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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 $\sim$15% are seen, along with local gain variations due to individual multifibers and multifiber edges. Also, 20 cm ALD MCP background rates of $\sim$0.055 event $cm^{-2}\,s^{-1}$ have been measured [5] and shown to be uniformly distributed. This compares with $\sim$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].

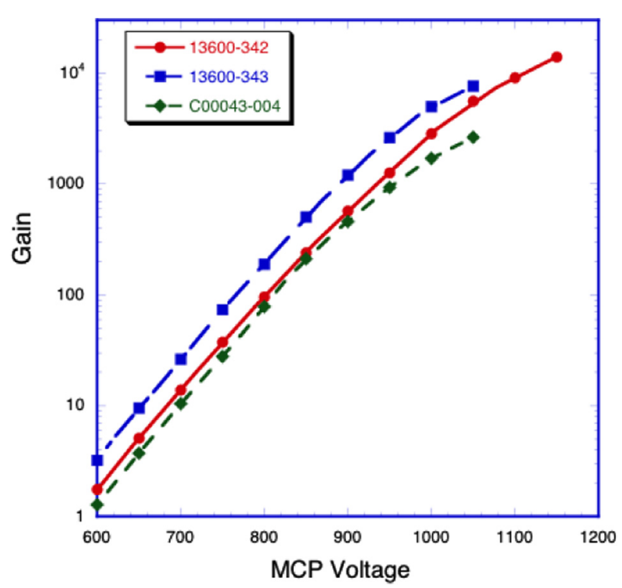

Fig. 1. Gain as a function of MCP voltage. ALD coated borosilicate MCPs with MgO ALD emissive layer, 20 μm pores, L/D=60:1, pore bias 8 degrees, 33 mm MCP (−342 & −343) and 20 cm MCP (−004), with 200 eV electron input flux.

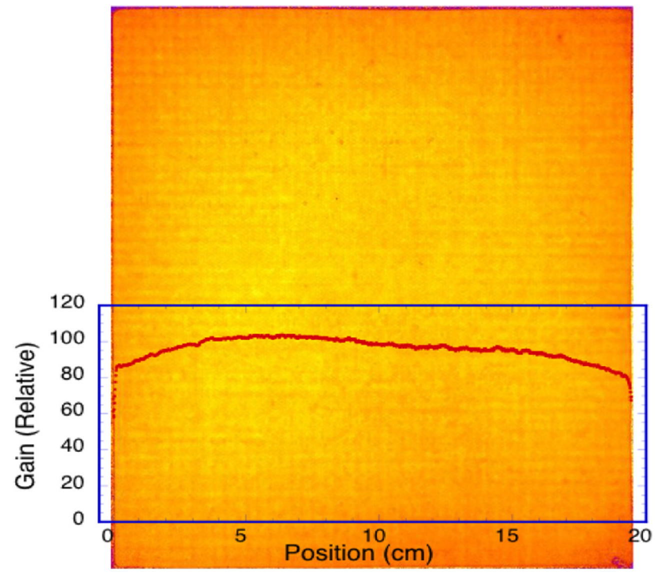

Fig. 2. Average gain map for a 20 cm × 20 cm ALD coated borosilicate MCP pair with 20 μm pores, L/D=60:1, pore bias 8 degrees. ALD emissive layer on the top MCP is Al_2O_3, and on the bottom MCP is MgO. The multifiber hexagonal boundaries are lower gain, but the overall variation in gain is $<20\%$ (overlay).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

