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Washington et al.

[11] **3,879,626**

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[54] **CHANNEL ELECTRON MULTIPLIER HAVING SECONDARY EMISSIVE SURFACES OF DIFFERENT CONDUCTIVITIES**

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[22] Filed: **Dec. 14, 1972**

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[52] **U.S. Cl.** **313/105;** 313/95

[51] **Int. Cl.** **H01j 43/22;** H01j 43/24

[58] **Field of Search** 313/105, 103, 104

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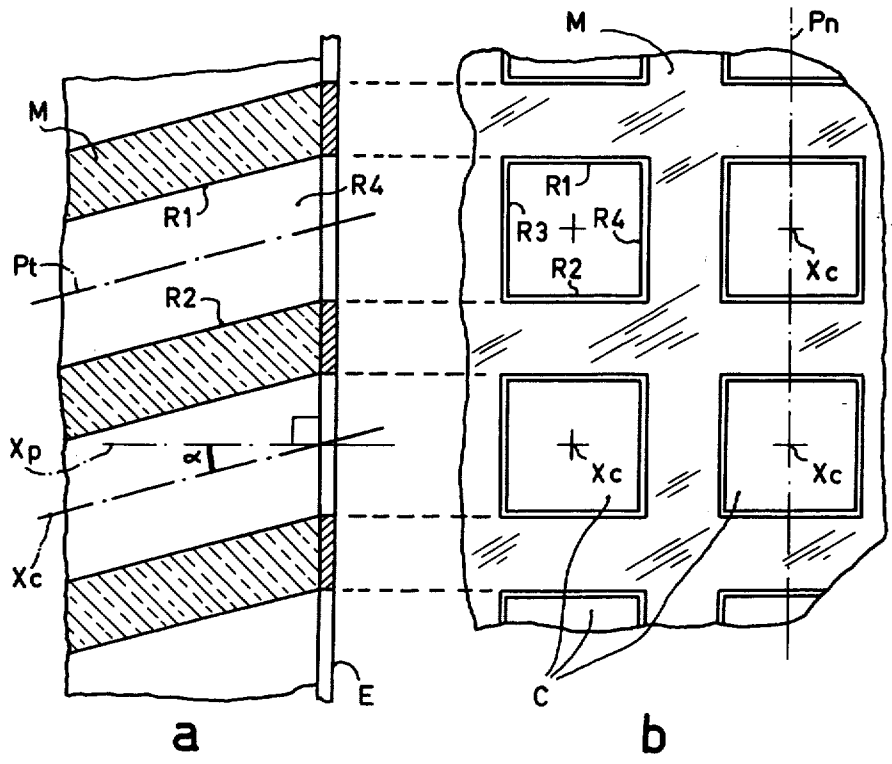
Attorney, Agent, or Firm—Frank R. Trifari; George B. Berka

[57] **ABSTRACT**

The surface conductive channels in the channel plate have areas of reduced conductivity sufficient to prevent the build-up of electrostatic charges. The areas extend continuously between the input and output electrodes and are normal to the plane of inclination of the channels.

