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Introduction

The success of this conference is due to the excellent work of the program committee and cochairs. Their efforts to encourage and solicit papers representing the latest developments in the various photoelectronic technology areas paid off. The high quality of the papers presented at this Image Intensifiers and Applications conference proves again that this technology is still thriving on new ideas and advancements in the state of the art. For example, the announcement of a 2-μm pore diameter microchannel plate should open the door to many new high-speed and high-resolution applications. I can remember when microchannel plates with channel center-to-center spacing of less than 50 μm were classified. The papers speak for themselves; I will not attempt to highlight them here, except to say that they covered the breadth and depth of the current trends in photoelectronic technology. In final analysis, it was the high quality of the work presented and described that made the conference a success and all the authors are to be commended.

C. Bruce Johnson

Contents

Product Development Update: 2 Micron Pore MCPs

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ABSTRACT

Burle is developing a new microchannel plate. What makes this significant is that this MCP should possess performance characteristics better than any other plate currently available. These advances should include but may not be limited to dynamic range, spatial and temporal resolution.

Keywords: Burle, Channel, Detector, Electron, Galileo, MCP, Multiplier, Night Vision, Plate

1. INTRODUCTION

On July 1, 1999, Burle Industries purchased the Scientific Detector Products Group from the Galileo Corporation. Galileo had been recognized as an industry leader in microchannel plate and electron multiplier technology for the past 35+ years. Galileo's roots extend back to the original MCP work of Goodrich (patent #3,374,380) at the Bendix Research Laboratories circa 1965. Since that time, many innovations have moved the state of the art to where it is today. One of the most well known publications describing microchannel plates and their usage was authored by Wiza (Nucl. Inst. & Mthd 1979). At that time it was thought that MCPs with channel diameters less than 8 microns would be a significant breakthrough. It was not until mid 1990's that a five micron pore MCP became readily available. Today we are presenting the progress we have made fabricating a 2 micron pore MCP and discussing some of the benefits which we hope to obtain.

2. OBJECTIVE

As part of our continuing effort to produce higher performance products, we at Burle set out to develop the world's smallest pore microchannel plate. Having established a benchmark with our five micron pore products (plates and detector assemblies), we decided that 2 micron pore MCPs would be a realistic leap of technology that should provide a device that is sure to set a new standard for performance. At 5 microns, our MCPs are capable of producing images with spatial resolution on the order of 80 lp/mm and our expectation is that at 2 microns, the plates should approach a limiting resolution of 200 lp/mm. Likewise, the temporal resolution of our 5 micron pore MCPs is $\leq$ 750 picoseconds (FWHM) and that a 2 micron pore plate should significantly improve this metric as well.

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 any 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. Our cladding (tube) material is a proprietary glass developed by Galileo, known as Long Life™ MCP glass and the core (rod) bar is a physically compatible glass (to the Long Life clad) which has been designed to be chemically unstable and therefore very soluble in acid. Figure 2 illustrates these items prior to the monofilament draw.

