PROCEEDINGS OF SCIENCE

Large Area Micro-Channel Plates for LAPPD™

Christopher A. Craven[1a], Daniel C. Bennis[1], Justin L. Bond[1], Michael J Minot[1], Aileen O'Mahony[1], Joseph M. Renaud[1], Michael E. Stochaj[1]

Karen Byrum[2], Jeffrey W. Elam[2], Anil U. Mane[2], Robert G. Wagner[2]

Jason B. McPhate[3], Oswald H.W. Siegmund[3]

Andrey Elagin[4], Henry J. Frisch[4], Richard Northrop[4], Matthew Wetstein[4]

[1]*Incom, Inc., 294 Southbridge Road, Charlton, MA 01507 USA*
[2]*Argonne National Laboratory, 9700 S. Cass Ave., Argonne, IL 60439, USA*
[3]*University of California, Berkeley, Space Sciences Laboratory, 7 Gauss Way, Berkeley, CA 94720 USA*
[4] *University of Chicago, 5640 S. Ellis Avenue, Chicago, IL 60637 USA*
[a]*Speaker, cac@incomusa.com*

Manufacturing plans for "next generation" microchannel plates (MCPs) and the technical advantages enabled by this evolving technology are presented. The Large Area Picosecond Photodetector (LAPPD) is an MCP based photodetector, capable of imaging, with high spatial and temporal resolution in a hermetic package with an active area of 400 square centimeters. A key component of LAPPD is a chevron pair of large area (20 x 20 cm) MCPs. The manufacture of these large-area high performance MCPs has been enabled by the convergence of two technological breakthroughs. The first is the ability to produce large blocks of hollow, micron-sized glass capillary arrays (GCAs) developed by Incom Inc. The Incom process is based on the use of an etchless "hollow-core" approach in the glass drawing process, eliminating the need to remove core material by chemical etching. The arrays are fabricated as large blocks that can be sliced to form large area wafers, without regard to the conventional limits of L/d (capillary length / pore diameter). Moreover, the glass used in these GCAs is physically more robust, does not have a tendency to warp, and has low levels of radioactive isotopes resulting in low dark noise. The second breakthrough is the advent of atomic layer deposition (ALD) coating methods and materials to functionalize GCAs to impart the necessary resistive and secondary emission properties suitable for large area detector applications. Recent results demonstrating the high performance, uniformity, and long term stability of the current MCP product are presented.

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1. Introduction

A new class of micro-channel plates (MCPs) is being commercialized by Incom, Inc. These MCPs have a far larger functional area of 400 cm^2 and greater physical durability than conventional MCPs, and have other desirable attributes such as low dark noise, uniform gain, and stable gain vs. extracted charge. This paper describes the novel fabrication process for producing the glass capillary array substrates and how they are functionalized with coatings deposited by atomic layer deposition (ALD) to achieve these performance benefits. Also described is the work being undertaken by Incom to manufacture sealed 20 cm x 20 cm (8” x 8”) LAPPD photodetector tiles.

These large area photodetectors are being designed for use in high energy physics applications such as water Cherenkov counters, large scintillation detectors, vertex separation and particle I.D. in time-of-flight measurements, and accelerator beam diagnostics. Other uses include neutron detection for defense and Homeland Security, medical PET scanners, and UV detection for space applications.

The technology for these large-format MCPs and photodetectors has been developed by the Large-Area Picosecond Photo-Detector (LAPPD) Collaborative, comprised of Argonne National Laboratory, the University of Chicago, the University of California, Berkeley, Space Sciences Laboratory, the University of Hawaii, Fermilab, and Incom, Inc. The sealed 20 x 20 cm (8” x 8”) photodetector tiles are known as LAPPDs.

2. Glass Capillary Arrays

The glass capillary arrays (GCAs) produced by Incom represent a significant departure from how conventional MCPs are fabricated. This difference in processing accounts for many of the performance benefits gained from this technology such as their physical durability, large size, flatness, and the lower background noise contribution from the glass. To highlight how these benefits are achieved, the fabrication process for conventional MCPs is reviewed, followed by a description of the Incom process.

