United States Patent [19]
Overall et al.
[11] 3,914,634
[45] Oct. 21, 1975

[54] CHANNEL PLATE ACTING AS DISCRETE SECONDARY-EMISSIVE DYNODES

[75] Inventors: **Colin Douglas Overall; Derek Washington,** both of Salfords near Redhill, England

[73] Assignee: **U.S. Philips Corporation,** New York, N.Y.

[22] Filed: **Dec. 21, 1972**

[21] Appl. No.: **317,411**

[30] **Foreign Application Priority Data**

Dec. 23, 1971 United Kingdom 59966/71

[52] **U.S. Cl.** **313/105**
[51] **Int. Cl.²** **H01J 43/10**
[58] **Field of Search** 313/105; 250/207

[56] **References Cited**

UNITED STATES PATENTS

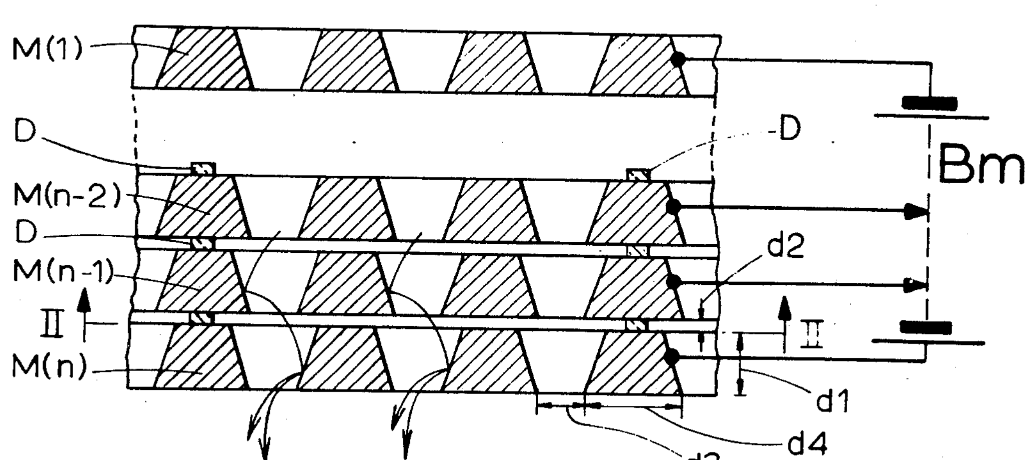
2,872,721	2/1959	McGee	313/105
3,408,532	10/1968	Hultberg et al.	313/105
3,634,712	1/1972	Orthuber	313/105

Primary Examiner—Ronald L. Wibert
Assistant Examiner—Richard A. Rosenberger
Attorney, Agent, or Firm—Frank R. Trifari; Ronald L. Drumheller

[57] **ABSTRACT**

Perforate metal layers having aligned apertures defining channels are closely spaced from each other by uniformly distributed arrays of separator elements which accurately maintain relative spacing under varying temperature conditions even though the separator elements and metal layers have different coefficients of thermal expansion.

