THE 2 MICRON PORE MICROCHANNEL PLATE
Development of the world's fastest detector

prepared by

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03 April 2001

1. INTRODUCTION

On July 1, 1999, BURLE INDUSTRIES purchased the Scientific Detector Products Group from the Galileo Corporation and established BURLE Electro-Optics (BEO). Galileo had long been recognized as an industry leader in microchannel plate and electron multiplier technology. Galileo's roots extend back to the original MCP work of Goodrich (patent #3,374,380) at the Bendix Research Laboratories circa 1965. In later Galileo research, Wiza authored a well-known publication describing microchannel plates and their usage (Nucl. Inst. & Mthd 1979). At the time this was written, the prevailing opinion was that MCPs with channel diameters less than 8 microns would be virtually impossible to fabricate. However, by the mid 1990's, BURLE began shipping a five micron pore MCP as a standard product.

The pore size of a microchannel plate ultimately determines three important performance characteristics. First, the temporal response of the device is determined by the pore size. Microchannel plates are used in specialized applications which take advantage of the rapid response time of this device. In applications such as high energy physics and Time-of-Flight Mass Spectrometry (TOF-MS) instruments, the ultimate performance of the instrumentation is directly dictated by the temporal resolution of the detector.

Time-of-flight mass spectrometers are used in such widely varying applications as quality control in the food canning industry, forensic law enforcement, drug discovery in the pharmaceutical industry, pollution monitoring, and energy research. In all these applications, the microchannel plate is used to detect minute amounts (single ions) of material, separated by mass while traveling down a flight tube. The high temporal resolution of the microchannel plate determines the precision with which the materials are detected and identified.

Reducing the pore size of the microchannel plate will improve the temporal response of the detector. Improvements in detector temporal response will enable instrument manufacturers to shorten the flight length needed to separate the ions by mass, leading to miniaturization and simplification of the vacuum system. These changes will ultimately translate to lower cost and higher performance instruments.

Another parameter that is affected by pore size is spatial resolution. The ability to recognize two adjacent point sources as two events (instead of one) is an important factor in all imaging and position sensing applications. These include such diverse applications as image intensification, night vision, threat warning and imaging secondary ion mass spectrometry. The spatial resolving capability of a microchannel plate is governed by the size of the pore and the corresponding channel pitch (center to center spacing), and the output electrode penetration. Decreasing the pore size of the microchannel plate enables manufacturers to produce devices with increased spatial resolution or smaller devices with the same performance as larger ones.

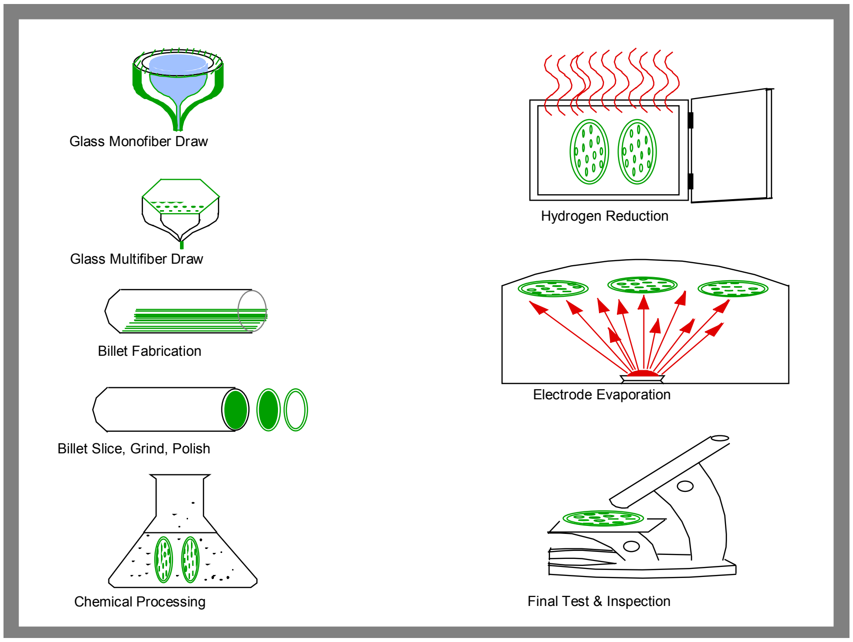
The last performance parameter influenced by pore size is dynamic range. In operation, a single pore of a microchannel plate can be considered as a resistor-capacitor network. An incoming event triggers a cascading of secondary electrons which, in essence, discharges the channel wall. Once discharged, the channel is unable to detect a subsequent event until the charge has been replenished. The dead time of the channel is dependant on the resistance and the capacitance of the channel. Smaller channels recharge faster than larger ones, therefore the dead time is reduced. In addition, the dynamic range is improved by the fact that the channel density increases as the pore size is decreased. Heretofore, the highest dynamic range microchannel plate available was the BURLE 5 micron pore, EDR (Extended Dynamic Range) MCP.

