July 7, 1970 A. O. JENSEN 3,519,870

SPIRALED STRIP MATERIAL HAVING PARALLEL GROOVES FORMING PLURALITY OF ELECTRON MULTIPLIER CHANNELS

Filed May 18, 1967 4 Sheets-Sheet 1

Fig. 1

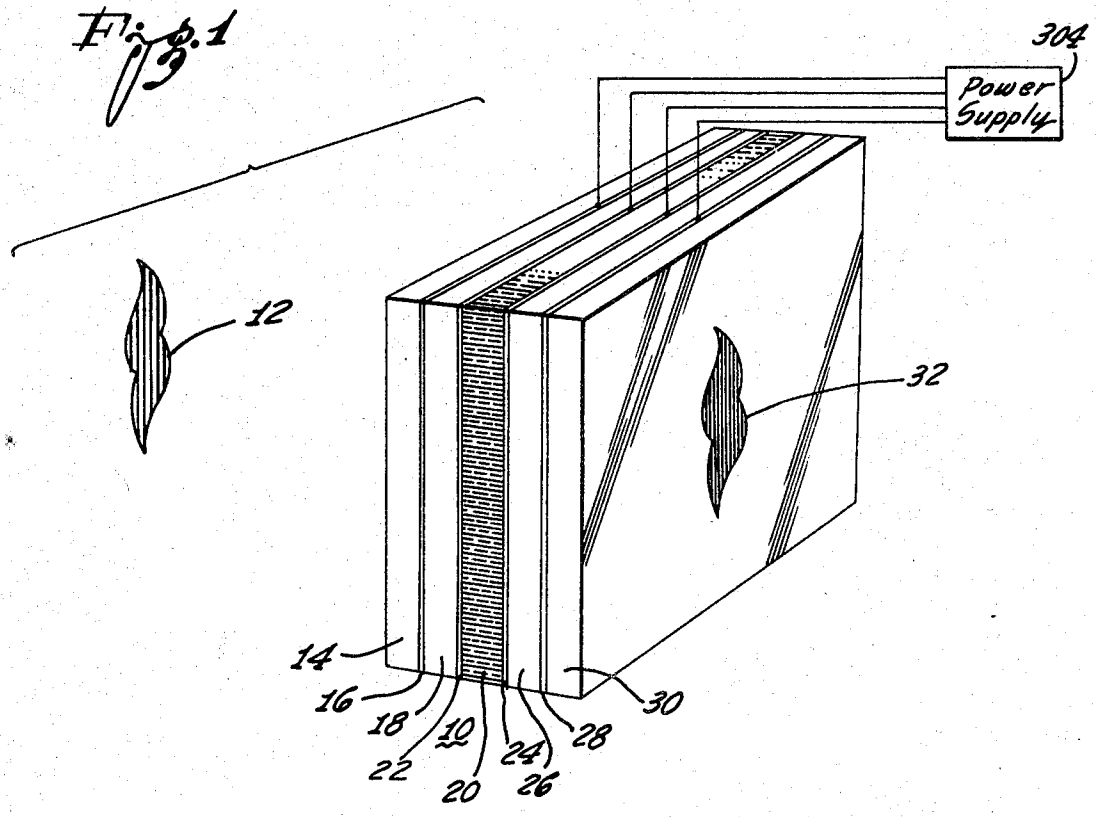
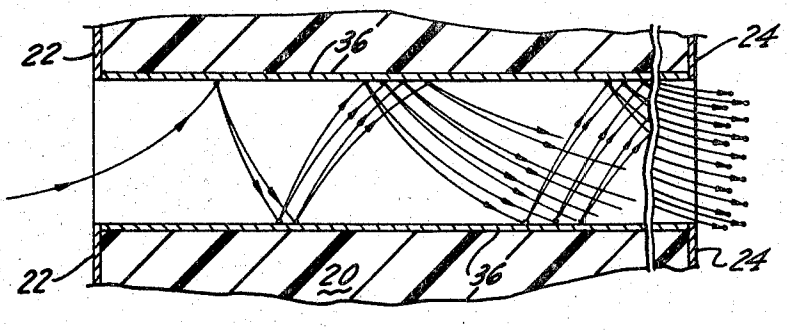