12 Claims, 13 Drawing Figures



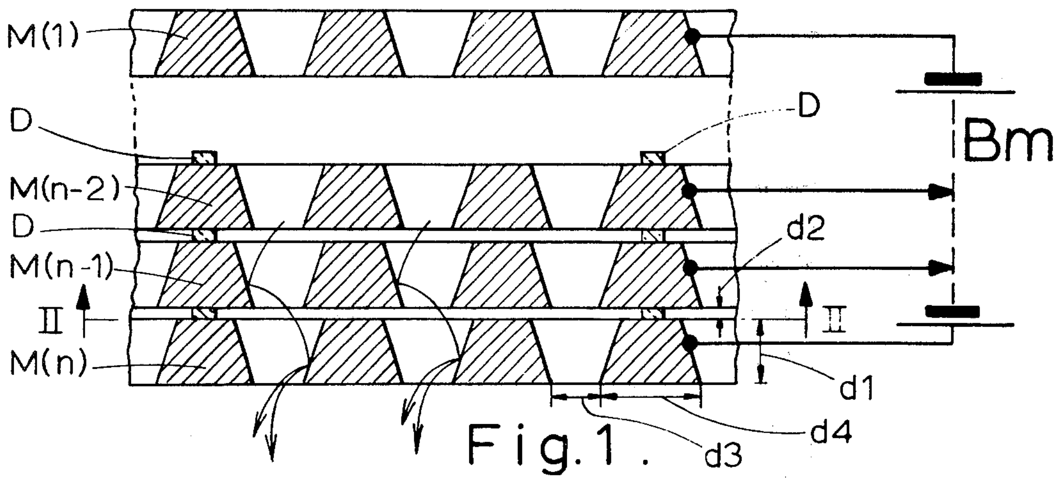


Fig. 1.

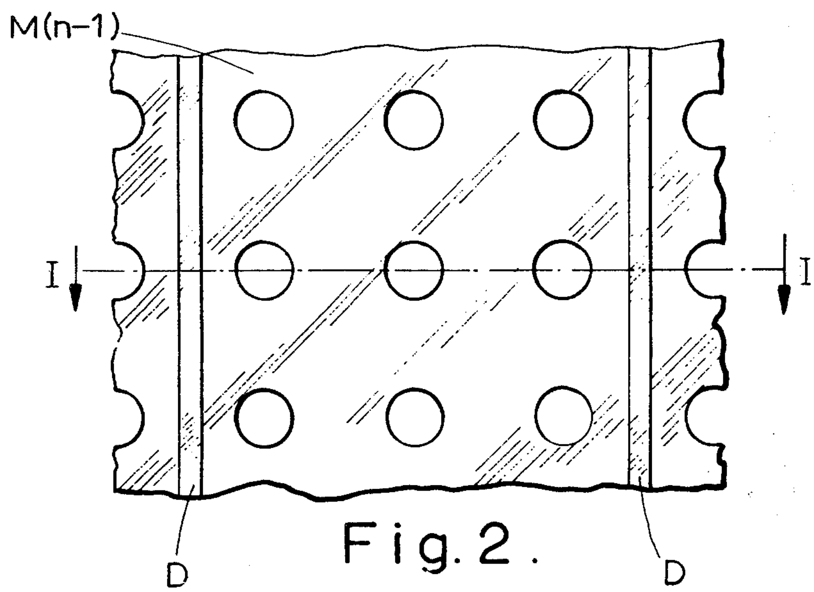


Fig. 2.

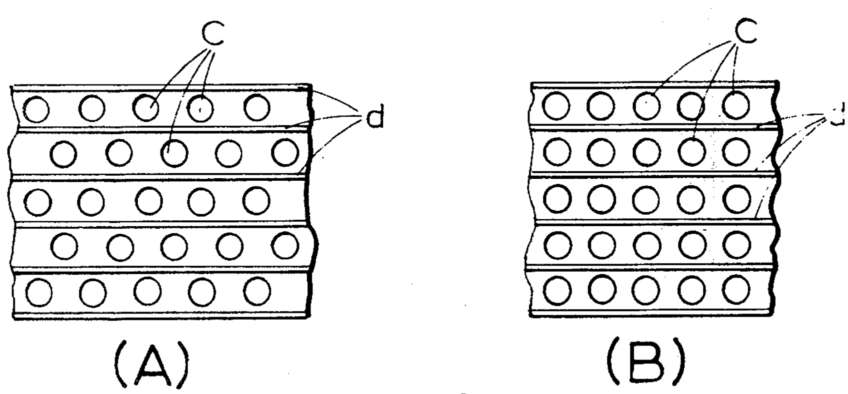


Fig. 3.

