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Plastic microchannel plates with nano-engineered films

D.R. Beaulieu, D. Gorelikov, H. Klotzsch, P. de Rouffignac, K. Saadatmand, K. Stenton, N. Sullivan, A.S. Tremsin *

Arradiance, Inc., 142 North Road, Sudbury, MA 01776, USA

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ABSTRACT

Since their invention decades ago, microchannel plate (MCP) performance has been defined by the properties of the substrate material, which defines both mechanical structure and electron amplification within the device. Specific glass compositions have been developed to provide the conduction and electron emission layer at the surface of the pores. Alternative technologies using quartz and alumina substrates have not matured enough to become a viable substitute to lead–glass-based MCPs.

In this paper we report on the development of new MCP devices from plastic substrates. The plastic substrate serves only as a mechanical structure: the electron amplification properties are provided by nano-engineered conduction and emission layers. The film deposition procedures were optimized for low temperatures compatible with the polymethyl methacrylate (PMMA) plastic chosen for this work.

The gain of the PMMA MCP with aspect ratio of ~27:1 and pore diameter ~50 μm spaced on 70 μm hexagonal grid exceeded 200 at 470 V accelerating bias.

Development of hydrogen-rich plastic MCPs should enable direct detection of fast neutrons through proton recoil reaction. Recoil protons with escape ranges comparable to the wall thickness will initiate an electron avalanche upon collision with the pore walls. The electron signal is then amplified within the MCP pore allowing high spatial and temporal resolution for each detected fast neutron. We expect to achieve ~1% detection efficiency for 1–15 MeV neutrons with temporal resolution <10 ns, spatial resolution of <200 μm and very low background noise.

1. Introduction

The development of nano-engineered conduction and emission films applied over non-lead glass microchannel plates [1,2] has enabled the complete separation of MCP electron amplifying characteristics from the mechanical properties of the substrate. The specific properties of MCP performance can be optimized individually for a broad range of substrate materials reducing the MCP manufacturing complexity. In this paper we describe the performance of a novel microchannel plate made on a polymethyl methacrylate (PMMA) plastic substrate which does not allow processing temperatures in excess of 130–140 °C. A graded temperature atomic layer deposition (ALD) process was developed for the low temperature deposition of the engineered conduction and emission films [1]. The PMMA substrate was chosen for the possibility to perform direct detection of fast neutrons through the neutron–proton recoil in the bulk of hydrogen-rich PMMA substrate. Fast neutron detection with high timing and spatial resolution and relatively high detection efficiency can be useful in such applications as special nuclear materials detection [3,4], fast neutron radiography [5], luggage screening with neutron time-of-flight spectroscopy [6,7] and others.

2. Experimental setup and results

A 1.35 mm thick PMMA substrate provided by the Paradigm Optics, Inc was used to produce novel plastic MCP with ~50 μm pores (27:1 aspect ratio) packed into a hexagonal pattern with relatively large distortions compared to standard circular-pore MCPs, Fig. 1. The wall thickness was chosen to be ~20 μm to match the escape range of recoil protons in the PMMA material in order to optimize the neutron detection efficiency. The resistance of the fully functional plastic MCP was found to be quite stable in the full range of accelerating bias (Fig. 2) and in the future it can be optimized to reach lower values if necessary. The gain of this MCP was first measured in the current amplification mode. A full-field electron illumination with calibrated input current was used in this measurement. A typical exponential gain curve was

* Corresponding author. Tel./fax: +1 800 659 2970.
E-mail address: atremsin@arradiance.com (A.S. Tremsin).

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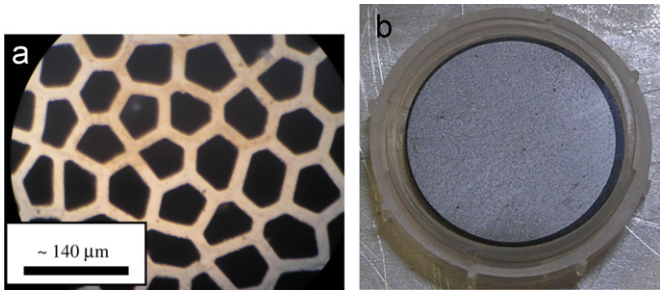

Fig. 1. (a) Optical microscope image of the polymethyl methacrylate (PMMA) plastic MCP substrate with ~50 μm pores and ~70 μm center-to-center spacing. (b) The photograph of a 25 mm diameter functionalized plastic microchannel plate with nano-engineered conductive and emissive films deposited by atomic layer deposition (ALD) methods. Metal electrodes were deposited over the top and bottom surfaces. The MCP thickness is 1.35 mm (aspect ratio L/D=27:1).

