Using Atomic Layer Deposition (ALD) to Enhance Microchannel Plates (MCPs) for Mass Spectrometry

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Scientific Detectors

Overview

A microchannel plate (MCP) is an array of identical parallel open channels with diameters typically between 5 and 25 microns in a glass plate with a thickness that is typically 40-60 times the channel diameter. MCPs are made of a special lead-silicate glass that, when properly processed, makes the MCP an excellent ion detector and electron multiplier, capable of high gain and low noise. While it has long been possible to coat the input and output surfaces of MCPs to enhance their performance, historically it has been prohibitively difficult to use a coating to affect the inner channel surface that is responsible for electron multiplication. Atomic layer deposition offers an opportunity to coat these surfaces and enhance MCP performance.

About Atomic Layer Deposition

ALD (atomic layer deposition) is a process by which coatings of single atomic layers of desired materials are conformally deposited on objects of interest one atomic layer at a time. The simplest ALD process involves the use of two chemical precursors. The precursors are chosen such that each cycle is a self-terminating gas-solid reaction, and so that the chemical reaction between the two precursors produces the desired coating. Coatings are formed by repeated cycles of the same basic process; exposure to the first precursor, flushing out the reaction chamber, exposure to the second precursor, and then another flushing out step. This process is repeated until the desired thickness is reached. The self-terminating nature of the ALD process makes it ideal for coating surfaces that are difficult to access with standard coating techniques, and leads to outstanding thickness uniformity.

Methods

A group of 10 microchannel plates were manufactured using standard MCP processing techniques. The MCP format chosen was a 32 mm outer diameter, 25 mm active diameter plate with 5 µm diameter holes on a 6 µm spacing and a 60:1 l/d ratio (300 µm thick), which is a typical configuration for a mass spectrometry application.

The gain and resistivity of the MCPs were measured and then eight of the MCPs were ALD-coated with aluminum oxide. After coating, the MCP gains were remeasured and then individual and sets of MCPs were used for characterization studies.

Results

MCP Gain

To measure the single MCP electron gain, the input surface of the MCP was illuminated with a uniform source of 300 eV electrons and the input and output currents were measured as a function of MCP bias voltage. The reported gain is simply the ratio of these two currents (Iout/Iin).

The single MCP gain results from a representative MCP are shown in Figure 1. Single MCP gain increased substantially with ALD coating. For the eight MCPs the gain at any given voltage was 10-15 times higher for the coated MCPs compared to their gain prior to coating.