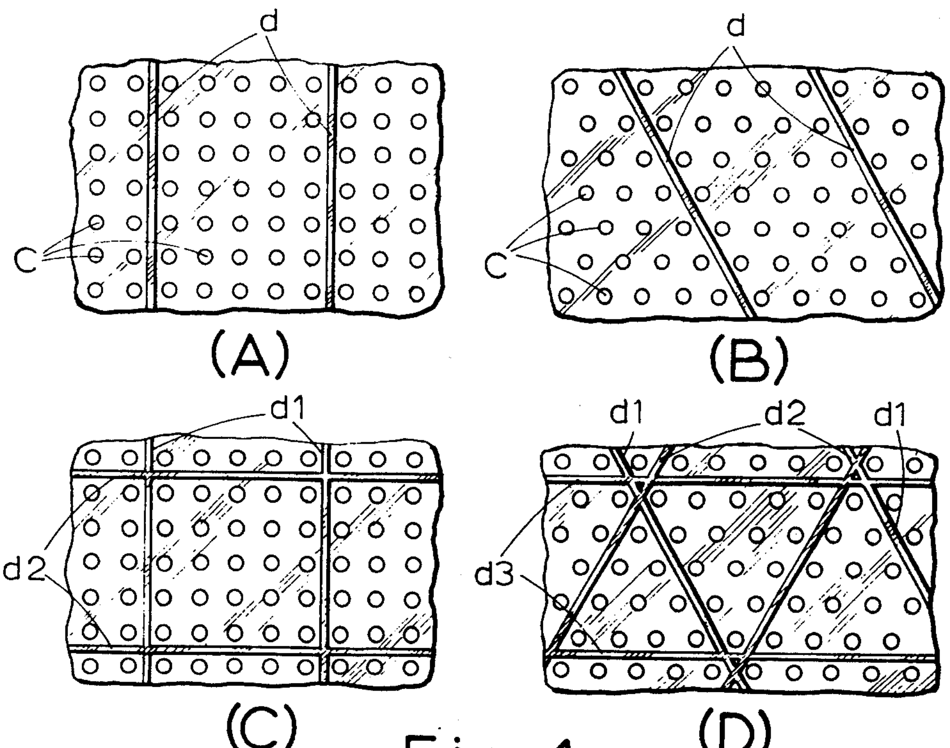


Fig. 4.

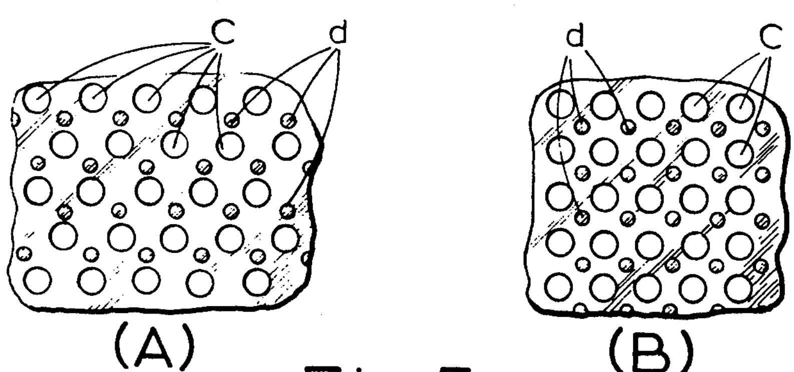


Fig. 5.

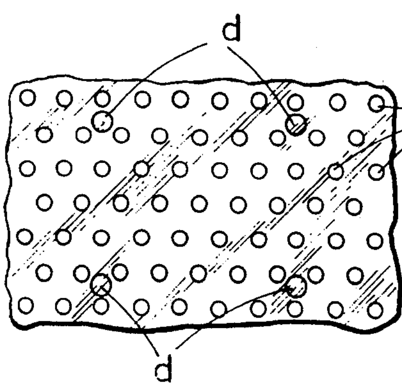


Fig. 6.

Fig. 7.