2. OBJECTIVE

As part of a continuing effort to produce higher performance products, BURLE Electro-Optics funded a project to develop the world's smallest pore microchannel plate. Having established the current benchmark with the five micron pore products (plates and detector assemblies), BURLE decided that 2 micron pore MCPs would provide a realistic leap of technology that will set a new standard for MCP performance. At 5 microns, MCPs are capable of producing images with spatial resolution on the order of 80 lp/mm. Theoretical calculations suggest that 2 micron pore MCPs should approach a limiting resolution of 200 lp/mm.. Likewise, the temporal resolution of 5 micron pore MCP Chevron ™ is ≤ 750 picoseconds (FWHM) and a 2 micron pore Chevron ™ should produce a temporal resolution (Pulse Width) of less than 200 picoseconds (FWHM).

3. EXPERIMENTAL PROCEDURE

The fabrication of microchannel plates is a multi step process that melds telecommunication fiber draw, optical glass forming, and silicon wafer processing technologies. Figure 1 is a flowchart that demonstrates a simplified overview of this procedure. In order to produce an MCP, one needs to create the appropriate building blocks to feed the process. Therefore, our effort began by melting new glass materials prior to starting any fiber draw. The cladding (tube) material is a proprietary glass developed by BURLE internally (known as Long Life MCP glass) and the core (rod) bar is a physically compatible glass that has been designed to be chemically unstable and therefore very soluble in acid.



. Figure 1 MCP Fabrication Flow Chart

The core and clad glasses are then drawn into monofibers. Once the monofibers have been fabricated, they are assembled into a hexagonal array and redrawn into multi-fibers. It is these multi-fibers that are used to create boule or billet. This bundle is fused and is then ready for slicing, grinding and polishing much like a boule of silicon. These slices (plates) are then wet chemically etched to remove the cores and leave the microchannel structure. The wet chemistry is followed by a hot hydrogen reduction that gives the material its electrical and secondary emissive properties (further descriptions on the reduction process may be found in a paper by Blodgett (J. Am. Cer. Soc. 1951)). Lastly, a nichrome metalization layer is evaporated onto both faces of the plate to provide for electrical contact.

Fabrication of ultra-small pore MCP's is fraught with difficulties. Microchannel plate manufacturing processes have always been sensitive to the introduction of contaminants from the ambient environment. In order to prevent defects introduced during the fabrication sequence it is important to operate in an environment nearly void of foreign material. BURLE employs world-class clean rooms at the Sturbridge facility for the fiber draw and fabrication of microchannel plate products. The development of ultra small pore microchannel plates requires the production of multi-fibers approaching 0.25 mm (flat to flat) which are very fragile and required the development of a new handling methods. In addition, several process obstacles had to be dealt with. The walls between the micro-pores are so small (sub-micron), they tend to etch completely through during the etch process. Also, microchannel plates with 2 micron pores, fabricated to the ideal aspect ratio of 42:1 would be abnormally thin (84 microns) as compared to the current state of the art MCP (254 Microns). The BEO engineering staff developed several proprietary modifications to the manufacturing processes in order to overcome these obstacles.

