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X-ray tests of a microchannel plate detector and amorphous silicon pixel array readout for neutron radiography

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Abstract

High-performance large area imaging detectors for fast neutrons in the 5–14 MeV energy range do not exist at present. The aim of this project is to combine microchannel plates or MCPs (or similar electron multiplication structures) traditionally used in image intensifiers and X-ray detectors with amorphous silicon (a-Si) pixel arrays to produce a composite converter and intensifier position sensitive imaging system. This detector will provide an order of magnitude improvement in image resolution when compared with current millimetre resolution limits obtained using phosphor or scintillator-based hydrogen rich converters. In this study we present the results of the initial experimental evaluation of the prototype system. This study was carried out using a medical X-ray source for the proof of concept tests, the next phase will involve neutron imaging tests. The hybrid detector described in this study is a unique development and paves the way for large area position sensitive detectors consisting of MCP or microsphere plate detectors and a-Si or polysilicon pixel arrays. Applications include neutron and X-ray imaging for terrestrial applications. The technology could be extended to space instrumentation for X-ray astronomy.

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1. Introduction

Fast neutron resonance radiography provides an element sensitive non-destructive inspection method for contraband and explosives detection, non-proliferation and industrial applications [1–4]. The resonances in the cross-sections of specific elements can be probed by tuning the neutron energy to coincide with the resonance of interest (see Fig. 1). The interaction of the neutrons (within the resonance energy range) with the element of interest experience a greater degree of scatter and absorption in comparison to those interacting with the medium surrounding the sample or feature, thus enhancing the contrast of this feature in the resulting image. This energy selection process requires a monoenergetic source of neutrons produced using a particle accelerator and suitable target. A great deal of work has been carried out using reactions such as $^{7}Li(p,n)^{7}Be$, $^{9}Be(d,n)^{10}B$ and $D(d,n)^{3}He$ [5,6]. Here the energy range of the source is chosen to coincide with a resonance or an energy region that favours the detection of a particular element in the specimen. The total number of neutrons that will interact depends on the width of the resonance (or region). An example of the most useful regions for resonance imaging is the broad, complex resonance between 7.3 and 8.2 MeV in the cross-section of

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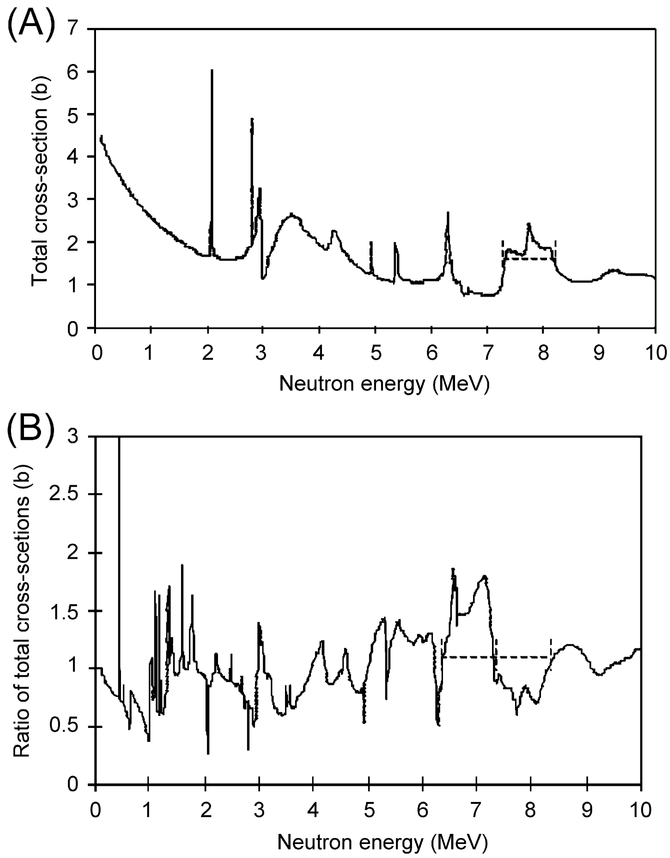