In conventional MCPs, the glass plates are fabricated as fused fiber optics, where the starting fiber is drawn from a core glass rod and tube. The drawn fiber optic strands are assembled, heated and pressed to produce a fully dense block of fiber optic glass, which is sliced, polished, and machined to produce the fiber optic plates [1]. To create the channels, the plates are immersed in an etchant to remove the original core glass. A firing operation in a reducing hydrogen atmosphere modifies the glass surface to provide the resistive and emissive functions of the MCP.

A significant limitation of the conventional MCP fabrication process is that there are few glasses available that can be drawn, fused, etched, and fired in this way to achieve the desired structure and functionality. Typically they are soft leaded glasses. It is impractical to produce large MCPs (>10 cm) with small pores in conventional MCP glass as they are exceedingly fragile and are almost impossible to keep flat after the hydrogen reduction step. Moreover, conventional MCPs can swell and crack with prolonged exposure to ambient conditions, and so must be stored in dry or vacuum conditions. Also, these glasses used in conventional MCPs

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typically contain potassium and sometimes rubidium, which have radioactive isotopes at natural abundance levels that cause significant background noise in photodetector devices.

The reduced lead oxide surface in conventional MCPs also has limitations. One is that the H-firing operation introduces hydrogen into the glass that slowly diffuses out, and can be a source of ion feedback in the detector. Another is that the plates require a lengthy “burn-in” to condition the surface to achieve stable gain at a given operating voltage. Importantly, the resistive and emissive functions of the coating cannot be independently optimized in the H-reduction operation.

In contrast, Incom draws the glass fibers using a proprietary “hollow-core” approach that does not include the etchable core glass. These hollow capillary are assembled to form a fused block which is then sliced, polished, and formed to produce the glass capillary array plates. No etching is required because the plates already contain the pores.

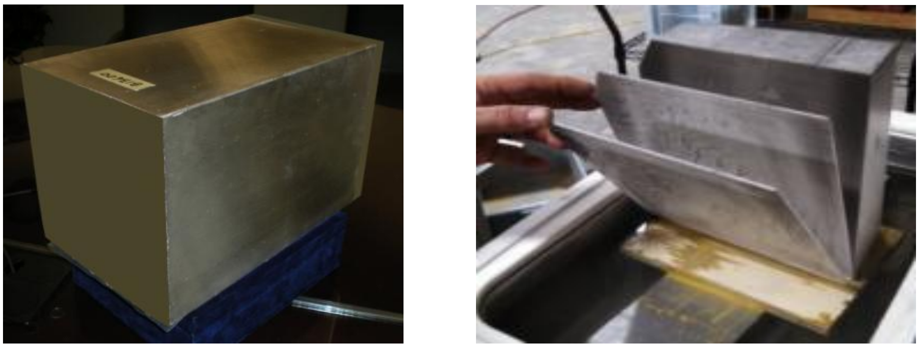

Figure 1. (Left) 229 cm (9”) square glass capillary array block produced by Incom. (Right) The block is sliced, polished and formed to produce the glass capillary array plates.

3. Atomic Layer Deposition Coating

Instead of H-firing to achieve the functional MCP coating, the capillary array plates are functionalized by applying resistive and emissive coatings via an atomic layer deposition (ALD) process [2]. ALD is a thin film coating method that utilizes alternating exposures of gaseous chemical precursors and a solid surface to deposit materials in an atomic layer-by-layer fashion. Because the chemical reactions between the precursors and the growing film naturally terminate after the adsorption of one monolayer, ALD provides precise control of thickness. This control, coupled with the ability of the gaseous precursors to diffuse into narrow pores, allows for highly conformal coatings to be applied on the inner surfaces of complex, three-dimensional objects such as the high aspect ratio glass capillary arrays.

Two ALD coatings are applied to functionalize the plates. The first coating, the resistive layer, is tuned to allow a small current through the pores to replenish the electrons produced in the cascade. A wide range of resistance values can be selected, with 10-25 MΩ typical for the 20 cm square MCPs. The second ALD coating, the emissive layer, generates secondary electrons when incident electrons strike the surface of the pores, producing the electron cascade driven by the voltage across the plate. Different materials can be used for the emissive layer. For example, Al_2O_3 and MgO are two materials that have been used to coat the Incom glass capillary arrays. Compared to the secondary electron yield (SEY) of ~2 in conventional MCPs, ALD Al_2O_3 has a secondary electron yield (SEY) of 2.5-3, and ALD MgO has a SEY of 4-5 or even greater depending on thickness [3].

