Large Area MCPs Coating by ALD

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Abstract

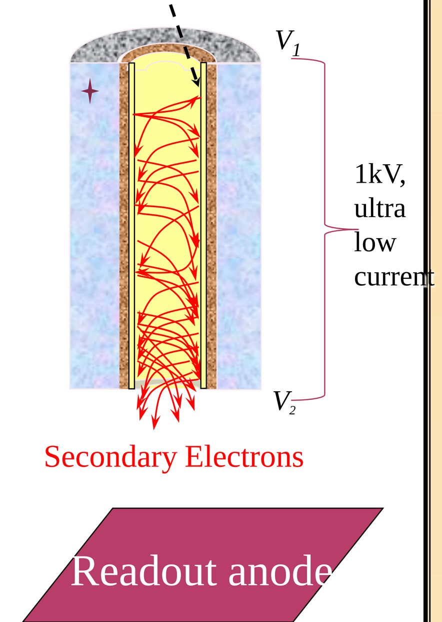
Atomic Layer Deposition (ALD) thin film technique has enabled substantial improvement of particle detectors in various applications such as astrophysics, high energy physics, biomedical imaging and many others. These detectors based on Microchannel Plate (MCP) electron amplifiers are capable of single event detection with high spatial (~10 µm) and temporal (<100 ps) resolution and no readout noise. The growth of ALD films inside the MCP pores substantially improves their performance and extends their use into novel applications such as Large Area Picosecond Photodectectors (LAPPD).

MCP structures are defined by small pore size (µm range), high pore density (10^8 to 10^{11} per m^2) and large pore length (tens of µm to mm). In recent times, large area MCP (203 mm x203 mm) is gaining attention because it is a key component of LAPPD. With a surface area of roughly 2.5 m^2 and 60:1 aspect ratio, it presents great challenge for developing ALD coatings over MCPs. Arradiance first came up with the idea of functionalizing small MCPs with separate resistive and secondary emissive layers, realizing effective MCPs with high electronic gain and robust performance. Recently we extended that work and optimized the resistive and emissive processes for large area MCP. It led to tunable resistance, gain increase, gain uniformity and fast time resolution (tens of ps) across the whole plate.

In our ALD process optimization for large area MCPs, we adopted anodic aluminum oxide (AAO) as a process optimization tool instead of large MCPs as a cost effective measure. High aspect ratio AAO sheets with surface area similar to that of prototype devices were used to optimize ALD film thickness uniformity, by studying the effects of ALD process parameters such as precursor and process temperature, purging time, exposure time and pulsing sequences. The conformality on AAO was evaluated using electron microscopy to confirm the ALD film characteristics. The optimized ALD process recipes developed with AAO were subsequently tested on actual device prototype structures with high surface area and high aspect ratio; conformal ALD thin film deposition on those structures confirmed the success of this surface area scaling approach.

MCP electron multipliers and their applications in single particle detection

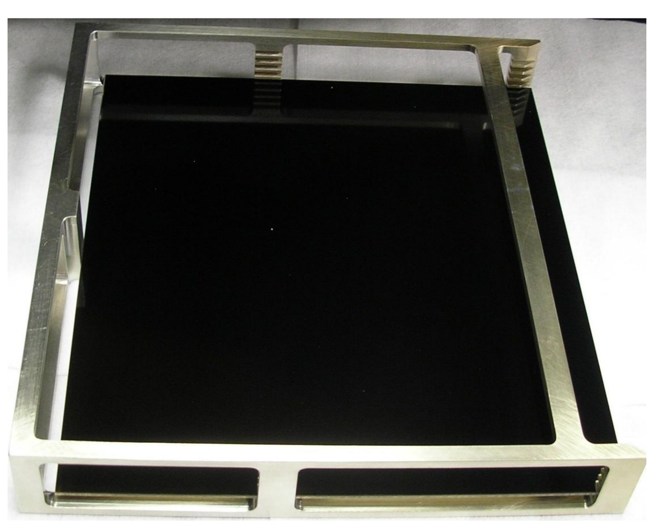
- Pores are typically 6-20 µm ∅
- Active area ~25 mm – 200 mm
- Resistance 10-100 MΩ at room T with negative coefficient of resistance