Fig. 2



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Fig. 3

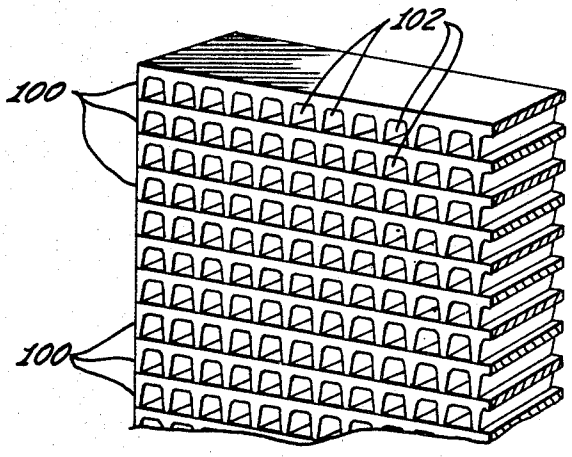


Fig. 3a

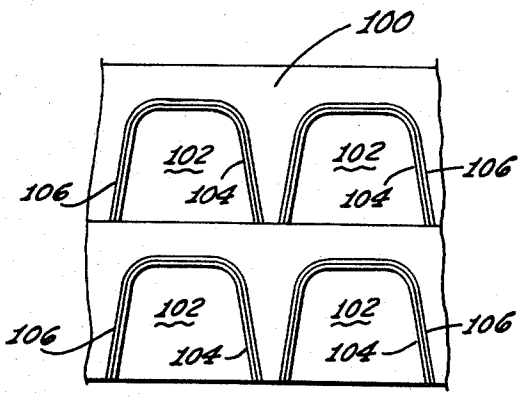


Fig. 4

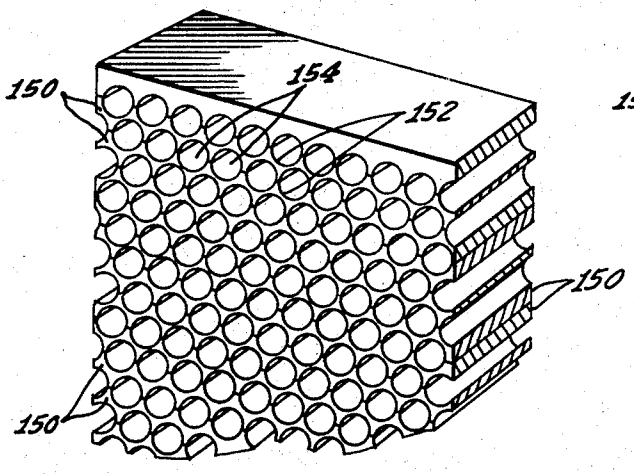
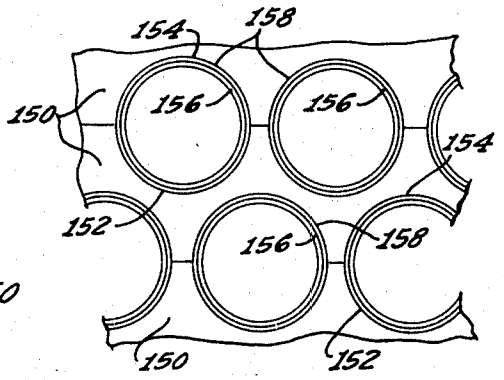


Fig. 4a



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SPIRALED STRIP MATERIAL HAVING PARALLEL GROOVES FORMING PLURALITY OF ELECTRON MULTIPLIER CHANNELS

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Fig. 5

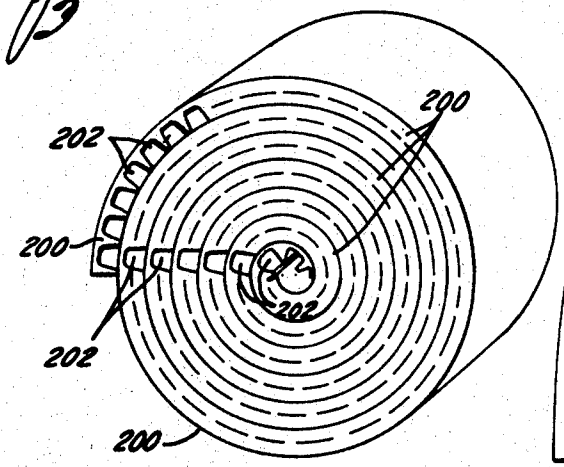


Fig. 5a

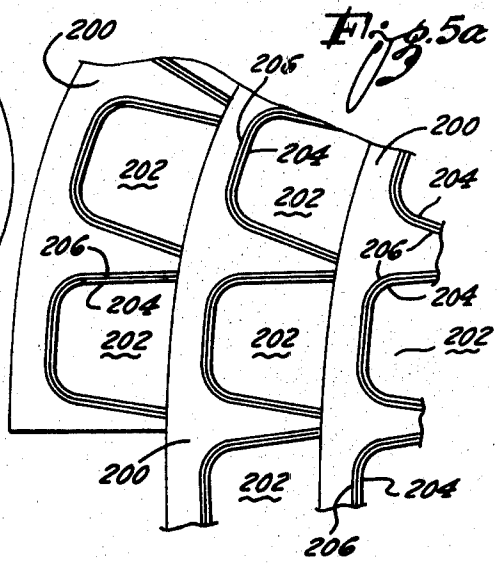
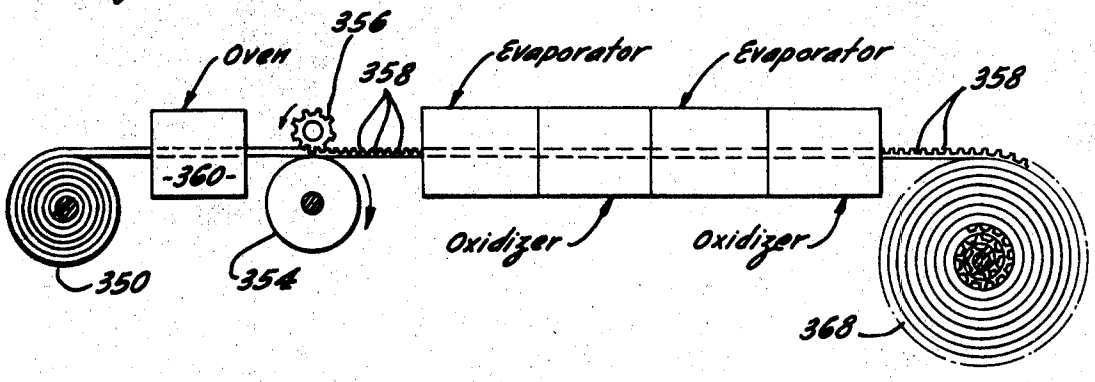