4. RESULTS

Working devices were created as a result of this effort. Figure 2 is an electron micrograph of the plate geometry. The first plates produced had pores that were measured at 2.5 microns on a 3.3 micron pitch (C-C). The next process run reduced the pore size to 2.3 microns. The plates exhibit gain greater than 1000 at 1100 volts applied bias and greater than 10,000 at 1300 volts (Figure 3). This was consistent with calculations since the aspect ratio (L/D) was 120:1 for the initial fabrication runs. For those interested in the relationship between gain and aspect ratio (L/D), see the work of Adams and Manley (IEEE Trans Nucl Sci 1966). The large aspect ratio was a result of making the plates 300 microns thick. This larger than optimal aspect ratio was an engineering decision to facilitate handling and initial testing (the optimal aspect ratio would require a plate 84 microns thick). This decision facilitated the grinding and polishing operations, however made the chemical etching portion of the project even more challenging.

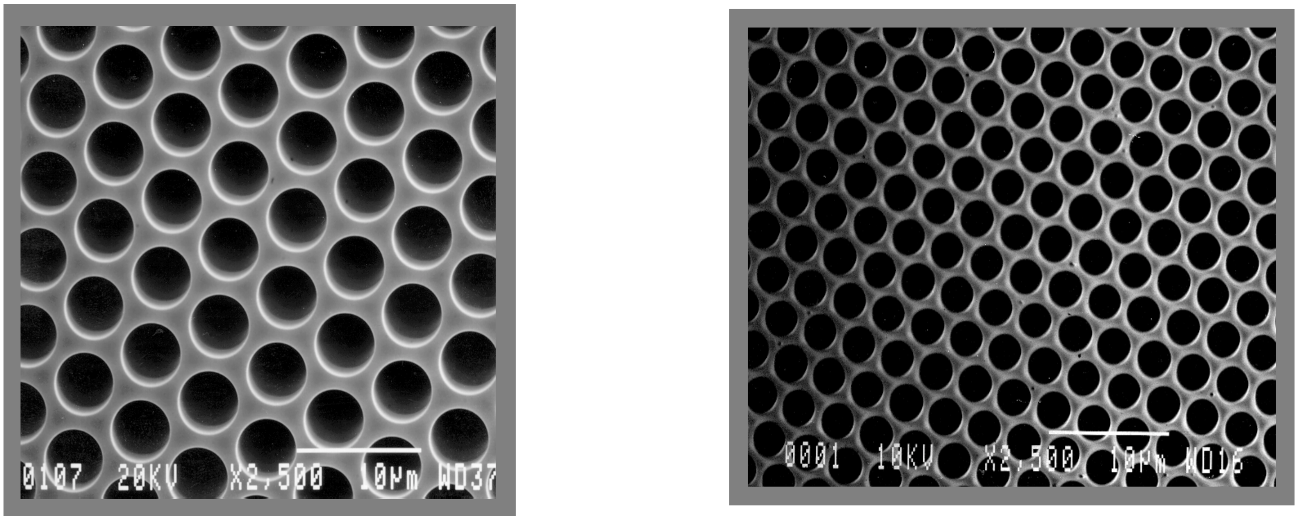


Figure 2 – Comparison of 5micron pore and 2 micron pore MCP's (same magnification)

Several subsequent fabrication runs have been made in which MCPs were ground and polished to a final thickness of 0.006". These MCPs exhibited great fragility in subsequent processing. New tooling and handling methods were required to implement this into production. However, when the MCP was mounted in a modified Time-of-Flight detector cartridge, the MCP showed no signs of greater susceptibility to damage than standard MCPs.

Both the high aspect ratio MCP (0.010") and the normal aspect ratio (0.006") MCPs were tested by mounting them in a standard TOF cartridge. Subsequent testing was done in the production test equipment with modified fixturing. Test data reported is for the 0.006" MCP unless otherwise noted.