4. Benefits of the GCA /ALD processes

Many benefits are gained by this technology for producing GCA plates. First, a wide range of glasses is available. For example, commercial borosilicate glasses similar to Pyrex® can be used, which are stronger and are not susceptible to warping. As a result, GCA can be made far bigger than conventional MCPs, and are significantly easier to handle. These GCAs and MCPs remain flat +/- 12.7 µm even when stored in ambient environments, greatly simplifying fabrication of detector devices. Another benefit is that alkalis such as potassium are present in the glass only at low or trace levels, depending on the glass used, which reduces background noise to 0.07 – 0.085 counts/cm^2/sec compared to ~3 counts/cm^2/sec in conventional MCPs [4, 5, 6]. Elimination of lead in the glass also reduces the cross section for gamma ray detection applications, improving the signal to noise ratio for discrimination of neutrons [7].

Shown in Figure 2 (left) is a 203 mm square glass capillary array with 20 µm pores, 1.2 mm thickness, and 60-65% open area (pore length/diameter ratio of 60:1). No commercially available MCPs of this pore size and L/D ratio approach this size. As a demonstration of the relative strength of this glass, Figure 2 (right) shows a 95 mm square of the same 20 µm pore material polished to 0.25 mm thickness. Though delicate, this plate is quite usable, where a conventional MCP of this size and thickness would be virtually unhandleable.

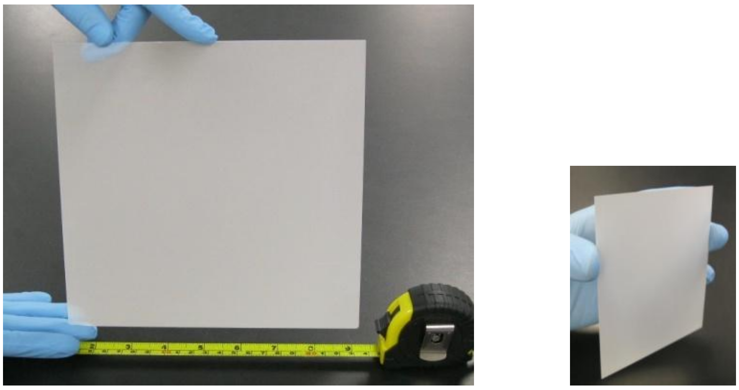

Figure 2. (Left) A 20 cm square glass capillary array, 20 µm pore size, 60-65% open area ratio, 1.2 mm thick. (Right) The same material 95 mm square and 0.25 mm thick, showing handleability.

The ALD coatings have a SEY greater than that obtained in conventional lead glass MCPs, which allows for either higher gain at a given operational voltage or less voltage to achieve a desired gain. Another important benefit gained from the ALD coatings is that they require little or no scrubbing before they can be used. When conventional MCPs are first turned on there is a large drop in gain before performance eventually stabilizes. This can take anywhere from several hours to several weeks of operation before the gain is stable enough for the MCP to be used in a detector. In comparison, as shown in Figure 3 (Center), the ALD-functionalized

MCPs achieved a stable gain almost immediately, and did not drop in gain after extended operation in which 7 Coulombs/cm^2 was extracted. As shown in Figure 3 (Right), these MCPs can be operated, removed from vacuum, stored, and reinstalled with no change in gain response. No repeat burn-in period, required for conventional MCPs, is needed.

Figure 4 shows that the ALD coating produces a highly uniform gain response across the MCP, within 15% across the 20 x 20 cm area. Figure 5 shows that spatial resolution in these MCPs is good (resolving the 20 micron pores in the MCP), as characterized at UC Berkeley, SSL using a high resolution strip delay line readout.