Fig. 8



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Fig. 6

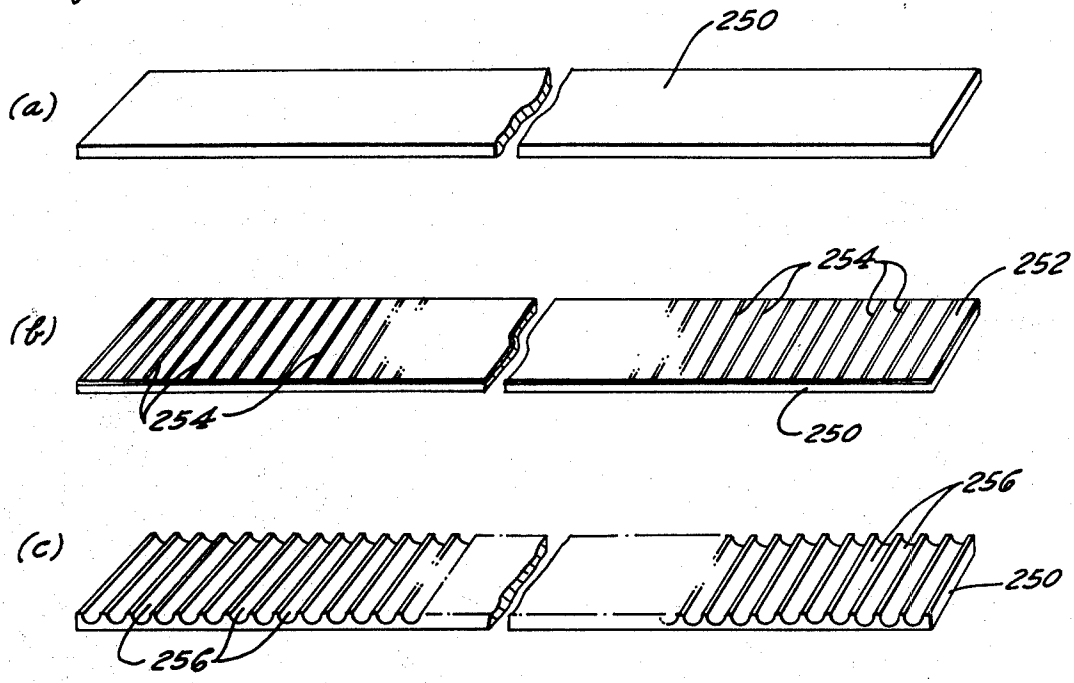
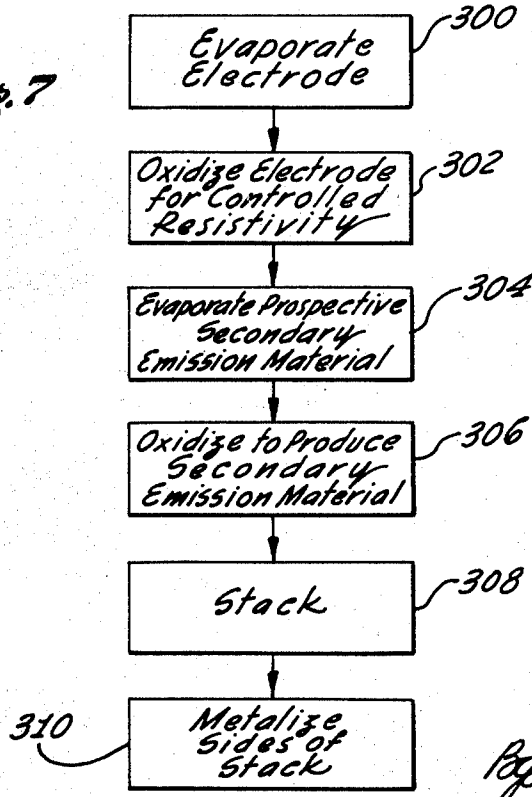