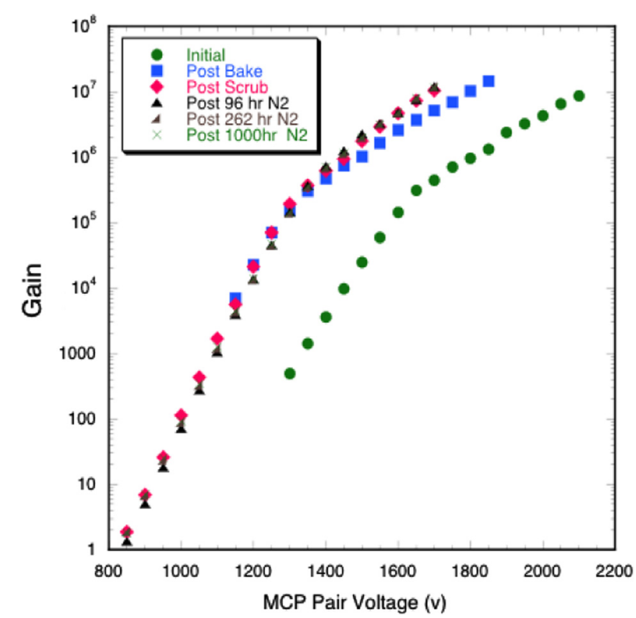

Fig. 3. Gain/voltage curves for a pair of 20 μm pore ALD coated borosilicate MCPs (MgO emissive layer), L/D=60:1, pore bias 8 degrees, 185 nm illumination. A 380 °C vacuum bake increases the gain x10, UV scrub to 7 C cm^{-2} changes this very little and subsequent exposure to dry N_2 for 1000 h causes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

Deposition of the same type of ALD MgO layer onto conventional MCPs produces similar results: a fast initial drop of gain ($\div 2$) followed by an increase of gain ($\approx$ 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 multialkali proximity photocathode is deposited, a pair of 53 mm square MCPs to achieve signal gain of the order 5×10^5, and an array of square pads to collect the charge clouds. We have used 10 μm pore borosilicate substrate ALD MCPs with Al_2O_3 emissive layer to evaluate in a Planacon device. These MCPs were tested in a cross strip [5] detector prior to Planacon construction. The gain achieved was $>10^6$, and the image map of the average gain (Fig. 5) shows lower gain (20% lower) for some multifibers (hexagonal) and their boundaries (~10%), but the overall variation in gain is <25% (Fig. 5 overlay). The MCPs were integrated into a Planacon and processed (vacuum bake, burn-in, cathode deposition and seal). The completed Planacon has peak quantum efficiency of ~20% at 350 nm which is typical for these devices, and the efficiency has not changed in the four month period since sealing. The gain achieved after processing is relatively low (5×10^5 @ 1250 per MCP). Pulse amplitude distributions (Fig. 6) for a laser pulse (610 nm 80 ps pulse) of approximately 20 photoelectrons per pulse were accumulated at several MCP bias settings and show tight distributions. We have since integrated a 64 channel preamplifier to the anode 8×8 pads, and can see single photon events. Firmware and software are currently in development to allow the data to be utilized for imaging and event timing (~20 ns).

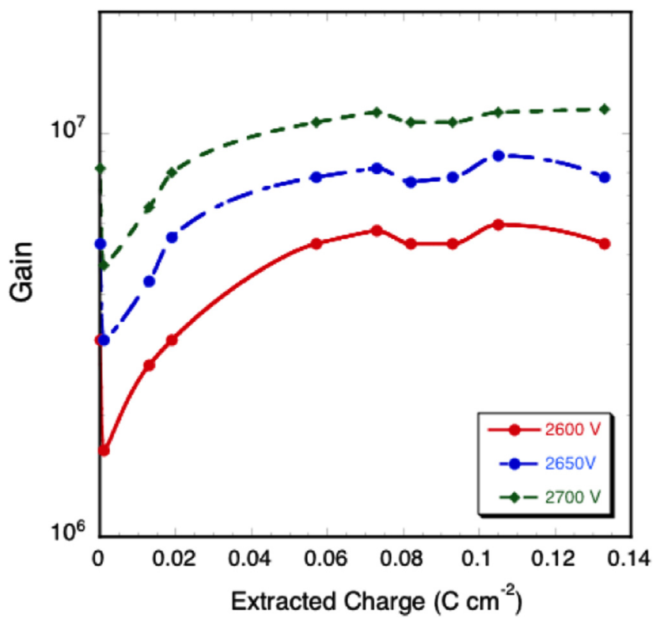

Fig. 4. Gain as a function of extracted charge for a 3 MCP stack of commercial lead glass MCPs with 10 μm pores, L/D=60:1, pore bias 12 degrees, 25 mm active area with MgO ALD emissive layer deposited on the bottom two MCPs. Typical scrub current ~1 μA.