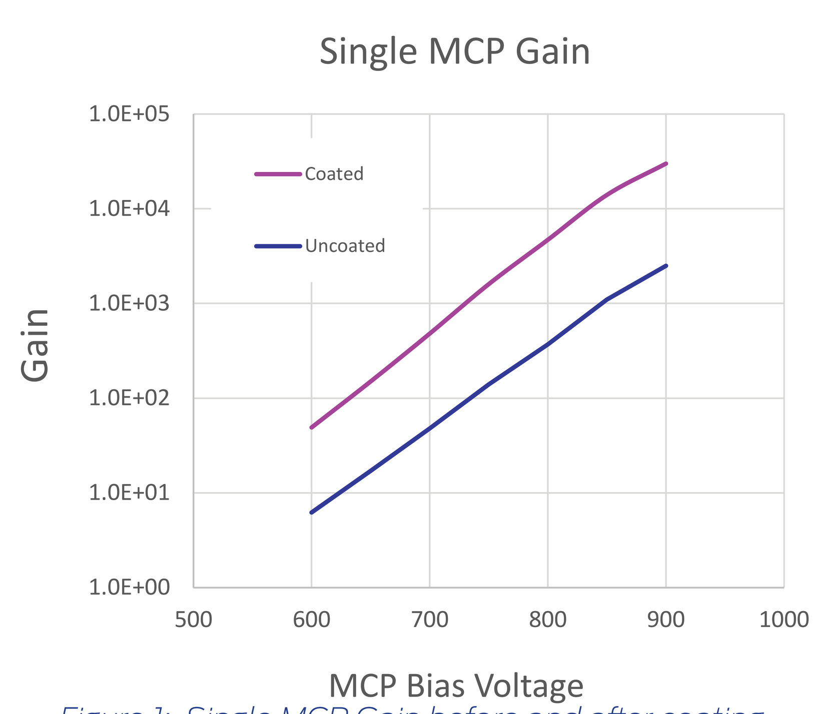

Figure 1: Single MCP Gain before and after coating

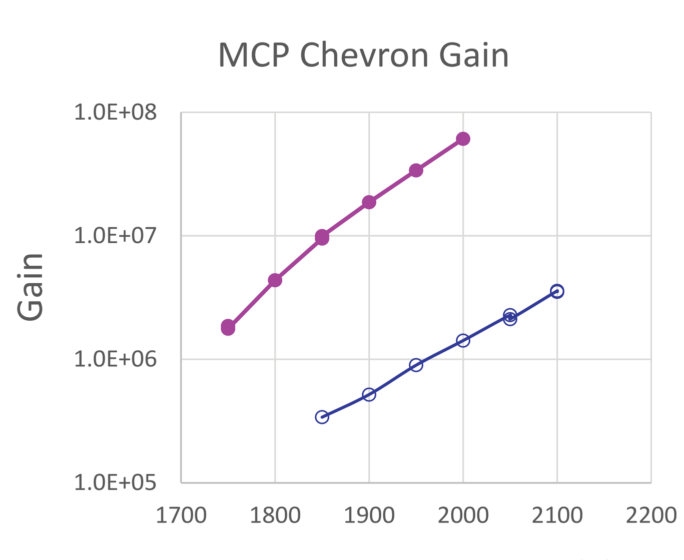

Figure 2: Increase in Chevron-MCP detector gain due to MCP coating

Typically, MCP-based detectors use two MCPs in a stack to produce the higher gains necessary for measuring single ions (1E6-1E7). The gain of the two MCP detectors was determined by measuring pulse height distributions accumulated from many single ion events using a multi-channel analyzer (MCA). Results are shown in Figure 2. The increase in gain for the coated MCPs is significant, increasing by more than an order of magnitude.

MCP Gain Stability (Lifetime)

The electron emission process that MCPs rely on depends critically on the state of the emissive surface, and the electron bombardment from the multiplication process can modify the working surfaces over time. Since electron bombardment drives the aging of the MCP, the process will depend on the gain of the MCP, so gain stability curves are typically plotted as a function of extracted charge rather than time.

Lifetime (gain stability) measurements for two MCP-Chevron detectors (coated and uncoated) were made at fixed voltage exposed to the same UV source. The detector bias voltages were chosen to give approximately the same initial gain.

Results

Chevron-MCP output versus extracted charge curves for coated and uncoated MCPs are shown in Figure 3. Both detectors experience the same initial loss in gain due to the desorption of water and hydrocarbons that are a result of the exposure of the MCPs to atmosphere. After the initial period, the gain is determined primarily by the underlying surface. The gain of the standard MCP is in line with previous measurements. The reason for the increase in gain with extracted charge for the ALD-coated MCPs is not known but has been demonstrated in several measurements of this kind. It may be due to electron-induced modification of the coating.