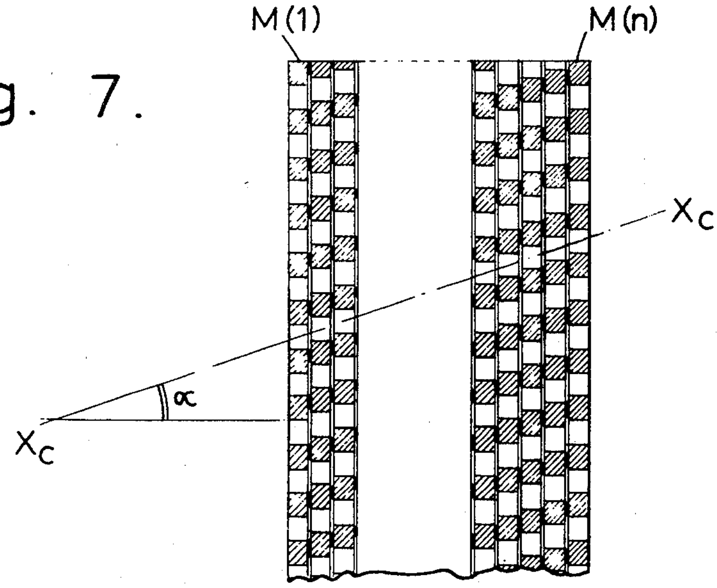
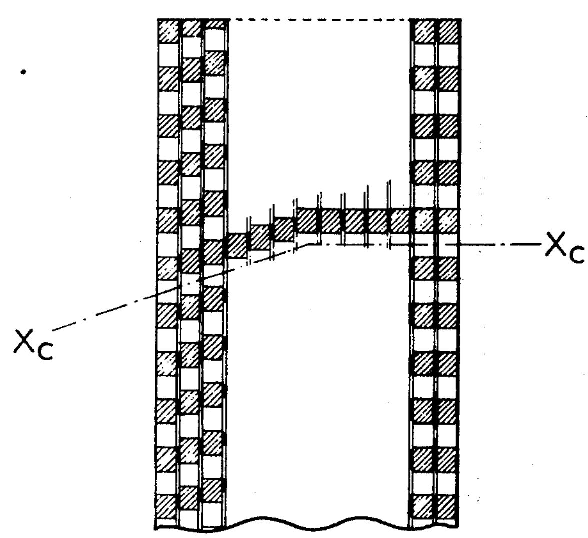


Fig. 8.



CHANNEL PLATE ACTING AS DISCRETE SECONDARY-EMISSIVE DYNODES

This invention relates to electron multipliers and more particularly to electron multipliers of the channel plate type. The invention is applicable to channel plates for use in electronic imaging and display applications.

The type of device now known as a "channel plate" is a secondary-emissive electron-multiplier device comprising a matrix in the form of a plate having a large number of elongate channels passing through its thickness, said plate having a first conductive layer on its input face and a separate second conductive layer on its output face to act respectively as input and output electrodes.

Secondary-emissive intensifier devices of this character are described, for example, in British Pat. No. 1,064,073 and in U.S. Pat. Nos. 3,260,876, 3,387,137, **3,327,151,** and 3,497,759, while methods of manufacture are described in British Pat. Nos. 1,064,072 and 1,064,072.

The channel plates described in these specifications can be regarded as continuous-dynode devices in that the material of the matrix is continuous (though not necessarily uniform) in the direction of thickness, i.e. the direction of the channels. In their operation a potential difference is applied between the two electrode layers of the matrix so as to set up an electric field to accelerate the electrons, which field establishes a potential gradient created by current flowing through resistive surfaces formed inside the channels or (if such channel surfaces are absent) through the bulk material of the matrix. As in all channel plates, secondary-emissive multiplication takes place in the channels.

In contrast with the present conventional continuous-dynode channel plates, plates of laminated construction have been described having a matrix formed of alternate conductor and separator layers so that the inner wall of each channel is discontinuous along its length.