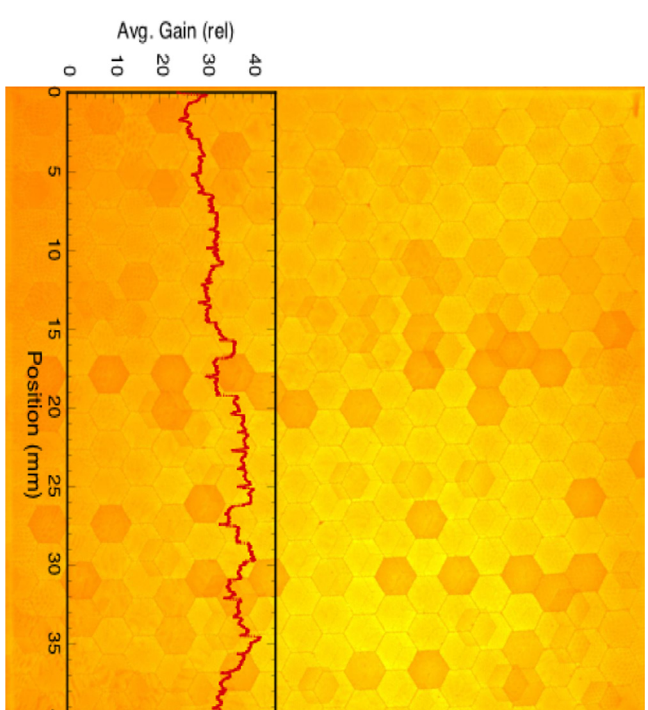

Fig. 5. Average gain map for a 5 cm × 5 cm ALD coated borosilicate MCP pair with 10 μm pores, L/D=60:1, pore bias 8 degrees. ALD emissive layer is Al_2O_3. Gain ~1×10^6.

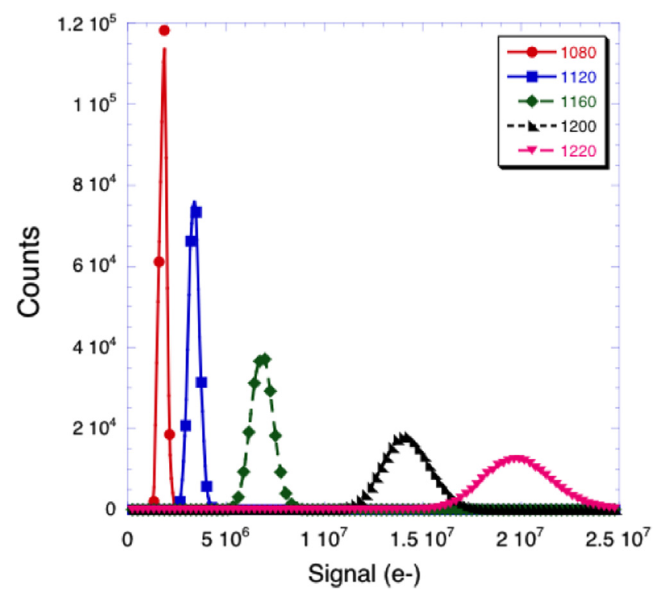

Fig. 6. Pulse amplitude distributions at several MCP voltages, for laser pulses (610 nm, ~80 ps pulse) giving ~20 photoelectrons per pulse from the bialkali photocathode of a Planacon. ALD coated borosilicate MCP pair (Al_2O_3 emissive layer) with 10 μm pores, L/D=60:1, pore bias 8 degrees. Voltages stated are for each MCP of the pair.

