Nano-engineered ultra high gain microchannel plates

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Abstract

Highly localized and very fast electron amplification of microchannel plates (MCP) enables a large number of high resolution and high sensitivity detection technologies, which provide spatial and/or temporal information for each detected photon/electron/ion/neutron. Although there has been significant progress in photocathode and readout technologies the MCPs themselves have not evolved much from the technology developed several decades ago.

Substantial increases in the gain of existing microchannel plate technology have been accomplished by utilizing state-of-the-art processes developed for nano-engineered structures. The gain of treated microchannel plates with aspect ratio of 40:1 is reproducibly measured to reach unprecedented values of $2x10^5$. This gain enhancement is shown to be stable during MCP operation. In addition, the initial experiments indicate improved stability of gain as a function of extracted charge and MCP storage conditions.

We also present results from a fully independent thin film process for manufacturing non-lead glass MCPs using engineered thin films for both the resistive and emissive layers. These substrate-independent MCPs show high gain, less gain degradation with extracted charge, and greater pore to pore and plate to plate uniformity than has been possible with conventional lead glass structures.

Keywords: High resolution, Event counting, Microchannel plate, Detection

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1. Introduction

The compact and efficient Microchannel Plate (MCP) electron multipliers are widely used in a variety of applications ranging from; astrophysical sensors to mass spectroscopy, synchrotron instrumentation, image intensifiers and many others. Recent advances in MCP readouts and their associated electronics allow 2-dimensional imaging of photon/ ion/ electron/ neutral particles with better than <10 μm positional [1] and < 20 ps timing resolution [2] and with very low background rates of less than 0.01 counts/cm²/s. At the same time developments in photocathodes technology have substantially improved and extended the range of sensitivity [3]. However, the state-of-the-art of MCP manufacturing has not advanced significantly since the mid-1970s. The parameters of electron amplification in an MCP device still have relatively large variation from one production run to another. This is the result of difficult to control glass composition and manufacturing processes.

Improved sensitivity, resolution and increased lifetime in image intensifier applications; higher detection efficiency, better time and spatial resolution in scientific instrumentation; emerging fluorescence imaging applications in biotechnology; all demand advances in MCP technology. Although several attempts have been made to produce MCPs with state of the art processing, such as silicon micromachining [4]-[7] and lithographic etching/punching of anodic alumina [8]-[10] none of those technologies matured enough to produce viable microchannel plates.

At the same time, the great progress that has been achieved in thin film engineering makes available many deposition and nano-technologies that can now be used to bring performance and manufacturing improvements to the MCP device. In this paper we demonstrate how these new technologies can be used to improve the performance of existing lead glass microchannel plates by improving their gain and lifetime. In addition, the same thin film technologies enable MCP production from a wide range of substrate materials, separating the MCP manufacturing from lead glass technology. The conduction and secondary electron emission layers of novel MCPs do not have to be determined by the substrate material and can be individually tuned for a particular application. A wide range of substrates can now be used in MCP manufacturing thereby improving many device parameters. The accuracy of lithographic etching can improve the spatial uniformity of MCP devices, the bulk conductive substrates may reduce the ion feedback problems [11], high temperature compatibility may extend the range of opaque photocathodes and the absence of radioactive elements in the substrate will further improve the dark count rate characteristics of MCP devices.

2. Experimental results

2.1 Improvements of existing glass microchannel plates

Gain, lifetime and uniformity are the crucial parameters determining the ultimate performance of an MCP device. Although the processes of MCP ageing are not completely yet understood on the microscopic level [12], it is well known that the secondary electron emission properties of pore walls degrade with the extracted charge [13]. To stabilize the detector operation a time consuming process of electron scrubbing is performed before the MCP devices are delivered. Moreover, gain degradation limits the overall lifetime of the device since the gain compensation, by increasing the operating voltage, has its limits.

