Nuclear Instruments and Methods in Physics Research A 652 (2011) 25–28

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

Microchannel plate special nuclear materials sensor

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A R T I C L E I N F O

Available online 5 February 2011

Keywords:
Neutron detection
Microchannel plate
Special nuclear materials

A B S T R A C T

Nova Scientific Inc., is developing for the Domestic Nuclear Detection Office (DNDO SBIR #HSHQDC-08-C-00190), a solid-state, high-efficiency neutron detection alternative to ^{3}He gas tubes, using neutron-sensitive microchannel plates (MCPs) containing ^{10}B and/or Gd. This work directly supports DNDO development of technologies designed to detect and interdict nuclear weapons or illicit nuclear materials. Neutron-sensitized MCPs have been shown theoretically and more recently experimentally, to be capable of thermal neutron detection efficiencies equivalent to ^{3}He gas tubes. Although typical solid-state neutron detectors typically have an intrinsic gamma sensitivity orders of magnitude higher than that of ^{3}He gas detectors, we dramatically reduce gamma sensitivity by combining a novel electronic coincidence rejection scheme, employing a separate but enveloping gamma scintillator. This has already resulted in a measured gamma rejection ratio equal to a small ^{3}He tube, without in principle sacrificing neutron detection efficiency. Ongoing improvements to the MCP performance as well as the coincidence counting geometry will be described. Repeated testing and validation with a ^{252}Cf source has been underway throughout the Phase II SBIR program, with ongoing comparisons to a small commercial ^{3}He gas tube. Finally, further component improvements and efforts toward integration maturity are underway, with the goal of establishing functional prototypes for SNM field testing.

1. Introduction

Neutron-sensitive MCPs have been shown theoretically [1] and experimentally, to be capable of neutron sensitivity levels comparable to small ^{3}He gas tubes, where ^{10}B and/or Gd is incorporated into the MCP structure, currently glass-based (Figs. 1–3). Together with an effective gamma ray rejection approach based on coincidence signals obtained from the MCP as well as an external gamma scintillator [2], this represents a plausible 'solid-state' replacement technology for ^{3}He neutron detection schemes. Recent progress in fabricating MCPs with high levels of ^{10}B and/or Gd [3–6], has already resulted in demonstration of neutron detection efficiency and gamma ray insensitivity levels comparable to small ^{3}He gas tubes, respectively, $\sim$54% and $\sim 10^{-5}$ using a moderated ^{252}Cf source. Although solid-state detectors including MCPs typically have an inherent gamma sensitivity orders of magnitude greater than ^{3}He, we avoid this using an ancillary coincidence rejection scheme exploiting the ultrafast nature of MCP output pulses ($\sim$1 ns), as well as the prompt gamma rays emitted by ^{10}B and Gd. A series of test runs using ^{252}Cf as an SNM surrogate, and comparing with a small ^{3}He tube, have been carried out during the past year. Sensor Sciences has been teaming with Nova Scientific, in both testing and in component improvements and efforts towards integration maturity. Current prototype form factors will be compatible with backpack or hand-held neutron detector operation. Also under separate IR&D development, are very large format MCPs ultimately capable of tiling into larger arrays for wider area coverage and enhanced signal-to-noise ratio.

2. Gamma rejection methods

Solid-state neutron detector approaches tend to be plagued with higher gamma ray absorption and thus substantial gamma sensitivity as compared with gaseous ^{3}He tubes. Earlier seen as a "show-stopper" of the MCP approach for SNM detection – with an inherent $\sim$1–2% gamma detection efficiency – this problem has been effectively solved using the 'first generation' solution of an ultrafast gamma coincidence technique, where an external gamma ray detector is employed (Fig. 4). Ultimately, a 'second generation' all-electronic method is also under development, which does not require a separate gamma detector.

The current coincidence method assumes that a valid neutron event has occurred when both an MCP output pulse and a surrounding gamma scintillator pulse, are registered simultaneously

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doi:10.1016/j.nima.2011.01.157

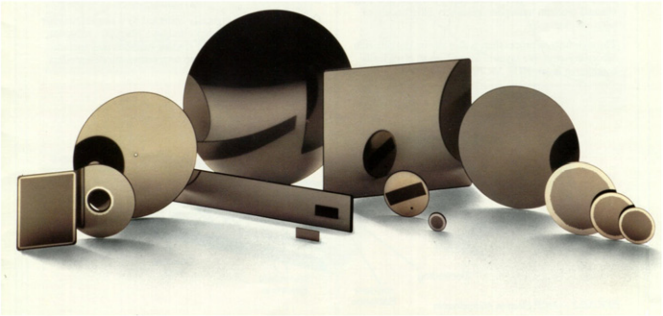

Fig. 1. Examples of MCP formats. The large rectangular plate is 9 cm × 11 cm. Development is underway on much larger neutron-sensitive MCPs, even approaching 40 cm × 40 cm (courtesy Photonis-USA).

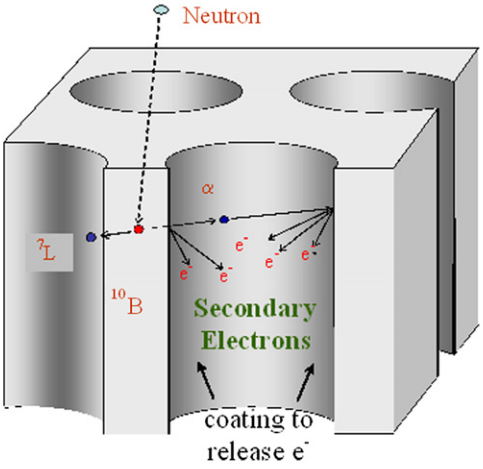

Fig. 2. Neutron detection process within MCP interchannel web. ^{10}B simultaneously releases ^{4}He and ^{7}Li nuclei in opposite directions; Gd releases a single conversion electron. These primary reaction products escape into the channel to create a secondary electron avalanche.