4 Claims, 14 Drawing Figures



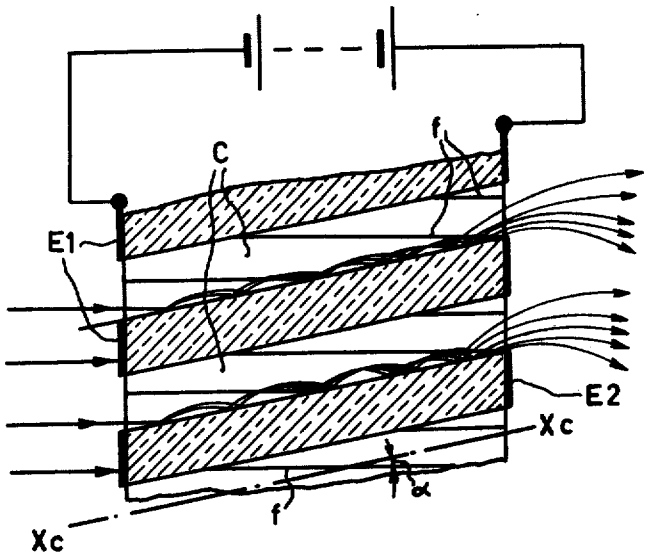


Fig.1

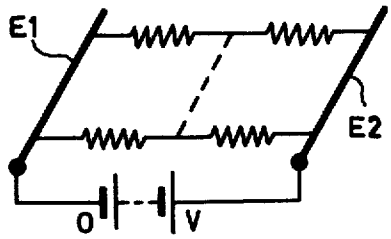


Fig.2

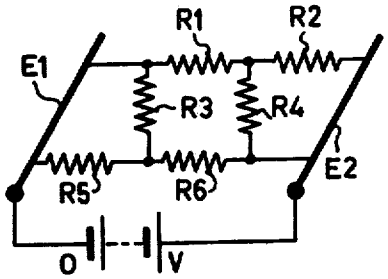


Fig. 3

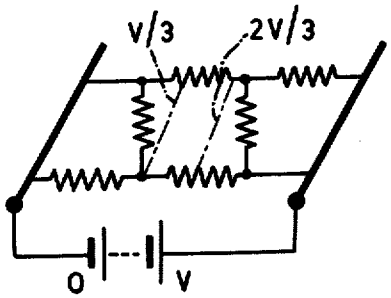


Fig. 4

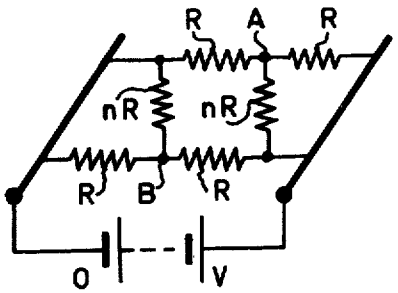


Fig.5

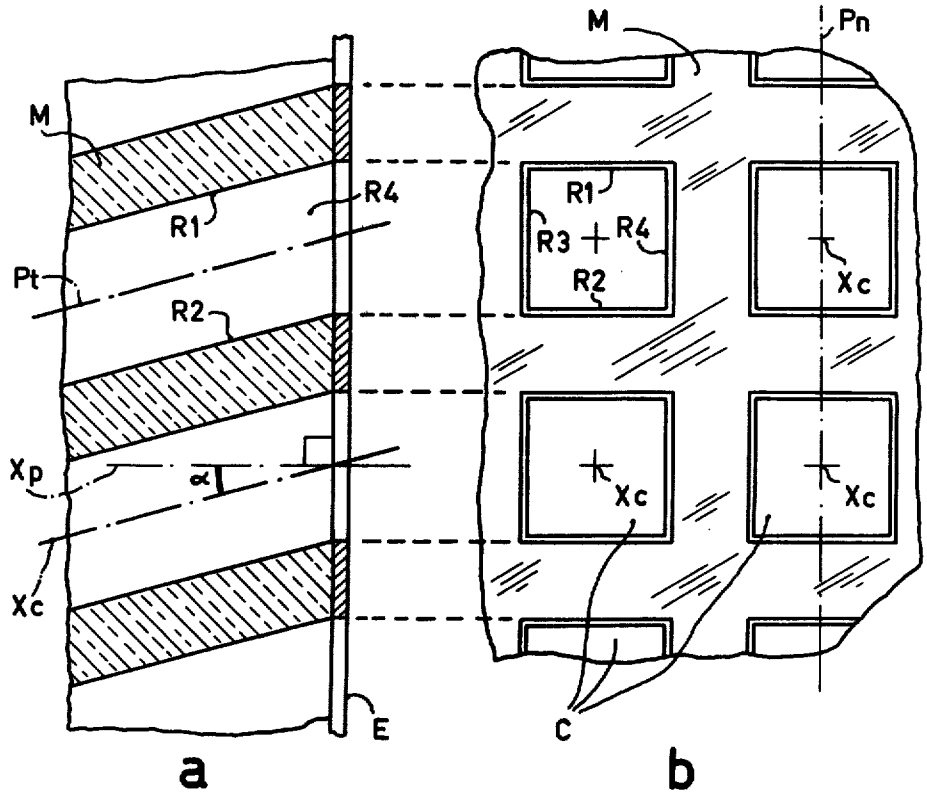


Fig.6

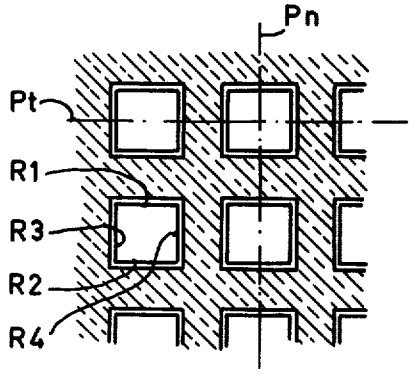


Fig.7

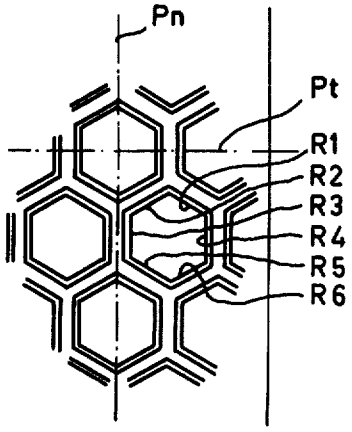


Fig.8

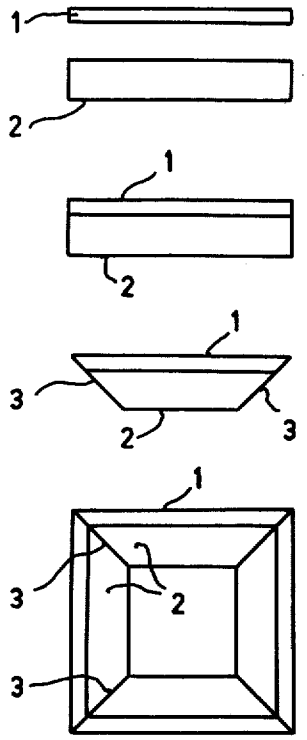


Fig.9

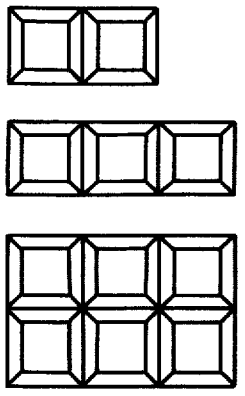


Fig.10

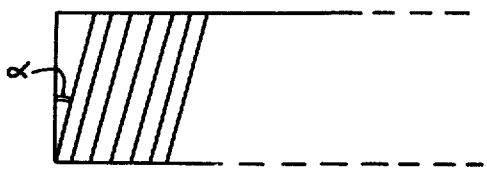


Fig.11

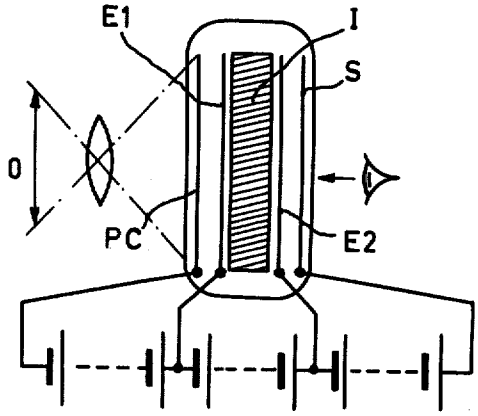


Fig.12

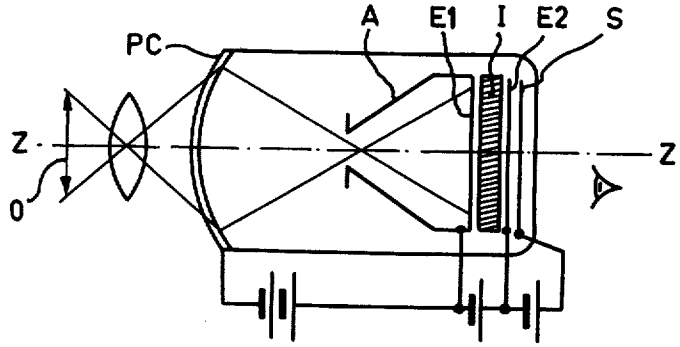


Fig.13

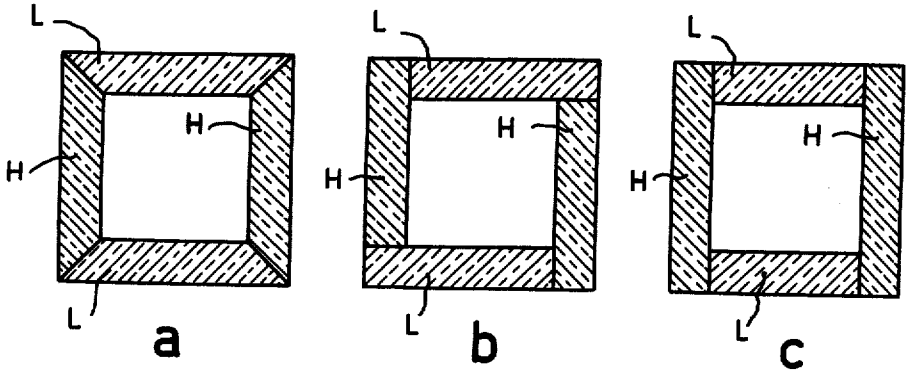


Fig.14

CHANNEL ELECTRON MULTIPLIER HAVING SECONDARY EMISSIVE SURFACES OF DIFFERENT CONDUCTIVITIES

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 tube applications.

The type of device now known as a "channel plate" can be defined as 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.

The invention relates more particularly to channel plates of the continuous dynode type. This is convenient term for channel plates having what is at present the conventional form of construction. Such channel plates 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. in the direction of the channels.

Continuous dynode channel plates are described, for example, in U.S. patent application Ser. No. 364,683, filed May 4, 1974, Ser. No. 359,855, filed Apr. 13, 1964. Ser. No. 363,496, filed Apr. 29, 1964, Ser. No. 390,760, filed Aug. 9, 1964 and Ser. No. 729,126, filed May 14, 1968, while methods of manufacture are described in U.S. patent application Ser. No. 362,158, filed Apr. 23, 1964.

In the operation of continuous dynode plates 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. Secondary-emissive multiplication takes place in the channels and the output electrons may be acted upon by a further accelerating field which may be set up between the output electrode and a suitable target, for example a luminescent display screen.

Channel plates can be used in imaging tubes of various kinds, for example scanning tubes such as cathode-ray tubes and camera tubes and non-scanning image intensifier tubes (this Specification will, for convenience, refer to an image intensifier tube in those terms rather than as an "image converter" tube even in applications where the primary purpose is a change in the wavelength of the radiation of the image).