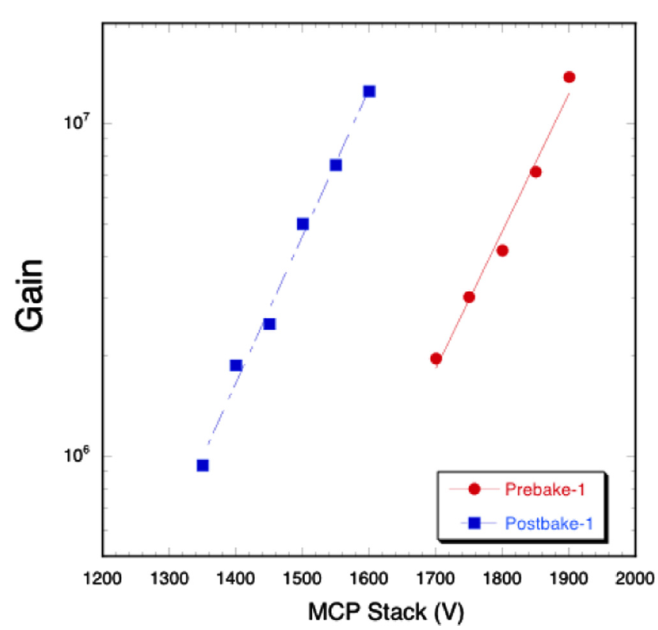

Fig. 7. Gain/voltage curves for a pair of 20 μm pore ALD coated borosilicate MCPs (Al_2O_3 emissive layer, GaN on top MCP), L/D=60:1, pore bias 8 degrees, 185 nm illumination, before and after a 350 °C high vacuum bake.

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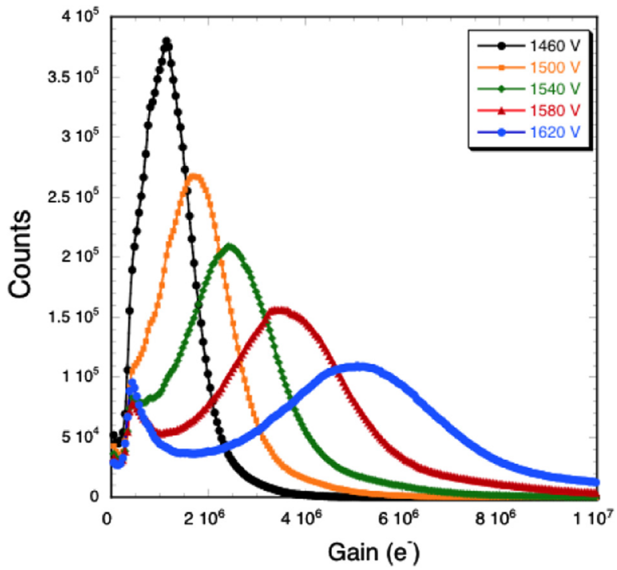

Fig. 8. Pulse height distributions for a pair of 20 μm pore ALD coated borosilicate MCPs (Al_2O_3 emissive layer, GaN on top MCP), L/D = 60:1, pore bias 8 degrees, after GaN cesiation and final tube sealing, 185 nm illumination.

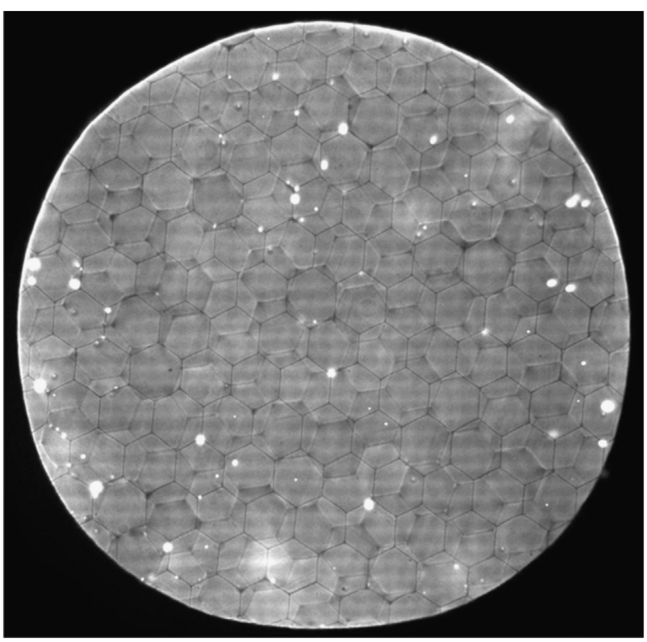

Fig. 9. Photon counting image (8×10^7 photons, 2048 × 2048 binning, XDL readout, 4×10^6 gain) using 185 nm UV illumination for the same sealed tube described in Fig. 8.