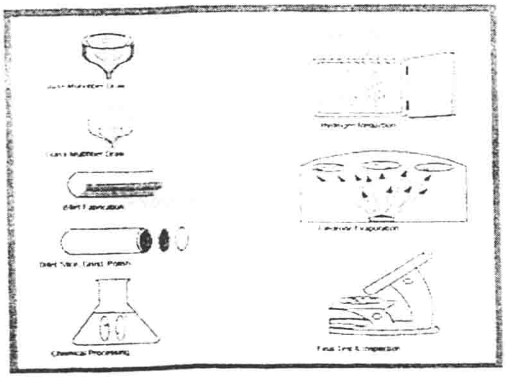

Figure 1 MCP Fabrication Flow Chart

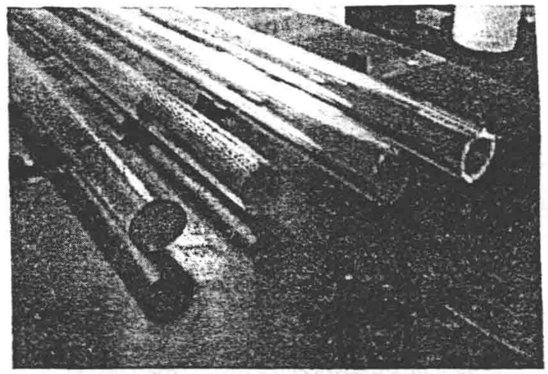

Figure 2 MCP Core and Clad Material

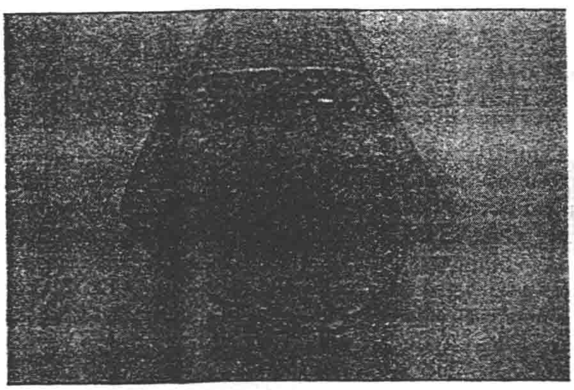

Figure 3 Hexagonal Stack of Monofilament Fibers

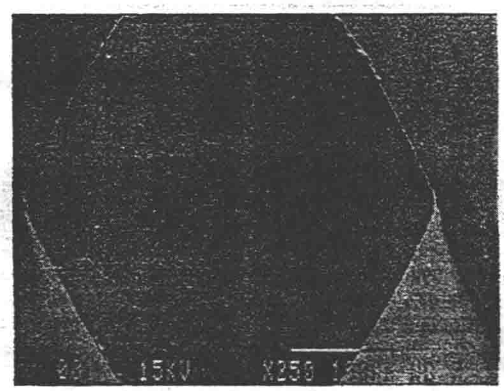

Figure 4 Electron Micrograph of Multi-Fiber

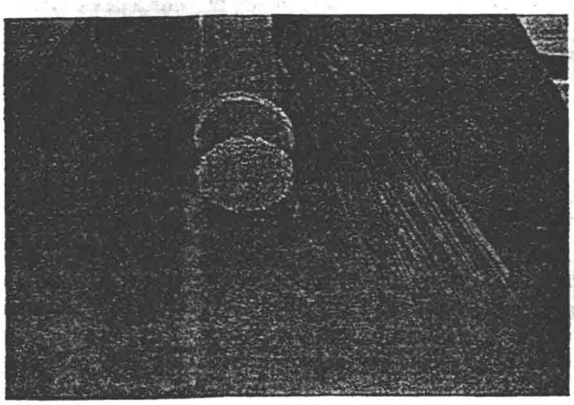

Figure 5 Loose Multi's and Packed as a Billet

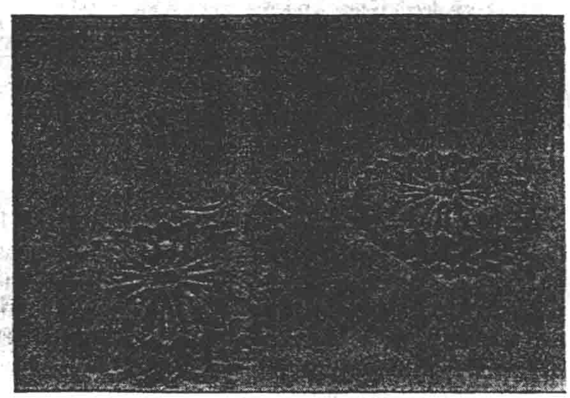

Figure 6 Fused Billets and Sliced MCPs

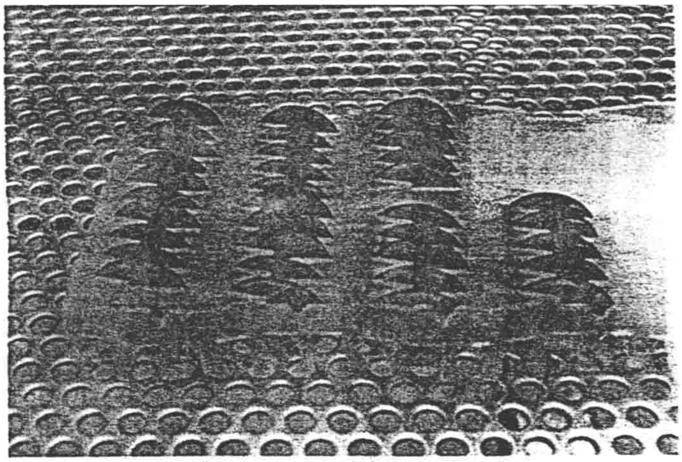

Figure 7 Finished MCPs (Reduced and Electroded)

Once the monofibers have been created, they are group into a hexagonal array (shown in Figure 3) and redrawn into multi-fibers. It is these multi-fibers (Figure 4) that are used to create bundle or billet (Figure 5). Once this bundle is fused, it is ready for slicing, grinding and polishing (Figure 6) 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 properties. For further descriptions on the reduction process I would suggest 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. The plates at this point are complete (Figure 7) and ready for evaluation.