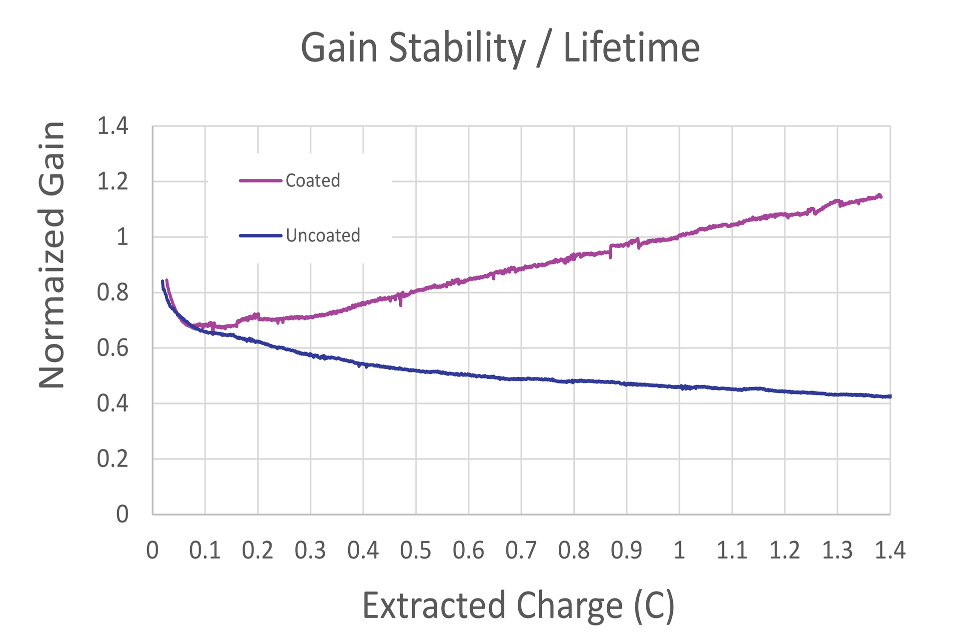

Figure 3: Relative gain as a function of extracted charge for coated and uncoated Chevron-MCP detectors

Resistance Stability

The reduction process used to form the resistive layer of standard MCPs relies on the conversion of lead oxide into lead ions via the removal of oxygen from the glass at high temperature. Because of this, long-term exposure to water in the ambient environment can result in increased MCP resistance.

The resistance changes of MCPs were measured in two ways. First, the change due to ALD processing was determined by measuring the MCP bias current in vacuum at 900V before and after processing. Next, long term resistance stability was measured by maintaining MCPs in air and then measuring the MCP bias current under vacuum at 900V once per day.

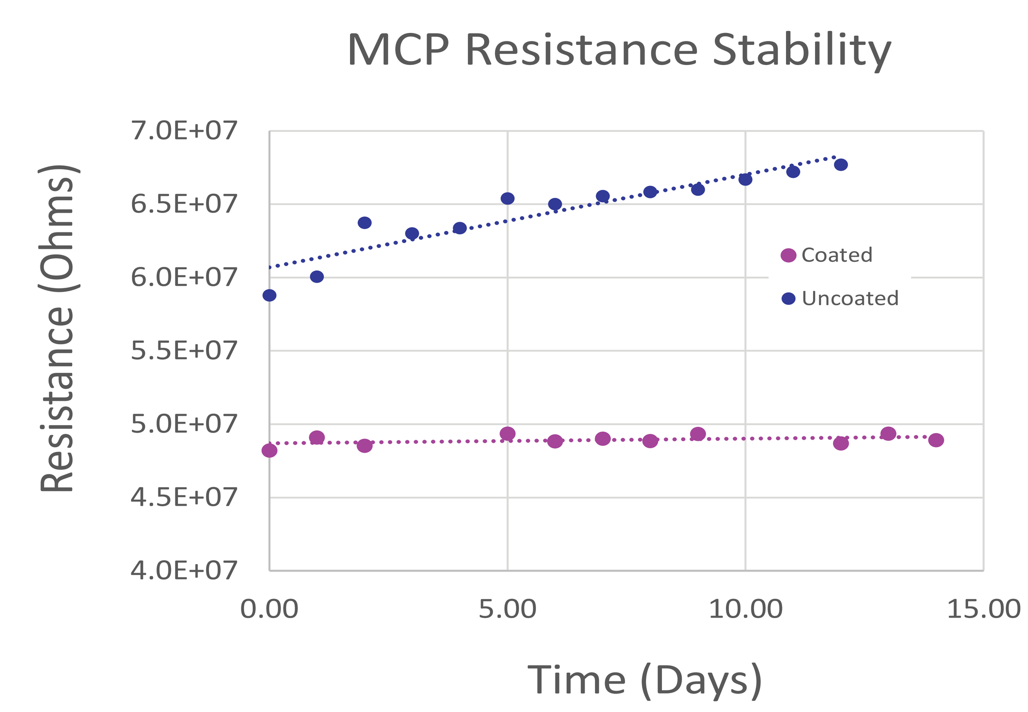

Figure 4: Resistance stability of coated and uncoated single MCPs exposed to atmosphere

