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Unique Microchannel Plate Process Doubles MCPI Resolution

Abstract

Applying a dielectric layer to the output of a microchannel plate (MCP) has allowed the screen voltage of a sealed microchannel-plate intensifier tube (MCPI) to be raised to over 10 kV, producing a field strength of 36 kV/mm without any detectable field emission or breakdown of the MCP/screen gap. Tube resolution exceeded 16 lp/mm at 50% modulation.

Breakdown is higher in a dielectric than in a vacuum. In a concept being patented by Gary Power, a few- μm -thick layer of a dielectric was sputtered onto the output surface of an 18-mm MCP, which was incorporated into a tube under a contract for four tube starts. This process is applicable to any device incorporating a proximity-focused MCP and screen, including streak tubes and gated MCP x-ray imagers.

Other improvements discussed include a patented use of a collimator for eliminating the electrons that are elastically scattered from the screen. This method also provides for further improvement in screen gap limited resolution to any desired degree by eliminating electrons with high transverse energy. This occurs at the expense of output brightness, which can be recovered through an appropriate increase in screen voltage.

1. Introduction

Image intensifier tubes are electro-optical devices that are used to detect, intensify, and shutter optical images from the near-ultraviolet to the near-infrared regions of the electromagnetic spectrum. These tubes are used for intensifying weak images for night vision and night blindness, for astronomy, electron microscopy, medical research, radiology, and as high-speed light shutters. In our applications, image tubes are used for intensifying images and as "active" light shuttering devices, permitting very short exposure times.

The microchannel plate intensifier (MCPI) is the most significant element limiting the resolution of all the systems in which it is used; this was emphasized in 1988 at the San Diego SPIE meeting. The primary impact is reflected on streak cameras using internal MCPs or external MCPIs and is being felt on other systems using the newer, high-resolution CCD readout devices. Many of these systems will require resolution improvements to continue their development and to advance diagnostic capabilities. Currently, standard second-generation intensifier resolution is about 8 to 12 line-pairs per millimeter (lp/mm) at 50% modulation and about 24 to 34 lp/mm limiting resolution. Manufacturers have shown an interest in achieving improvements in this area, and recent developments have resulted in significant improvements.

Recent tests¹ concluded that the screen region is the most significant contributor to the poor resolution of MCPIs. Major factors include the high transverse energy and the large energy spread of the electrons leaving the MCP. Additionally, electrons are elastically scattered from the screen aluminizing layer, with the second impact at distances up to twice the MCP screen spacing from the first impact. These concerns represent the main focus of this paper.

2. Background

The intensifier tube we use is shown schematically in Figure 1. It consists of an evacuated enclosure containing an image sensor (a photocathode) for converting an incident radiant image to a low-energy

Figure 1. Factors affecting intensifier resolution.

electron image; a proximity-focusing electron lens for focusing the electron image; a microchannel plate (MCP) for amplifying the electron image current; a second proximity-focusing lens and a phosphor screen for converting the electron image to a light image.

Several parts of these proximity-focused MCP "wafer" intensifier tubes have been suspected of contributing to the poor resolution of these tubes. (Refer to Figure 1 for a schematic representation of these regions of the tube.) The areas of concern are described below.

2.1 Cathode Window Fiberoptic NA and MCP Scattering

While light entering the core glass of a fiberoptic faceplate within the numerical aperture (NA) of the fiber is restrained to stay within the core, light that enters the cladding is free to scatter, unrestrained, inside the faceplate and exit some distance laterally from its entrance. Additionally, light that enters the core glass at an angle greater than the numerical aperture angle leaves the core glass and propagates within the cladding. Using large numerical aperture fibers minimizes the latter effect. The NA of faceplates is 1.0 for nearly all intensifier applications. The cathode thickness is sub-micron and, therefore, no significant image spreading occurs within the cathode material. However, a light ray passing through the cathode scatters when it strikes the shiny surface of the MCP and may return to the cathode, producing electrons from areas far from the original position, an effect that is independent of window type. This condition would be worse for light coming in at greater angles. Lowering the NA of the cathode faceplate, effectively blackening the MCP surface, and using plated webbing (see below) to block cladding transmission, may be of benefit. However, reducing the NA of the cathode window will reduce the tube sensitivity, since most input sources for intensifiers have NA 1.0 output fibers.

We have investigated the effect on resolution of blackening half of the MCP input surface with two to three microns of carbon, to reduce reflection from the MCP surface. The attempts were unsuccessful in producing any MTF change. We concluded that carbon is specular at two to three microns, and reflects light instead of absorbing it. It would require thicknesses comparable to the MCP pore size, or greater, to produce the desired effect. Cr_2O_3 and other materials were tried, without success, and the project was abandoned.