4. RESULTS

Working devices were created as a result of this effort (Figure 8). Figure 9 is an electron micrograph of the plate geometry. The pores were measured at 2.5 microns on a 3.3 micron pitch (C-C). This was slightly larger than our target of 2 micron but a factor of 2 better than our current best. The plates exhibit gain greater than 1000 at 1100 volts applied bias and greater than 10,000 at 1300 volts. This was consistent with expectation since the aspect ratio (L/D) was 120:1. For those interested in the relationship between gain and aspect ratio (L/D), the work of Adams and Manley (IEEE Trans Nucl Sci 1966). The reason for the large aspect ratio was that it made the plates 300 microns thick which is considerably more robust than the same wafer at 100 microns thick. This assisted us during handling and testing but worked against us during etching /core removal. To date we have not yet attempted any of the resolution measurements that were initially described but plan on this as the next step along our journey.

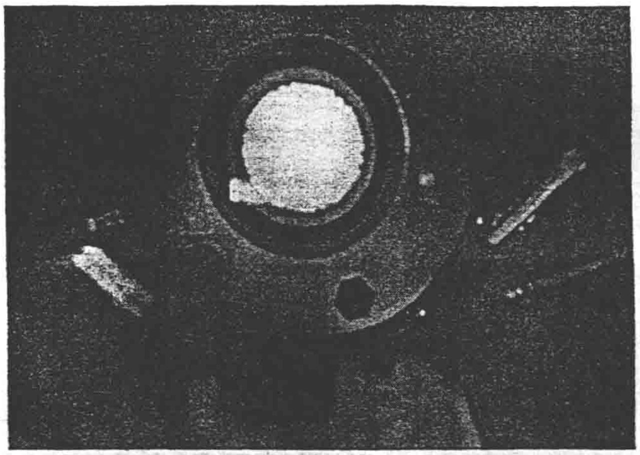

Figure 8 MCP (18mm AA) Lit On Screen

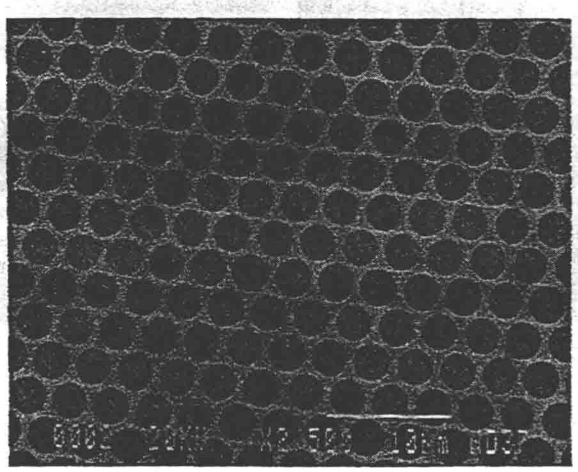

Figure 9 Micrograph of 2.5 micron pore MCP

5. ACKNOWLEDGEMENTS

This work is the result of the hard work and patience of my entire team. I would like to especially like to thank the following people for their contributions as well as putting up with me: Wendy Ciesla, Alex Ferguson, Stan Banford, Noni Lundberg and Serena Woods. Thanks again.

New Frontiers in 21st Century Microchannel Plate (MCP) technology: Bulk Conductive MCP Based Image Intensifiers.

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ABSTRACT

This paper details an image intensifier enhancement program at Litton Electro-Optical Systems (LEOS) and the U.S. Army Night Vision and Electronic Sensors Directorate (NVESD) for the development of an unfilmed bulk conductive glass (BCG) Microchanel Plate (MCP) for use in any image intensifier (I^2) to enhance signal-to-noise, reliability, and lifetime. We will discuss the material characterization associated with this new class of MCP glass. Then we will explore the outgassing and ion feedback properties of a BCG MCP in vacuum demountable experiments. Electrical and optical measurements on BCG MCPs with standard Generation III configuration (9-13 micron channel pitch) will be discussed. Test results will be presented for I^2 made with BCG MCPs. The goal of this program is to produce a high performance Generation IV or greater I^2 with a state-of-the art bulk conductive glass MCP in order to provide enhanced imaging capability for 21st century night vision systems.

