CHANNEL ELECTRON MULTIPLIERS: PROPERTIES, DEVELOPMENT AND APPLICATIONS

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CHANNEL ELECTRON MULTIPLIERS: PROPERTIES, DEVELOPMENT AND APPLICATIONS

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SUMMARY

The object of this paper is to acquaint high energy physicists with the properties and numerous applications of microchannel plates as well as with the resulting improvements of particle detectors.

Properties of channel electron multipliers and of microchannel plates are described. We review and discuss the major applications of these devices, with emphasis on high performance photomultipliers and on electronic imaging at high speeds and low light levels.

INTRODUCTION

Microchannel plate electron multipliers have several unique features which render them extremely useful in scientific research; among these are high gain, imaging capability, very low transit time practically negligible time spread, excellent energy resolution, good tolerance to magnetic fields, ability to detect various particles and radiations with low intrinsic noise.

Besides their applications as electron multipliers, microchannel plates can be used as parallel bore collimators and as γ-ray converters.

Devices incorporating microchannel plates, such as photomultipliers, electronic imaging photon detectors image intensifiers, streak cameras, ultrafast cathode ray tubes, perform better and are usually simpler than their classical counterparts.

Microchannel plates were evolved with image intensifiers as the primary goal, mainly for military purposes. Some plates designed for other applications are available as prototypes, but often devices incorporating microchannel plates could be further optimized by specific plate design.

This paper is an attempt to summarize the evolution, present status, performance and applications of continuous dynode electron multipliers.

DEVELOPMENT OF CONTINUOUS DYNODE ELECTRONS MULTIPLIERS

The early form of such multipliers consisted of two parallel plates coated with a high resistivity secondary emissive material[1,2] (Fig. 1). A magnetic field parallel to the plates and perpendicular to the input-output axis curves the electron trajectories. This type of multiplier proved to be extremely rugged and useful for detection of far UV, heavy ions, x rays and electrons.

Plates were then replaced by a glass tube, with an inside coating. It is not necessary to apply a field, provided that the length to diameter ratio is kept above 30 to 40.[3] Large useful diameters would require excessively large tubes, so input collectors were introduced, usually cones made of the same material as the channel, and did improve the useful diameter by five to ten times.

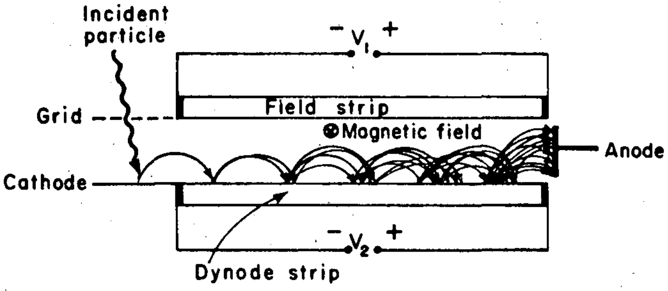

Fig. 1 Early form of continuous dynode electron multipliers.

At gains above 10^3 to 10^4, ionic feedback appears in a straight channel, but gains above 10^8 can be obtained in curved structures. Curvature may be obtained in several ways, leading to what is called channeltrons and spiraltrons (see next section), the second structure being advantageous wherever an array of stacked high gain multipliers is required.

Arrays of either straight or curved channels have imaging capabilities, so to obtain good spatial resolution, it is tempting to decrease channel diameters. Nowadays plates with straight channels 10 to 15 microns in diameter are commercially available. At the same time, channel length is decreased, resulting in much lower transit time, time spread and sensitivity to magnetic fields. Also, because of its compactness, such a multiplier can be incorporated into a fully coaxial structure, thereby reducing rise time and delta response. Furthermore, because of its relatively large area, the multiplier can be used with a proximity focused input, suppressing transit time differences between center and edge of the photocathode and leading to compact photomultipliers having low time spread and good immunity to magnetic fields.

Microchannel plates do present a challenge to manufacturers; plates incorporating straight channels are difficult enough to produce, but a way of suppressing ionic feedback is necessary if high gain is required; plates having curved channels 40 µm in diameter are manufactured, but since facilities exist to build straight channel plates, chevron and Z arrangements with channels cut at a bias angle were introduced. Gains in the range 10^6 to 10^7 are currently obtained. At low gains, channels operate in the linear mode, but saturation effects appearing at high gain can be used, under certain conditions, to further improve the performances.

PROPERTIES OF CHANNEL ELECTRON MULTIPLIERS

First proposed in 1930,[4] but realized only three decades later in a practical way, the device consists of a glass tube having a high resistivity, secondary emissive internal coating. A sufficiently high voltage difference is applied between the input and the output so that electrons are accelerated between collisions with the walls to produce secondaries (Fig. 2). This device can be considered as a conventional multiplier having a number of dynodes which is proportional to its length/diameter ratio. A typical gain curve appears in Fig. 3. Variations of length to diameter ratio (L/d) and of voltage affect the gain[5] as illustrated in Fig. 4. (A discussion of the model leading to such curves appears in Ref. 6.) Gain is plotted against L/d with both voltage and voltage divided by L/d as parameters.