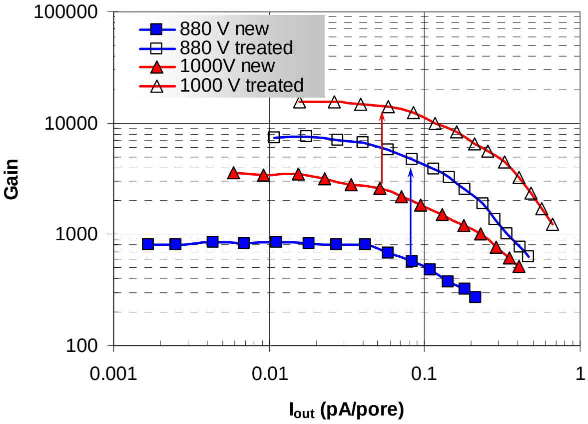

Fig. 1. Variation of commercial MCP gain measured as a function of output current. The gain is measured for a fresh MCP and after the MCP was treated with high secondary electron emission film. The MCP pores are 4.8 µm in diameter, 18 mm^2 active area, aspect ratio of ~50:1, plate resistance ~250 MΩ.. The gain saturates at output currents ~10% of the strip current. The MCP is illuminated with a uniform flux of electrons.

Modification of the emission properties of the existing glass microchannel plates was the first step towards fully nano-engineered conduction and emission films. A set of commercially available MCPs was used. Fig. 1 shows the gain of those MCPs measured before and after the treatment. The gain of treated microchannel plates was routinely measured to increase by a factor of 5-10 for a variety of MCP geometries and initial gains. The gain saturation at high input currents did not change after treatment, as expected, and was measured to onset at usual ~10% of the strip current. Indeed, the current saturation is determined by the ability of the pore to recharge and is mostly governed by the resistance of the pore conduction layer, which we did not modify in these devices. The tunneling of the charge into the emission layer was still the limiting factor for the count rate capabilities of the MCP treated with the emission layer. The uniformity of the treated MCPs was also found to remain unchanged, Fig. 2, confirming the good spatial uniformity of the new treatment.

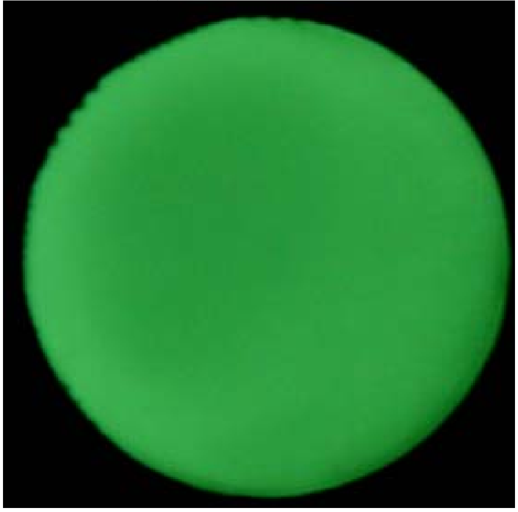

Fig. 2. Photograph of a phosphor screen illuminated by a treated microchannel plate. The same MCP as in Fig. 1 operated at 1000V.

The gain degradation of the treated MCP was found to be substantially reduced, as shown in Fig. 3. The gain reached stable operation after 0.02 C/cm^2 was extracted at a typical output current equal to 10-20% of the strip current, while a similar pre-treated plate required 0.1 C/cm^2 charge extraction.

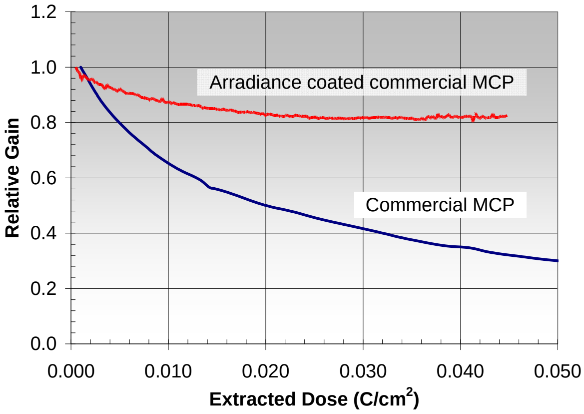

Fig. 3. The relative gain variation measured as a function of extracted charge (ageing curves). Two initially identical microchannel plates are measured: one as received from the manufacturer, while the other was treated for high secondary electron emission. 4.8 µm pores, L/D=50:1, R_{MCP}=100-200 MΩ. The scrubbing was performed at 880 V bias, the output current ~10-20% of strip current.

The same treatment of commercially available MCPs can be used to revive the aged microchannel plates and increase their gain to levels higher than their measured un-aged values.