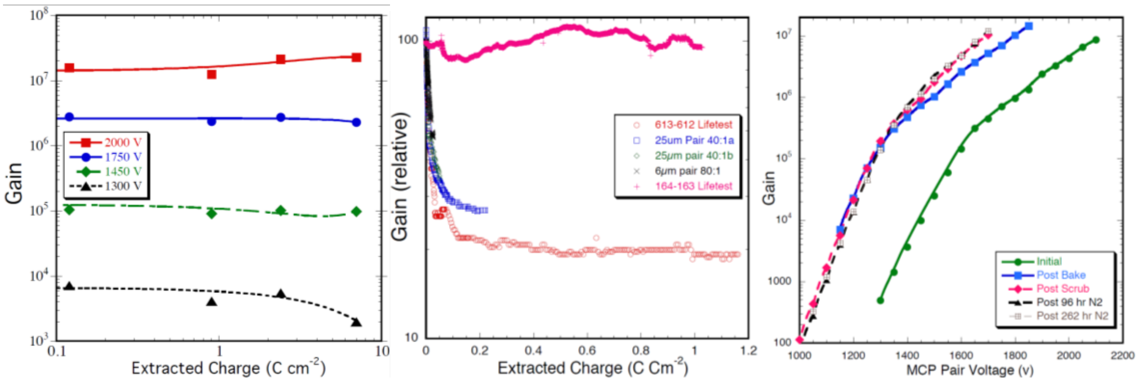

Figure 3. (Left) Gain is high and stable vs. extracted charge. Plot is of MCP gain at several fixed voltages during a "burn-in" test extracting 7 C/cm^2 at ~3 µA output current for a pair of 33 mm, 60:1 L/D, 20 µm pore ALD MCPs [8]. (Center) Conventional MCPs require an extensive "burn-in" to achieve a stable gain. Little or no burn-in is required for Incom MCPs (magenta trace) [9]. (Right) Gain of a pair of 33mm 20 µm pore, 60:1 L/D, MgO-ALD MCPs during preconditioning steps. Gain increases 10x after initial bake, and does not drop after storage for ten days in N_2. No reconditioning is needed after breaking vacuum [6].

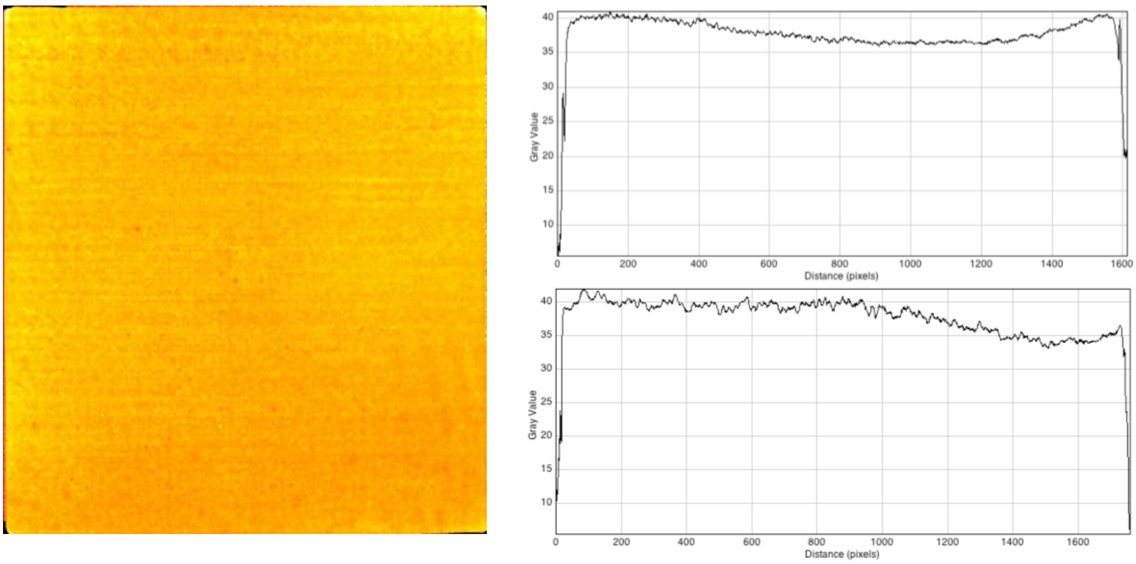

Figure 4. (Left) Gain map image for a pair of 20 µm pore, 60:1 L/D, ALD borosilicate MCPs, 950 V per MCP, 184 nm UV illumination. (Right) Gain vs. position along horizontal (top) and vertical (bottom) traverses of the plate. Gain is uniform within ~15% across the full 20 x 20 cm area [10].