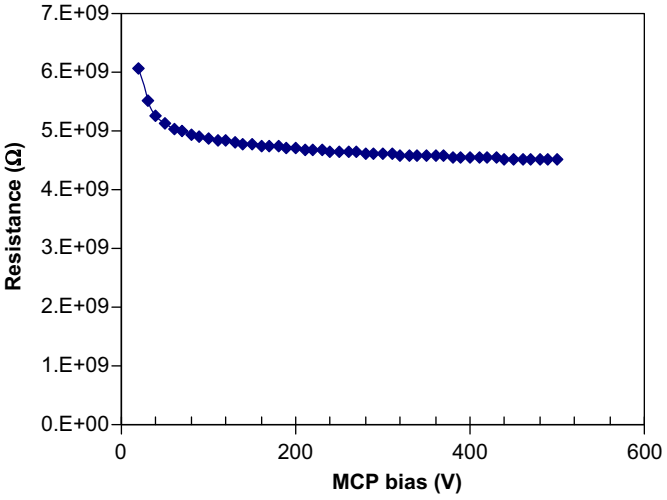

Fig. 2. Measured resistance of the ALD-functionalized plastic MCP as a function of applied bias. Lower resistance values can be achieved if necessary to allow operation at moderate to high counting rates.

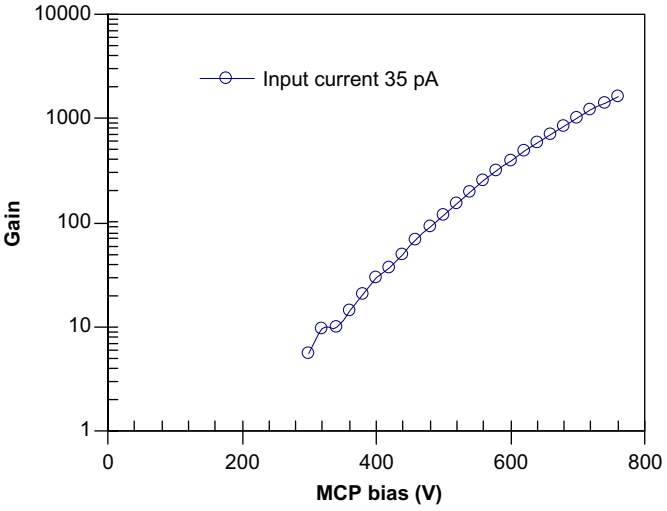

Fig. 3. PMMA MCP gain as a function of applied bias measured in a current amplification mode under full-field electron illumination. 35 pA input current was spread over the entire MCP active area of ~20 mm containing ~7.4e4 pores (~3000 input electrons/pore/s).

observed with the gain reaching value of 10^3 at 700 V accelerating bias, Fig. 3.

The uniformity of electron amplification in plastic MCP was qualitatively tested with a phosphor screen placed ~2 mm from the output face of MCP. The image shown in Fig. 4a indicates that there are no hotspots or large-scale non-uniformity in the plastic MCP, despite the non-ideal geometry of the original substrate. A more detailed high spatial resolution study will be performed in the near future.

Photon counting capabilities of the same plastic MCP were tested in the detector configuration shown in Fig. 4b. UV photons produced photoelectrons at the input surface of the plastic MCP, which then were amplified by that plate operating at 600 V followed by a commercial 40:1 glass MCP with 10 μm pores on 12 μm centers operating at 900 V. Single event pulse height distributions were recorded for both UV photoelectrons and the dark noise counts, Fig. 5. The latter did not exceed 1 event/cm^2/s, while the count rate of the UV response was very similar to that of a commercial glass MCP. Both pulse height distributions (PHDs) were quasi-exponential due to the large gap between the MCPs which resulted in a non-saturated mode of operation. PHDs

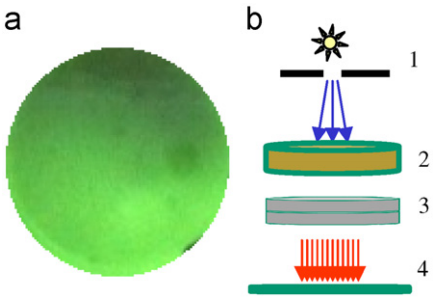

Fig. 4. (a) Photograph of the phosphor screen with detector under UV illumination. No noise spots or artifacts from PMMA MCP are observed. The defects on the image are due to the phosphor internal features. (b) Schematic diagram of the pulse counting detector configuration (not to scale). 1—UV light source with an aperture, 2—PMMA MCP, 3—standard lead glass MCP (or a chevron stack) used for post-amplification of electron signal produced by the PMMA MCP and 4—phosphor screen/charge collecting anode.

