was successfully used previously in combination with solid-state neutron converter films [2,3] by our colleagues from the Czech Technical University in Prague.

2. Experimental setup

Two sets of radiographic images of test objects were obtained at both thermal (NEUTRA facility) and cold (ICON facility) neutron imaging beamlines of Paul Scherrer Institute (PSI). The NEUTRA beamline provides thermal neutrons with most probable energy of 25 meV, the aspect ratio $L/D = 550$, flux $5.4\times10^6\,n/cm^2/s$. The ICON beamline with cold neutron spectrum peaking at 5 meV has aspect ratio $L/D = 355$, flux $7.8\times10^6\,n/cm^2/s$. Our detector contained ^{10}B-doped microchannel plates developed by Nova Scientific, which were installed ~0.7 mm above Medpix2 sensor. Medipix2 was read out by a Muros electronics allowing frame rates up to 30 frames per second [11]. The Medipix2 sensor [12] has $14\times14\,mm^2$ active area with 256×256 independently operating 14 bit counters, each with ~1 μs dead time, providing

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the opportunity for very high counting rates exceeding $10^8\,cm^{-2}$. In high counting rate mode the spatial resolution of our detector was limited by the 55 μm pixel size of the Medipix2 readout. The detection efficiency of our detector was ~40% for the cold beamline at ICON facility and ~16% for the thermal beamline NEUTRA [9]. We have also tested the high-resolution mode using the charge centroiding technique with the Timepix readout, Section 3.2. The latter provides information on detected charges by a "time over threshold" method [13].

3. Results

A set of test objects was imaged in the proof-of-principle experiments aimed at a preliminary calibration of MCP-Medipix imaging capabilities. The objects were placed next to the input window of the detector. The distance between the active area of the detector and the objects was ~5–6 cm, except for the case of high-resolution test described in Section 3.2. The images were integrated over a period of several minutes. Flat-field correction by the open beam was applied in order to eliminate the beam and detector nonuniformities.

3.1. High counting rate mode

The resolution, detection efficiency and imaging contrast of our detector were tested first with a wrist watch containing some plastic and metal parts. Fig. 1 shows two images obtained at cold and thermal beamlines. The higher contrast of the cold neutron image is due to the higher probability of cold neutrons to interact with object under study due to larger cross-sections in the cold region. The acquisition time was chosen to provide equal statistics for both the measurements. These tests were followed by imaging

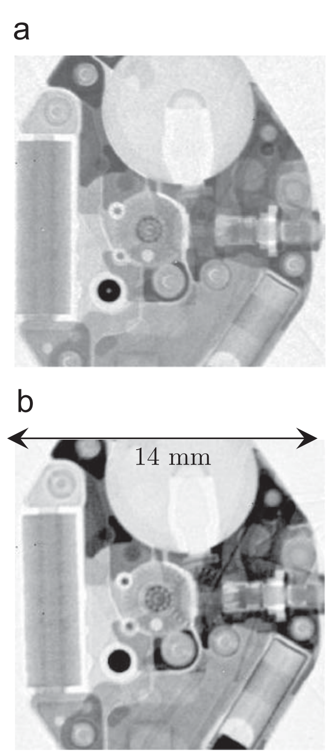

Fig. 1. Neutron radiographic images of a wrist watch obtained with MCP-Medipix2 detector. Image area $14 \times 14\,mm^2$: (a) thermal neutron beamline NEUTRA, acquisition time 15 min and (b) cold neutorn beamline ICON, acquisition time 3 min. The teeth of gear mechanism, core of the coil and small plastic parts are clearly resolved.

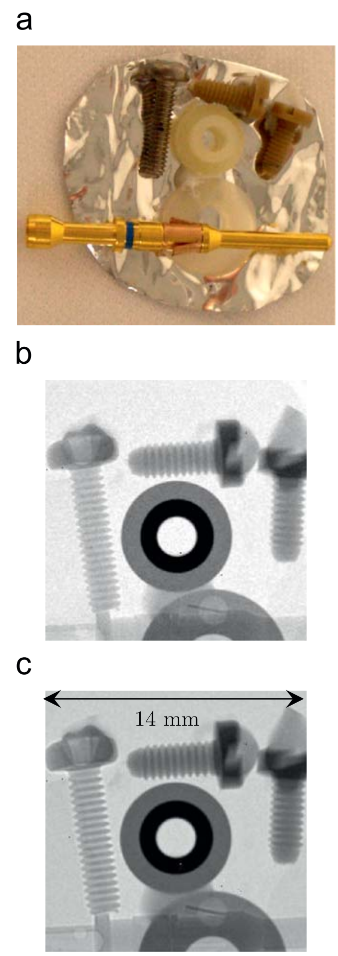

Fig. 2. Photograph (a) and neutron radiographic images of an imaging mask containing M2 PEEK (Polyetheretherketone) screws, M2 stainless screw, nylon washers and a connector pin. The mask was placed on the input window of the detector; (b) thermal neutron beamline NEUTRA, acquisition time 15 min; (c) cold neutron beamline ICON, acquisition time 3 min. Some edge enhancement effect is seen on the image of the stainless screw (left), while plastic objects do not exhibit it.

a mask containing small object of known materials, which was imaged at both beamlines, Fig. 2. The test objects were glued to an aluminum foil by a 1C Hysol epoxy seen at the top of the screw heads and in between two washers. The threads of M2 screws are clearly resolved on these images. Another test object was a bee suspended on a stainless hypodermic needle, Fig. 3. The edges of the stainless needle also exhibit some edge enhancement at the cold neutron beamline. We are planning to investigate that effect in more detail in the future experiments in conjunction with MCP neutron optics capable of neutron collimation at 0.1° levels as well as scatter rejection [14].

3.2. High-resolution mode with event centroiding

In these measurements we used the capability of Timpix readout to measure the charges accumulated by each pixel after each neutron absorption event [13]. The voltage between the MCPs and the Timpix readout was adjusted to provide spreading of the MCP output electron cloud into several pixels. The position of neutron absorption within the microchannel plate was then calculated from those charge values by event centroiding [8], providing each readout frame had no overlaps between the footprints of individual events. The relatively slow serial readout of Muros electronics limited the counting rate of accepted neutron