In a conventional channel plate the gain is critically dependent on the ratio of channel length to diameter (the "L/D" ratio). This results in a number of manufacturing problems, and the solution of two of these is particularly desirable. The first is the extremely high degree of fibre size control required during the tube drawing processes normally used. Fibre diameter variations of little more than ± 1 percent have been detected as gain variations over the finished plate. The second problem is the "chicken-wire" pattern produced by the partial collapse of channels around the periphery of the multifibre units when a multi-draw hollow fibre system is used. The most common solution is to support the tubular fibres from within by soluble or etchable supporting cores which are removed after the matrix has been formed. The manufacture and fitting of the cores (which are usually of glass) and their subsequent removal are very costly processes and between 30 percent and 50 percent of the total cost of channel plate manufacture may be expended on these two items. A satisfactory hollow fibre method would result in a significant cost reduction and it is an object of the present invention to render this practicable by providing a construction in which gain is substantially independent of channel diameter.

One solution has been given in the aforesaid U.S. patent application Ser. No. 364,683. This describes the effect of tilting the channels relative to the plate axis i.e. to the normal to the plate faces. This effect is illustrated in FIG. **1**. In the example shown the channel axes (*Xc*) are tilted at an angle α to the plate axis. The equipotentials within the channel are parallel to the plate faces and to the input and output electrodes (E1–E2) and hence the lines of force *f* remain parallel to the plate axis thereby deflecting the electrons towards one side of each channel as shown diagrammatically in the drawing (this will be referred to as "one-sided multiplication"). At that time it was assumed that this solution was valid for both bulk-conduction and surface-conducting channel glasses, i.e. where the plate or standing current flowed through the whole glass matrix (bulk) and where it was restricted to a layer on the inside of each channel (surface). Applicants have since demonstrated that in the surface conduction case the equipotentials are normal to the channel axes Xc (and not the plate axis) over most of the channel length except for end portions about two diameters in length (this theory is fully described in U.S. patent application Ser. No. 358,510, filed Apr. 9, 1964. In other words the construction of FIG. **1** can only provide one-sided multiplication if bulk conduction is used, and this is also true of a similar proposal contained in British Pat. Specification No. 979,687 (Bendix).

There are other advantages in bulk conduction for tilted channel plates, notably the possibility of preventing ion feedback and of achieving this with a single plate instead of the two-plate tandem arrangements described in British Pat. Specifications No. 1,126,088 (Bendix) and the U.S. patent application Ser. No. 358,510.

From this it will be seen that a tilted channel plate of the bulk conduction type has considerable advantages. Although bulk conduction has been considered from the beginning of the channel multiplier art, there has been great difficulty in finding bulk-conductive materials suitable in all respects for channel plate manufacture and operation, so much so that all the channel plates hitherto commercially available for imaging purposes appear to have been of the surface-conduction type. In fact, for technological reasons it has been found preferable hitherto to construct channel plates from an insulating glass which is then subjected to a treatment which renders the glass surface slightly conductive inside the channels.

The usual treatment is chemical surface reduction of a metal containing glass and examples of suitable glasses and treatments are described in British Pat. Specification No. 1,168,415, these being lead glasses on which surface-conducting channel layers are formed by chemical reduction.

Thus it is a further object of the invention to provide a tilted surface-conduction structure which will enable a channel plate to have electrical properties similar to those of a tilted bulk-conduction plate, notably the property of maintaining the equipotentials substantially parallel to the faces of the plate even though the channels are tilted. Such a structure has been evolved as a result of the aforesaid theory.

Accordingly, the invention provides a matrix for a surface-conducting channel plate of the continuous dynode type in which matrix the channels are inclined at an acute angle α with respect to one of two orthogonal planes normal to the matrix faces and the inner surface of the matrix surrounding each channel provides areas of reduced conductivity, extending between two electrodes and being substantially coplanar with the other orthogonal plane.

The derivation of such a structure from the aforesaid theory will now be explained with reference to FIGS. **2** to **5** by considering channels of square cross section (this is the simplest configuration to understand and also the simplest to produce, but the invention is not restricted to square cross-sections). In developing the theory described in U.S. patent application Ser. No. 358,510 a resistor network was used to represent a short length of channel. It is convenient to restate part of the argument.