Approximately 10% of the light travels within the cladding and is free to scatter and affect resolution. This light can be effectively reduced by two orders of magnitude without affecting transmission within the core glass by a special process for which we are currently pursuing patent protection.

Typical data on faceplates show resolution to be 42 to 55 lp/mm for 50% modulation. In contrast, intensifiers typically have resolutions of 8 to 10 lp/mm for 50% modulation. However, with the race to improve intensifier resolution, application of this technology may soon be beneficial.

2.2 Cathode Focusing Lens

The transverse energy of the electrons leaving the cathode, and the characteristics of the proximity-focusing electron optics lens between the photocathode and the MCP input, affect the spot size at the input of the MCP.

This section discusses the issues of cathode and screen focusing. For a typical tube, the cathode-MCP proximity-focusing lens operates with an electric field of 1 kV/mm while the electric field in the MCP-screen lens is typically 4.8 to 8 kV/mm. The spot size of a proximity-focusing lens is proportional to the gap distance and the square root of the ratio of the initial transverse energy to the voltage across the gap. Transverse energy from the cathode is only about 0.2 eV, while it is about 2.4 eV from the MCP.²

We have tested three intensifiers to determine the effects of increasing the voltages on each section.¹ Cathode voltage was raised from 125 to 300 V, and the screen was changed from 4 kV to 8 kV (approximately equal percentages of increase). Maximum fields for these voltages are 1.5 kV/mm for the cathode and 6.4 kV/mm for the screen. Results indicate a factor of about 1.15 improvement in MTF at 15 lp/mm due to increasing the cathode voltage, and a factor of 9 improvement due to increasing the screen voltage. It is likely that a collimator at the screen (see below) will provide improvements by eliminating the higher transverse energy electrons.

2.3 MCP Elastic Scattering

Electrons from the cathode scatter elastically as they strike the MCP surface. It has been estimated that 20% of the electrons will be elastically scattered, maintaining nearly 100% of their initial energy. They will rebound in the direction of the cathode, be repelled by the electric field within the gap and eventually strike the MCP again at a point of up to two times the cathode-MCP gap distance (2g) from the original impact point. The effect is a halo with a 4g maximum diameter (or about 800 μm). Because the area over which these electrons are scattered is great, the intensity generated is relatively low. This effect only becomes a problem when a large dynamic range is needed, such as for a dim object near a very bright object, a condition often encountered in laser diagnostics using streak cameras.

2.4 MCP Resolution

The pore size of the MCP limits its resolution. This is undoubtedly one area that contributes significantly to the tube's poor resolution.

The limit to reducing the pore size (l) is controlled by the plate thickness (d), which must be great enough to allow handling and minimize warping. Good uniformity MCPs with l/d ratios of 60 or more (the standard for years was 40) are now available, permitting smaller-pore MCPs to be made with plate thickness great enough to prevent warping.³ Six- to eight-micron pore MCPs are currently available.

2.5 End Spoiling

By metalizing the ends of the MCP pores—to remove the electric field gradient and reduce effective secondary electron emission near the channel output—the electrons can be collimated, reducing their exit angle.

This process removes mainly low-energy electrons, leaving electrons with energies of approximately 10–200 eV. One result is an increase in the average electron energy. Although some collimation is achieved, the higher energy electrons are harder to focus. In one experiment, a single MCP channel was excited and a spot on the screen was observed, which had a "hole" or decreased brightness in its center. This was attributed to an anomaly of end spoiling. All the easily focused, low-energy electrons had probably been removed, leaving only electrons with energies above about 10 eV. End spoiling does work, however. Spot size was measured in a demountable setup with an end-spoiled MCP, and then the MCP was reversed. The end-spoiled end produced higher resolution.

2.6 Output Focusing Lens

The transverse energy of the electrons leaving the MCP, and the characteristics of the proximity-focusing electron optics between the MCP output and the screen, affect the spot size in this area. This effect was discussed above. It is greater in the screen area than in the cathode area because the electron transverse energy is greater. To improve the resolution here, the screen voltage can be increased and the spacing can be decreased. The limit is set by the electrical breakdown threshold.

ITT recently reported³ on a tube with a 6- μ m pore MCP, which yielded 15 lp/mm at 55% modulation and over 50 lp/mm limiting resolution. It is likely that this is the practical limit for MCPs of the conventional design. The screen voltage of this tube was limited because of breakdown to 3800 V (about the aluminizing dead layer voltage) by the close MCP-to-screen spacing of 250 microns, which, in turn, limited the output brightness to a level not useful for any of our applications. Using the dielectric coated MCP can remove this barrier, as discussed below.