4.1 Gain

The gain characteristics of the new ultra-small pore microchannel plate have been characterized. The gain of a single microchannel should not vary with pore size. For a given aspect ratio (L/D), an MCP's gain is relatively unaffected by the pore diameter (there is a lower limit of less than one micoron). The saturated gain, however,

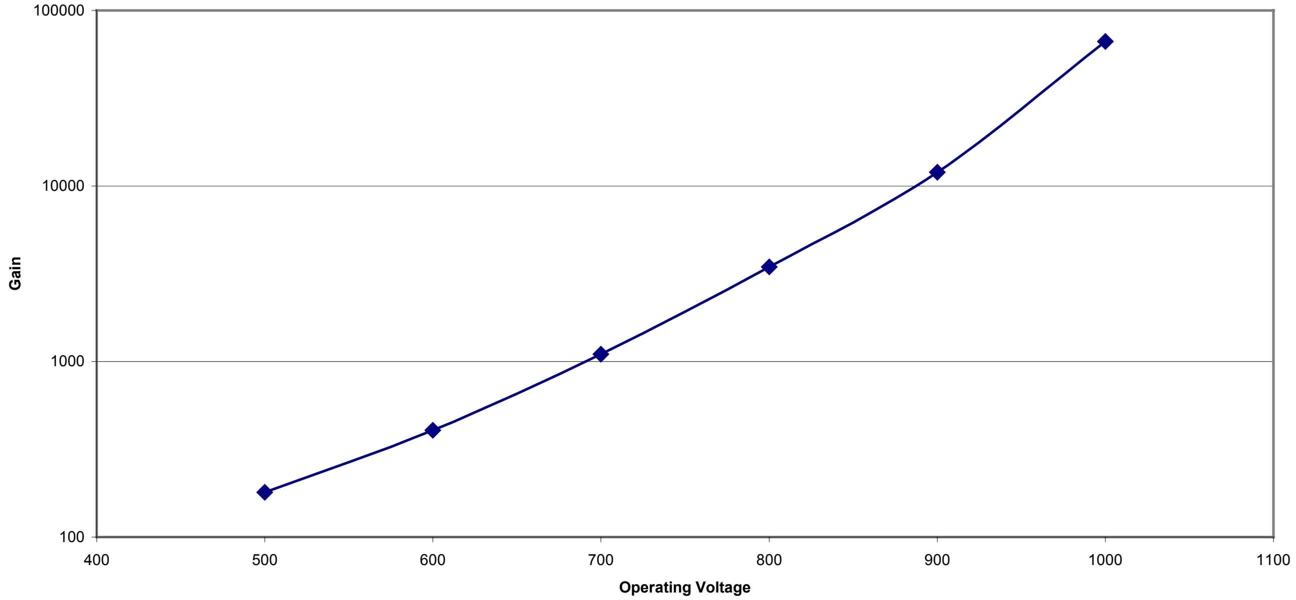


Figure 3 - Gain Curve

may decrease. Saturation is determined by the final space charge of the channel and smaller pores will have smaller space charges. Figure 3 indicates a typical gain response. The measured gains for the 2 micron pore MCP were substantially equivalent to standard 5 micron MCPs and with predicted values.

4.2 Gain Uniformity

The gain uniformity across the imaging area of the developmental MCPs has been evaluated. Uniformities are typically within the 10% specification used for typical image intensifier tube applications.

4.3 Dark Visual, Noise

All microchannel plates are screened for noise. Noise is manifested in a microchannel plate as unwanted output electrons produced in the absence of any input signal. Noise screening on microchannel plates is most often done by proximity focusing the output from the test microchannel plate onto a fiber optic phosphor screen. The dark-adapted eye is then used to ascertain the presence of emission points, hallations or turn on. Some scattered emission points have occasionally been observed, which have been associated with fabrication defects. Further manufacturing process optimization will eliminate these types of defects.

4.4 Bias Current

The bias current of a microchannel plate is the sum total of the DC current that flows through each microchannel. The extremely high channel density of this microchannel plate necessitated that the conductivity of each channel be carefully controlled to limit the maximum current in each channel. The reduced lead silicate glass used for these devices has a negative temperature coefficient of conductivity and as such will overheat and melt down if excessive current is drawn. BURLE engineers have been successful in tailoring the conductivity of each channel in such a way as to produce stable operation at conductivity levels compatible with the micro-miniature power supplies used in night vision systems. Bias currents for the low aspect ratio MCPs have been demonstrated for applications in image intensifier and TOF detector applications.

