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Design of a prototype microchannel plate detector with cooled amorphous silicon 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 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 the detection of fast neutrons is based on neutron capture in silicon rather than proton recoil in hydrogen-rich converters. This will reduce the effect that light spreading has on image resolution when using conventional phosphor-based converters. The threshold in the silicon capture cross-section will reduce the effect of neutron scatter on the detectability of small features in fast neutron radiographs. In this study we highlight the prototype detector design, present its main advantages and the current status of the detector build phase.

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1. Introduction

Fast neutron resonance radiography provides an element-sensitive non-destructive inspection

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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 with the element of interest experiences a greater degree of scatter and absorption in comparison to those interacting with the medium surrounding the 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 carbon. This resonance is almost 1 MeV wide with an average height of about 1.8 barns 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 barns. Thus by changing the neutron energy by 1 MeV, images with a contrast ratio of 2:1 can be obtained for carbon in

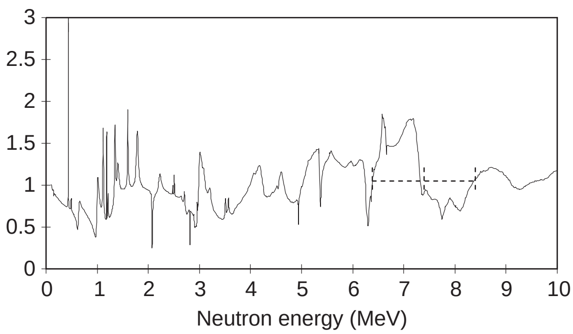

Fig. 1. Ratio of the total neutron cross-sections of nitrogen and carbon as a function of neutron energy. The dotted line defines two regions where the contrast ratio changes by a factor of 1.9 when the neutron energy is changed by 1 MeV [2].

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 their composition and 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].

The primary energy range of interest for this study is the 5–14 MeV energy range [9,10].

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 cm × 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