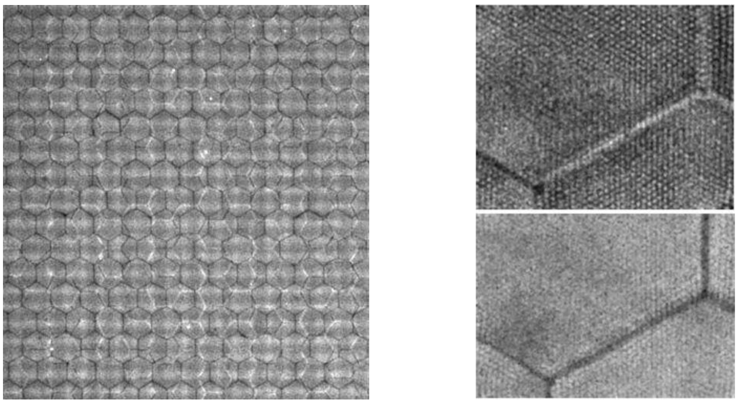

Figure 5. (Left) Section (~15 x 15 mm) of an accumulated image for a pair of 20 µm pore 60:1 L/D ALD MCPs at ~10^6 gain taken with a 95 mm cross strip detector, 184 nm UV illumination. Using high resolution cross-strip delay line readout, individual 20 µm MCP pores are resolved. (Upper right) Small section of image on left. (Lower right) Gain map image of the same area [6].

5. Commercialization of LAPPDs

In addition to the existing capability for producing the 20 x 20 cm glass capillary arrays and MCPs, Incom is establishing capabilities for the fabrication of LAPPD detector tiles. Pilot production of prototype LAPPDs is expected to begin by early 2016.

5.1 LAPPD design

The detector tile design is shown in Figure 6 (top) [10]. A bottom strip-line anode plate is fritted (joined with a low melting point glass) to a sidewall. Two 203 mm square MCPs are loaded into the anode/sidewall assembly with spacers to provide structural support. The top window is coated with a bialkali photocathode, and joined under vacuum to the sidewall with an indium alloy seal. The anode plate, sidewall, spacers, and top window are all commercially available, low-cost borofloat glass. Figure 6 (bottom left) is a schematic of the LAPPD cross-section, and Figure 6 (bottom right) is a mock-up of the sealed LAPPD tile, with all components except the deposited photocathode layer. The functional area is 20 x 20 cm, and overall size is expected to be 220 x 229 x 18.5 mm (8.66” x 9.02” x 0.73”).

A useful element of this design is that the striplines of the anode pass through the frit seal and are accessible from the outside of the sealed detector. No electrical pins passing through the structure are needed, which simplifies the design and makes the package more robust.

5.2. LAPPD Performance

Timing resolution in the LAPPD detector tile has been measured using the 20 x 20 cm “demountable” test station developed by Argonne and the University of Chicago. For these tests an aluminium photocathode was used instead of an air-sensitive bialkali cathode to allow for opening and closing of the actively pumped tile for repeat characterization measurements. As shown in Figure 7, timing resolution of 40 psec has been demonstrated in the LAPPD detector tile for single photon events, and 17 psec for larger signals from multiple photons, tested using a 610 nm laser with a spot image of <5 mm FWHM at high pulse amplitudes.

In a test of the bialkali photocathode, an alternate ceramic tile design was used with a chevron pair of the 20 cm square MCPs. In this test the photocathode was deposited onto the window in an ultra high vacuum chamber, and the window was then indium-sealed to the tile assembly. While still in the chamber the detector tile performance was tested. A quantum efficiency of 20-25% at 350-400 nm illumination was measured with ±15% uniformity over the full 20 x 20 cm area.