Fig. 4 shows the gain of two initially identical commercial microchannel plates measured as a function of the extracted charge. One of them (MCP2) was treated immediately after it was received from the manufacturer, while the other was treated after it was scrubbed with ~0.025 C/cm² (MCP1). As seen in Fig. 4, the gain of aged microchannel plate increased by a factor of ~8. After that the ageing curves of two MCPs appeared to be very similar with further scrubbing. The latter fact may suggest that the ageing in lead glass commercial MCPs may be determined by the variation in the interface of resistive/emissive films, rather than solely by the degradation of the secondary electron emission properties of the emissive layer.

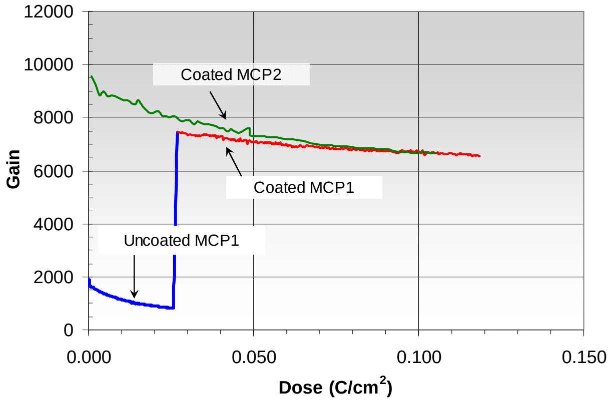

Fig. 4. Ageing curves of two initially identical MCPs with the same parameters as in Fig. 3. The untreated MCP1 was treated for high emission after initial ~0.025 C/cm^2 scrubbing, while MCP2 was treated before the ageing measurements. The gain of aged MCP1 was increased to the values similar to the aged MCP2, after which the ageing curves were found to be very similar to each other. Gain is measured for amplification of electrons.

2.2 MCPs with nano-engineered conduction and emission layers

The conduction and emission properties of the pore walls in the existing commercial microchannel plates are determined by the composition of the lead glass. Hydrogen firing is used for the reduction of the lead glass in order to achieve a desired conductivity, optimized between two conflicting requirements of efficient charge replenishment and low Joule heat generation. The emission properties are also predetermined by the substrate composition as the thin emission layer (silicon oxide), in turn, is formed from the conduction film during this same reduction process. The natural extension of the work reported in the previous section was to build both conduction and emission layers by the newly designed deposition techniques. Since these films are very different in composition, thickness and functionality it is possible, in contrast to the lead glass process, to independently optimize the performance of each film.

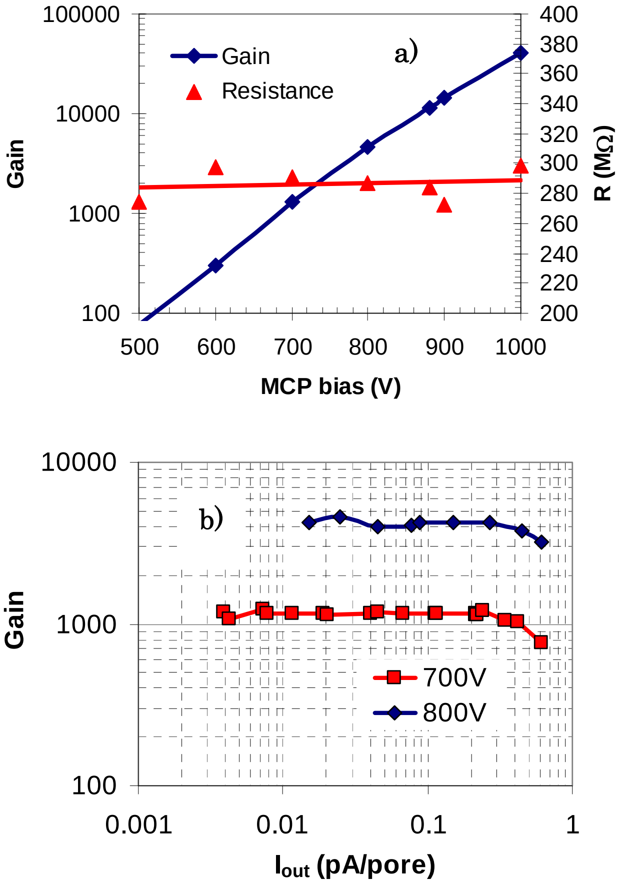

Fig. 5. (a) Resistance and gain of MCP with nano-engineered conduction and emission films. (b) MCP gain measured as a function of output current. Non-lead glass MCP substrate with 10 μm pores, 18 mm active area, L/D=40:1 was coated with both conduction and emission films. Measurements are performed under uniform illumination of electrons.