Keywords: Image intensifier, night vision, microchannel plate, MCP, bulk conductive, BCG

1. BACKGROUND

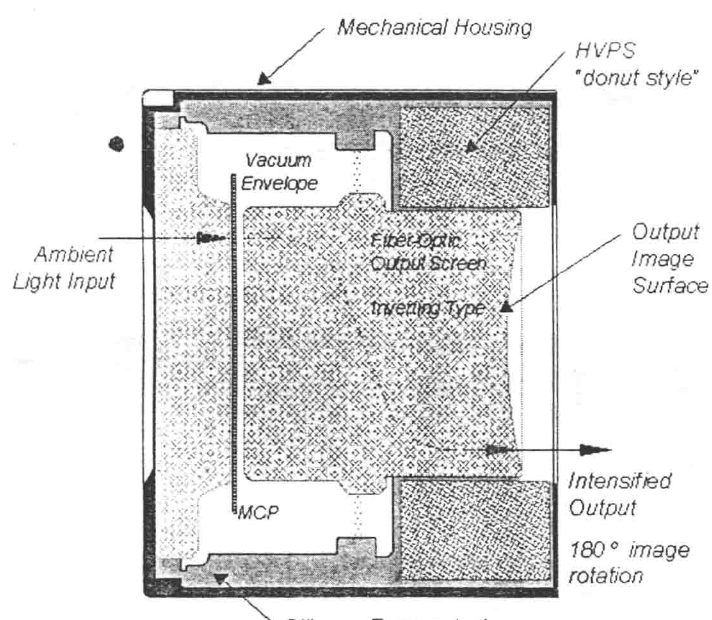


Fig. 1 Structure of a conventional image intensifier device

Fig. 1 above illustrates the structure of the modern Generation III image intensifier tube (I[2]), comprising a gallium arsenide (GaAs) photocathode, a microchannel plate (MCP), and a phosphor screen[1]. The photocathode comprises a semiconductor material, usually GaAs, that produces photoelectrons in response to incident photons. The photogenerated photoelectrons are accelerated toward the MCP by an applied voltage. The MCP amplifies the incident electron flux approximately one thousand times. The amplified electrons exiting the MCP are in turn accelerated toward the phosphor screen and converted to a visible image by the phosphor. The performance of the photocathode is highly improved by the formation of a thin negative electron affinity (NEA) layer on the photocathode surface facing the MCP[2,3,4]. This layer is usually composed of cesium/oxygen (Cs:O). The continued effectiveness of the NEA layer is dependent on the preservation of its chemical integrity. To achieve this, the interior of the I[2] tube is pumped and sealed to ultra-high vacuum. The amplification mechanism of electron flux formation by the MCP is the following: every time an electron strikes the inner wall of a microchannel, an avalanche of secondary emission electrons is formed. These electrons strike in turn the walls of the microchannels to generate more electrons, and so on. The process is illustrated below in Fig. 2.

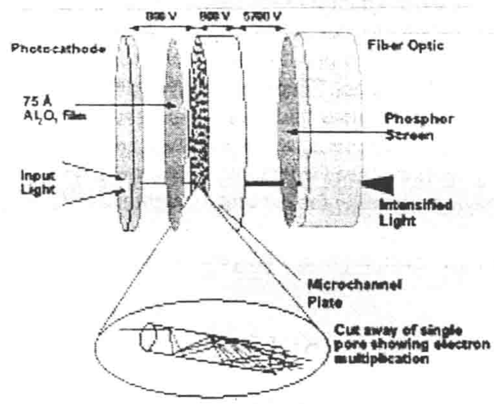


Fig. 2. Electro-Optical Mechanism for Filmed MCP based I[2]

Unfortunately, the electrons impinging on the walls of the MCP channels also release ions and neutral gases adsorbed on the surface of the microchannel walls. These ions and neutral gases are conventionally referred to as "poison species." Positive ions are especially dangerous, as they are accelerated toward the photocathode and can damage the NEA layer, thus compromising the photoemissive property of the photocathode. The predominant poison species in an I[2] tube are oxygen, water, hydrogen, carbon monoxide, and carbon dioxide, all of which generate positive ions. Fig. 3 below shows a residual gas analyzer (RGA) spectrum taken at LEOS of the gases emitted by a conventional MCP during high temperature processing.

