Nuclear Instruments and Methods in Physics Research A 784 (2015) 486–493

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

High resolution neutron imaging capabilities at BOA beamline at Paul Scherrer Institut

A.S. Tremsin [a,*], M. Morgano [b], T. Panzner [b], E. Lehmann [b], U. Filgers [b], J.V. Vallerga [a], J.B. McPhate [a], O.H.W. Siegmund [a], W.B. Feller [c]

[a] Space Sciences Laboratory, University of California at Berkeley, Berkeley, CA 94720, USA
[b] Paul Scherrer Institut, 5232 Villigen PSI, Switzerland
[c] NOVA Scientific, Inc., 10 Picker Rd., Sturbridge, MA 01566, USA

ARTICLE INFO

Available online 18 September 2014

Keywords:
Neutron imaging
High resolution
Beamline facilities

ABSTRACT

The cold neutron spectrum of the Beamline for neutron Optics and other Applications (BOA) at Paul Scherrer Institut enables high contrast neutron imaging because neutron cross sections for many materials increase with neutron wavelength. However, for many neutron imaging applications, spatial resolution can be as important as contrast. In this paper the neutron transmission imaging capabilities of an MCP/Timepix detector installed at the BOA beamline are presented, demonstrating the possibilities for studying sub-20 μm features in various samples. In addition to conventional neutron radiography and microtomography, the high degree of neutron polarization at the BOA beamline can be very attractive for imaging of magnetic fields, as demonstrated by our measurements. We also show that a collimated cold neutron beamline combined with a high resolution detector can produce image artifacts, (e.g. edge enhancements) due to neutron refraction and scattering. The results of our experiments indicate that the BOA beamline is a valuable addition to neutron imaging facilities, providing improved and sometimes unique capabilities for non-destructive studies with cold neutrons.

1. Introduction

Neutron radiography and microtomography have proven to be very effective non-destructive testing techniques because of the unique ability of neutrons to penetrate materials opaque to X-rays (e.g. various metals) and at the same time interact with light elements such as hydrogen or lithium. The cold spectrum, high intensity, good collimation and low gamma content of modern neutron beamline facilities [1–5] enable imaging of relatively large objects (up to 40 cm) with high spatial resolution due to substantial progress in both beamlines themselves and the detection systems used in the experiments. The resolution of neutron imaging has not yet reached the sub-micrometer levels, as in case of X-rays. A 10 μm neutron radiography or tomography is currently state-of-the-art [6–8] as there are no efficient neutron optics which can be used to enhance the resolution. The ongoing developments of Wolter optics will be a great improvement in neutron imaging if it is successful [9]. Without optics, the field of view of very high (~10 μm) resolution imaging detectors is typically limited to a few centimeters as in case of thin scintillator screens coupled to a CCD or CMOS camera [6], or direct conversion detectors based on Microchannel Plates (MCPs) [7],[8]. At the same time the developments of novel neutron imaging techniques partially compensate the lack of spatial resolution as they can provide unique information in some cases. For example, dark field imaging or grating interferometry [10–12], or imaging of magnetic fields with polarized neutron beams [13,14], extend the contrast of neutron imaging experiments beyond the conventional radiography modes where the contrast is provided by the difference of the attenuation coefficient. The crucial parameters of a neutron beamline facility in such experiments are the intensity of neutron flux, its spectrum, the degree of collimation, gamma content and, in some cases, the degree of polarization. The BOA beamline, which was recently converted from the fundamental physics facility [1] is one of the best beamlines for neutron imaging due to its cold spectrum, high intensity flux, good collimation and low gamma background. A unique feature of the BOA beamline is its high degree of polarization (96.6%) which eliminates the need of an additional beam polarizer for experiments requiring polarized neutrons. In this paper we present a few examples of high resolution neutron imaging with an MCP/Timepix neutron counting detector installed at the BOA beamline, demonstrating the high resolution imaging capabilities of the BOA beamline at Paul Scherrer Institut.

* Corresponding author. Tel.: +1 510 642 4554.
E-mail address: ast@ssl.berkeley.edu (A.S. Tremsin).

http://dx.doi.org/10.1016/j.nima.2014.09.026
0168-9002/

2. Experimental setup

The relatively cold spectrum of the BOA beamline, shown in Fig. 1, allows imaging with high contrast as the attenuation coefficient generally increases with neutron wavelength. The curved neutron guide (24 channel polarizing bender unit) of the BOA beamline eliminates epithermal neutrons and gamma photons while simultaneously polarizing the neutron beam. A neutron counting detector with Microchannel Plates coupled to a 2×2 array of Timepix readouts was used in our experiments [15,16]. The active area of the detector was 28×28 mm^2. The high detection efficiency (exceeding 70% for the BOA spectrum [17,18]), the absence of readout noise of our detector, and a high brightness of the BOA beam [1] allowed acquisition of images within relatively short exposure times. Two acquisition modes of the MCP detector were used in the experiments: event counting which allows high neutron event rates (exceeding 5×10^7 n/cm^2/s) at the native 55 μm pixel resolution of the Timepix readout; or event centroiding mode which enables sub-pixel imaging with a resolution of ~11–15 μm limited by the size of the MCP pores [7,8], but at a reduced event rate. The beam collimation in our experiments was set by a 1 cm or 2 cm pinhole installed at ~6 m distance from the detector, providing beam aspect ratios of 600:1 and 300:1, respectively. The neutrons used in this measurement propagated in air between the beam port and the detector. The objects were placed in front of the detector at ~1–2 cm distance from the active area (except for the magnetic field imaging measurements, where an analyzer had to be placed between the object and a detector). The data acquired by the detector was transferred over a 10 Gb link to a PC computer where it was processed in real time in the case of the event centroiding mode used for the high resolution imaging and subsequently stored on a hard drive. The beam non-uniformity and variation of the detector response over the active area were normalized by an open beam correction – all neutron radiographs of samples were divided by the corresponding open beam images.