Resistance stability results are shown in Figure 4. The ALD processing had the effect of decreasing the overall resistance of the MCPs by approximately 20% compared to their pre-processing values. This is likely because the ALD process occurs in vacuum at a relatively high temperature. The long term resistance drift in the standard MCP is approximately 1% per day, whereas the coated MCP resistance did not drift. This serves as an indication that the aluminum oxide coating has completely covered the channels of the MCP and may serve as a useful method for maintaining a desired resistance over a long period of time.

Operation in a QTOF

To determine the effect of using a coated MCP in a mass spectrometer, three different MCP configurations were subsequently tested in an an optically coupled TOF detector. The normal MCP used in this detector has an MgO coating on the input surface. For this experiment, a completely uncoated MCP was tested, as well as one that had been coated with aluminum oxide. An Agilent 6550 QTOF was run through the autotune sequence and resolution, abundance, and MCP voltage values were compared. Overall abundance and resolution were not strongly affected, except for a slight reduction in abundance at high mass for the uncoated MCP. The gain voltages for the MCPs were significantly different as can be seen in Figure 5.

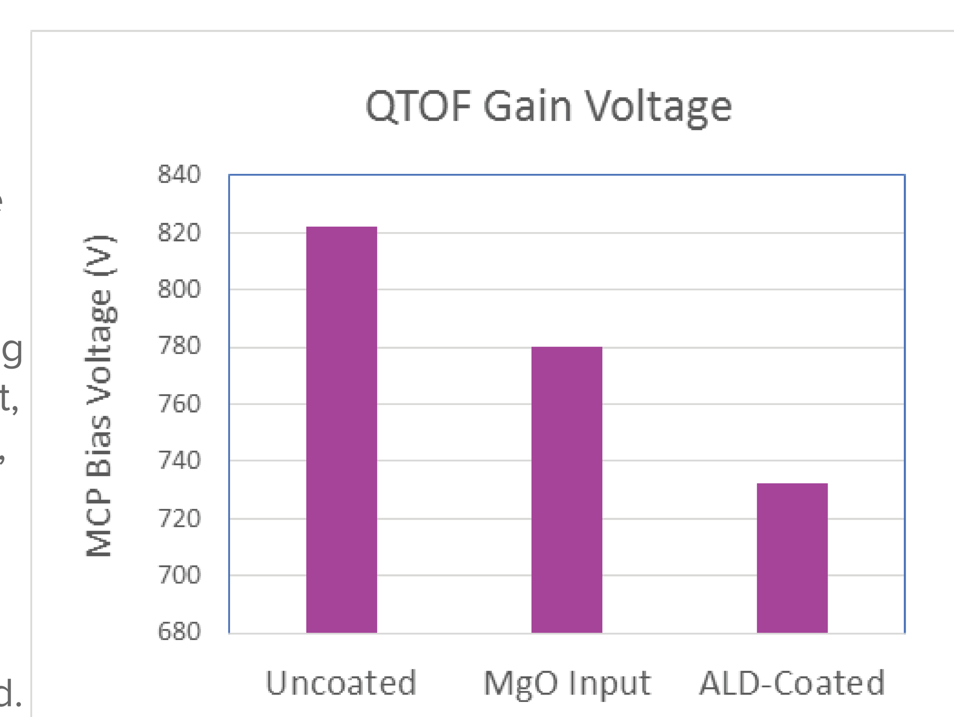

Figure 5: Effect on QTOF tune voltage

Conclusions

- Aluminum oxide coating offers higher gain at the same voltage than the standard MCP surface.
- While the long-term gain stability of MCPs coated with aluminum oxide films includes some drift, the drift is initially upward and may ultimately result in a longer lifetime.
- Coated MCPs have lower resistance drift than standard MCPs.
- ALD coated MCPs offer lower initial tune voltages in a commercial QTOF with no apparent sacrifices in terms of abundance or resolution.