By representing opposing walls of an isolated channel as resistor chains, one of the channels of FIG. **1** appears as shown in FIG. **2** where the potential across the channel plate is V volts and the two chains are connected at their ends by the conductive electrodes E1–E2 on the two faces of the channel plate. If the resistors R are of equal value, the dotted line will represent the equipotential V/2 which will be parallel to the end electrodes.

However, in normal practice the two resistor chains are effectively interconnected by resistors which will have their minimum effective value at right angles to the channel axis as shown in FIG. **3** (it will be assumed again, for the sake of argument, that all resistors are of equal value R). In this case the current flowing between E1 (at potential **0**) and E2 (at potential V) travels through two parallel paths. The upper path consists of R1 in series with two R's (R2 and R4) in parallel i.e. R in series with R/2. The lower path is the same but reversed (R3 and R5 in series with R6). In each path the potential across the single resistor R will be 2V/3 and V/3 will be the potential across the pairs of resistors R in parallel. The V/3 and 2V/3 equipotentials will thus appear as in FIG. **4** and are clearly closer to the normal to the channel axis than in the case of FIG. **2.**

Let us now consider the case where the resistors across the channel are of a higher value than those along the length (say, n times) and let us consider the resulting potentials at points A and B (FIG. **5**).

If $n = 10$, the potential dividing action of this network gives potentials of almost equal value across the single resistor and the two parallel resistors, i.e. 11/21 V at A and 10/21 V at B.

Hence over this short channel length an equipotential V/2 will lie very close to points A and B and therefore the equipotentials will be substantially parallel to the end electrodes. If the transverse resistors are $n = b\ 100$ times the value of the longitudinal resistors the effect is even more pronounced, and the potential of point A will be 101/201 V while that of point B will be **100**/201V.

Specific embodiments of the invention will now be described by way of example with reference to FIGS. **6** to **13** of the drawings accompanying the Provisional Specification in which:

FIGS. **6** and **7** show square matrix structures,

FIG. **8** shows a hexagonal matrix structure,

FIGS. **9** to **11** illustrate methods of manufacture and

FIGS. **12** to **13** show tubes employing channel plates according to the invention,

Finally, FIG. **14** of the drawings accompanying the Complete Specification shows cross-sections representing further variants in methods of manufacture.

The surfaces of relatively low conductivity should have sufficient conductivity to prevent the build-up of electrostatic charges. On the other hand the surfaces of higher conductivity should have sufficient conductivity to carry the standing current required for operation of the channel plate. In principle, the material of the matrix lying between one channel and another could also provide a small degree of conductivity equal to or less than that of the low-conductivity channel surfaces but leakage paths from channel to channel are undesirable and therefore in practice the material of the matrix should as far as possible provide full insulation between adjacent channels.

In the case of square channels, the structure may be as shown in FIG. **6** which is a generalized representation of a section taken along the channel axes Xc (FIG. **6***a*) and an end view of one face of the plate with the end electrode (E) removed (FIG. **6***b*). The matrix material is shown as an insulator M occupying the space between the channels C.

Each channel has two tilted walls or surfaces R1–R2 of lower resistivity (higher conductivity) and two walls or surfaces R3–R4 of higher resistivity (in principle the latter could have infinite resistivity but, in practice, this would cause electrostatic charging of the surfaces and other problems). Walls R1–R2 provide most of the electron multiplication and are shown tilted at an angle α to the normal to the faces of the plate.

For the purposes of reference it is convenient to adopt a notional plate axis or matrix axis Xp (FIG. **6***a*) which is normal to the faces of the plate or matrix and therefore forms the angle α with any channel axis Xc. Similarly, it is convenient to refer to a "normal plane" Pn (FIG. **6***b*) for each channel, such plane containing the channel axis Xc and being normal to said faces so that it represents the direction in which the channel is not tilted. A second useful reference plane is the plane Pt (FIG. **6***a*) which also contains the channel axis but is normal to the plane Pn and represents the degree of inclination α of the channel (it is therefore referred to as the inclined or "tilted" plane of the channel). When considering a cross-section normal to the channel axes (as in FIGS. **7** and **8**) both planes Pn–Pt become normal to the plane of the drawing.