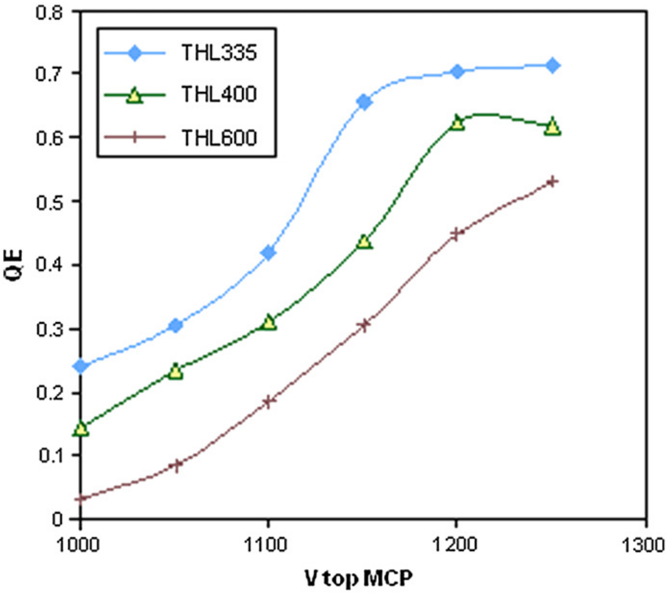

Fig. 3. Graph of MCP neutron detection efficiency (~5 meV neutrons, ICON beamline, Paul Scherrer Institute), at different threshold settings for Medipix/Timepix readout [3]. Somewhat lower efficiencies for moderated ^{252}Cf neutron source at 2 m, was measured at ~54% (not shown). Further MCP processing improvements should increase neutron efficiency levels even further.

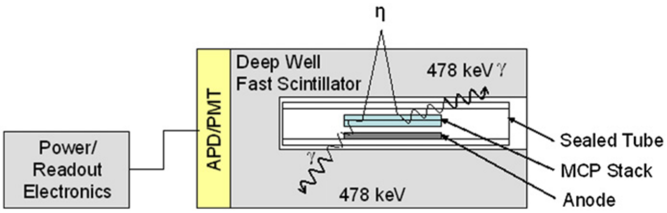

Fig. 4. Coincidence method used for gamma rejection: MCP and scintillator pulses must fall within an ultrafast ~10 ns timing window to qualify as valid neutron events.

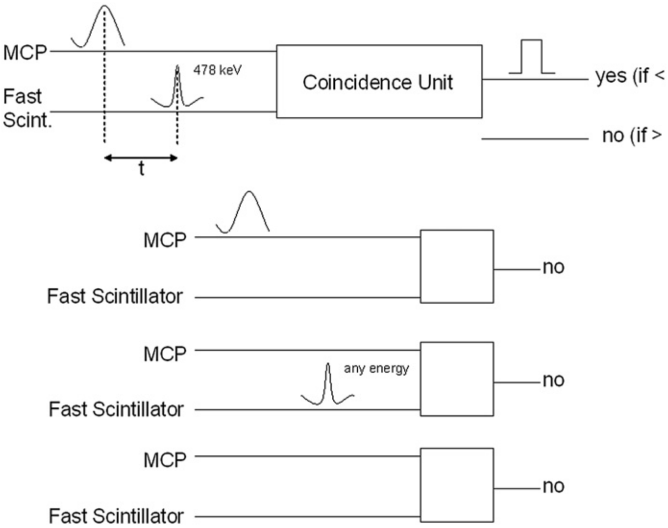

Fig. 5. Logic diagram of MCP coincidence method. Valid neutron events require < 10 ns separation between pulses in both MCP and gamma scintillator.

inside an ultrafast ~10 ns timing window (Fig. 5). For ^{10}B reactions with neutrons, a single 478 keV gamma ray is emitted 93% of the time, and for Gd, a spectrum of gamma lines is emitted for each neutron interaction. External random gamma rays, even up to MHz count rates, will have an extremely low probability of being detected in both detectors within the ultrafast timing window. Compton gammas of course will also be detected in this regard, and add to the continuum in the measured coincidence spectrum. However, use of a peak search algorithm to extract the enhanced peaks at 182 and 199 keV (Gd lines) as well as at 478 keV (^{10}B line), can allow quick identification of valid neutron events (Fig. 6). Neutron flux levels down to the sea-level cosmic ray ~4 GeV muon background (~.03 cm^{-2} s^{-1}, or "1 muon/cm^2/min") are in principle detectable. Measured levels of gamma rejection with sealed MCP detectors were found comparable to a 4 in. LND ^{3}He tube (1×10^{-5} vs. 2×10^{-5}). In the experiment, 4π NaI(Tl) scintillator coverage surrounding the MCP sealed tube (Fig. 8) was used in conjunction with ~30 ns anticoincidence veto.

3. Experimental setup

For the current Phase II SBIR program nearing completion (Q4'10), demonstration of the effectiveness of Nova's neutron-sensitive MCPs as compared with small ^{3}He detectors was accomplished using components which are still at an intermediate development stage—for example, a gamma scintillator crystal coupled to a commercial PMT, and NIM module electronics. In further Phase III refinement oriented towards potential commercialization,