Fig. 1. (A) Total neutron cross-section for carbon. Note the broad resonance in the region between 7.3 and 8.2 MeV. (B) Ratio of total neutron cross-sections of nitrogen and carbon as a function of neutron energy. The dotted line defines two regions where the contrast ratio changes by a factor of 1.9, when the neutron energy is changed by 1 MeV.

carbon. This resonance is almost 1 MeV wide with an average height of about 1.8 b over this region (see Fig. 1). Adjacent to this is a region between 6.5 and 7.3 MeV where the average cross-section is about 0.9 b. Thus by changing the neutron energy by 1 MeV, images with a contrast ratio of 2:1 can be obtained for carbon in the presence of other elements such as nitrogen or oxygen.

The interaction of neutrons with the nuclei of atoms rather than the electrons implies a reduced interaction probability but enhanced penetrability, which makes this non-intrusive inspection method suitable for imaging large structures of the order of 1 m^3 in size. Larger or smaller structures can be probed depending on the neutron energy used.

Fast neutrons are detected indirectly via a proton recoil reaction in a hydrogen rich converter doped with a scintillator or a phosphor or via neutron capture. The former produces charged particles (protons), electrons and light photons [5], which can be used to produce the radiographs; the latter produces charged particles and electrons which can also be used to generate images [7,8].

Although the primary neutron energy range of interest lies between 5 and 14 MeV [9,10], a medical X-ray source was used in the tests carried out for this study as part of a proof of concept experimental trial of the system. The next phase of the project will involve neutron testing at a suitable facility.

2. The detection problem

In order to detect small millimetre sized features in large structures conventional scintillator-based detector systems can adopt two configurations: the first consists of a continuous converter and scintillator (or phosphor) structure where the resolution is limited by the thickness of the converter; the second is a fibre-based converter and scintillator structure that has a fibre pitch of the order of the required resolution limit. Either converter–scintillator structure can be read out by single or multiple charge coupled device or CCD-based position sensitive sensors in a variety of configurations including image intensifiers or fibre optic tapers [5]. Alternatively, large area detectors such as amorphous silicon (a-Si) pixel arrays [5] can be used. These arrays are commercially available in formats as large as 40 × 40 cm. The scintillating-fibre converter–scintillator option can be made thicker (50–100 cm) to improve detection efficiency (from 2% for a 2 mm thick conventional slab scintillator to more than 50%) but at the same time increasing low-energy neutron scatter and light spreading which contribute to reducing the resolution and contrast of the features of interest in the image [5,11–13]. Using a CCD-based detector system to image large scintillator structures that are tens of square centimetres in size requires a significant demagnification ratio and hence results in significant light loss, where fractions of a photon may be detected by the CCD per incident neutron [5,14]. This results in the stochastic noise limit of detection being imposed by the photon interactions with the CCD rather than the neutron interactions with the scintillator [15]. Image intensifiers are often used to speed up the detection process and increase the photon signal at the CCD. Large area, more radiation tolerant detectors such as a-Si arrays have been used in the past to collect more of the light from scintillator-based fast neutron converters; however, the high readout noise of these systems (4000–5000 electrons rms) has always made them a less attractive option [5,16,17]. This readout noise has been reduced five-fold to less than 1000 electrons rms [18] but the noise levels are still high for low-light applications that rely on low image acquisition times of the order of less than 1 s.

A CCD-based detector is best suited to a dynamic imaging system for objects in motion given that CCDs can be operated in time delay integration, where the charge transfer rate in the CCD is synchronised with the speed of motion of the object of interest. This can only be achieved with a-Si flat panel detectors if the detector moves at the same speed as the object. In this case a multiple detector system is required to allow for the few second readout times associated with these flat panel detectors.