In microchannel plates, it is necessary to minimize gain variations from channel to channel due to slight differences in channel diameters. (This consideration is especially important for image intensifiers, where constant gain all over the field is required.) So, for a given voltage, an optimum L/d ratio exists. At high gain, with straight channels, after-pulses appear and damage may result. The importance of this effect depends on the vacuum; the delay between the main and after pulses varies with the mass of the ions present in the vacuum chamber. After-pulses are attributed to ionic feedback, positive ions accelerated toward the channel input hit the channel wall and produce secondary electrons which are in turn multiplied. Operations in high vacuum only partly solve the problem, as ions are also released from channel walls during the multiplication process. Careful cleaning and outgassing somewhat improve the situation, but best results are obtained with curved channels,[7] so that ions travel only a short distance before hitting the wall (Fig. 5).

Many types of channel electron multipliers are commercially available, as illustrated in Fig. 6. Typical performances are: gain above 10^8, channel diameter around 1 mm, useful input area from 1 to 150 mm^2, dark count rate lower than 0.5 pulse/sec at room temperature. The adjunction of an input

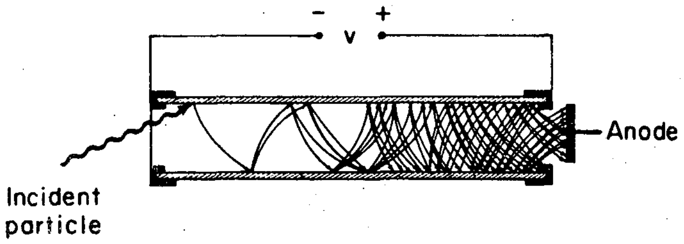

Fig. 2 Channel electron multiplier.

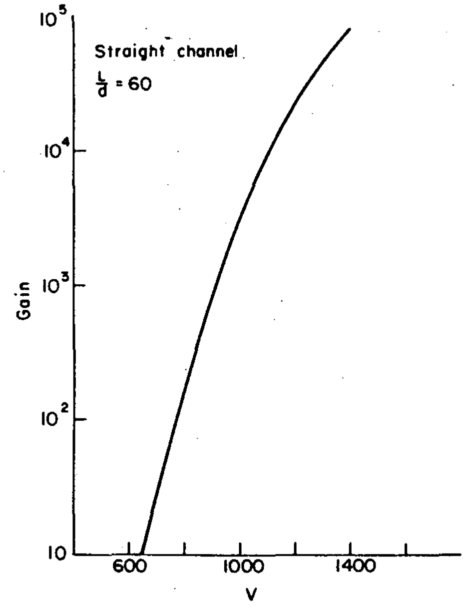

Fig. 3 Typical gain curve of a straight channel electron multiplier.

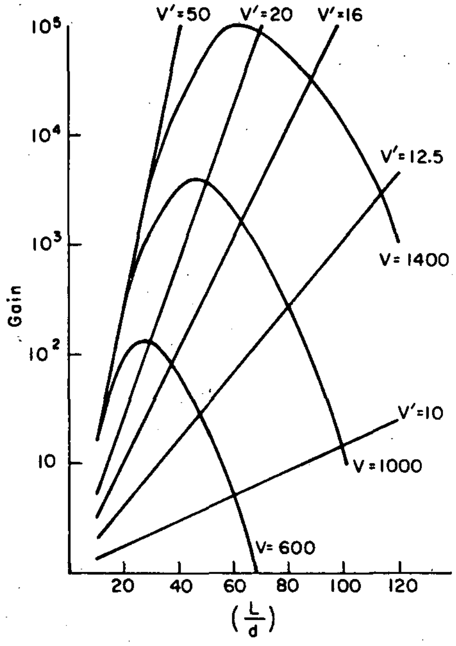

Fig. 4 Effect of (L/d) and of the applied voltage on the gain of a straight channel electron multiplier (from Ref. 5); V' = Vd/L.

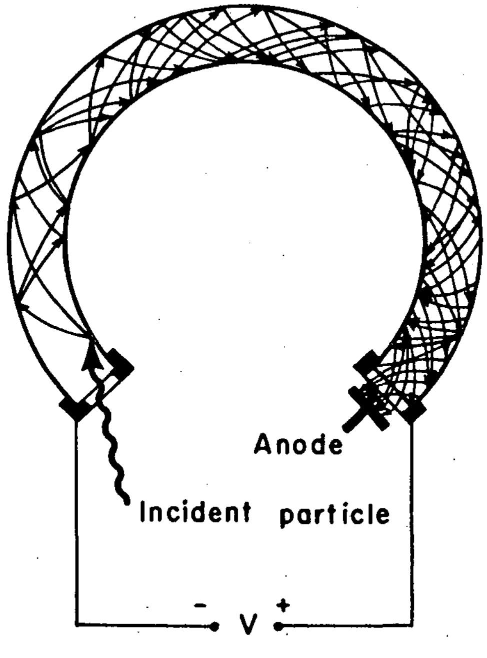

Fig. 5 Curved channel electron multiplier.