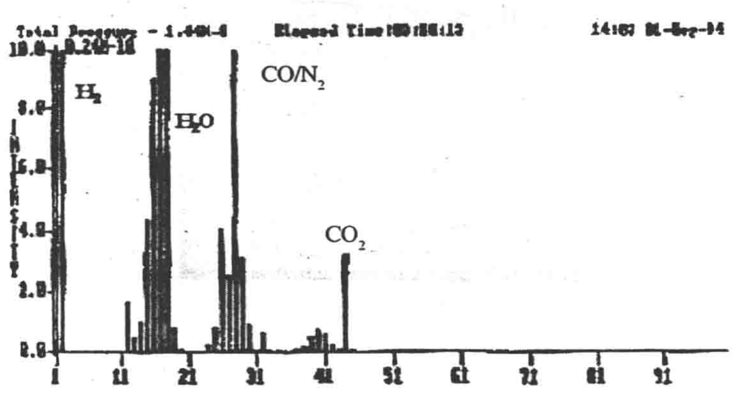


Fig. 3 RGA spectrum from the bakeout of a conventional MCP

The phenomenon of the incidence of the ionized species outgassed from the MCP onto the surface of the photocathode is commonly known as "ion feedback." The technique conventionally used to prevent the poison species from damaging the photocathode is the placement of a barrier layer at the input of the MCP[5,6]. This ion barrier layer is usually formed of a dielectric material. Fig. 2 shows a barrier layer formed of aluminum oxide (Al_2O_3), but other insulators, such as for example silicon monoxide (SiO), can also be used. The ion barrier layer is very effective in reducing ion feedback, but it has the drawback of acting as a scattering/absorbing medium for the electrons emitted by the photocathode, thus decreasing the signal-to-noise ratio and the resolution of the I^2 device.

2. UNFILMED MCP BASED IMAGE INTENSIFIER TECHNOLOGY

In an attempt to avoid the drawbacks of the ion barrier layer, several authors[7,8] have experimented with building Generation III I^2 tubes containing MCPs without the dielectric film. The resulting intensifiers had a useful lifetime of less than 100 hours, due to the contamination of the Cs:O surface. Litton Electro-Optical Systems (EOS) was the first company to successfully fabricate a long lifetime I^2 with a single uncoated (unfilmed) MCP[9]. The I^2 performance was comparable to the performance of a conventional filmed I^2, as illustrated in Figs. 4a and 4b below, in standard U.S. Army accelerated (5X) lifetime testing.

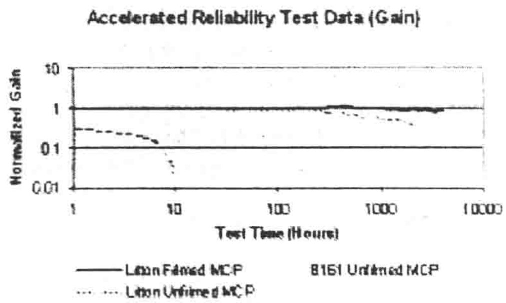


Fig. 4a Gain comparison for intensifiers containing a filmed MCP, an unfilmed MCP with 8161 glass, and an MCP formed of Litton high performance glass.

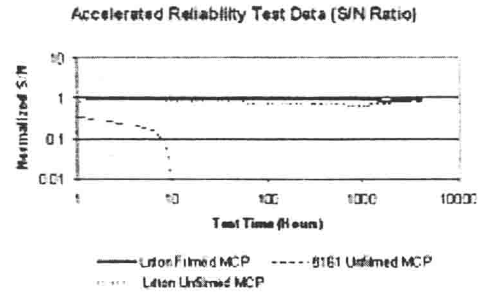


Fig. 4b Signal to noise ratio comparison for intensifiers containing a filmed MCP, an unfilmed MCP with 8161 glass, and an MCP formed of Litton high performance glass

The use of unfilmed MCP I^2 technology, coupled to autogating of the power supply and halo reduction, has allowed the achievement at LEOS of unprecedented and industry leading I^2 performance as shown in Fig. 5. The LEOS halo free I^2 and autogated power supply technologies are discussed in more detail in another article in this SPIE volume.