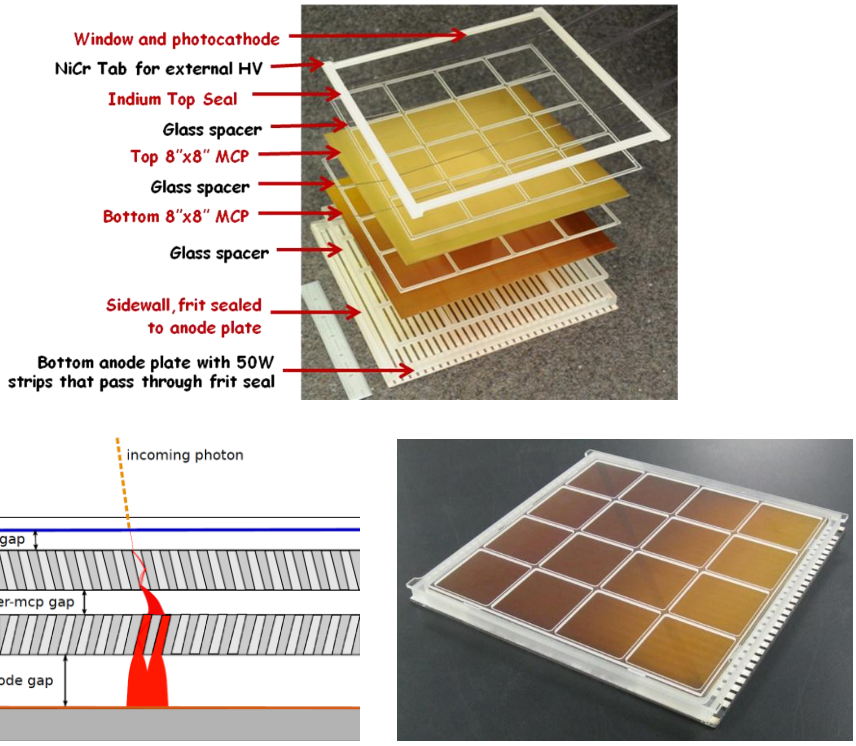

Figure 6. (Top) Components of the LAPPD. (Bottom left) Schematic cross-section of the LAPPD. (Bottom right) Mock-up of the LAPPD tile, which contains all elements except the photocathode layer.

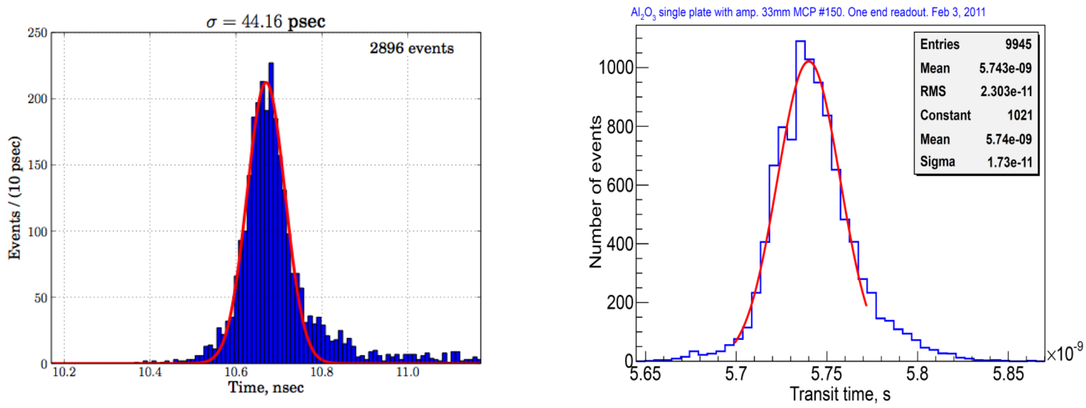

Figure 7. Using the "demountable" test station, temporal resolution of 44 psec has been demonstrated for single photoelectrons, and 17 psec for large, multiple photoelectron signals [12].

6. Summary

The technology for producing large area, 20 x 20 cm MCPs and LAPPD detector tiles is rapidly being advanced, with demonstrated performance characteristics that are superior in many ways to conventional MCPs. Installation of equipment and facilities for pilot production of these devices is underway, with the first prototype LAPPD tiles expected to be produced by early 2016. Key elements of the process for fabricating the glass capillary arrays, ALD coating, and detector tile fabrication have been demonstrated, with no "show stoppers" identified. The significant performance improvements over conventional MCPs are expected to benefit high energy physics, defense, homeland security, medical imaging, and space applications.

7.Acknowledgements

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