FIG. **7** shows the same structure as a cross-section normal to the channels and, by way of comparison, FIG. **8** shows a similar cross-section of a hexagonal arrangement. In FIG. **8** there are four tilted low-resistance walls or surfaces providing most of the electron multiplication (R1–R2 and R5–R6) and two high-resistance walls R3–R4 which are parallel to the normal plane (Pn) and therefore are not tilted. Other cross-sections are possible according to the invention and it

is possible to envisage these examples extended to a limit case in which the channel section is circular and the resistivity is continuously graded from a minimum value on the generatrices where the channel wall intersects the normal plane P*n* to a maximum value on the generatrices where the channel wall intersects the tilted plane P*t* (although such an arrangement is possible it would be very difficult to reduce to practice with present techniques).

Reverting to the square channel configuration of FIGS. **6** and **7**, let us consider how the resistance differentials can be achieved in practice. Applicants have previously described a method of making channel plates using flat strips of glass which are assembled into polygonal channel tubes instead of the more usual glass in integral tube form (U.S. patent application Specification Ser. No. 220,270, filed Jan. 24, 1970. One such example is given in FIG. **9** which shows the cross section of a tubular unit and its components prior to drawing into fibres.

This example illustrates one particular way in which a matrix according to the invention can be manufactured from fibres of square or rectangular cross-section by a method which includes the steps of:

a. making glass strips of two kinds, the cross-sections of said strips being geometrically compatible,
b. assembling together four strips to form an assembly of the desired cross-section such that one pair of opposite parallel strips differs in composition from the other corresponding pair of opposite parallel strips,
c. drawing said assembly to form the desired monofibre, and
d. assembling lengths of said monofibre so as to form a matrix structure having inclined channels.

If the above strips are of metal-containing glass, channel plates can be made from matrices thus obtained by a method including the further steps of

e. applying input and output electrode layers to the matrix faces and
f. reducing the internal surfaces of the channels so as to cause one pair of opposite surfaces in each channel to have a conductivity differing from that of the other pair.

As part of step (d), and as shown in FIG. **11**, a resulting boule of parallel fibres can be sliced by cutting at the angle α, one example of a suitable angle being $\alpha = 13°$.

After step (d) the normal processing is carried out whereby the slices or matrices are turned into channel plates in known manner. In addition to steps (c) and (f), supporting cores (if present) are removed.

FIG. **9** shows three stages in the formatin of composite strips **1** – **2** having bevelled longitudinal edges **3** (FIGS. **9**(*a*) to **9**(*c*)). Four such strips are assembled into tubular structure (FIG. **9**(*d*)) which can then be drawn down to fibre.

For the present purposes, the assembly may be a tube of channel glass **1** with a supporting core **2** of differentially etchable glass which is hollow to facilitate etching out.

Alternatively, the assembly may be a tube of channel glass **2** having an external sheath of low-melting-point glass **1** to facilitate the fusing of adjacent tubes (and the filling of any interstices).

(The term "channel glass" is used herein to denote the material forming the walls of the channels in the final matrix regardless of whether the material requires any surface treatment to enable it to provide the required conductivity and secondary-emissive properties (a typical example of such a treatment is the aforesaid chemical reduction applied to the surface of a metal-containing channel glass such as lead glass)).

In a structurally simpler case, the low-melting-point glass is also dispensed with and a single glass is used on each side of the square. This is illustrated in FIG. **14** of the accompanying drawings which shows three possible variants (a), (b) and (c) which only employ a pair of high-resistance strips H and a pair of low-resistance strips L (the conductivity of all four strips is preferably confined to the inner surfaces modified by the reduction process referred to above). Since only one kind of glass is used for each strip, the glasses L and H are preferably insulators (except for their inner surfaces because leakage paths from channel to channel are undesirable.