Preliminary attempts used unfired glass substrates (some of which were lead-free) that had both conductive and emissive films consecutively deposited. The resulting properties of these novel MCPs do not depend on the substrate type on which they are deposited on as long as the adhesion to the substrate is sufficient. Figs 5.a and 6.a show the measured resistance of the nano-engineered microchannel plates with two different types of geometry: ~5 μm and ~10 μm pore diameters. The resistivity of the conduction film was intentionally tuned in order to produce MCPs with target resistances of few hundred MΩ. The resistance was found to be stable at accelerating biases up to 1 kV and the thermal coefficient of resistance was comparable to standard values observed with standard lead glass MCPs. The same graphs show the measured gains under electron bombardment. The gain reached very high values of 40000 for a single stage 40:1 L/D device biased at 1000V. The gain saturation was observed to appear at output currents equal to ~10-30% of strip currents, as seen in Figs. 5.b and 6.b.

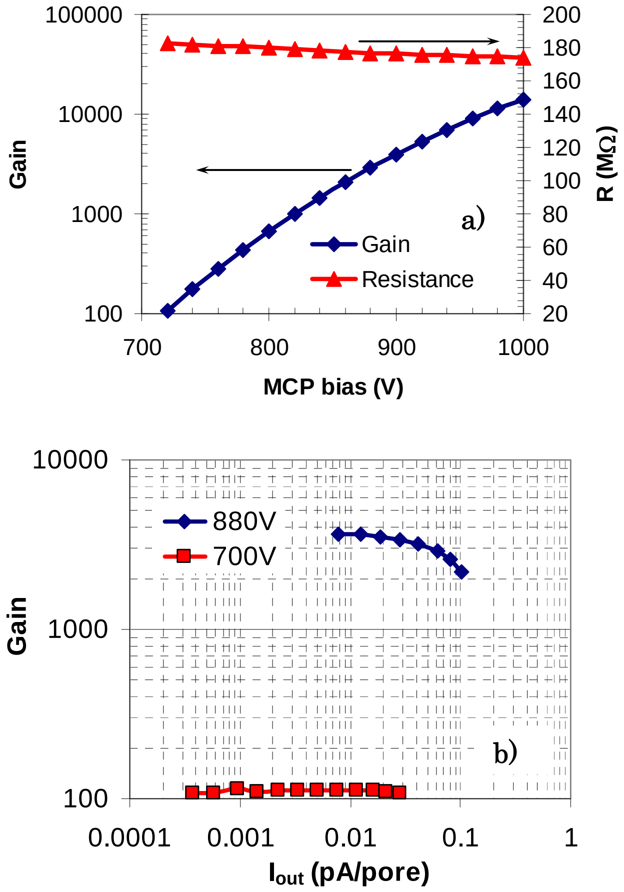

Fig. 6. (a) Resistance and gain of MCP with nano-engineered conduction and emission films. (b) MCP gain measured as a function of output current. Unfired glass MCP substrate with 4.8 µm pores, 18 mm active area, L/D=50:1 was coated with both conduction and emission films. Measurements are performed under uniform illumination of electrons.

5. Conclusion

The novel nano-engineered films were shown to be successfully and uniformly deposited onto microchannel plates. The MCP treatment with high secondary electron emission film leads to a substantial, 5x-10x, gain increase over commercial lead glass MCPs. These devices exhibited extended lifetime and required a reduced scrubbing dose for preconditioning to stabilize gain. Moreover, the same treatment can be used to revive the aged microchannel plates. Very high gains measured with a single stage device may eliminate the need for a multiple stacking configuration where it was necessary in order to achieve acceptable amplification factor.

The demonstrated deposition of both conduction and emission films on a non-lead glass substrate enables the separation of the electrical properties of the resulting MCP from the substrate material, enabling MCP production from a wide range of substrate materials and geometries, including micromachined structures, bulk conductive and/or high temperature compatible substrates.

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