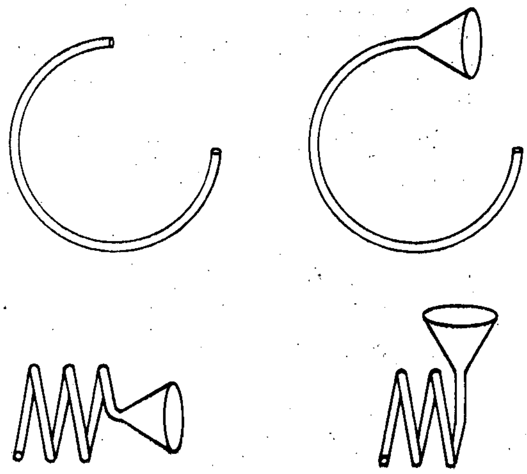

Fig. 6 Some types of channel electron multipliers.

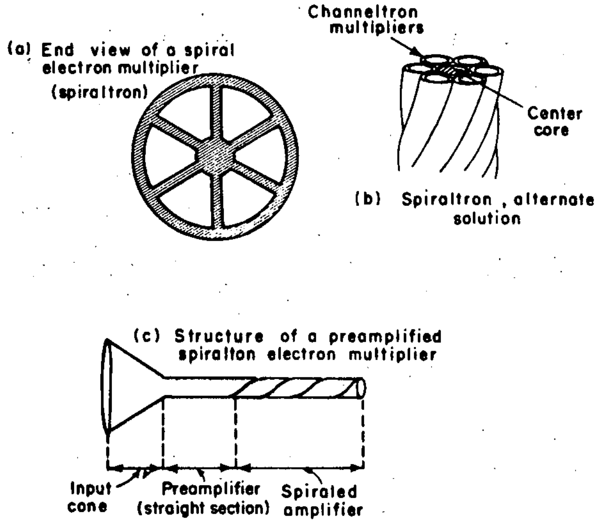

Fig. 7 Spiral electron multipliers.

cone leads to nonuniform detection efficiency, but a grid placed in front of the cone and correctly polarized will improve uniformity.[8] Another way to obtain curvature is illustrated in Fig. 7: a bundle of tubes stacked around a glass bar or a glass tube with a central core, divided into six longitudinal segments, is twisted around its longitudinal axis.[9] The multiplier remains a straight structure and can be easily stacked. Some efficiency loss is introduced by the extra obstruction, so a preamplifier stage is often added, consisting of a short section of straight channel electron multiplier, providing enough electrons to the main stage, but having a gain low enough to avoid ionic feedback.[10]

Figure 8 shows the typical gain curve of channeltrons and spiraltrons; saturation effects are apparent and we will now discuss their possible causes. Power dissipation problems related to low thermal conductivity of the glass, and in some cases the limitations of the manufacturing process itself, preclude the use of low resistivity coatings; typically at room temperature, the average conduction current in a 1 mm diameter channeltron or spiraltron is a few microamperes. In microchannel plates, further difficulties arise from the nonuniformity of resistance from channel to channel, with an average conduction current per channel of the order of 10^{-11} A. The high channel resistivity is a self-protecting feature, particularly useful in image intensifiers, since it minimizes bright spots and helps tolerate exposure to high light levels.

The average DC anode current will depart from linearity when it reaches 5 to 10% of the conduction current, and recovery time will result in a gain decrease in pulsed mode at high rates (Fig. 9), but, as long as the rate is low enough, instantaneous anode currents considerably larger than the strip currents can be extracted from the channel. The maximum charge instantly available at the output can be limited by space charge effects or by the accumulation of positive charges on the channel wall, near the output, reducing the field and suppressing multiplication. An extensive study of these mechanisms in curved channels appears in Ref. 11. Departure of proportionality between input and output signals occurs at a gain of 10^7 for channels 1 mm in diameter and full saturation, that is, constant output amplitude for any input excitation, is obtained at gains of 10^8. The authors observe that, in fully saturated mode:

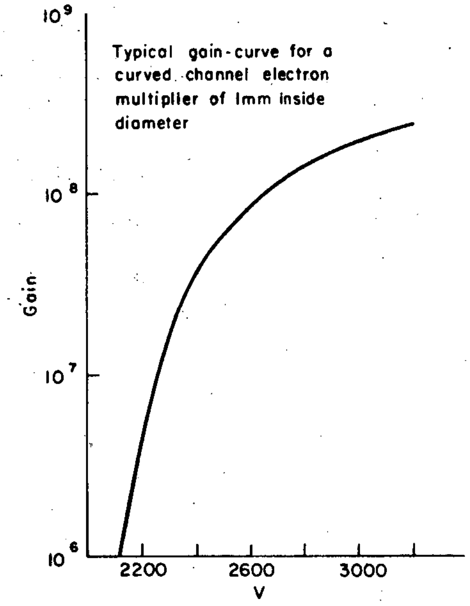

Fig. 8 Gain versus applied voltage for a curved channel electron multiplier.

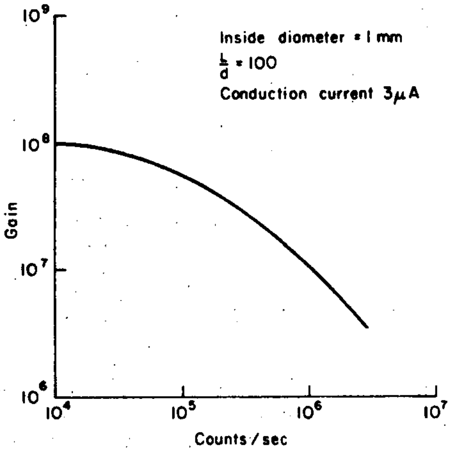

Fig. 9 Effect of the channel recovery time.

