Engineered Nanofilms for improved MCP performance in Mass Spectrometry applications

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Overview

Atomic Layer Deposition (ALD) modification of the emission properties of the Microchannel Plate (MCP) pore surface has demonstrated significant MCP performance improvements including gain improvements of as much as 50 times and lifetime improvements over commercial MCPs such that the nanofilm MCPs achieve stable operation within 0.03C/cm2 extracted charge vs. the typical 0.3C/cm2, at a higher fraction of initial gain (80% vs 40%) as compared to state-of-the-art MCP devices. ALD provides the flexibility to engineer, at the sub-nanometer level, functional films to optimize MCP performance in applications such as mass spectrometry (MS).

Introduction

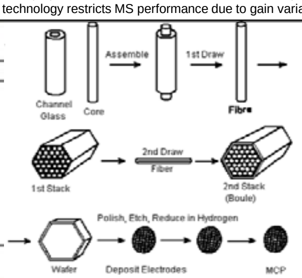
A mass spectrometer (MS) consists of a mass analyzer and a detector - typically a lead-glass based microchannel plate detector (MCP) or channel electron multiplier (CEM). Current lead-glass technologies utilize fiber optic manufacturing processes, which remain fundamentally unchanged since the 1970s. Functionalization of the detector relies on a high temperature hydrogen reduction of the surface film to simultaneously form the conductive and secondary electron (SE) emissive layers. These devices lack the capability to independently optimize mechanical, resistive and emissive properties, which contributes to limited dynamic range, device variability, dark noise and lifetime degradation. This technology restricts MS performance due to gain variation, noise, dynamic range and response time limitations.

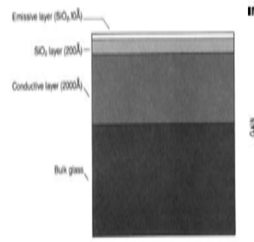
Elemental composition of MCP glass[a].

Z	Element	Weight percent
82	Pb	47.8
8	O	25.8
14	Si	18.2
19	K	4.2
37	Rb	1.8
56	Ba	1.3
33	As	0.4
55	Cs	0.2
11	Na	0.1

[a] Density – 4.0 g/cm³.

Wiza, Nuclear Inst. & Meth., Vol 162, 1979, 587





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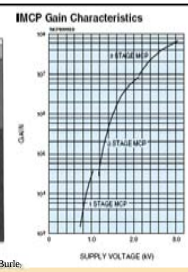
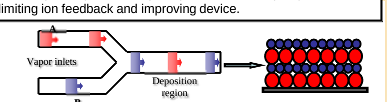


Method

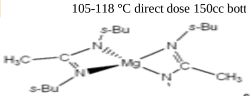
ALD is used to precisely control the composition, emissivity, conduction and ion barrier properties of the functional nanofilms. ALD is a low temperature, thin film growth technique that relies on two sequential, self-limiting surface reactions between gas-phase precursor molecules and a solid surface in a moderate vacuum The self-limiting nature of the reactions precisely and conformally coats high aspect ratio structures (>500:1) and complex, large area, geometries (e.g. MCP) with smooth, dense films. ALD can deposit a variety thin films including oxides, nitrides, metals and combination of these materials in complex nanostructures. It is possible to achieve layers consisting of high secondary electron yield (SEY), pure materials, at required conductivity to meet timing and dynamic range requirements. The purity and barrier properties of the ALD films can be selected to inhibit the release of ions from the film or bulk material, limiting ion feedback and improving device.

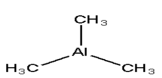
All film depositions performed in Arradiance GEM-D2 ALD system: Oxidant H_2O, 25 °C, direct dose

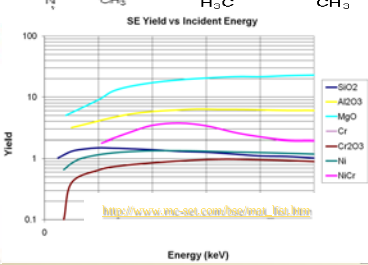


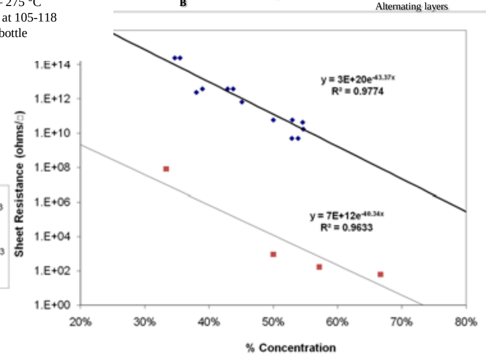
MgO
- Films grown at 225 – 275 °C
- Magnesium Bis(Disecbutylacetamidinate) at 105-118 °C direct dose 150cc bott

Al_2O_3
- Films grown at 225 – 275 °C
- Trimethylaluminum at 105-118 °C direct dose 150cc bottle