Fig. 7



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United States Patent Office 3,519,870 Patented July 7, 1970

3,519,870

SPIRALED STRIP MATERIAL HAVING PARALLEL GROOVES FORMING PLURALITY OF ELECTRON MULTIPLIER CHANNELS

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Filed May 18, 1967, Ser. No. 639,555
Int. Cl. H01j 43/20, 43/24
U.S. Cl. 313—105 2 Claims

ABSTRACT OF THE DISCLOSURE

This invention relates to an electron multiplier. Generally, the electron multiplier of the present invention is constructed from a plate of insulating material. The plate of insulating material contains a plurality of parallel grooves on at least one surface of the insulating plate. A layer of secondary emission material covers the walls of the grooves so that the plurality of grooves provides for a plurality of electron channels. A plurality of grooved plates of insulating material or a single spiraled plate may be used to provide for a two-dimensional electron multiplier.

Electron multipliers provide for a multiplication of electrons and may be thought of as an electron amplifier. For example, an electron multiplier may be used as part of an image intensifier so as to provide for an increased brightness of a dim image.

In particular, the invention relates to a simplified construction for an electron multiplier. The simplified construction of the electron multiplier of the present invention provides for an improved performance over electron multipliers of the prior art. In addition, the electron multiplier of the present invention allows for a reduction in cost over prior art electron multipliers.

As indicated above, the electron multiplier of the present invention includes a plate of insulating material which contains a plurality of grooves coated with secondary emission material. In the use of the electron multiplier of the present invention, electrons are introduced at a first side of the grooved plate and the electrons move down the length of the grooves and strike the secondary emission material at progressive positions along the grooves. Ultimately the electrons emerge at a second opposite side of the plate and there is a multiplication of the number of electrons emerging from the second side in comparison to the number of electrons introduced at the first side of the plate.

In one particular use of the electron multiplier of the present invention a plurality of such grooved plates may be stacked together or a single elongated plate may be spiraled so as to provide for a two-dimensional electron multiplier. Specifically, the two-dimensional type of electron multiplier may be used in a structure such as an image intensifier, since it would be desirable to provide for an increase in intensity of a two-dimensional image. Also, in the construction of the electron multiplier of the present invention an accelerating field may be provided so as to compel the movement of the electrons in the proper direction along the grooves. The use of the accelerating field insures successive collisions of the electrons with the secondary emission material at successive points along the grooves.

The prior art electron multipliers were constructed of a plurality of small tubes of insulating material such as glass to form a plurality of electron channels. For example, in the prior art, small tubes of glass would be stacked together to provide for a two-dimensional electron multiplier. The size of the channels would be reduced by

progressively drawing the tubes smaller and smaller so as to reduce the dimensions of the tubes and provide for a great number of electron channels in a small area. The openings through the glass tubes were, therefore, very small and it was extremely difficult to deposit secondary emission material on the interior surface of the tubes.

Since it was difficult to deposit secondary emission material on the interior surface of the tubes, the prior art electron multipliers were constructed of lead glass and the lead glass was processed by a hydrogen reduction of the interior surface of the tubes so as to produce a layer of secondary emission material on the interior surface of the tubes. However, it is to be appreciated that it is difficult to provide for such a hydrogen reduction of the interior surface of the lead glass tubes and, moreover, it is difficult to provide for uniformity of the layer of secondary emission material. A non-uniformity of the layer of secondary emission material between different electron channels can result in errors in the output from the electron multiplier.

The prior art electron multipliers using a plurality of small tubes were extremely expensive to construct and did not provide for uniform results. Another limitation with the prior art electron multipliers of the type using a plurality of the small tubes was that the electron multipliers were limited to the use of a layer of secondary emission material which was produced by hydrogen reduction and it was not possible to provide for the deposition of other secondary emission materials which have secondary emission ratios higher than that provided by the hydrogen reduction.

The present invention uses a plate of insulating material having a plurality of grooves along at least one surface of the plate. The grooves are open so that it is simple to perform further operations on the interior of the grooves. For example, the grooved plate of insulating material may be constructed of a lead glass and the plate of lead glass is processed by hydrogen reduction, so as to provide for a layer of secondary emission material covering the walls of the grooves. Since the grooves are open, it is much simpler to control the uniformity of the layer of secondary emission material formed by the hydrogen reduction process.

However, one of the significant advantages of the electron multiplier of the present invention is that other secondary emission materials may be deposited to cover the walls of the grooves so as to provide for the layer of secondary emission material. Also, since the grooves are open, the secondary emission material may be deposited uniformly throughout the length of the grooves. It is, therefore, possible with the present invention to provide for the deposition of materials having relatively high secondary emission ratios in place of the lower secondary emission ratio materials used in the prior art electron multipliers. For example, with the present invention, materials such as magnesium oxide may be used for the layer of secondary emission material so as to provide for electron channels having relatively high multiplication factors.