(a) The amplitude of the anode signals is independent of channel diameter, but is proportional to the normalized field (volts per diameter).

(b) The output pulse width is proportional to the absolute length of the channel.

Thus, for identical normalized field strengths, large channels will have higher saturated charge gain than small channels, delivering the same peak current, but wider pulses. On the other hand, increase of normalized field, leading to higher saturated gain for a given channel diameter, is limited by breakdown problems. The amplitude of the saturated anode signal is also independent of the distributed capacitance between dynode surface and ground, leading to the conclusion that gain saturation is not produced by accumulation of positive charges on the walls, but more likely by the retardation of the secondary electrons due to space charge effects. In linear mode, the situation is different as the end-of-channel capacity to ground affects the output amplitude; so it is plausible that, in linear mode, accumulation of positive charges has a detrimental effect on gain.

Channel electron multipliers can detect a wide range of electromagnetic radiations, as well as electrons, positive ions and metastable atoms[12-14] being at the same time insensitive to thermal electrons (except if an accelerating field is used). Detection efficiencies vary also with angle of incidence, so comparisons between published data are sometimes difficult. Typical detection efficiencies can be summarized as follows:

(a) Better than 10% for electrons from 50 eV up to 40 keV (approximately 90% around 500 eV).

(b) 1% for positive ions (He^+) at 200 eV, more than 80% from 2 to 40 keV.

(c) Ultraviolet light and soft x rays from 1300 to 0.2 Å as well medical x rays between 60 and 100 keV can be detected with quantum efficiency above 1% (up to 20-25% between 600 and 800 Å).

These properties are not adversely affected by repetitive cycling between atmospheric pressure and vacuum.

Timing characteristics of channel electron multipliers are favorable enough to obtain prompt coincidence curves of 4,3nS FWHM[15] between two channeltrons detecting single electrons and to allow half life measurement of excited nuclear levels as short as half a nanosecond.

Channel electron multipliers have also some unfavorable properties; for example their resistive layer has a negative temperature coefficient,[17] resistance increasing by two orders of magnitude from room temperature down to 78°K and by another three orders of magnitude when cooling further to 20°K, introducing serious rate limitations at low temperature. Another cause of concern in early multipliers was the long term stability.[18] Typical behavior of a curved channel can be divided in three phases (Fig. 10):

(a) A clean up period; gain decrease being attributed to progressive suppression of after pulses when the channel finishes releasing trapped gas.[16] Percentage of gain drop and duration of this period are strongly dependent on previous channel handling.

(b) The plateau region is considered as representing normal operating conditions: gain and output amplitude distributions remain stable.

(c) In the fatigue region, gain begins to drop and amplitude distribution becomes wider; this can be interpreted as a relaxation of the saturation conditions and can, to some extent, be compensated by operation at a higher voltage.

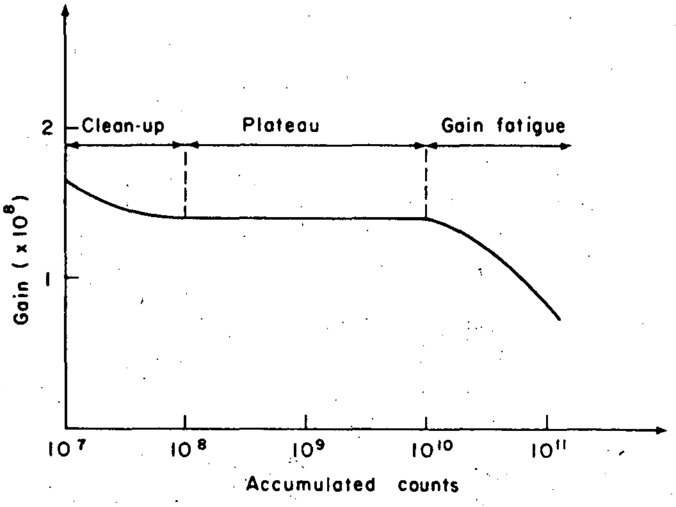

Fig. 10 Aging process in channel electron multipliers.

The advantages of channel electron multipliers are important enough to have lead already to many applications[13-16,19] among them:

- Detection of secondary electrons in scanning beam electron microscopy;
- Mass spectrometers;
- 10000 g subminiature photomultipliers;[9]
- Aboard satellites, to study Van Allen belts and solar wind, detecting low energy electrons, protons and ions, as well as for UV and soft X-ray telescopes.

STRUCTURE AND PROPERTIES OF MICROCHANNEL PLATE ELECTRON MULTIPLIERS

Straight channels or spiraltron electron multipliers can be stacked to form imaging devices with relatively large sensitive areas. For example, an early matrix of spiraltrons[20] contained approximately 4000 channels with a length to diameter ratio of 100 and a 6×30 mm^2 frontal area, with a maximum gain of approximately 10^7.