2.7 Screen Elastic Scattering

Elastic scattering from the aluminizing layer covering the phosphor is similar to the condition at the MCP input. Here the gap distance is in the order of 0.75–1.25 mm or four to six times that of the cathode-MCP spacing, so the halo is four to six times as large, or about 3–5 mm. Tests have shown that the intensity of the halo is two to four orders of magnitude below the peak.⁴ Reducing the gap will reduce the halo diameter and increase its brightness. Using a collimator at the screen is a likely method of controlling this problem.

2.8 Phosphor and Aluminizing Scatter

Light generated in the phosphor is released in all directions. Light which goes toward the aluminum layer may hit it and be scattered into an adjacent area from which it can enter the fiberoptic faceplate. Light can be reflected back and forth between the fiberoptic faceplate and aluminum layer and enter the fiberoptics at large distances from its source, albeit at greatly reduced intensity, due to absorption within the phosphor. Thin, brushed-phosphor screens and intagliated phosphor screens, discussed below, can alleviate the scattering problem.

2.9 Aluminizing Layer X-ray Generation

X rays generated when electrons strike the screen aluminizing layer can travel through the MCP pores and strike the cathode. They will generate photoelectrons, which will be amplified by the MCP and return to the screen at some distance from the x-ray origin. The collimation of the MCP allows only about 0.0027% or less of the x rays to reach the cathode, but the electrons they generate are multiplied by the MCP gain (≤ 500) before they strike the phosphor, so the intensity can be only about 0.16% of the probability of generating an x ray. This figure will be higher if the electrons generated by x rays hitting the MCP walls are included, and if the x rays penetrate the MCP glass. Using a collimator (discussed below), with a low efficiency x-ray generation material deposited on the input surface, will likely solve this problem.

2.10 Screen Fiberoptic Faceplate Cladding Transmission

This is identical to the condition for the cathode faceplate.

2.11 Screen Fiberoptic Faceplate Numerical Aperture

For the screen, the situation is quite different from the cathode. Here an NA 1.0 fiber will collect light from a large area, determined by the several-micron thickness of the phosphor. We have previously investigated this effect for a tube with NA 0.66 fibers in the output faceplate, but other effects probably masked any improvement, since MTF did not improve. As tube resolution is increased, using intagliated phosphor screens, discussed below, could have a positive effect.

Galileo and others make intagliated screens. In this process, the core glass is etched away, producing holes or pockets, with depths greater than 10 μm , into which phosphor can be deposited. The hole walls can be metalized for reducing scattering to adjacent fibers and for greater light reflection, which increases the light collection efficiency of the fiber. The phosphor can be aluminized, covering the holes to reduce optical transmission when the tube is gated off, reduce light feedback to the cathode, and reflect light toward the fiber, further increasing collection efficiency. Tests on tubes with intagliated screens show a few percent to 50% increase in the spatial frequency for 50% modulation.^{5, 6} For application with a collimator, the smoothness of the intagliated surface will facilitate contacting, or nearly contacting, the screen with the collimator without damaging the aluminizing layer.

3. Discussion

This paper describes the progress made recently in an ongoing project to improve MCPI resolution. The current effort concentrates on a method that permits raising the electric field in the MCP-to-screen section by using a dielectric layer deposited on the MCP output surface. Taking advantage of the fact that the electrical breakdown voltage threshold is higher in a dielectric than in a vacuum, we have deposited aluminum oxide (Al_2O_3) over the electroding on the output side of MCPs. The electron microscope photograph (Figure 2) shows a 3-micron-thick layer of Al_2O_3 deposited over the output side of an 18-mm MCP, typical of the type used in the first tube discussed below. We reduced the Al_2O_3 thickness to 1 micron for the second tube to improve the process yield, and have detected no reduction in breakdown voltage. This process has been in use at LLNL quite successfully for several years for x-ray detectors that consist of an MCP and a phosphor screen on a fiberoptic faceplate. Other materials besides Al_2O_3 are being investigated, and a patent has been applied for on this invention.

We decided to try this process out in a sealed MCPI tube; we contracted with Varo Electron Devices to supply us with MCPs, which we coated and returned to them for inclusion in tubes. The first tube has 483- μm MCP-to-screen spacing, and supported in excess of 10.5 kV across this gap. There was no indication of impending breakdown, and the voltage was limited to this value due to test station power supply voltage limitations. Additional voltage could have been provided by modifying the supply, but

Fig. 2 Electron microscope photo of a three-micron-thick Al_2O_3 coating on a typical 18-mm MCP. The bright section between the MCP and Al_2O_3 coating is the inconel conductive electroding.

