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Atomic layer deposited borosilicate glass microchannel plates for large area event counting detectors

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ABSTRACT

Borosilicate glass micro-capillary array substrates with 20 μm and 40 μm pores have been deposited with resistive, and secondary electron emissive, layers by atomic layer deposition to produce functional microchannel plates. Device formats of 32.7 mm and 20 cm square have been fabricated and tested in analog and photon counting modes. The tests show amplification, imaging, background rate, pulse shape and lifetime characteristics that are comparable to standard glass microchannel plates. Large area microchannel plates of this type facilitate the construction of 20 cm format sealed tube sensors with strip-line readouts that are being developed for Cherenkov light detection. Complementary work has resulted in Na_2KSb bialkali photocathodes with peak quantum efficiency of 25% being made on borosilicate glass. Additionally GaN (Mg) opaque photocathodes have been successfully made on borosilicate microchannel plates.

1. Introduction

As part of a collaborative program the University of California, Berkeley, the Argonne National Laboratory (ANL), the University of Chicago and other University and Industrial partners, are developing a 20 cm square sealed tube microchannel plate (MCP) detector [1]. Potential applications, including detection of Cherenkov light, require imaging, and good quantum efficiency and timing characteristics. One significant challenge is implementation of large area MCPs with low cost and good functionality. To address this we have been collaborating with INCOM Inc. to make MCPs using borosilicate glass micro-capillary array substrates [1]. Unlike conventional MCPs, the resistive and photo-emissive surfaces of the MCP are sequentially applied by atomic layer deposition (ALD) [2]. Progress in development of these devices has been rapid, with good overall results.

The conceptual design for a large area sealed tube assembly is shown in Fig. 1. A borosilicate Schott Borofloat 33 entrance window transmits incoming photons (>300 nm) and semi-transparent proximity focused (0.5 mm gap) bialkali photocathode converts photons to photoelectrons. A pair of MCPs (gain $\sim 3\times10^6$) amplifies the signal, which is then detected on a strip-line readout anode. The latter will give modest spatial resolution and should provide timing accuracy of a few picoseconds [1]. The Berkeley detector design (Fig. 1) uses standard brazing techniques with an alumina ceramic tube body, hot indium seal well and strip-line anode substrate (the Argonne National Laboratory design has a glass envelope [1]). All connections to internal parts are made using hermetically sealed brazed pins through the anode substrate and we have incorporated non-evaporable getters inside the tube to maintain high vacuum. Given the large size of the detector there are "X" shaped ceramic spacers to maintain the internal spacing ($\sim$0.5 mm between the MCPs, and $\sim$6 mm between the MCPs and anode) of components and to reduce the deformation of the window and anode under atmospheric pressure.

2. Borosilicate microchannel plate design

INCOM, Inc. has constructed MCP substrates with 40 μm pores (65% and 83% open area ratio, 60:1 channel length/diameter (L/D)) and 20 μm pores (65% open area ratio, 60:1 L/D) using borosilicate glass micro-capillary arrays. Beginning with hollow tubes, the MCP substrates are made by a furnace drawing/stacking/fusing/slicing/and polishing process. Both the 32.7 mm round and 20 cm square substrates (Fig. 2) have 8° pore bias angle. The quality of substrates is now quite good, with no "triple point" stacking voids and minimal blocked pores [3]. The hexagonal multi-fiber boundaries are still seen (Fig. 2) due to the

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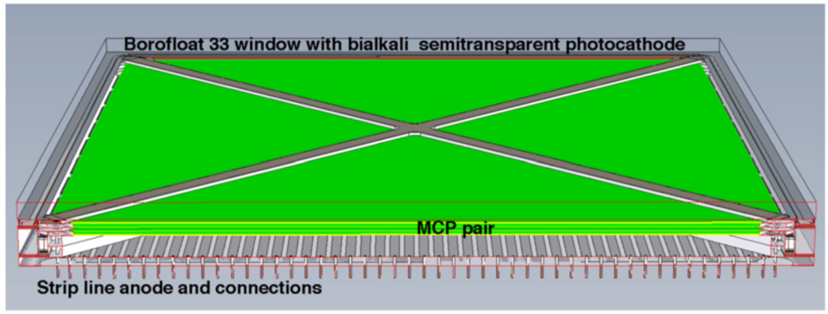

Fig. 1. Cut-away section of a model for a 20 cm sealed tube detector. The entrance window is borosilicate with a semi-transparent bialkali photocathode on the inner surface. Photoelectrons emitted by the photocathode are multiplied by a borosilicate substrate MCP pair that are functionalized using atomic layer deposition. The resulting electron clouds are then deposited onto a strip-line anode for position and arrival time determination.