Arrays of microchannels were mostly developed for image intensifiers, where an electronic gain of 10^3 to 10^4 is sufficient. Another factor of 10 to 100 can be obtained by accelerating the electrons in a focused configuration before they hit the phosphor. Straight channels can be used, since little ionic feedback is present at these low gains; an offset channel angle is necessary to avoid having direct light paths between phosphor and photocathode; angles of 5 to 8° with respect to the plate surfaces are the most commonly used. Gain variations from channel to channel will appear as a fixed pattern in the output image, so it is necessary to control very precisely the channel lengths to diameter ratio. Typically, diameters are constant within 2%, yielding gain uniformity of 5%.[21] To obtain good spatial resolution, an extremely small channel diameter is required; presently available plates incorporate channels of 10 to 50 μm in diameter, with a length to diameter ratio around 45, and overall plate diameters range from 18 to 75 mm.

Gain, operation in linear mode, rate limitations, spectral sensitivity and ionic feedback in microchannel plates are similar to those for channeltrons; basic differences are smaller channel diameter, some interactions between channels and higher channel resistivity due to limitation on power dissipation. Plate transparency, that is, ratio of open to total area, is usually 50 to 75%, but it was found that collection efficiency can be higher. With the help of a positive ion microprobe, it was shown[22] that the interchannel areas exhibit only slightly less gain than the channels themselves, apparently because secondary electrons produced outside of the channel have a high probability of penetrating into the channel. Uniformity of channel resistance is not well documented. Some information suggests that resistance can vary by an order of magnitude from channel to channel in the same plate; if this is true, better control over resistance uniformity would permit decrease of the average channel resistance without danger of thermal runaway problems.

Penetration of the input electrode into the channel is limited to 0.5 to 0.8 diameter, so that the impact of the incident particle has a good probability of occurring on the glass, but output electrode penetration attain one to two diameters in order to improve spatial resolution by focusing the electrons leaving the channel.

Life test results[21] are similar to what is observed with channeltrons in that an initial clearing period is observed, followed by a plateau, but after 7800h testing (at 1000 V and 3×10^{-12} A/cm^2 input current), no drop appeared in the gain.

Other typical characteristics of conventional microchannel plates include: strip current around 1 μA/cm^2, gain 10^3 to 10^4, transit time approximately one nanosecond and time spread below 100ps FWHM.

Properties of microchannel plates, coupled with the introduction of proximity focusing at the input as well as at the output of the multiplier result in a combination of unique properties, not fully taken advantage of in image intensifiers, namely: excellent spatial resolution, free of geometrical distortions; self protection due to the high channel resistivity; extremely compact high gain tube and consequently good immunity to magnetic fields; very low transit time due to short channel length and small interelectrode spacing; negligible time spread, even for full photocathode illumination; sub-nanosecond delta response in a suitable coaxial holder.

In photomultipliers, a gain of at least 10^6 is required for photon counting at high speed. Two problems are immediately evident if such a gain must be obtained with conventional microchannel plates: the first one is the appearance of ionic feedback, which not only induces afterpulses, but will also damage the photocathode by ionic bombardment. The second problem is that individual channels will not usually operate in a linear mode, but more likely at saturation; as we will see later, this mode of operation has in fact advantages provided that some specific operating conditions are respected.

Some authors[23,24] did cascade two conventional microchannel plates, with channel offset angles oriented in opposite directions. This device, the so called chevron multiplier, can then operate at high gain (1 to 5×10^7) and in pulse saturated mode. Spatial resolution is degraded compared to single plate, but values from 5 to 14 line pairs per mm are reported. As the electrons leaving the first plate spread over several channels of the second plate, maximum gain is somewhat higher than with single channels of the same diameter, but the width of single electron amplitude distribution is degraded (130% FWHM compared to 50% for a channeltron). Dark noise below one count per cm^2 per second is commonly achieved and single electron counting rates of 10^5 counts/sec·cm^2 are obtained without significant gain drop. Timing characteristics[23,25] are similar to single plate performance.

Another approach to the suppression of ionic feedback at high gain is the use of plates incorporating curved channels.[26,27] Compared to the previous arrangement, single electron energy resolution is improved (better than 70%, compared to 130%), but maximum gain is limited to approximately 10^6.

A third approach to high gain microchannel plate multipliers was recently suggested,[28] similar in principle to a chevron arrangement, but consisting of three stacked plates, without interelectrode gap. The performance of this structure is undergoing evaluation by ITT at the Lawrence Berkeley Laboratory.

When the voltage is increased, saturation effects appear with microchannel plates as with the channeltrons, and anode amplitude distribution changes from exponential to quasi gaussian, but at the same time the intrinsic plate noise distribution remains exponential; therefore, good multiplier noise rejection is possible.

Operation of each channel in a saturated mode has interesting features: as we operate at low light level with plates of 5×10^4 to several 10^6 channels, the probability to have two electrons hitting the same channel simultaneously is negligible; if saturated gain is constant from channel to channel, the total charge delivered at the anode is strictly proportional to the number of channels hit and the energy resolution can be quite good not only for single electron input signals but also for inputs corresponding to thousands of electrons, provided that a given channel has time to recover between pulses. It seems therefore logical to increase the number of channels to obtain a wide dynamic range, although the diameter of each channel should be kept large enough so that a satisfactory saturated gain can be obtained. On the other hand, low channel resistivity is desirable to maintain tube performances at high rates, but here nonuniformity of resistivity, negative temperature coefficient of the coating and poor thermal conductivity of the lead glass are the present limiting factors.