Not only does the use of the grooved plates allow for the deposition of materials so as to provide for an improved performance in the electron multiplier of the present invention, but, in addition, the use of the grooved plates provides for a much simpler construction of an electron multiplier and allows for a greater freedom in the manufacturing of the electron multiplier of the present invention. The electron multiplier of the present invention, therefore, is much simpler to build than prior art electron multipliers and is less expensive than such prior art electron multipliers.

As indicated above, a plurality of the grooved plates may be stacked or a single grooved plate may be spiraled

so as to form a two-dimensional electron multiplier. The construction of the two-dimensional electron multiplier of the present invention is much simpler than the use of a plurality of small tubes as with the prior art electron multipliers. The stacking or spiraling of the grooved plate is a much simpler construction for the electron multiplier of the present invention when compared with the prior art electron multipliers. The simpler construction for the electron multiplier of the present invention leads to a reduction in cost of the electron multiplier of the present invention over the prior art electron multipliers.

An accelerating field may also be used in the electron multiplier of the present invention by providing a difference in potential across the opposite sides of the grooved plate. The secondary emission material may be constructed to have a controlled high resistance or a separate layer of material having a controlled high resistance may be deposited between the surface of the grooved plate and the secondary emission material. The controlled high resistance provides for a uniform drop in voltage along the lenth of the grooves due to the difference in potential applied across the sides of the grooved plate and the uniform drop in voltage produces a uniform electric field in the grooves parallel to the surface of the grooves.

Contact areas may be included at the sides of the grooved plate so as to provide for attachment points for the voltage potential. The electric field operates to accelerate the electrons within the grooves which serve as electron channels and the electric field insures the movement of the electrons in the proper direction so as to provide for a multiplication of electrons by successive contacts between the electrons and the secondary emission material.

When the electron multiplier of the present invention is being used as part of an image intensifier, the electrons may be introduced to the first side of the grooves from a source of electrons such as a plate of photo-emissive material. The plate of photo-emissive material may receive an image which is to be intensified so that the electrons which are introduced to the grooves are in accordance with the image. The electrons in accordance with the image are multiplied as they progress along the grooves and the electrons emerge at the second opposite side of the grooves.

The electrons from the second side of the grooves are multiplied in accordance with the particular multiplication factor of the electron multiplier which depends upon various factors such as the secondary emission material, the number of contacts between the electrons and the secondary emission material, etc. The electrons from the second side of the grooves which emerge are then directed to a screen such as a fluorescent screen so as to provide for an image on the screen having an intensity greater than the intensity of the original image. The electron multiplier may, therefore, be used as an image intensifier so as to provide for an intensification of a weak or dim image.

The present invention is, therefore, directed to a new construction for an electron multiplier which provides for improved performance over electron multipliers of the prior art. In addition, the electron multipler of the present invention may be produced with a reduced cost over prior art electron multipliers. A greater understanding of the electron multiplier of the present invention may be had with reference to the further description of the invention and with reference to the following drawings wherein:

FIG. 1 is an illustration of an image intensifier using an electron multiplier;

FIG. 2 is an illustration of a single electron channel of an electron multiplier illustrating the multiplication of the electrons;

FIG. 3 is a first embodiment of an electron multiplier constructed in accordance with the present invention;

FIG. 3*a* is an enlarged fragmentary view of a portion of the electron multiplier of FIG. 3;

FIG. 4 is a second embodiment of an electron multiplier constructed in accordance with the present invention;

FIG. 4*a* is an enlarged fragmentary view of a portion of the electron multiplier of FIG. 4;

FIG. 5 is a third embodiment of an electron multiplier constructed in accordance with the present invention;

FIG. 5*a* is an enlarged fragmentary view of a portion of the electron multiplier of FIG. 5;

FIGS. 6*a*, 6*b* and 6*c* illustrate three steps in the production of an electron multiplier constructed in accordance with the present invention;

FIG. 7 diagrams a process which may be used to produce an electron multiplier from a physical structure such as shown in FIG. 6*c*; and

FIG. 8 illustrates a technique for mass producing an electron multiplier constructed in accordance with the present invention.

In FIG. 1, an image intensifier using an electron multiplier is illustrated. The image intensifier **10** is used to intensify an image **12**. A first plate **14** of translucent insulating material supports a sheet of photo-emissive material **16**. The photo-emissive material **16** receives the image **12** and produces electrons at particular positions along the sheet of photo-emissive material in accordance with the intensity of the image at various positions within the image.

The electrons from the photo-emissive sheet of material **16** are directed through a second plate of insulating material **18** and toward an electron multiplier **20**. The electron multiplier includes a plurality of channels, each having secondary emission material so as to provide for a multiplication of the electrons in a manner to be described later. The electron multiplier also includes conductive coatings **22** and **24** on either side of the electron multiplier.