One known type of laminated construction is in the form of a channel plate wherein the matrix is formed as a sandwich of alternate conductor layers and insulating separator layers with aligned apertures providing the channels, the arrangement being such that each insulator layer is set back with respect to the preceding conductor layer in order to prevent charging of the insulator, and the conductor layers act as discrete dynodes. An alternative laminated construction is described in British pat. application No. 53371/**71** in the form of a channel plate as herein defined wherein the matrix is formed as a laminated structure comprising alternate conductor layers and resistive separator layers with aligned apertures providing the channels. In this case the insulating separator layers have been replaced by resistive separator layers, so that the laminated channel plate structure has alternate layers of conductor and resistor. As the separator layer between two conductors is resistive, any charge accumulated thereon by the arrival of electrons will flow to the more positive adjacent conductor. Similarly, electrons will flow from the more negative adjacent conductor to replace any secondary electrons emitted from the resistive layer.

In the laminated structures referred to above, each separator layer is a continuous layer which surrounds each of the apertures in the adjacent conductor layers.

The present invention provides a channel plate comprising a laminated structure formed by perforate conductor layers having aligned apertures defining the channels and separated from each other by separator elements which are discontinuous in the sense that they do not completely surround the individual apertures of the conductor layers, and wherein the conductor layers constitute discrete secondary-emissive dynodes of the channel plate.

Each separator element may, for example, be formed as a set of parallel lines of separator material having the same pitch as the channels (i.e. as the array of apertures in an adjacent conductor layer) and an example will be given with reference to FIGS. **3A–3B**. Alternatively a set of separator lines may have a multiple of said pitch (e.g. as in FIGS. **4A–4B**).

As a further alternative, a separator may be formed as two (e.g. as in FIG. **4C**) or three (e.g. as in FIG. **4D**) intersecting sets of parallel lines having a pitch which is a multiple of the channel pitch.

Instead of lines of separator material, islands of separator material may be used. Such islands may be dots provided in rows having the same pitch as the channels in both of two co-ordinate directions (e.g. as in FIGS. **5A–5B**) or a pitch which is a multiple thereof (e.g. as in FIG. **6**).

For optimum electron trajectories and optimum gain it appears desirable that the thickness of the separators be less than the thickness of the conductor layers.

The fact that the apertures C are not individually surrounded by separator material is a reason why resistive separators (when used) are not relied upon for providing secondary emission, the dynode action being provided entirely by the conductor layers which, in practice, may be perforate metal plates of sheet metal.

In addition to acting thus as dynodes, the first and last conductor layers or plates can take the place of the input and output electrodes of a conventional continuous-dynode channel plate. Thus if the separators are resistive, it is possible to eliminate external resistor chain and other external means of setting the potentials of intermediate conductors, it being sufficient in some cases to apply an overall potential between the input and output dynodes or electrodes and to rely on the current flowing through the resistive elements to determine the potentials of the intermediate dynodes. Conversely, if the separators are of insulating material, each conductor layer or dynode must be supplied individually from the EHT source.

The apertures of successive conductor layers have to be aligned with sufficient accuracy to form uninterrupted channels through the channel plate structure, but such alignment does not imply that the channels are necessarily straight and normal to the input and output faces of the channel plate. In fact, as will be explained more fully, successive conductor layers may be deliberately displaced progressively with respect to each other so as to enable their apertures to form channels which are not straight and/or not normal to the channel plate faces.

Discontinuous separators have two main advantages over continuous separators. First, the more restricted separator coverage means that the separators are less likely to be exposed to electron trajectories, hence in the insulating separator case charging is less of a problem. Secondly, wider differences in expansion coefficient can be tolerated between the conductor and separator. Slight expansion differences can result in bending of the conductor-separator combination when separator coverage is continuous (as in the prior arrangements) thus making subsequent assembly of a number of such combinations difficult.