As pointed out before, microchannel plates should be relatively immune to magnetic fields; typically,[29] for a plate incorporating straight channels, 14 μm in diameter, a field parallel to the channel axis produces a 20% gain increase at 5 kG, and the gain returns to zero field value at 9 kG. A transverse field of 10 kG still permits a gain of 45% of the zero field value.

SOME APPLICATIONS OF MICROCHANNEL PLATE ELECTRON MULTIPLIERS

Before discussing the application of microchannel plates to photomultipliers, let us review briefly the properties of some other devices incorporating such plates, in order to gain a better understanding of what improvements these multipliers bring.

A. Image Intensifiers

Microchannel plate image intensifiers can be divided in two classes:[30,31] Inverter and Proximity Focused types. The first class (Fig. 11) uses electrostatic optics between the photocathode and multiplier and proximity focusing at the output. This allows a better suppression of ionic feedback; the output image is inverted and a short ocular can be used. At the same time, some distortion is introduced by the optics. The other class (Fig. 12) uses proximity focusing for the input and output so that the tube is free of distortions, is more compact, and usually has a fiber optics image inverter.

The primary reason for developing microchannel plates was the possibility of building a compact, distortion free lightweight Image Intensifier, with a luminous gain in excess of 5×10^4 and a resolution of 15 to 25 line pairs/mm. At the same time, other attractive characteristics like self-limiting plate properties and nanosecond gating capabilities were obtained. Such high gain intensifiers and image converters, operated either in DC mode or gated in combination with a pulsed laser light source have numerous civilian and military applications: night survey and driving in passive or active mode (using ambient light or illuminators); selective, fixed distance active night vision system, stroboscopic observations.[32] More complex tubes, derived from image correlators,[33] could even be made sensitive only to moving objects; such tubes, used in conjunction with pulsed illumination, make attractive observation systems.

Gating techniques are discussed in Refs. 34 and 35; nanosecond gating is possible when the photocathode is covered by a semi-transparent, low resistivity coating; shutter ratios of 10^6 can be obtained, making these tubes ideal for high speed photography.

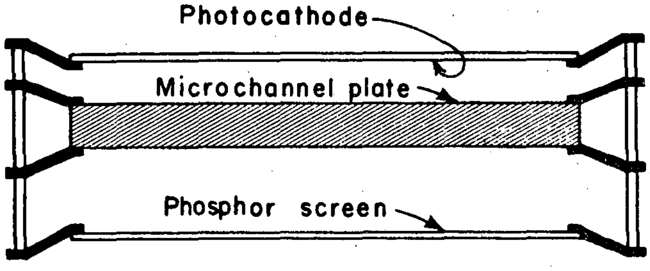

Fig. 12 Proximity focused image intensifier.

B. X-Rays and Neutron Image Intensifiers

These tubes are similar to proximity focused image intensifiers, in which the photocathode is replaced by a suitable converter: tantalum or gold for x rays, gadolinium, boron or lithium for neutrons. 120 mm usable diameters and resolution of 4 line pairs/mm with channels 100 μm in diameter are typical for these applications.[36]

C. Ultrafast Cathode Ray Tubes

By putting a microchannel plate near the screen to amplify beam current, it is possible to use lower accelerating voltage so that excellent deflection sensitivity is obtained with enough electronic gain to have a high writing speed.[37] A commercial tube of this type offers 70 ps risetime, 50 to 100 cm per nanosecond writing speed, a vertical sensitivity of 70 mm/Volt and a useful screen area of 42 x 70 mm^2. This tube is capable of displaying a 6 GHz sine wave in real time and in a single sweep.

D. Streak Camera

As in cathode ray tubes, a microchannel plate placed near the screen to amplify beam current will allow faster writing speed and higher deflection sensitivity (Fig. 13). Another approach uses the channel plate as an electron collimator,[38] minimizing initial dispersion of the electrons leaving the photocathode, this dispersion apparently being one of the major effects limiting the resolution of present streak tubes.

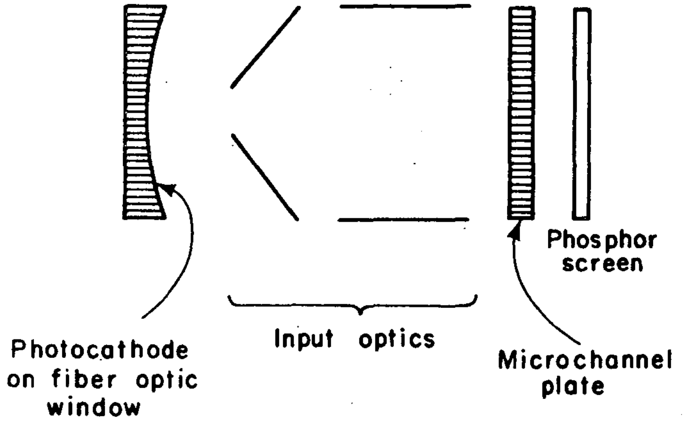

Fig. 11 Microchannel plate inverter image intensifier.

