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Application of atomic layer deposited microchannel plates to imaging photodetectors with high time resolution

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ABSTRACT

Novel microchannel plates have been constructed using borosilicate glass micro-capillary array substrates with 20 μm and 10 μm pores and coated with resistive, and secondary electron emissive, layers by atomic layer deposition. Microchannel plates in 33 mm, 50 mm and 20 cm square formats have been made and tested. Although their amplification, imaging, and timing properties are comparable to standard glass microchannel plates, the background rates and lifetime characteristics are considerably improved. Sealed tube detectors based on the Planacon tube, and a 25 mm cross delay line readout tube with a GaN(Mg) opaque photocathode deposited on borosilicate microchannel plates have been fabricated. Considerable progress has also been made with 20 cm microchannel plates for a 20 cm format sealed tube sensor with strip-line readout that is being developed for Cherenkov light detection.

1. Introduction

Atomic layer deposited microchannel plates with borosilicate glass micro-capillary array substrates [1] are being developed for a number of applications. Although their visual appearance is much like conventional MCPs the details of their construction are not the same. The substrates used are made with hollow borosilicate tubes by a furnace drawing / hexagonal multifiber stacking / fusing / slicing / and polishing process. Incom, Inc. has constructed MCP substrates with 20 μm pores and 10 μm pores from 65% up to 83% open area ratio, and 60:1 up to 80:1 channel length/diameter (L/D) ratio. Substrates from 32.7 mm round and up to 20 cm square have been made, typically with 8 degree pore bias angle. The hexagonal multi-fiber boundaries, as seen in conventional glass MCPs, due to deformation of a single row of pores at the multifiber interface, are still visible but significantly reduced from early development devices. Subsequently, Argonne National Laboratory (ANL) has applied resistive and photo-emissive coatings (Al_2O_3 or MgO) by atomic layer deposition (ALD) [2] on all surfaces to "functionalize" the MCP, and finally NiCr electrodes are applied to the input and output surfaces. The MCP resistances achieved cover a wide range from 3 MΩ to > 500 MΩ allowing a broader range than conventional glass MCPs.

Potential advantages of the borosilicate substrate ALD MCPs stem from basic materials properties as well as the separation of nanofabrication steps used to make them [1,2]. The substrates and materials are low outgassing and capable of higher temperature processing (~700 °C) than conventional glass MCPs with advantages for sealed tube processing and lifetimes. The borosilicate glass also has lower intrinsic radioactive content, giving lower background, and has a lower gamma ray cross-section since there is no lead in the glass. The higher open area ratios increase the effective quantum efficiency, yet the substrate is stronger than conventional MCP glasses and can be made much larger (20 cm) than standard MCP products. We discuss recent improvements in ALD MCPs and several sealed tube devices that have been made.

2. Borosilicate microchannel plate development

Recent borosilicate ALD MCP development efforts have focused on a number of detector applications [3] requiring imaging, good quantum efficiency and timing characteristics, including a 20 cm square sealed tube microchannel plate (MCP) detector. The design

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for sealed tube detector assemblies typically uses an entrance window and semitransparent proximity focused photocathode to convert photons to photoelectrons. Open faced and sealed tube detectors then use a pair, or triplet, of MCPs to amplify the signal, which is detected on a readout anode giving the position of events and timing potentially as good as few picoseconds [4]. Recently [3], sealed tube trials have shown encouraging performance results, with good large area stable Na_2KSb photocathodes, but no fully operational devices with ALD borosilicate MCPs had yet been commissioned.

The gain performance of ALD borosilicate MCPs has been measured for many devices [1], although most have been coated with Al_2O_3 emissive layers. Recent measurements of MgO ALD deposited MCPs show that the gain (Fig. 1) for individual MCPs, in formats from 33 mm to 20 cm, is comparable to conventional glass and Al_2O_3 ALD MCPs [1]. MCP pair gain of $\sim 10^7$ has been achieved (Section 4) with narrow peaked pulse amplitude distributions. The average gain maps for 20 cm ALD MCPs (Fig. 2) with MgO emissive layers are now comparable with the earlier results for Al_2O_3 emissive layers [3]. Overall gain variations of the order ∼15% are seen, along with local gain variations due to individual multifibers and multifiber edges. Also, 20 cm ALD MCP background rates of ~ 0.055 event $cm^{-2}\,s^{-1}$ have been measured [5] and shown to be uniformly distributed. This compares with ~ 0.25 event cm^{-2} for conventional MCPs [1], and is commensurate with the reduction in radioactive emission from alkali metal isotopes in borosilicate glass compositions compared with normal MCP lead glass. Event time tagging < 100 ps has also been demonstrated [4].

Earlier results on preconditioning (350 °C vacuum baking and operational burn-in to $7\ C\ cm^{-2}$) [1] of borosilicate ALD MCPs with MgO showed low residual out-gassing, and the post-bake gain had risen by about an order of magnitude (Fig. 3). This and other vacuum bake data (Section 4) indicate increases in the secondary emission coefficient as a consequence of surface cleaning. The subsequent operational burn–in to $7\ C\ cm^{-2}$ also demonstrated a very stable gain. We have since subjected the same MCPs to long duration exposure to atmospheric pressure dry N_2 (Fig. 3) and find that no significant changes of gain occur even after 1000 h of exposure. Furthermore, without the benefit of a high vacuum bake the MgO ALD borosilicate MCPs have shown increases in gain when subjected to a charge extraction “burn-in” [1] or surface cleaning process [6].