After the electrons emerge from the electron multiplier **20**, they pass through a plate of insulating material **26**. The plate of insulating material **26** supports a sheet of fluorescent material **28** which serves as a fluorescent screen. A second plate **30** of translucent insulating material serves to protect the fluorescent material **28**. As can be seen in FIG. 1, the original image **12** is reproduced by the fluorescent material **28** as a new image **32**, and the image **32** has a greater intensity than the original image **12**.

The image intensifier **10** of FIG. 1 also includes a power supply **34** which provides a plurality of voltage potentials which are connected to the sheet of photo-emissive material **16**, the contact areas **22** and **24**, and the sheet of fluorescent material **28**. The potential on the sheet of photo-emissive material **16** is less than the potential on the contact area **22** so as to provide an accelerating field for the electrons produced by the photo-emissive material **16**. The accelerating field produced by the voltage potential between the contact area **22** and the photo-emissive material compels the movement of the electrons produced by the photo-emissive material **16** towards the electron multiplier **20**. Also, the potential on the sheet of conductive material **22** is greater than the potential on the sheet of conductive material **24** so as to produce an accelerating field within the electron channels to compel movement of the electrons within the various electron channels contained in the electron multiplier **20**. Finally, the potential on the sheet of conductive material **24** is less than the potential on the sheet of fluorescent material **28** so as to produce an accelerating field to compel movement of the multiplied electrons towards the sheet of fluorescent material **28**.

FIG. 2 illustrates a single one of the electron channels of an electron multiplier such as the electron multiplier **20** of FIG. 1. In FIG. 2, the contact material **22** and **24** is shown on opposite sides of the electron multiplier

and it can be seen that the contact material does not cover the various openings for the individual channels in the electron multiplier **20**. The electron multiplier **20** also contains a layer of secondary emission material **36** so as to provide for a multiplication of the electrons. Depending on the particular configuration of the electron channel, the secondary emission material **36** may completely surround the electron channel or the electron secondary emission materials **36** may partially surround the electron channel.

As an illustration of the operation of the electron multiplier **20** and in particular the operation of a single one of the electron channels of the electron multiplier, a single electron is shown entering the electron channel on the first side of the electron multiplier **20**. It is assumed that the secondary emission material **36** has a secondary emission ratio of 2; that is, for every electron which strikes the surface of the secondary emission material **36**, two electrons are released from the secondary emission material. Therefore, as shown in FIG. 2, as each electron strikes the secondary emission material **36**, two electrons are shown to be released. The single electron shown entering the electron channel in FIG. 2 strikes the secondary emission material **36** and releases two electrons. These two electrons also strike the secondary emission material **36** and each electron releases two electrons to produce a total of four electrons. The four electrons in turn strike the secondary emission material to produce eight electrons.

As shown in FIG. 2, a large number of electrons are shown to emerge from the side of electron multiplier **20** containing the conductive material **24**. It is to be appreciated, however, that in the actual operation of the electrofin multiplier, a large number of collisions of the electrons occur along the length of the electron channel so as to provide many more electrons than those shown emerging from the electron channel of FIG. 2. Also, it is to be appreciated that secondary emission material may be used which has a higher secondary emission ratio than that assumed for the illustration of FIG. 2. Therefore, it is possible to obtain an extremely large multiplication of the electrons.

FIG. 3 illustrates a first embodiemnt of an electron multiplier constructed in accordance with the present invention which may be used as part of the image intensifier of FIG. 1. FIG. 3*a* is an enlarged fragmentary view of a portion of the electron multiplier of FIG. 3. The electron multiplier of FIG. 3 includes a plurality of plates of insulating material **100**. The plates **100** are stacked together so as to form a composite electron multiplier structure. Each of the plates contains a plurality of parallel grooves **102** on at least one surface of the plate. The grooves **102** are lined with a layer of secondary emission material **104** which is more clearly shown in FIG. 3*a*. The secondary emission material **104** is used to provide for the multiplication of the electrons as they pass through the grooves **102** and strike the secondary emission material at progressive positions along the grooves **102**.

The electron multiplier of FIG. 3 may also include a layer of material **106** which has a controlled high resistivity as shown in FIG. 3*a*. The layer of controlled high resistivity material **106** would be connected, for example, to contact areas such as contact areas **22** and **24** shown in FIG. 1, so that the difference in voltage potential applied to the contact areas **22** and **24** would have a uniform voltage drop throughout the grooves **102** shown in FIG. 3, due to the controlled high resistivity of the layer **106**. The uniform voltage drop would provide for a uniform electric field within the grooves **102**. The uniform electric field is parallel to the walls of the grooves **102** and is an accelerating field to insure that the electrons flow in the proper direction while making the successive contacts with the secondary emission material **104**. It is to be appreciated that the secondary emission material **104** may itself have a controlled high resistivity so as to eliminate the necessity for an additional layer of controlled high resistivity material.