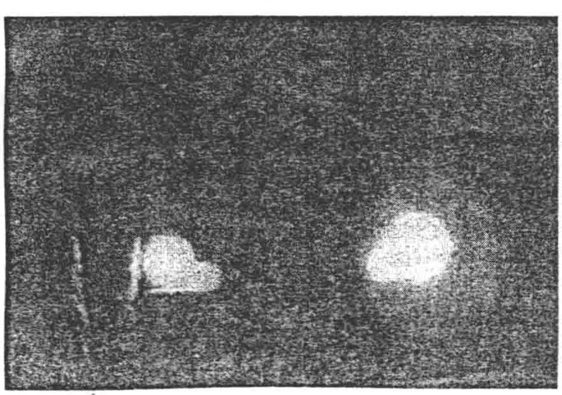


Fig. 5a Standard Generation III I^2

Fig. 5b Unfilmed Generation IV "Halo Free" I^2

3. UNFILMED BULK CONDUCTIVE GLASS MCP TECHNOLOGY

LEOS has shown that it is possible to build long life I^2 tubes by using unfilmed MCP technology. In this process, the MCP is fabricated of a proprietary high-performance glass, a type of insulating glass having the property of producing a low amount of poison species. Conventionally the MCPs used to fabricate I^2 devices, including Litton high performance MCP and the standard 8161 MCPs, are formed of insulating glass having as main components silicon and/or lead oxides. Conductive contact films are formed on the insulating MCP so as to apply a bias to the electrons crossing the MCP channels and cause the electrons to move through MCP channels forming avalanches of secondary emitted electrons, as discussed above. One of the drawback of MCPs formed of insulating glass is the amount of ions and neutral gases adsorbed to the surface of the MCP and emitted in the tube during operation. Even when special glasses are used, the elimination of poison species from the MCP channels is a very difficult procedure. The process of preparing a MCP formed of insulating glass, is also complicated. For the electrons to move through the MCP's microchannels and the I^2 to be operational, it is necessary to form on the MCP wall surface a thin conductive film layer. This is conventionally accomplished by applying to the MCP a surface heat treatment, known as hydrogen firing, in a hydrogen atmosphere [5, 9]. This process creates a thin surface layer in the microchannels that provides electron conduction. This surface layer becomes unstable due to long duration electron bombardment occurring during normal operation of the I^2. The surface instability contributes to the degradation of the device.

The degradation of the thin conductive layer is due mainly to two factors[10]. The ability of the thin conducting layer to emit and replenish electrons decreases gradually with time of operation, causing a decrease in the efficiency of the MCP as an electron multiplier. Also, large amounts of hydrogen from the hydrogen firing process are present at the surface of the thin conducting layer. The hydrogen produces either hydrogen ions or, reacting with oxygen in the glass, water ions. Hydrogen and water ions are positively charged and are accelerated toward the photocathode by the voltage bias of the intensifier. The ions impinging on the photocathode damage its NEA layer and decrease the useful lifetime of the intensifier. The high resistivity of the insulating glass is also undesirable, as it limits the dynamic range of the I^2. In a standard MCP made of insulating glass the electric field is necessarily parallel to the channel walls, as the only conductor in the microchannels is the thin surface layer.

In a MCP formed of bulk conductive glass (BCG) glass the electric field can propagate inside the MCP glass. Therefore, the microchannels can be shaped so that the electric field is at an angle with respect to the channel walls. Thus any liberated ions from the MCP surface during I^2 operation will follow these electric field lines back to the MCP walls and not to the photocathode. The use of bulk conductive glass to replace insulating glass in MCP fabrication was suggested many years ago[11,12] as a solution to the problems discussed above. However, the lack of glass chemistries with adequate composition and of the technology to shape such glass was an obstacle to the practical realization of an I^2 with a BCG MCP. In recent times, studies performed by Yi, Yu, and Huen[9,10] indicated that phosphate glasses may have the properties needed for the successful fabrication of a BCG MCP.

4. LEOS BCG MCP DEVELOPMENT APPROACH

An evaluation of phosphate glasses for the fabrication of MCPs to be used in I^2 was conducted at LEOS. The evaluation was conducted using known theoretical results and a newly developed demountable system, and focused on the reduction of poison species from the microchannels of the MCP and the development of a new technique to handle the phosphate glasses.

4.1 Theoretical Tools

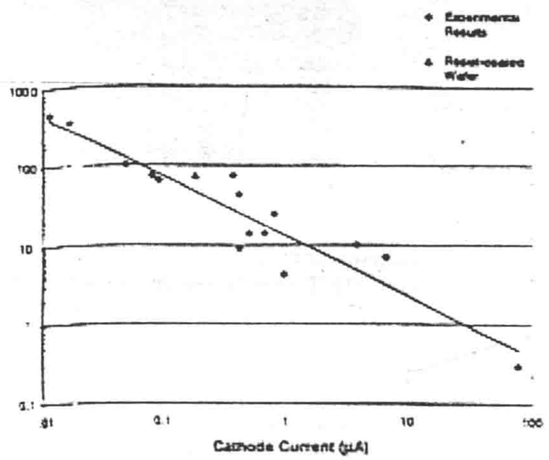
Several studies have been performed by previous authors on the mechanism and effects of poison species in I^2. The results of the studies were crucial in determining the significant tests to be performed and in interpreting the results of the tests. The studies are briefly described below, to clarify the development strategy. Sandel et al.[13] developed a model to help understand the effect of different amounts of poison species in an I^2 device. This model can be used to help identify the amount of poison species in an I^2 tube. Sandel's general equation to describe the normalized gain decay of an I^2 tube is,