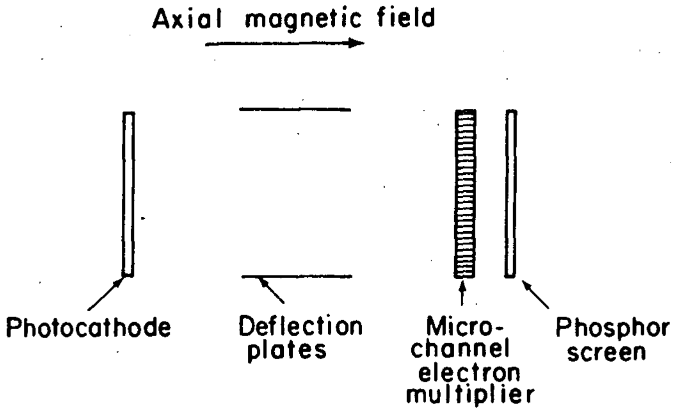

Fig. 13 Streak tube.

MICROCHANNEL PLATE PHOTOMULTIPLIERS AND THEIR APPLICATIONS

Timing performances of conventional photomultipliers are limited by two major factors: transit time spread in the electron multiplier and center to edge of photocathode transit time differences. This second factor becomes dominant for large photocathode diameters, preventing accurate timing measurement at the single photoelectron level. For tubes 1" to 2" in diameter, at gains above 10^6, and after careful optimization of the operating conditions, typical time spread is 400 to 500 pS FWHM for single electron response and full photocathode illumination, decreasing to 100 - 200 pS FWHM for a large number of photoelectrons. Furthermore, the immunity of classical photomultipliers to magnetic fields is poor: one-gauss fields will seriously affect the tube performances.

Microchannel plate photomultipliers potentially offer better timing performances and considerably improved immunity to magnetic fields. The first approach[39] to such photomultipliers is to use conventional input optics and a chevron microchannel plate multiplier; gains between 10^6 and 10^7 can be obtained and one of the two major contributions to the time spread is reduced, but the other one remains, and the sensitivity to magnetic fields is also large in this configuration.

Microchannel plate photomultipliers designed with proximity focus[40-42] are more attractive; prototypes had a maximum gain of 10^5, and sub-nanosecond delta response (mostly dependent on the tube housing). It is interesting to note that dark count rate remains comparable to that of conventional tubes, despite the high electric fields used between the photocathode and the microchannel plate. Later versions of these tubes[43] incorporated plates with curved channels and gains of 10^6 were obtained, in which each channel operates at saturation. Provided that the probability of having more than one electron entering a channel during its recovery period is low, energy resolutions from such tubes can be similar to those that can be obtained from conventional photomultipliers incorporating gallium phosphide dynodes.

At the Lawrence Berkeley Laboratory, two such tubes were tested extensively,[44] with impressive results. At gains of 10^6, these tubes showed a time spread, for full photocathode illumination and single photoelectron response of less than 200 pS FWHM, and a multiphotoelectron time spread better than 30 pS FWHM; in both cases, the figures obtained were limited by the experimental resolution, so these quoted numbers should be regarded only as upper limits. The energy resolution is illustrated in Fig. 14. These tubes operate properly in axial fields of at least 2 kG and in transverse fields of more than half a kG, despite the fact that they were not optimized for operation in magnetic fields.

The properties of a chevron microchannel plate photomultiplier are described in Ref 45. The gain is higher (10^7) than with the previous tubes; operation in 10 kG axial and 2.25 kG transverse fields is described, with the multiplier voltage being increased to compensate for the gain loss induced by the field. Satisfactory operation over a 1000 hours period is reported, with a cleaning phase observed during the first 200-300 hours.

As previously noted, microchannel plate photomultipliers have unique features which are valuable for otherwise impossible or difficult applications, such as improved time of flight measurements at low light levels (thin scintillators with minimum ionizing particles, Cerenkov detectors), one- and two-dimensional readout from flat scintillators, operation in magnetic fields, fast fluoroscopy, high resolution photon limited laser rangefinders.

Microchannel photomultipliers are still in a developmental phase and should evolve toward larger diameters, gains well above 10^6, better availability and lower cost before they can be extensively used in high energy physics. They can already be used in small numbers when high quality performance is important and cost is a secondary factor.

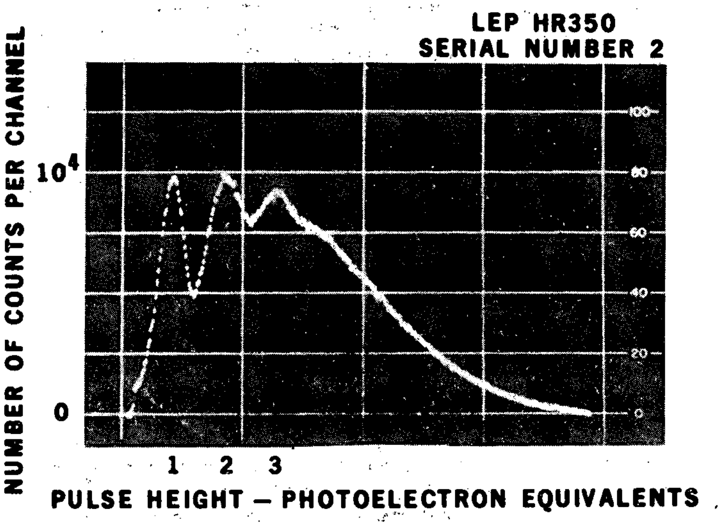

Fig. 14 Energy resolution of the LEP HR 350 microchannel plate photomultiplier.