In the embodiment of the electron multiplier shown in FIG. 3 and FIG. 3*a*, it can be seen that the plates **100** have the grooves **102** open along one surface before the plates are stacked. It can, therefore, be seen that it is easy to control the deposition of the layers **104** and **106** since the grooves are open along the one surface. It is, therefore, possible to use secondary emission materials, for example, materials such as magnesium oxide, which have a high secondary emission ratio. It is also to be appreciated that the plates **100** may be composed of lead glass such as the prior art electron multipliers and the lead glass may be subjected to a hydrogen reduction so as to form the layer of secondary emission material covering the surface of the grooves **102**. However, since the grooves are open along the one surface, it is easier to control the uniformity of the layer formed by the hydrogen reduction than the prior art electron multipliers.

FIGS. 4 and 4*a* illustrate a second embodiment of an electron multiplier constructed in accordance with the present invention. FIG. 4*a* is an enlarged fragmentary view of a portion of FIG. 4. In FIG. 4, a plurality of plates **105** have grooves **152** on one surface of the plates and grooves **154** on the other surface of the plates. As shown in FIG. 4*a*, the grooves **152** and **154** may contain dual layers including secondary emission material **156** and a controlled high resistivity material **108**.

It is to be appreciated that the embodiment of FIG. 4 is more difficult to stack since the grooves **152** and **154** in adjacent plates **150** must be accurately aligned whereas the plates **100** of the embodiment of FIG. 3 do not have to have the grooves **102** aligned. The embodiment of FIG. 4 also has an electron channel having secondary emission material completely surrounding the electrons whereas the embodiment of FIG. 3 has the electron channel having secondary emission material only partially surrounding the electrons. However, the simplicity of the construction of the embodiment of FIG. 3 makes the structure such as shown in FIG. 3 a preferred embodiment of the invention. It is also to be appreciated that secondary emission material may be deposited on the flat surface of the plates **100** shown in FIG. 3 so that the electron channel has secondary emission material completely surrounding the electrons.

FIG. 5 illustrates a third embodiment of the invention including a single plate of insulating material **200** spiraled so as to form a two-dimensional electron multiplier. The plate **200** includes grooves **202** spaced along the plate. As shown in FIG. 5*a*, the grooves **202** may have a first layer of secondary emission material **204** and a second layer of controlled high resistivity material **206**. It is to be appreciated as indicated above that the secondary emission material itself may have a controlled high resistivity so as to eliminate the second layer of controlled high resistivity material. Also, as indicated above, the plates may be constructed of lead glass so that the secondary emission material may be formed by a hydrogen reduction of the lead glass. However, the present invention also has the capability of using secondary emission materials which may be deposited within the grooves and which provide a high secondary emission ratio.

The embodiment of FIG. 5 is relatively simple in construction since the plate **200** is merely spiraled so as to form the two-dimensional electron multiplier. Also, in the embodiment shown in FIG. 5, wherein the grooves are contained on the inside surfaces of the plate **200**, the sidewalls of the grooves flex inward as the plate is spiraled so as to provide for a more complete encircling of the grooves which serve as electron channels.

The electron multipliers as shown in FIGS, 3, 4 and 5 are simpler in construction than the prior art electron multipliers and result in a great reduction in cost for elec-

tron multipliers of FIGS. 3, 4 and 5 over the prior art electron multipliers. In addition, since the electron channels are open along one surface prior to stacking or spiraling, it is possible to use secondary emission material which is deposited within the channels, whereas the prior art electron multipliers which use small tubes could not have the secondary emission material deposited within the tubes. The electron multiplier of the present invention, therefore, provides for an improved performance over the electron multipliers of the prior art. The electron multiplier of the present invention may be constructed by various methods and, as examples, FIGS. 6, 7 and 8 illustrate two methods of constructing the electron multipliers.

In FIGS. *6a, 6b* and *6c*, a single sheet of insulating material is shown transformed to a grooved plate. In FIG. *6a*, an elongated flat plate of insulating material **250** is shown. The plate of insulating material **250** may be composed of material such as glass. In FIG. *6b* the plate **250** is coated with a layer of photo-sensitive material **252** and a pattern **254** is developed on the photo-sensitive material. FIG. *6c* shows the plate **250** etched away in accordance with the pattern **254** shown in FIG. *6b* so as to produce a plurality of grooves **256**. The plate **250** containing the grooves **256** which serve as electron channels is further processed as shown by the method of FIG. 7.

In FIG. 7, the plate **250** first has an electrode material such as chromium or other suitable metal evaporated with the grooves by a first step **300**. The evaporative process produces a layer of an electrode such as chromium or other suitable metal within the grooves. The electrode material is then oxidized by a second step **302** so as to provide for a controlled high resistivity of the electrode material. The material such as chromium oxide, therefore, provides for a controlled resistivity so as to produce a uniform electric field in the grooves **256** when a difference in potential is applied across the ends of the grooves. The uniform electric field acts as an accelerating field within the grooves.