$$G/G_0=\{1-\beta\ [1-\exp(Q/Q_H)]\}^{-1} \qquad (1)$$

where G is the gain, G_0 the initial gain, Q the total charge per unit of MCP area extracted from the MCP, Q_H is the "half life" charge density characterizing the decay, and the "population constant" β is defined as:

$$\beta=[1-n_1/n_2]^{-1} \qquad (2)$$

where n_1 is the "source" species population responsible for the photoemission and n_2 is the poisoning species population. The model predicts an exponential gain decay for the case of an infinite poison species source (such as a vacuum leak), a hyperbolic gain decay when the poison species population is comparable to the source species population, and a substantially constant gain when the poison species population is much smaller than the source species population. Thus, fitting the decay curve with equation (1) can be used to calculate the population constant β and estimate the amount of poison species generated from the MCP. This theoretical analysis allows the identification of the processes causing a change in the poison species population in the I^2 tube. Rodway and Allenson[4] and Sen et al.[14] proved that cathode fatigue measurements provide an indication of the cathode reliability. Figs. 6a and 6b, quoted from Sen et al.[14], illustrate how the cathode lifetime is shorter at higher cathode currents, and that the slope of the decay of the cathode current of the time decreases and stabilizes as the cathode is aged. Thus, the measurement of the cathode current versus time can be used as an indicator of cathode reliability.



1. Experimental results of cathode I/e lifetime vs cathode current, making all other parameters constant (e.g., no cesium replenishment).

Fig. 6a Dependence of cathode lifetime on cathode current[14]

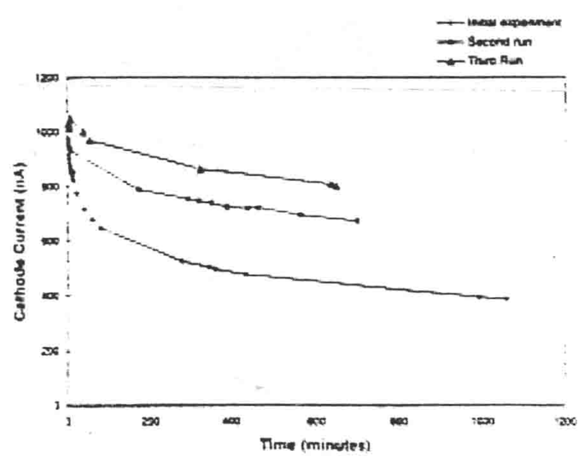


FIG. 2. Decay of cathode current with time. Three consecutive runs were performed at the same position on the cathode. At the end of each run, the laser power was increased to bring the cathode current back up to its initial value. Increasing lifetime with each consecutive run illustrates one way in which lifetime depends on the history of the cathode.

Fig. 6b Decay of cathode current with time[14]

4.2 Experimental Tools

A demountable system, allowing the testing of the MCP without the need for its insertion in a fully-built I^2, was developed at LEOS. The results of experiments conducted in the demountable system were interpreted with the help of the theoretical tools described above. The schematic of the demountable is shown below, while Fig. 7b illustrates the final configuration of the assembled system.