4. GaN sealed tube

GaN(Mg):Cs photocathodes [7] provide a potentially high efficiency photocathode material for UV detection. We have continued our work on opaque GaN(Mg) photocathodes by depositing a GaN photocathode onto a borosilicate MCP with ALD resistive and Al_2O_3 emissive layer, and incorporating this into a working sealed tube photon counting imaging sensor. The GaN deposition (1 μm thick on 14 nm Al_2O_3) was done by molecular beam epitaxy (by SVT Associates Inc.) onto a 33 mm borosilicate MCP with 20 μm pores, L/D 60:1, pore bias 8°. This was used as the top MCP of a pair that was installed into a sealed tube with a MgF_2 entrance window and cross delay line (XDL) readout anode [8]. Testing was accomplished at each stage of the tube processing and show that during the initial vacuum bake (~350 °C) the gain of the MCPs increased (Fig. 7) by a factor of ~10, as previously observed for MgO ALD MCPs (Fig.3). The subsequent "burn-in" extracting ~0.05 C cm^{-2} made a relatively small change in the gain, and no gain changes were observed after cesiation of the GaN photocathode. The final sealed tube MCP pulse amplitude distributions are quite narrow (Fig. 8) and occur at low bias voltages (750 to 800 V per MCP) which is good for low gain, high event rate devices. The imaging (Fig. 9) achieves ~40 μm resolution, but shows features of the developmental ALD MCP substrates used (hexagonal multifiber for both MCPs) and hotspots from particulate debris. The quantum efficiency is relatively low (~10% of best QE [7]) due to the thicker than optimal GaN photocathode, but serves as a good demonstration for the optimization of the overall processing for future devices. No changes of operational characteristics have been seen in the four months since the final device sealing.

5. Conclusions

Borosilicate substrate ALD MCPs in formats up to 20 cm have been demonstrated to have good gain, low background and overall uniformity. Burn-in and vacuum bake conditioning of ALD MgO coated MCPs show a significant and stable gain increase that is advantageous for making sealed tubes. Working trial sealed tube detectors with ALD MCPs in 25 mm and 50 mm format with GaN and bialkali photocathodes, respectively have been made, and are good precursors for further device optimizations.

Footnotes

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References

[1] O. Siegmund, N. Richner, G. Gunjala, J. McPhate, A.S. Tremsin, H.J. Frisch, J. Elam, A. Mane, R. Wagner, C.A. Craven, M.J. Minot, Proceedings of the SPIE 8859 (2013) 88590Y.
[2] A.U. Mane, A., et al., Phys. Procedia 37 (2012) 722–732.
[3] O. Siegmund, J. McPhate, A.S. Tremsin, J.V. Vallerga, H.J. Frisch, R.G. Wagner, A. Mane, J. Elam, G. Varner, Advanced Maui Optical and Space Surveillance Technologies Conference Proceedings (2013).
[4] B. Adams, A. Elagin, H.J. Frisch, R. Obaid, E. Oberla, A. Vostrikov, R. Wagner, M. Wetstein, Nucl. Instrum. Meth. A 732 (2013) 392–396.
[5] O.H.W. Siegmund, J.B. McPhate, J.V. Vallerga, A.S. Tremsin, H. Frisch, J. Elam, A. Mane, R. Wagner, J. Instrum. 9 (4) (2014) C04002.
[6] S.J. Jokela, I.V. Veryovkin, A.V. Zinovev, J.W. Elam, A.U. Mane, Q. Peng, Z. Insepov, the LAPPD Collaboration, Phys. Procedia 37 (2012) 740–747.
[7] O.H.W. Siegmund, J.B. McPhate, S.R. Jelinsky, J.V. Vallerga, A.S. Tremsin, R. Hemphill, H.J. Frisch, R.G. Wagner, J. Elam, A. Mane, IEEE. T. Nucl. Sci. 60 (2) (2013) 923–931.
[8] O.H.W. Siegmund, J.V. Vallerga, B. Welsh, J. McPhate, A. Tremsin, Proceedings of the Advanced Maui Optical and Space Surveillance Technologies Conference (2009) 90.