A layer of prospective secondary emission material is then evaporatively deposited on top of the layer of electrode material in a third step **304**. For example, magnesium may be deposited on top of the electrode material. A fourth step **306** is to oxidize the prospective secondary material so as to produce the secondary emission material. For example, if magnesium is used, the magnesium is oxidized to magnesium oxide which has a high secondary emission ratio.

A fifth step **308** in the method of FIG. 7 is to stack the various plates **250** together so that the plurality of grooves **256** which now include layers of controlled high resistivity material and secondary emission material form a two-dimensional array of electron channels. A final step **310** is to metalize the ends of the stack of plates so as to produce contact areas. The contact areas receive the voltage potential so as to produce the accelerating field within the grooves. The metalized ends would be similar to the metalized ends **22** and **24** shown in FIG. 1.

The methods illustrated in FIGS. 6 and 7 may be used to produce electron multipliers of the type shown in FIGS. 3 and 4. It is to be appreciated that the plate **250** shown in FIG. *6a* may be much longer than that shown and the plate may then be spiraled to produce an electron multiplier as shown in FIG. 5.

FIG. 8 illustrates a method for mass producing electron multipliers of the type shown in FIGS. 3, 4 and 5. In FIG. 8, a roll of insulating material **350** is unrolled and passed through an oven **352** so as to soften the material **350**. The insulating material **350**, for example, may be glass. The softened insulating material **350** is then corrugated by a structure including a large wheel **354** having a smooth surface and a smaller corrugated wheel **356**. The wheel **356** produces a plurality of grooves **358** in the surface of the material **350**. The grooved insulating material **350** after passing through the wheel **356** is similar to the grooved structure shown in FIG. *6c*.

The grooved insulating material **350** passes through a first evaporator **360** which evaporatively deposits a layer of electrode material. An oxidizer **362** oxidizes the electrode material to produce a layer of controlled high resistivity material in the grooves. The controlled high resistivity material may be chromium oxide. The grooved insulating materal then passes through a second evaporator **364** whch evaporates a prospective secondary emission material. Finally, a second oxidizer **366** oxidizes the prospective secondary emission material to produce a layer of secondary emission material in the grooves. The secondary emission material, for example, may be magnesium oxide.

The grooved material now has a plurality of grooves which contain layers of secondary emission material and high resistivity material so as to form the electron multiplier. For example, as shown at position **368**, the material **350** as it passes out of the oxidizer **366** may be rolled directly to form an electron multiplier of the type shown in FIG. 5. Also, the material **350** as it passes out of the oxidizer **366** may be chopped into smaller sections which in turn may be stacked to form an electron multiplier of the type shown in FIG. 3. It is to be appreciated that the particular manner in which the material **350** is handled after the oxidizer **366** would be a matter of choice.

The present invention is, therefore, directed to a new simple construction for an electron multiplier which is less expensive than prior art electron multipliers and which provides for an improved performance over prior art electron multipliers. The performance of the electron multiplier of the present invention is improved in part because secondary emission materials may be used having a higher secondary emission ratio than those used in the prior art electron multipliers.

The present invention has been described with reference to particular embodiments and, in addition, two illustrative methods have been shown for producing the electron multipliers of the present invention. In addition, it has been indicated that the electron multiplier of the present invention may be used as part of an image intensifier so as to provide for an increase in intensity of a dim image.

It is to be appreciated that although the invention has been described with reference to particular embodiments, various adaptations and modifications may be made. The invention, therefore, is only to be limited by the appended claims.

What is claimed is:

1. An electron multiplier comprising:

(a) a roll of insulating strip material having a plurality of parallel grooves forming a plurality of electron channels on one surface of the strip material extending from a first side of the strip material to a second side of the strip material, said roll forming a spiral with the lands between said grooves in contact with the second surface of a different turn of said spiraled strip material to close said electron channels intermediate said first and second sides,

(b) means for producing an accelerating electric field within the grooves from the first side of the strip material to the second side of the strip material for accelerating electrons introduced into the grooves from the first side of the strip material to the second side of said strip material, said means comprising contact areas at the first side of the strip material and the second side of the strip material and an electrical potential coupled to said contact areas, and

(c) a layer of secondary emission material having controlled high resistivity covering the surface of the grooves for providing a multiplication of the number of electrons introduced into the grooves at the first side of the strip material to the number of electrons emerging at the second side of the strip material in accordance with the electrons striking the secondary emission material at successive points along the grooves.

2. The electron multiplier according to claim 1, and wherein the secondary emission material having controlled high resistivity is magnesium oxide.

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3,128,408	4/1964	Goodrich et al.	313—103 X
3,182,221	5/1965	Poor	313—103
3,341,730	9/1927	Goodrich et al.	313—104 X
3,343,025	9/1927	Ignatowski et al.	313—105
3,387,137	6/1968	Adams	313—104 X
2,160,799	5/1939	Teal	313—95
3,244,922	4/1966	Wolfgang	313—95
3,436,590	4/1969	Wolfgang et al.	313—104 X

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