Specific embodiments of the invention will now be described by way of example with reference to the diagrammatic drawings accompanying the Provisional Specification in which:

FIG. 1 is an enlarged fragmentary axial section, i.e. a section containing the axes of several adjacent channels,

FIG. 2 is an elevation taken from the line II—II of FIG. 1,

FIGS. 3A and 3B show two examples of separators formed as sets of parallel lines having the same pitch as the channel pitch,

FIGS. 4A, 4B, 4C and 4D show examples of separators formed as sets of parallel lines having a pitch greater than that of the channels,

FIGS. 5A, 5B and 6 show separators formed as arrays of islands in the form of dots, and

FIGS. 7 and 8 show, in fragmentary axial section, arrangements in which the apertures of the dynode plates are in staggered alignment.

Referring first to FIGS. 1 and 2, this construction can, for example, have relative dimensions $d1$–$d3$ and γ (where γ is the angle formed between the channel wall and the plate surface) as follows:

TABLE I

$d1 = 100$
$d2 = 25$
$d3 = 50$
$\gamma = 75°$

(the dimension $d4$ is also shown as 100 but does not affect the efficiency of the individual channels).

In FIG. 1 the last three stages of the channel plate are shown having metal plates or dynodes $M(n\text{-}2)$, $M(n\text{-}1)$ and $M(n)$ separated from each other by separators D each separator comprising one set of parallel elements of line form. Since the dynode plate $M(n)$ is the last one of the series, it also takes the place of the output electrode of a conventional channel plate. Similarly, there is a first dynode plate M(1) which takes the place of the input electrode of a conventional channel plate. (In operation, all these plates may be fed, as shown, with increasing potentials by a D.C. supply source shown schematically at Bm or, if the separators are resistive, only the end electrodes M(1) and M(n) may thus be fed, or only M(1) and the last few stages). The stack of plates $M(2)$-$M(n\text{-}1)$ (with the adjacent separators) corresponds effectively to the matrix of a continuous dynode channel plate.

In this example the apertures of the metal plates are shown conical although this is not in any way essential and may be very difficult to achieve in practice. Equal or greater efficiencies can be obtained with curved profiles which depart from the conical form of FIG. 1 and have the added advantage of being easier to achieve with present technologies (the "efficiency" of a channel in the present context can be considered as the percentage of the secondary electrons of one conductor layer M which proceed to cause further secondaries in the next conductor layer).

Some of the more suitable separator patterns will now be described with reference to FIGS. 3 to 6, these being divided into two categroies, line separators and dot separators.

FIG. 3 shows two arrangements, each using a single array of parallel lines d of separator material deposited on a metal plate or sheet having apertures C which define the channels. Instead of being straight as shown, the separator lines d of FIG. 3A may be waved in accordance with the pattern of apertures C.

More economic patterns can be achieved by reducing the number of lines d so that not every channel has separator adjacent to it, the rigidity of the metal components being relied on to maintain accurate spacing. A few such arrangements are shown in FIG. 4 by way of example, FIGS. 4A and 4B employing one set of lines, FIG. 4C two sets and FIG. 4D three sets. (The FIG. 4A arrangement is similar to that of FIGS. 1–2).

FIG. 5 shows two patterns of dot separators in which there is one separator dot d per channel while FIG. 6 shows a pattern in which there is less than one dot per channel. In cases where the separator dots can be of substantially the same size as the apertures C, the FIG. 5 arrangement can be obtained conveniently by using one perforate metal plate as a template for the deposition of the separator material on an identical metal plate.

A wide variety of methods may be used to deposit the separator patterns, these depending to some extent on separator and metal compositions and including such techniques as screen printing, electrophoresis, anodising and evaporation.

Screen printing and electrophoresis are suitable methods when the separator material is glass and mild steel is suitable for the plates when glass separators are used. The steps of manufacture may be:

1. Formation of perforate metal plates.
2. Application of glass separator pattern on one side of each metal plate.
3. Bonding a series of plates together by partly melting the separators.