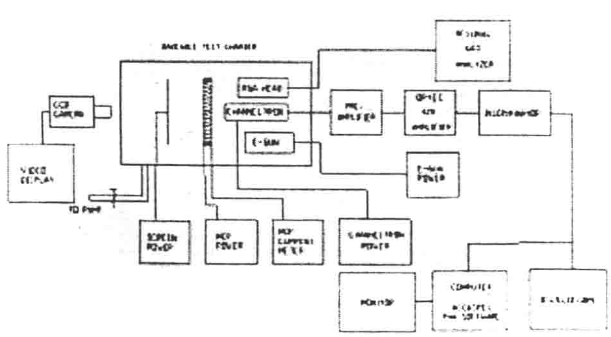


Fig. 7a Schematic layout of the LEOS demountable apparatus for MCP evaluation

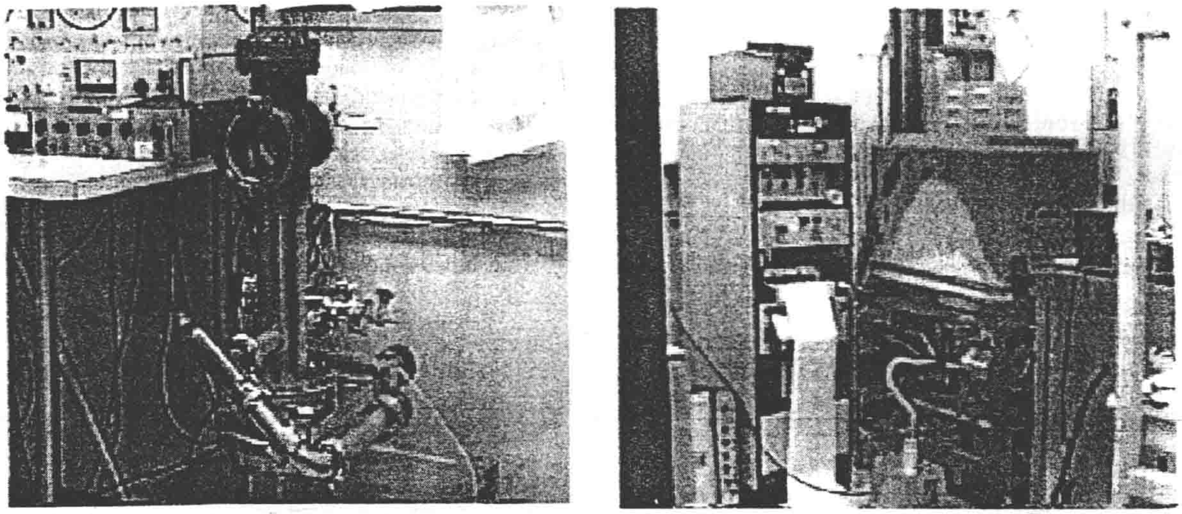


Fig. 7b Physical appearance of the LEOS demountable apparatus.

Several materials were considered for the fabrication of BCG MCPs at LEOS. Semiconductor materials such as silicon would appear to be a natural choice. However, detailed studies of the electric field within a MCP soon caused this avenue to be discarded. While silicon is economical and easily available, and the silicon processing technology is well developed, the material cannot be fabricated to have a resistivity high enough to support the high electric field needed for the use of a silicon MCP as an effective electron multiplier within an I^2. Other semiconductor materials were soon discarded for similar reasons. The phosphate glasses studied by Yi and Yu[10] were soon identified as the most promising candidates for the attempts at fabricating a BCG MCP. Yi and Yu's experiments on phosphate glass show that it can be used to produce MCPs having high gain at voltages comparable to voltages conventionally used in I^2. In addition, the phosphate glass had a more homogeneous composition and its surface contained much less hydrogen than the surface of a similarly processed MCP of conventional MCP glasses after hydrogen firing. The reduced amount of hydrogen causes the BCG glass to have a much smaller ion feedback with respect to MCPs formed from conventional MCP glass. The reduced ion feedback allows the construction of I^2 tubes having increased lifetime and reduced noise figure. Fig. 8[10] shows the percentage of elemental hydrogen with increasing depth from the wall of microchannels from a confentional MCP (Fig 8, dotted) and a BCG MCP (Fig. 8 solid) as measured by Yi and Yu with the use of Rutherform Backscattering Spectroscopy (RBS), Particle-Induced X-ray Emission (PIXE), and Elastic Recoil Detection (ERD). It should be noted how much higher is the hydrogen concentration at the surface of the microchannel in the MCP composed of conventional insulating glass, compared to the minimal hydrogen concentration at the surface of the BCG MCP (Fig. 8). Yi and Yu's results[10] shown below are consistent with RGA monitoring of bakeout products from BCG and conventional MCP's and ion feedback measurements conducted at LEOS.

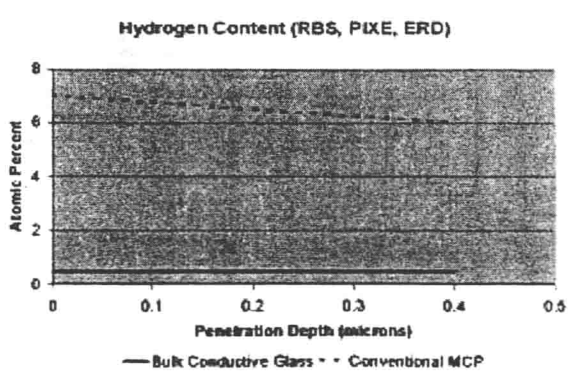


Fig. 8 Hydrogen penetration depth comparison with convention