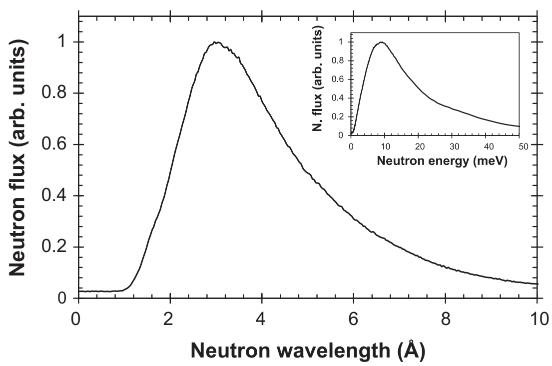

Fig. 1. The spectrum of BOA beamline measured with the MCP detector through Time of Flight technique. A 20 Hz chopper with a 2 mm slit was installed at 5.32 m distance from the detector. The cold spectrum of the beam provides high contrast for neutron imaging.

For the imaging of a magnetic field with polarized neutrons, a reflective-type analyzer [19] was installed in front of the detector, which increased the distance between the active area and the sample to ~20 cm leading to image blurring on the scale of

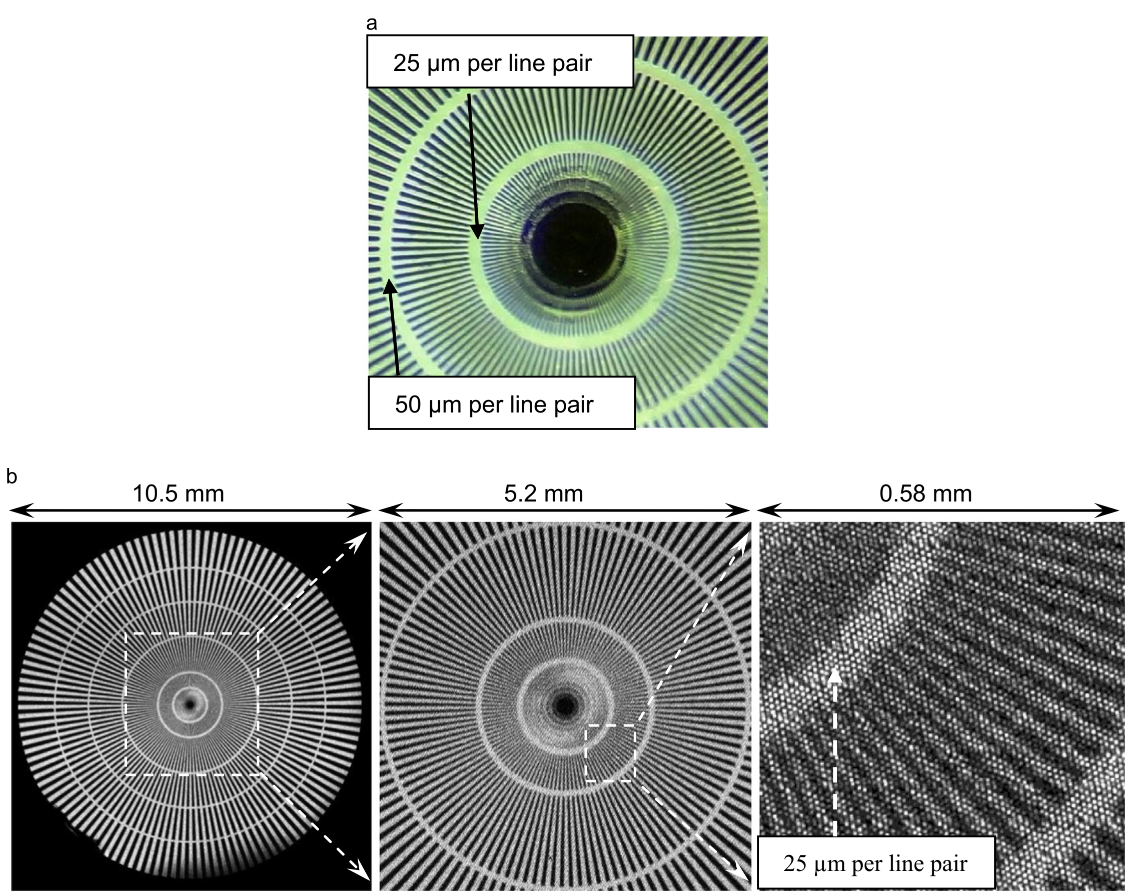

Fig. 2. (a) The optical microscope image of the center section (2.5 mm wide) of the Gd test target used for the calibration of spatial resolution. (b) The neutron transmission images obtained with the test target installed ~12 mm from the active area of the detector. The pores of the Microchannel Plate are seen in a hexagonal packing on the right image. The distance between the pores (~11 μm center-to-center) determines the ultimate spatial resolution of our experimental setup.