A problem may arise in maintaining accurate spacing between plates during bonding due to the softened separator changing shape. One method of overcoming this is to use two types of separator, one for spacing and one for bonding plus support. These may for example be arranged as alternate lines in the arrangements of FIG. 3 or as alternate dots in the arrangements of FIG. 5. The spacing separator should be applied first and it may be glass having a high melting temperature or a PYROCERAM type material. These spacer elements may be machined to accurate thickness after application. The bonding separator elements can then be applied and plates subsequently joined by heating them to such a temperature that the bonding separator softens but the spacing separator does not.

When resistive separators are required, glasses of high lead (Pb) content may be used, in which case a resistive surface layer can be produced on the glass by heating the finished channel plate structure in hydrogen, so reducing PbO to Pb at the exposed glass surfaces. Many enamel-type glasses have high Pb content and may be used in this manner. Alternatively, glasses described in U.S. Pat. No. 3,641,382 can be adopted.

Another approach is to use vitreous carbon as the resistive material. Vitreous carbon is made from various plastic-like materials which, when fired at high temperature, are converted to carbon. The resistivity is a bulk property (as opposed to the surface conduction property of lead glasses) and it can be controlled by the firing temperature (see B. Lersmacher, H. Lydtin and W. F. Knippenberg Chemie. Ing. Techn. 42 Jahrg 1970/Nr 9/**10** pages 659/**669**).

As a further alternative, aluminium or aluminium alloy plates may be used with aluminium oxide separator elements formed thereon.

Although FIG. **2** shows the cross-sections of the channels to be circular, this is not essential and may not be the preferable form. For example, a substantially rectangular channel cross-section may be preferred in some applications and such a channel form can be achieved by manufacturing methods as described above.

In FIG. **1** the input and output plates M(1) and M(n) are shown having the same thickness and apertures as the plates M(2)—M(n-1) of the matrix. In practice this may not be the best arrangement:- for example it may be desirable for M(1) to have a greater effective open area and this may be achieved by increasing the diameter of its apertures or by increasing its thickness outwardly so that the continuing taper of the apertures results in a larger aperture diameter at the input face of M(1).

If the material adopted for the conductor layers (e.g. mild steel) is not sufficiently secondary emissive for a particular application, the secondary-emissive properties of some or all of the conductors can be enhanced by providing a coating of a more emissive material on the exposed surfaces of the conductors inside the channels. This may be done on all the conductors but it may be preferable to apply the coatings only on the first few conductors located on the input side of the channel plate.

Channel plates according to the present invention can incorporate various features which have been described and claimed for continuous dynode channel plates.

First, the laminated construction of the matrix permits successive conductor layers to be displaced with respect to each other as aforementioned so as to enable their apertures to form channels which depart from the conventional configuration of straight channels normal to the channel plate faces. This may be done to achieve various effects which have been described earlier in relation to continuousdynode plates, and the following are specific examples:

A. Progressively staggered conductor layers arranged to provide channels which are at an acute angle to the normal to the faces of the channel plate (this arrangement can e.g. prevent orthogonal electrons from passing through the channels and it can also prevent optical and ion feedback from a display screen to a photo-cathode on the input side of the plate). An example of such a construction is shown schematically in FIG. **7** where a stack of about 13–15 stages is staggered to tilt the channel axes Xc Xc at an angle α to the normal to the faces. The conductors which act as input and output electrodes are shown at M(1) and M(n).

B. Variably staggered conductor layers arranged to provide curved channels to prevent ion and optical feedback in a manner similar to that described in copending U.S. Pat. application Ser. No. 247,955, filed Apr. 27, 1972, now abandoned. A simpler construction providing similar effects can be achieved by combining two oppositely tilted stacks of the FIG. **7** type into a single stack in which the channels follow a "chevron" pattern. Alternatively, a tilted stack can be combined with an orthogonal one (as shown in FIG. **8**) to provide channels which approximate some of the curved channel forms described in the Patent Specification just referred to.