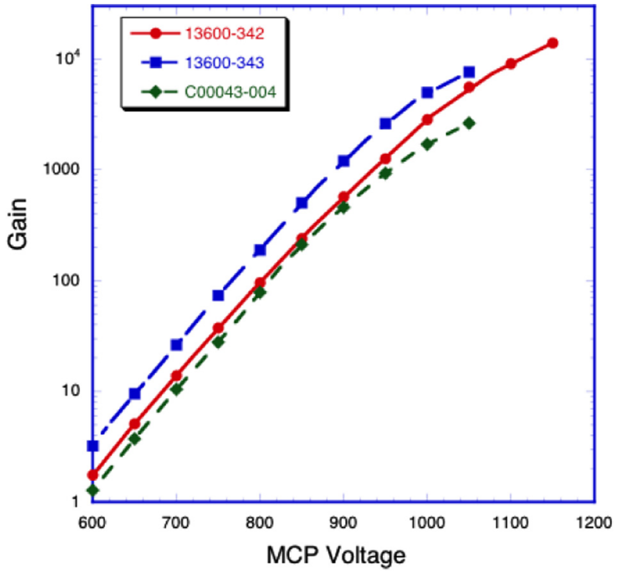

Fig. 1. Gain as a function of MCP voltage. ALD coated borosilicate MCPs with MgO ALD emissive layer, 20 μm pores, L/D=60:1, pore bias 8 degrees, 33 mm MCP (−342 & −343) and 20 cm MCP (−004), with 200 eV electron input flux.

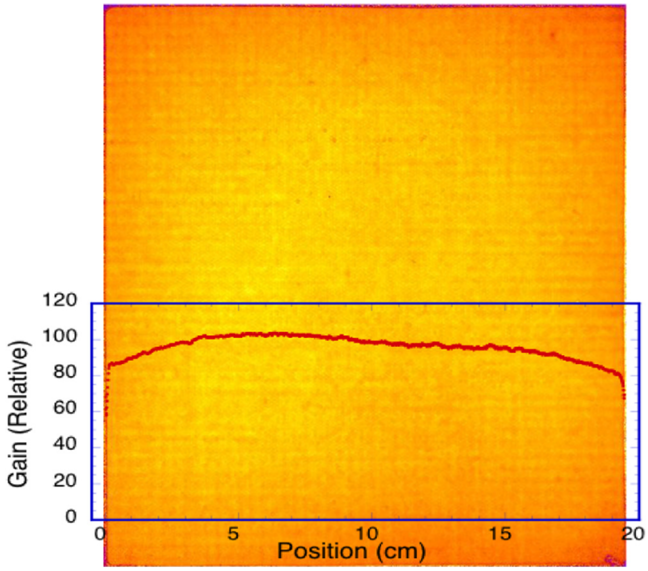

Fig. 2. Average gain map for a 20 cm × 20 cm ALD coated borosilicate MCP pair with 20 μm pores, L/D=60:1, pore bias 8 degrees. ALD emissive layer on the top MCP is Al_2O_3, and on the bottom MCP is MgO. The multifiber hexagonal boundaries are lower gain, but the overall variation in gain is $<20\%$ (overlay). Gain $\sim 5\times10^6$.

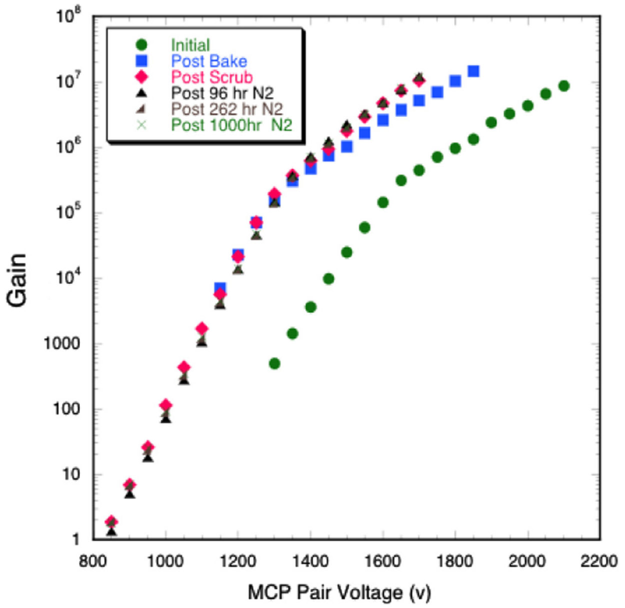

Fig. 3. Gain/voltage curves for a pair of 20 μm pore ALD coated borosilicate MCPs (MgO emissive layer), L/D=60:1, pore bias 8 degrees, 185 nm illumination. A 380 °C vacuum bake increases the gain x10, UV scrub to $7\ C\ cm^{-2}$ changes this very little and subsequent exposure to dry N_2 for 1000 h causes no change.

Deposition of the same type of ALD MgO layer onto conventional MCPs produces similar results: a fast initial drop of gain (÷2) followed by an increase of gain (≈ x5) to a stable level within $\approx 0.07\ C\ cm^{-2}$ (Fig. 4). All these observations suggest that the overall performance and stability for MgO ALD coatings on MCP surfaces can be improved compared to standard glass MCPs.

3. Planacon sealed tube

To obtain comparative results for ALD borosilicate MCPs in sealed tubes we have begun to evaluate the performance of these MCPs in a commercial product, namely the PHOTONIS Planacon. The Planacon comprises an entrance window onto which a semitransparent