Fig. 3 MFT data for the first tube with 700 V on the MCP. (a) shows the results with 200 V on the cathode and 6 kV on the screen. In (b), the cathode is raised to 500 V. In (c), the cathode is 500 and the screen is 10.5 kV. Curve (d) shows a "standard" tube with 200 V on the cathode and 6 kV on the screen for comparison.

our goals had been achieved and we did not want to test the tube to destruction. The MTF curves shown in Figure 3 show the data on the first tube, all with 700 V on the MCP. Curve (a) was taken with 200 V on the cathode and 6 kV on the screen. Curve (b) shows the results of raising the cathode voltage to 500 V, and curve (c) shows the results with 500 V on the cathode and 10.5 kV on the screen. The MTF of one of our inventory of 18-mm tubes is shown for reference in curve (d). It is clear from the difference between (a) and (b) that the cathode lens affects the tube performance, and that curve (c) may exhibit even higher resolution if not limited by the cathode lens (calculations indicate 18 lp/mm at 50% modulation should be achieved). Additionally, the MCP has 10- μ m pores, and it is likely an additional improvement will be realized when pore size is reduced. The most significant result from the first tube was that 10.5 kV was sustained across the 483- μ m gap, producing an electric field of 22 kV/mm.

The screen spacing in the second tube is 280 μ m. It supported 10 kV with no sign of impending breakdown, for a field strength of 36 kV/mm. This is 4.5 to 6 times higher than the screen field in normal tubes. The second tube exhibits 10 lp/mm at 50% modulation for cathode voltages of 300–500 V and screen voltages of 6 kV to 10 kV. It is unclear why the resolution seems to be independent of these voltages. Possibilities include problems with the phosphor screen; we continue to explore other factors. However, again, the most significant result is the extremely high electric field supported through the use of the dielectric layer.

The third tube will have 280- μ m spacing and use an MCP with 9- μ m pores. Test results are expected to yield further resolution improvements while exceeding normal output brightness.

Using a collimator near or in contact with the screen is being investigated as a method for improving resolution of MCPs by eliminating the scattered electron problem and by reducing the numbers of high transverse energy electrons reaching the screen. A collimator will stop all electrons coming in at angles greater than the collimator acceptance angle, which is determined by the l/d ratio of the collimator. A collimator will also increase the extinction ratio of an intensifier due to its optical absorption. Additionally, the smooth surface of the collimator will permit a higher focusing field to be employed in the MCP-to-collimator region than is currently permitted in the MCP-to-screen region by the relatively rough and fragile aluminum layer covering the screen. Ten kV across a 280- μ m gap with an aluminized screen has been demonstrated with the dielectric coating mentioned above; with a smooth, glass surface it will likely be higher. These higher voltages will result in increased screen gain and brightness.

An MCP with zero bias angle will be used, electrically connected to the screen. Gold or other metals can be coated inside the pores of MCPs to eliminate wall charging. Galileo makes capillary arrays from various types of glass (possibly conductive and opaque), which could be used.

In all of our applications, the input light source is a short-duration pulse of less than 200 to 300 microseconds for streak cameras and less than about 50 ns for other applications. The stored charge in the MCP walls near the MCP exit is all that is available to excite the phosphor because the charge-replenishing time is in the millisecond region. As a result, electron transmission efficiency for MCP collimators or other types of collimators with high conductivity walls to prevent wall charging must prove to be acceptable before this approach will be useful. The output brightness of the intensifier will be reduced about 35% by the transmission efficiency (open-area-ratio) of the collimator. Additionally, the electrons with high transverse energy, which are responsible for degrading resolution, will be eliminated by collimation, further reducing transmission by an unknown factor, probably less than 25%, for a net loss of about a factor of two. (Some of this loss may be recovered by not end-spoiling the MCPs.) The resulting loss of brightness can be offset by increasing the energy of the electrons, e.g., raising the screen voltage to about 8 or 10 kV, since this is tolerated as mentioned above. Additionally, many applications can tolerate a reduction in gain by a factor of about two or three (in many of our applications, the luminous gain is set at three or four thousand for tubes rated at 20,000); for others, increasing the MCP voltage by about 30 to 100 volts will recover the overall gain without significantly increasing the noise. Preliminary electron beam code calculations using EBQ indicate that the proposed effort will increase resolution of these tubes by a factor greater than two. We have applied for a patent for this application of a collimator.

4. Conclusion

Adding a dielectric layer to the output side of an MCP permits in excess of a 36 kV/mm electric field to be used in the MCP-to-screen gap. It is likely that a collimator placed near the screen will permit still higher fields to be used, eliminate elastically scattered electrons, improve extinction ratio, and remove high transverse energy electrons, all of which will improve resolution. A design proposal for a high-resolution tube includes a 1-kV cathode lens, a dielectric coated MCP with 6- to 8- μ m pores, a collimator near an intagliated screen, and 10 kV screen voltage. We intend to pursue these and other approaches to improve the performance of imaging devices; we are interested in sharing this technology, and in establishing licensing and partnering arrangements with manufacturers and users of these devices.

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