ELECTRONIC IMAGING WITH MICROCHANNEL PLATES

Microchannel plate Image Intensifiers have demonstrated high gains, good resolution and fast gating capability down to extremely low light levels, but it would often be desirable to extract imaging information completely electronically. Other devices with similar performances exist, but use intrinsically slow serial scanning techniques. A gated detector able to generate an electronic image at high speed and low light level opens the door to extremely attractive instruments.[46]

The most immediate approach to two-dimensional readout is to use a multianode structure in place of the output phosphor. Provided that the anodes are small enough and that capacitive coupling between them is kept low, it is possible to record images in parallel mode at high speeds. The recovery time of the plate will be the limiting factor. Several such tubes are described in the literature; for example, a chevron multiplier was coupled to a 10 x 10 anode array, with 1.8 mm center to center anode separation.[47] Another tube incorporated a curved channel multiplier and either 5 x 5 or 16 x 16 anode arrays.[48]

Crossed arrays of wires or strips can replace multianode collectors,[49] since such a structure is easier to extrapolate to a large number of picture elements. By using thin film technology, a collector of this type having 50 µm resolution over a 1.6 x 1.6 mm^2 sensitive area (32 x 32 picture elements) was developed.[50] Crossed arrays use 2n amplifiers instead of n^2 to read an image with n^2 elements, but ambiguities arise when more than one signal at a time has to be detected. Common practice to solve this problem in spark chambers is to use a third array of wires, but to our knowledge this technique has not yet been applied to microchannel plates.

If some loss of speed is acceptable, several other one- and two-dimensional readout techniques are available: Use of RC delay lines[51] leads to a resolution $\sigma = 18$ μm over an 18 mm linear field with a Chevron Multiplier having channel pitch of 20 μm. Current division and charge equilibration techniques[52,53] give resolutions in the 50-100 μm range. Two-dimensional readout can be performed with a resistive anode having three or more peripheral contacts,[54] or one can measure the relative amounts of charge received by several anodes.[55] A resolution of 10 μm, good enough to see individual channels, over a field 420 μm in diameter was demonstrated with four anodes. By varying the voltage and distance from multiplier to anodes, magnification, resolution and useful field can be adjusted. This last technique could probably be extended to multianode tubes, giving good resolution and multitracks capabilities with a reasonable number of anodes.

MANUFACTURE OF CHANNEL ELECTRON MULTIPLIERS

A secondary emissive coating with some conductivity must be deposited on an insulated base to make a channel electron multiplier; resistivity should be controllable during the manufacturing process, so that power dissipation of the final product can be adjusted to the thermal properties of the substrate. Glasses can be shaped easily, offer good secondary emissive properties and wide range of resistivities; they are presently used in most cases despite their low thermal dissipation and often negative temperature coefficient of the emissive coating. Glasses having some bulk conductivity, especially phosphovanadate glasses were considered, but their properties are affected by thermal treatment in a way difficult to control, so the present trend is to use glasses containing lead oxide, which have good insulating properties, and to bake them in an hydrogen furnace. Surface reduction of lead oxide produces a semiconductive layer having a maximum secondary emissive coefficient of 1.9 to 3 and whose resistivity can be controlled over a wide range of values.[56]

Microchannel plates use a similar technology but the manufacturing process is much more complex, owing to the small channel diameter and to the high degree of uniformity required from channel to channel.

Photoetching process and even piercing glass plates with electron beams were considered, but present techniques[57,58] use glass tubes, either hollow or with solid cores, drawn to the required diameter and assembled in a bundle. Direct drawing of hollow tubes is used to obtain fibers more than 200 μm in diameter; smaller fibers are obtained in two or three stages, bundling being carried out between drawing stages. Temperature and drawing speed must be carefully controlled and some overpressure is generally maintained inside the fibers during the drawing process. Solid cores make the fibers less fragile and allow easier bundling by application of higher pressures without deforming the tubes. Metal or soluble glass cores are currently used. Glass tubes having an external coating of low melting point glass to facilitate bundling have also been used. The bundle is then sliced, the slices are polished, the cores dissolved and the plates are carefully cleaned. After application of the secondary emissive layer (by reduction in hydrogen for lead glass), nickel-chromium is deposited by vacuum evaporation onto the faces of the plate. The final cleaning process[59] consists in several hours of outgassing at 300°C, followed sometimes by glow discharge cleaning of the secondary emissive layer.

CONCLUSIONS

Besides allowing the construction of completely new detectors, microchannel plate electron multipliers help to overcome some basic limitations of conventional image intensifiers, cathode-ray tubes and photomultipliers. Their applications are presently limited more by cost considerations than by technical factors. Hopefully, this situation should improve with increased demand and with the development of large scale manufacturing processes by several companies.

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