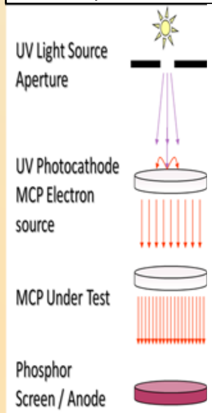


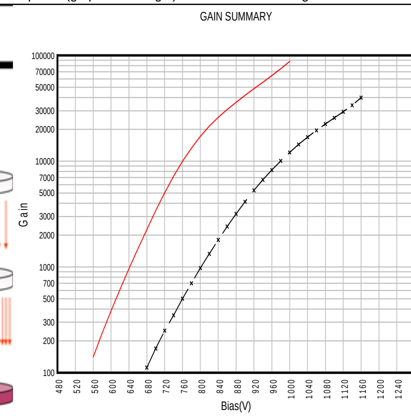


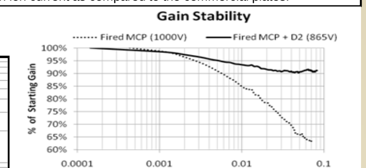


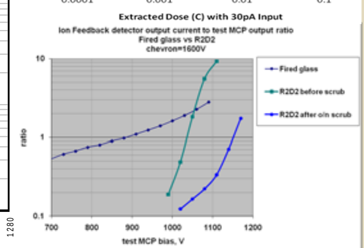
Results – Testing Alumina Dynode

Testing of nanofilm functionalized MCP devices is accomplished using the test configuration shown below left, wherein a UV light source (Penray lamp) is projected thru an aperture onto an MCP (electron source) generating photoelectrons through the interaction of UV light with the NiCr metallization. These photoelectrons produce an amplification cascade within the source MCP which provides a well controlled and uniform flux of input electrons for the MCP under test whose response is measured on the anode. Typical gain vs. voltage response is shown in the middle figure below for a commercial MCP (black) and the Al_2O_3 nanofilm (or D2) functionalized MCP (red) which shows nearly an order of magnitude higher gain due to the engineered nanofilm's secondary electron emission response. MCP lifetime (gain stability with extracted charge) is compared in the top right graph below, which depicts significantly less time to gain stability at a higher percentage of initial gain for the engineered nanofilm. Finally, the ion feedback response (graph bottom right) shows an order of magnitude reduction in ion current as compared to the commercial plates.



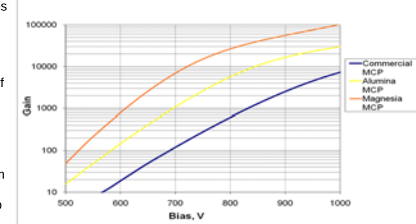






Results – Magnesia Dynode

MgO has a high dielectric constant (8-10), a wide band gap (7.8 eV) with potential applications as: gate insulator, buffer layer for superconductors and ferroelectrics, and high SEY film for plasma displays. MgO has been deposited via ALD using a variety of precursors, (B. B. Burton et al J. Phys. Chem. C 2009, 113, 1939–1946) however the full electrical characterization of the material has yet to be published. MgO is a negative electron affinity material with very high SEY. The chart right shows MCP gain increase due to the high SEY of MgO as compared to a commercial MCP and the same MCP treated with Al_2O_3 nanofilm. Riccardi (P. Riccardi et al. Surface Science 571 (2004) L305–L310) has shown that the electrons emitted from MgO surfaces by a variety of slow ions possess essentially similar energy distributions suggesting the decay of an intrinsic excitation in the solid, as the source. Measurements of the photoelectric threshold performed by Riccardi, show that the position of the surface exciton above the vacuum level, is likely the cause of the high electron yields from MgO compared to other oxides, demonstrating the importance of the surface structure in electron emission from insulators. The precision and control of ALD creates an opportunity to engineer the atomic structure of the surface to further enhance SEY for MS applications.



Conclusion

ALD modification of the emission properties of the MCP pore surface has demonstrated significant performance improvements in: gain (~50 times) and lifetime (achieve stable operation within 0.03C/cm2 extracted charge vs. the typical 0.3C/cm2, at a higher fraction of initial gain -80% vs 40%) as compared to commercial MCP devices. ALD is used to precisely control the thickness, composition, emissivity, conduction and ion barrier properties of the functional nanofilms relying on the self-limiting nature of the surface reactions to conformally coat the complex, large area, geometries of MCPs with smooth, dense films. ALD allows for the exploration of a variety thin films: oxides, nitrides, metals and combination of these materials in complex nanostructures. It is possible to achieve layers consisting of high SEY, pure materials, at required conductivity to meet timing and dynamic range requirements. MCP performance of MgO-based nanofilms has been described, using a novel liquid precursor, Magnesium Bis(Di-secbutylacetamidinate), developed specifically for Arradiance. Negative electron affinity materials, such as MgO, are of interest for MS applications due to the high SEY and energy distributions which are independent of the type of incident particle. ALD brings this capability to MCPs and MS allowing for nanofilm engineering to further enhance the surface response to ions.

More generally, application of the nanofilm technology to mass spectrometer (MS) whereby independent optimization of MCP mechanical, resistive and emissive properties, can improve dynamic range, device variability, dark noise and lifetime performance.