In the above cases one pair of opposite strips of channel glass will differ in its properties from the other pair so that one pair has higher resistivity than the other in the final matrix. For example, by selecting channel glass of two suitable compositions it is possible to arrange for the strips corresponding to **R3–R4** to have a higher surface resistance on reduction than the strips corresponding to **R1–R2**. With the glasses described in the previously mentioned British Pat. specification No. 1,168,415 differences of surface resistivity of up to four orders of magnitude may be obtained. Moreover, very large differences can be obtained by very small changes in composition so that the two kinds of matrix glass can fuse together readily at the corners. To obtain full benefit of the advantage of the present invention the four strips are held together without a core glass in the middle while the assembly is drawn down to a hollow fibre.

It is, of course, necessary that the fibres be correctly orientated with respect to the angle α at which the plate subsequently cut, so as to ensure that the high-resistance components **R3–R4** are parallel to the plate axis X*p* (i.e. normal to the cuts) while the low resistance elements **R1–R2** are at an angle α to said axis. When drawn to fibre, the dimensions are small enough to make such orientation difficult. It may therefore be advantageous to determine the orientation before drawing, and to draw an assembly of several correctly aligned units together so as to obtain a multi-tube fibre of oblong rectangular cross-section (some examples are shown in FIGS. **10***a* to **10***c*).

In a two-draw-process the multi-fibre assembly for the second draw can similarly be given an oblong rectangular cross-section. This provides a simple method of identifying the high and low resistance planes corresponding to planes P*t* and P*n* respectively.

FIG. **11** shows a resulting boule of parallel fibres which is sliced by cutting at the angle α, one example of a suitable angle being $\alpha = 13°$.

The normal processing is then carried out whereby the slices or matrices are turned into channel plates in known manner. Notably, the cores (if present) are removed and the conductive channel surfaces are obtained e.g. by chemical reduction. Also, the input and output electrodes are formed on the matrix faces.

FIGS. **12** and **13** illustrate the use of channel plates in accordance with the invention in imaging tubes. In the examples given, a channel plate I is shown inside the envelope of an image intensifier tube containing

also a photo-cathode PC and a lumninescent screen S. FIG. **12** shows a tube of the "proximity" type while FIG. **13** shows a tube of the "electronoptical diode" or "inverter" type employing a conical anode A.

When a display screen S is used, the plate I can be made opaque so as to prevent optical feedback from S as well as ion feedback.

The invention may also be used for other imaging tubes, for example cathode-ray display tubes and camera tubes.

In addition to ion and optical blindness, a channel plate according to the invention can prevent the "dark cross-sections or "black spot" defect described in U.S. Pat. No. 1,164,894.

What we claim is:

1. A surface-conducting channel plate of the continuous dynode type, comprising a matrix of elongate channels having polygonal cross-section and extending between two opposite planar and parallel faces of the plate, an input electrode and output electrode provided on said faces, said channels being inclined at an acute angle with respect to one of two substantially orthogonal planes normal to said faces, the conductive inner surface of the plate surrounding each channel having secondary emissive areas facing said one orthogonal plane and extending continuously in the longitudinal direction between said electrodes and further having areas of reduced conductivity extending continuously between said secondary emissive areas and being substantially parallel with the other orthogonal plane.

2. A plate as claimed in claim **1** wherein the channels have substantially square or rectangular cross-sections

3. A plate as claimed in claim **2** wherein the angle of inclination α is approximately 13°.

4. A matrix as claimed in claim **2** wherein the low-conductivity and the higher-conductivity walls of each channel are made of metal-containing glasses of similar composition except for a difference which allows the required difference in conductivity to be obtained by differential response to chemical reduction.

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