- Detection of single photon (visible with special photocathodes, UV, soft X-ray), electron, ion, neutral, alpha, neutron.
- High gain – 10^5 from a single MCP and up to 10^7 from a stack.
- Low background count rate < 0.1 count/cm^2/s.
- Large dynamic range.
- High spatial (10-20 µm) and temporal (10-50 ps) resolution.
- Event counting (Particle Detector) or integrating (Image Intensifier) modes are possible.
- Output current limited to ~10% of strip/conduction current – that introduces limitation on count rate per pore. Both MCP resistance and operational gain define the maximum count rate per pore.
- Event counting with ~1 GHz rate per MCP is possible with fast low-noise readout electronics (e.g. Timepix requiring gain of only ~5x10^4).

- Night vision goggles; Mass spectroscopy; Astrophysics; Biomedical research (FLIM, FRET,…); Diagnostics of storage rings; High energy physics; Synchrotron instrumentation;

Custom table-top ALD tool optimized for large area MCP



GEMStar-8 system is designed for extreme surface area, high aspect ratio structures: Multi-channel precursor delivery system isolates & distributes precursors combine with a tapered exhaust to provide exceptional nanofilm uniformity.

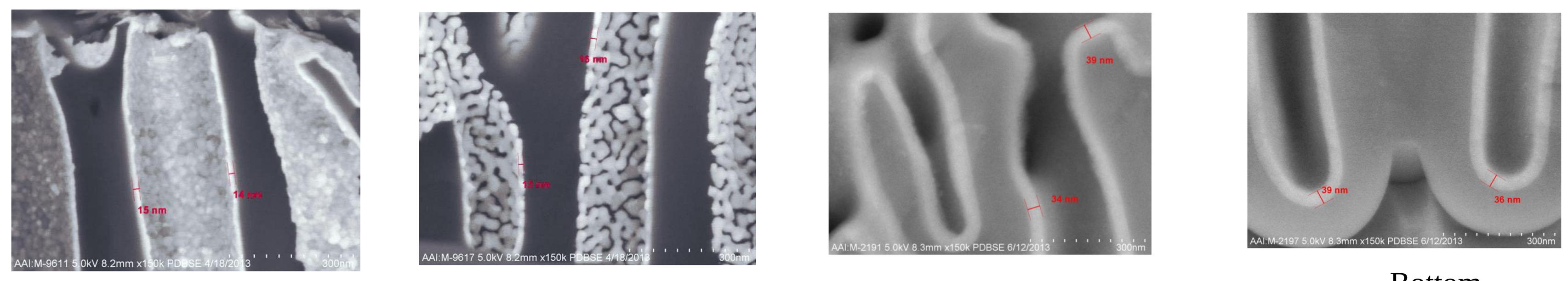
The differentially pumped system seals eliminate gas permeation which along with separate and actively heated Oxidant and Metal-Organic manifolds eliminate parasitic nanofilm production.

MCP resistance and stability under applied bias was measured in the vacuum chamber at room temperatures.

Aluminum oxides (AAOs) possess very high pore density (>10E8) and high aspect ratio (>300:1), which are similar to MCPs. Large area MCPs are difficult to prepare, expensive and hard to analyze. So AAO was used as a good cost-effective alternate testing vehicle for large area MCP process optimization. Instead of using large area MCP (6.4 m^2), several pieces of AAO with comparable total surface were used to get optimal process parameters such as dosage, purge times, temperature and pressure . After that a dummy large area MCP was used to validate the recipe and expected resistance and gain.