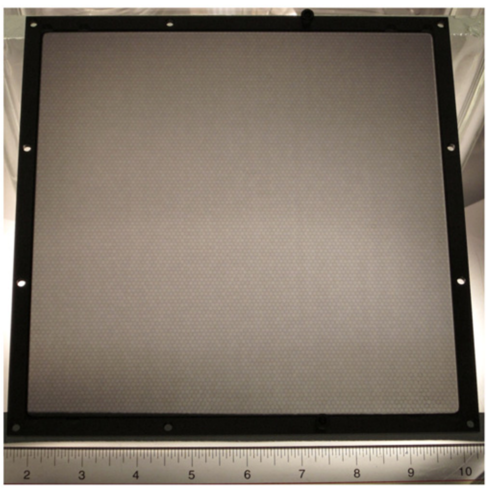

Fig. 2. Photograph of a 20 cm × 20 cm MCP made using ALD treatment of a borosilicate glass micro-capillary array. 20 μm pores, L/D = 60:1, pore bias 8°. The multifiber hexagonal boundaries are visible in this backlit image.

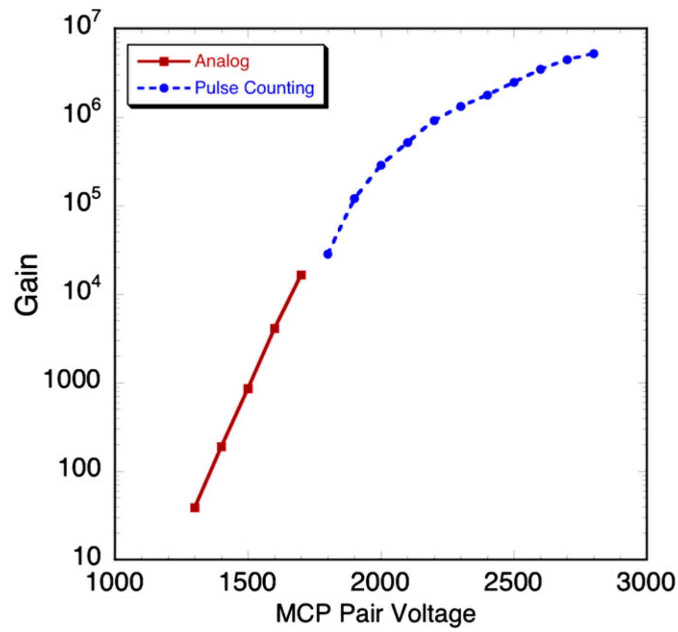

Fig. 3. Gain/voltage curve covering both photon counting and analog operation regimes for a pair of back to back 20 μm pore ALD coated borosilicate MCPs, L/D = 60:1, pore bias 8°, 185 nm illumination.

deformation of a single row of pores at the interface, much like those seen in large area conventional glass MCPs made by ram fusion. Atomic layer deposition of resistive layers and secondary electron emissive layers on the surfaces of the substrates has been accomplished on 32.7 mm substrates by Arradiance, Inc. and at ANL. ANL has also done the ALD processes to produce 20 cm MCPs. The MCP resistances achieved cover a wide range from < 10 MΩ to > 500 MΩ accommodating all values seen for conventional glass MCPs.

3. Borosilicate microchannel plate tests

Detectors with either phosphor screen or cross delay line photon counting readouts have facilitated evaluations of borosilicate ALD MCPs. A significant number (> 20) of 32.7 mm MCPs have been tested at this point and the results presented are representative of this data set. The gain (Fig. 3) for a back-to-back MCP pair shows similar characteristics to conventional MCPs [4] with evidence of gain saturation above 5×10^5 gain. The gain saturation is demonstrably seen by the achievement of peaked pulse amplitude distributions (Fig. 4), and is within expectations for MCP pairs [4]. Higher gain ($> 3 \times 10^7$) has also been achieved when using a biased gap (0.7 mm, 300 V) between the two MCPs. Initial tests with a 20 cm square, 20 μm pore single MCP shows a gain–voltage curve, and current–voltage characteristic, that is essentially the same as the 32.7 mm test article MCPs.

Initial imaging tests were done using single MCPs with a phosphor screen readout and UV illumination (185 nm). The images (Fig. 5) show a uniform overall response with sharply defined MCP multifiber boundaries, and a small number of dark spot defects. This is considerably improved over prior results [3] where the substrates had a considerably larger incidence of defects. Images with pairs of MCPs and the cross delay line readout detector (Fig. 6) show two sets of multifiber patterns, a strong modulation from the top MCP, and a fainter modulation due to the bottom MCP. From the photon gain data we determine that in both cases the multifiber boundaries show lower gain than the surrounding areas, as might be expected from the pore crushing that occurs at these locations. The bright edge effect seen is due to optical and electronic reflections from the MCP mounting hardware. However, the overall response uniformity is reasonable ($\pm 10\%$), with small variations caused by slight variations in the pore size.

The background rate for the newest MCPs is quite uniform (Fig. 7), and less than 0.1 event $cm^{-2}\,s^{-1}$. This is less than conventional MCPs [4], and is expected since the radioactive emission from alkali metal isotopes is significantly reduced for borosilicate glass compositions compared with normal MCP lead glass. Measurements of MCP pulse shapes show Gaussian profiles with widths of the order 1 ns for a 20 μm pore MCP pair.