(In FIGS. **7** – **8** the separator elements shown may be lines such as the lines d of FIG. **3B** normal to the plane of the drawing or they may be arrays of dots as in FIG. **5B**).

Another possibility is to provide a thin layer or membrane across an end (usually the entrance) of each channel, and the following are specific examples:

C. The provision of a photo-emissive layer across each channel entrance as described in U.S. Pat. No. 3,497,759) and for reasons given therein.

D. The provision of electron-permeable conductive membranes across the channel entrances as described in U.S. Pat. NO. 3,603,832 and for reasons given therein.

E. The provision of membranes by methods as described in U.S. Pat. No. 3,781,979 and for reasons given therein.

Yet another possibility is to provide a photo-cathode in the form of photo-emissive surface areas on, or in contact with, the input electrode as described for example:

F. in British Patent 1,090,406, or

G. in British Patent 1,303,889.

Channel plates according to the present invention can be used in a variety of imaging tubes, typical examples being image intensifiers and cathode-ray tubes. As aforesaid, the invention has particular advantages in applications requiring large-area viewing screens, for example television display applications. In particular, channel plates according to the invention may replace those used in the colour display applications described in copending U.S. Pat. application Ser. No. 529,263, filed Dec. 4, 1974, which is a continuation of copending U.S. Pat. application Ser. No. 288,597, filed Sept. 13, 1972, now abandoned.

The separator lines d of FIG. **3A** may be waved in accordance with the pattern of apertures C.

What we claim is:

1. A channel plate comprising a laminated structure of perforate electrically conducting metal layers having aligned apertures defining channels, said metal layers being spaced from each other by a distance less than the thickness of said metal layers by uniformly distributed arrays of mutually spaced individual separator elements that do not surround or block individual apertures of said metal layers, the material of said separator elements being substantially less conductive than said metal layers, thereby allowing said metal layers to be maintained at successively higher electrical potentials in order to act as discrete secondary-emissive dynodes, said uniformly distributed arrays of mutually spaced individual separator elements accurately maintaining said metal layers in a parallel relationship even though the coefficients of thermal expansion of the material of said separator elements and said metal be different and a temperature change occurs.

2. A channel plate as defined in claim **1**, wherein said apertures are tapered, each aperture having a cross-sectional area which reduces in the same direction, thereby tending to prevent electrons from entering the space between metal layers when said metal layers are maintained at successively higher potentials in said same direction.

3. A channel plate as defined in claim 2, wherein said alignment of said apertures is staggered, thereby resulting in channels which are either not straight or are not everywhere normal to said metal layers.

4. A channel plate as defined in claim 1, wherein said separator elements are in the form of strips of material.

5. A channel plate as defined in claim 1, wherein said separator elements are in the form of individual islands of material.

6. A channel plate as defined in claim 1, wherein the material of said separator elements is insulating material.

7. A channel plate as defined in claim 1, wherein the material of said separator elements is resistive material.

8. A channel plate as defined in claim 1, wherein the material of said metal layers is mild steel.

9. A channel plate as defined in claim 8, wherein the material of said separator elements is glass.

10. A channel plate as defined in claim 1, wherein the material of said metal layers is aluminum.

11. A channel plate as defined in claim 10, wherein the material of said separator elements is aluminum oxide.

12. A channel plate as defined in claim 1, wherein said alignment of said apertures is staggered, thereby resulting in channels which are either not straight or are not everywhere normal to said metal layers.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 3,914,634

DATED : October 21, 1975

INVENTOR(S) : COLIN D. OVERALL ET AL

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 1, line 21, "1064072" should be --1064075--;

Col. 2, line 41, "chain" should be --chains--;

Col. 5, line 59, delete "Xc".

Signed and Sealed this

Eighteenth Day of *October 1977*

[SEAL]

Attest:

RUTH C. MASON — *Attesting Officer*

LUTRELLE F. PARKER — *Acting Commissioner of Patents and Trademarks*