ALD Process Optimization on Large Area MCP

1. **Conformality of each unit process in AAO by SEM with total 2.5 m^2 of surface area**

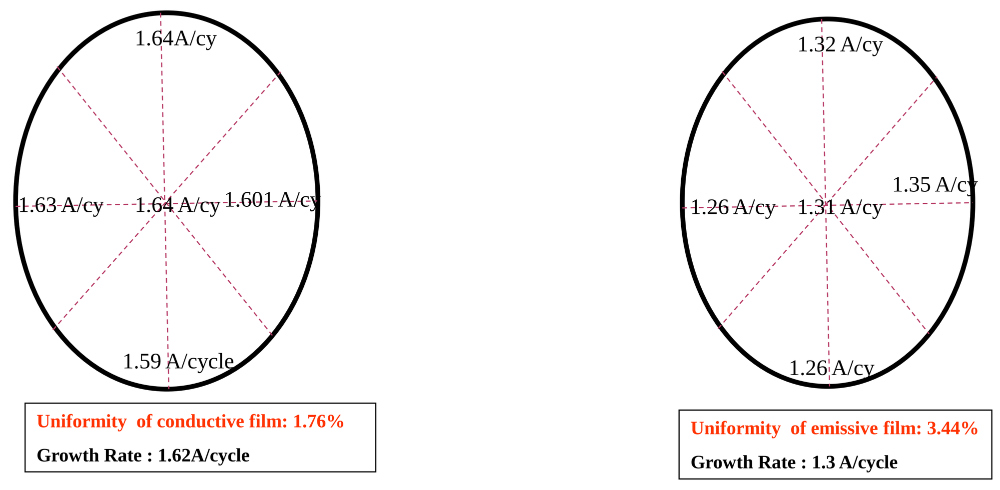


Pt ALD :1.0 A/cycle GR
>90% conformality in AAO

Resistive ALD film for MCP:
~100% conformality in AAO

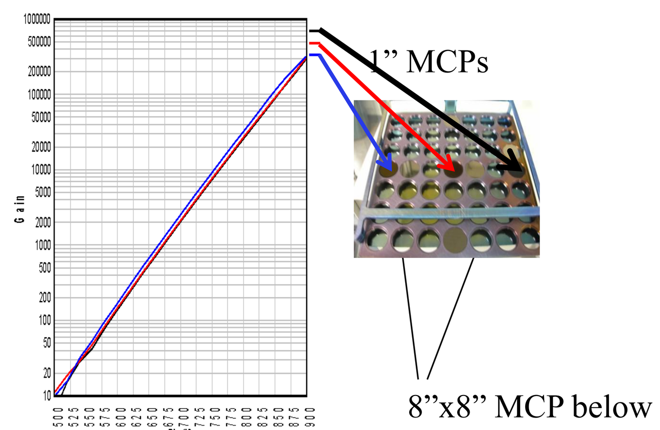
▪ The high conformality over the AAO (A.R. >300:1) meets the requirement of large area MCP(A.R. 60:1)

2. **Uniformity of unit process on 8" Si wafer by SE with total 2.5 m^2 of surface area**

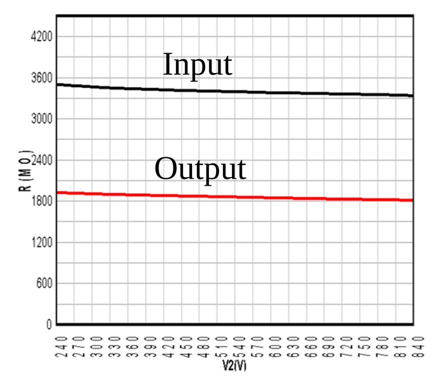


▪ The good uniformity of unit processes meets the requirement of large area MCP.

3. **Using quality reject "dummy" LAPPD MCPs with inverted (face down) 8" Si wafers directly on top of the LAPPD device and 1" MCPs and silicon wafers in a multi-device fixture allowed to check the gain uniformity, growth rate and resistance variation.**



Gain is very uniform across the chamber after scrubbing the small MCP.