4.5 Spatial Resolution

The limiting resolution for the 2.3 micron pore MCP's manufactured by BEO has been calculated based upon the Nyquist limit. The Nyquist limit is calculated using the following equation.

Limiting Resolution (lp/mm) = 1000 microns/mm / (C-C spacing in microns X 2 lines)

Under optimum conditions, this new microchannel plate will have a limiting resolution of 156 lp/mm. The current configuration of test equipment in the testing facility is unable to resolve resolution greater than 100 lp/mm, although these MCPs easily exceed that figure. The current Gen IV night vision image intensifier standard is 62 lp/mm and manufacturers routinely achieve 75 lp/mm resolution. Engineering estimates predict that image intensifiers with resolutions of 120 lp/mm should be easily achieved in a production environment with these MCP's.

4.6 Temporal Resolution

Time-of-Flight (TOF) mass spectrometers use MCP based detectors to detect charged particles. Increasing the speed of MCP based detectors allows the instrument manufacturer to either resolve smaller differences in arrival time (hence greater mass resolution) or reduce the length of the flight path while achieving equivalent resolution. Smaller pore size increases the temporal resolution of an MCP. The smaller channel diameter results in a decreased path length across the channel and consequently, shorter transit time. In addition, the overall length of the MCP channels is reduced, further reducing the transit time.

Figure 4 – The 2 micron pore MCP mounted in a Time-of-Flight Detector configuration

The 2 micron pore MCP (0.006" thick) pulse characterization was done in a BURLE standard TOF detector body. The 2.3 micron pore MCP Chevron™ produces a pulse width of less than 400 ps and a rise time of less than 200 ps. Figure 5 is an actual oscilloscope trace produced by a single ion from the BURLE TOF detector with the small pore MCP. The detector was stimulated with nitrogen ions and the output pulse was collected using the 50 ohm, impedance matched, conical anode of the TOF detector.

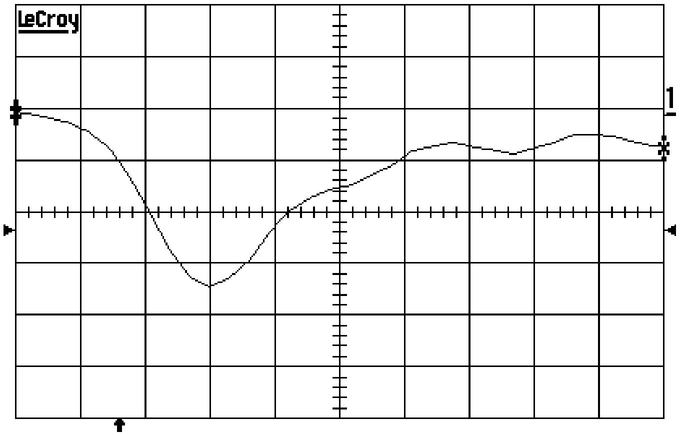


Figure 5 – Actual pulse width of 2 micron pore TOF detector (200 ps/div)

5. CONCLUSION

This engineering program at BURLE Electro-Optics has resulted in the development of a viable manufacturing process for 2 micron pore microchannel plates. Manufacturing of 2 micron pore MCP is continuing and production of small quantities for sale has been completed. Development of high volume processes is continuing. The 2 micron pore MCP meets all design goals and has resulted in an exceptional new detector technology..

Release of this advanced MCP is expected to allow the rapid improvement of several diverse instrumentation systems. Night vision manufactures can take advantage of the increased spatial resolution to almost double the resolution of their image intensifiers. TOF-MS manufacturers can provide significantly increased mass resolution or considerably reduce the size of their units due to the improved temporal resolution of this device. The significant increase in virtually all performance parameters of this device may well yield new and exciting applications for the microchannel plate.