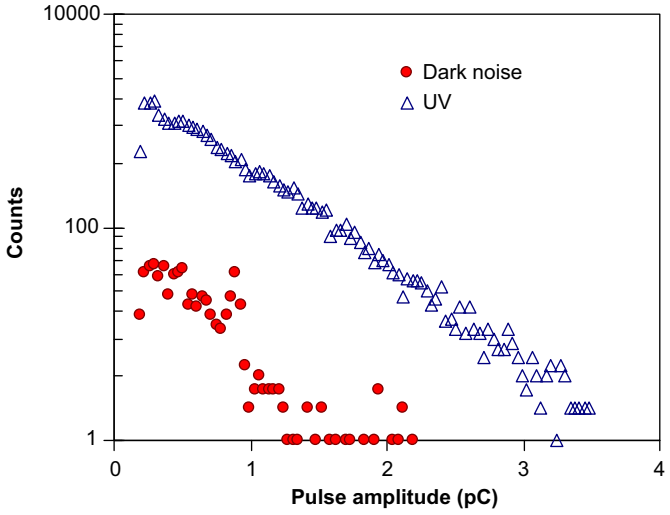

Fig. 5. Pulse height distributions obtained with the detector of Fig. 4 under UV illumination (triangles) and dark counts (circles). Single standard lead–glass MCP used for event amplification (L/D=~40:1, V_{MCP}~900 V). Dark noise count rate of entire stack was ~1 event/cm^2. PMMA MCP bias 600 V. Despite the irregularities in the plastic MCP substrate there were no hotspots or field emission observed.

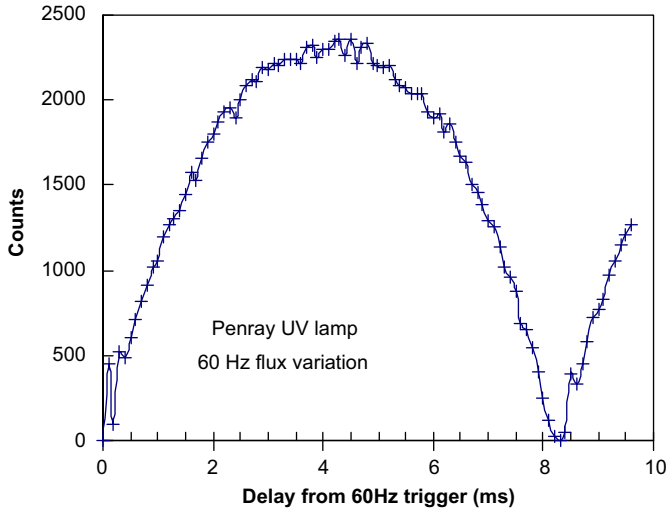

Fig. 6. Timing histogram of events detected with 60 Hz-modulated UV illumination. A mercury vapor penray lamp provided full-field illumination of the detector. Switching power supply modulated the intensity of the lamp to 8.33 ms periodic variation. The histogram of time differences between detected photon events and the 60 Hz trigger demonstrates the event counting and timing resolution of plastic MCP. Note the absence of the pedestal at the timing histogram confirming the low dark noise operation.

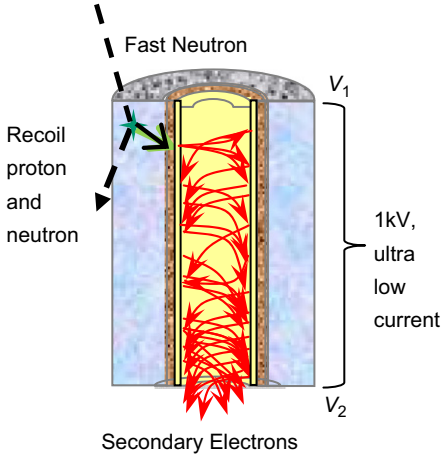

Fig. 7. Principle of fast neutron detection in hydrogen-rich plastic MCP. The recoil proton releases secondary electrons upon collision with the pore walls, which are coated with conduction and emission ALD films. The rest of detection process is similar to photon detection.

shown in Fig. 5 indicate that a very accurate event counting can be performed with the plastic MCP, leading to the possibility to use it for fast neutron event counting with high spatial (<100 μm) and temporal (<10 ns) resolution.

The ultimate timing resolution of plastic MCP (<10 ns) was not tested in the first experiments reported here, but a crude timing resolution on the scale of 10 μs was verified by measuring the 60 Hz intensity variation of the UV lamp. In this experiment the timing of individual photon events was measured relative to the 60 Hz line trigger. The histogram of the measured delays is shown in Fig. 6, clearly demonstrating that the number of photons per unit time bin varies with 120 Hz frequency (as expected from the intensity variation of the 60 Hz AC powered UV lamp). The ns-scale timing resolution tests will be reported elsewhere.

3. Conclusion

The functional characteristics of a novel, hydrogen-rich, plastic microchannel plate proved to be comparable to that of a commercial lead–glass MCP: uniform gain, sensitivity to UV photons across the active area, capability to count single events and low dark noise count rate. The resistive and secondary electron emissive films were conformally deposited over the low melting temperature plastic MCP substrate. We believe that, with some process development, the deposition technique is scalable to large format MCPs. One of the possible applications of these novel plastic MCPs is the direct detection of fast neutrons. Fig. 7 explains the principle of fast neutron detection within the hydrogen-rich MCP bulk. The detection efficiency of this device is predominantly determined by the probability of proton recoil within the bulk. Detection efficiency exceeding 1% for an MCP with $L/D=100{:}1$ (5 mm thick with 50 μm pores and 20 μm walls) has been experimentally verified [4]. These plastic MCPs may become a very attractive alternative in special nuclear material monitoring applications as well as in the fast neutron radiography and tomography [5] enabling non-destructive testing of thick samples due to high penetration depth of fast neutrons.

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