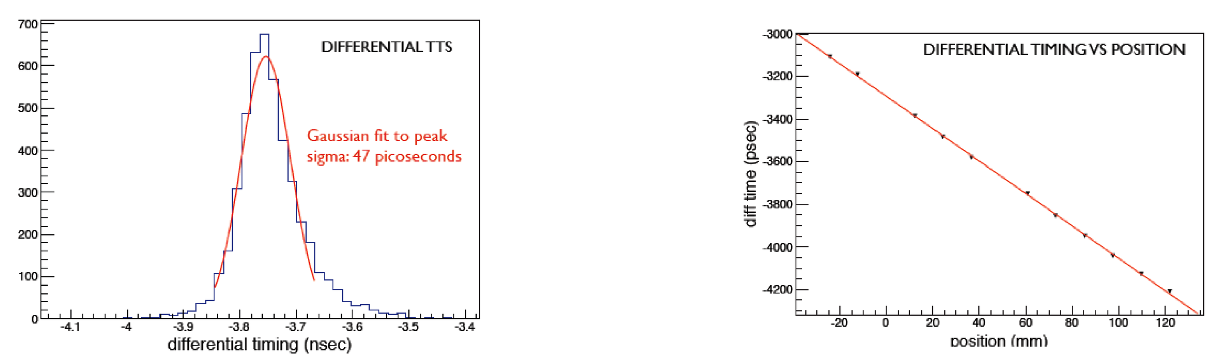
2X resistance variation across the chamber
Input – precursor supply side; Output – exhaust side

▪ Deposition on the 1" MCPs with dummy large area MCP present directly below in the chamber, using the same recipe developed with AAO shows good gain uniformity and small resistance variation.

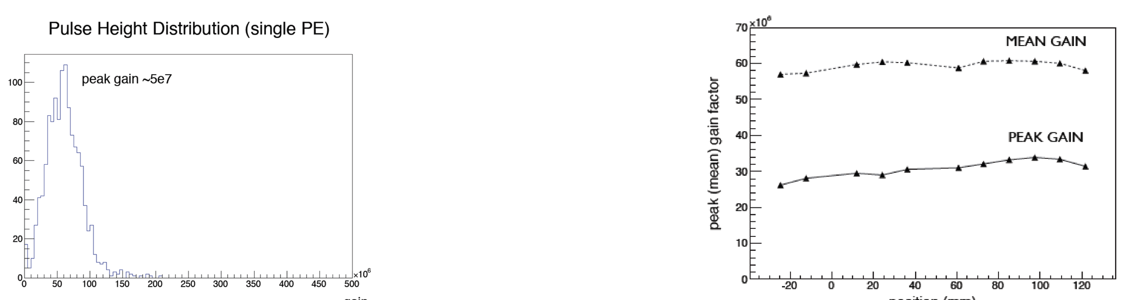
▪ Only after the above practice, we are confident that the recipe developed can be used on final metallized large area MCP.

Performance of large area MCP coated by GEMStar

1. Current state of the art detection for HEP is done with PMTs. For example the performance of 20" devices used in super Kamiokande is: spatial resolution = 20", timing resolution = 3ns. The verified performance of the detector incorporating the Arradiance MCPs is: spatial resolution 0.7mm and timing resolution 40ps – SEVERAL Orders of magnitude better!



2. MCP-PMT devices of larger size exist (e.g. planacon) but have always possessed poor lifetime due to photocathode degradation. Arradiance ALD films have been shown to improve this by at least an order of magnitude (from 0.1C to ~ 10C) to the point where these devices rival PMT lifetime performance. Excellent gain and gain uniformity are also achieved.



Summary

▪ Using AAO as a surface area "surrogate" processed alongside 1" MCP substrates, allowed for rapid cycles of learning with high surface area, high aspect ratio structures prior to large process chamber availability.
▪ Using quality reject "dummy" LAPPD MCPs over multiple experimental runs with inverted (face down) 8" Si wafers directly on top of the LAPPD device and 1" MCPs and silicon in a multi-device fixture, allowed for LAPPD process development with MCP-based feedback.
▪ Subcomponent nanofilm optimization prior to full integration reduced experimental confounding
▪ Final integration showed excellent gain-voltage chamber uniformity, consistent film growth and controlled resistance variation over the whole chamber.
▪ Large MCP coated by Arradiance recipe and tool outperforms the current state of art technology: unparalleled spatial and tempo resolution; excellent gain, excellent gain uniformity over 200mm x200mm and 10 times improvement in life time.

Acknowledgements

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