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(54) IMAGE INTENSIFIER

(71) We, TOKYO SHIBAURA ELECTRIC COMPANY LIMITED, a British company of 72, Horikawa-cho, Saiwai-ku, Kawasaki-shi, Kanagawa-ken, Japan, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed to be particularly described in and by the following statement:-

This invention relates to image intensifiers comprising an input screen for converting a radiation image such as an X-ray, γ-ray or a weak light image into an electron image, and an output screen for converting the electron image into a visible light image.

It is desirable that the visible light image at the output screen should have a high resolution which depends mainly upon the converting fidelity of the input screen.

The input screen has a substrate usually made of aluminium which is effectively permeable to such radiations. An alkali halide phosphor layer emitting luminescence effectively by the radiations is formed on the substrate by vacuum deposition. A photocathode for example cesium antimonide (Sb-Cs) sensitive to the luminescence of the phosphor is deposited on the phosphor layer.

Hitherto, to improve the resolution of the input screen, a phosphor layer comprising a plurality of columnar structures separated from each other by cracks is known from U.K. Patent Specification 1425021. In this screen the light generated in each columnar structure is scattered only within the same structure by total reflection and the light cannot travel to other blocks. Consequently, each columnar structure has a light guiding effect. Such a screen can be prepared by depositing a phosphor material such as cesium iodide on an aluminium substrate and thereafter heating them to generate cracks in the deposited phosphor layer by means of a difference of thermal expansion coefficients between the substrate and the phosphor.

However such an input screen has the following drawbacks:

As cracks are generated by a strain caused by a difference between the temperature of the substrate and that of the surface of the phosphor layer, which is higher than the former, they are liable to be generated from the upper surface of the phosphor layer. Consequently it is difficult for the cracks to extend to the substrate. The light guiding effect of the phosphor layer is then insufficient because columnar structures formed by cracks generated from the substrate are few). Resolution of the X-ray image intensifier having such an input screen is therefore 28-30 1p/cm.

As the cracks are generated by heat treatment of the screen, it is difficult to consistently obtain an input screen having stable quality.

Another method for making a cracked phosphor layer, comprises the step of impressing a metallic gauze (e.g. copper gauze) upon an aluminium substrate followed by the step of depositing cesium iodide on the impressed substrate. This method is known from U.S. Patent Specification No. 3825763. However this method has a disadvantage. Namely, it is difficult to impress the metallic gauze upon the substrate without generating any folds because the substrate is usually of domed shape.

An object of the present invention is to provide an image intensifier having an improved resolution.

An image intensifier according to the present invention comprises

an input screen for converting a radiation image into an electron image,

an electro-optical system for accelerating and focusing the electron image, and

an output screen for converting the accelerated and focused electron image into a visible light image and wherein the input screen comprises

a substrate,

electro-chemically deposited members in the form of a net on one surface of the substrate, and

a phosphor layer interposed between said one surface and a photocathode, said phosphor layer having cracks therein extending from the deposited members towards the photocathode thereby dividing the layers into a multiplicity of columns or blocks.

In one embodiment of this invention, the surface of the substrate has electrically insulating material in mosaic form between the electro-chemically deposited members. In another embodiment, the surface of the substrate has only the electro-chemically deposited members in the form of a net thereon.

When the height of the net members is more than a fifth of the thickness of the phosphor layer and a quarter of the average diameter of the columnar blocks, the luminous light is effectively intercepted and prevented from spreading transversely. In this case the net members operate as interceptive walls for light. Using this input screen, an image intensifier having high resolution can be obtained. The interceptive walls for the light are preferred not to protrude from the surface level of the phosphor layer.

A reflective layer deposited on such a substrate results in an improvement of brightness of the image intensifier. The reflective layer makes the excited light directed towards the substrate return therefrom to the photocathode and covers some impurities on the substrate to prevent the phosphor layer from reacting with them.

The members in the form of a net are deposited reproducibly by an electrochemical method conveniently only in the fine grooves dividing the mosaic material formed previously on the electrically conductive substrate. This may be followed by a step of removing the mosaic material by some etching method. The layer of the mosaic material is termed "auxiliary layer".

In order that the invention may be more readily understood it will now be described, by way of example only, with reference to the accompanying drawings, in which:-

Figure 1 is a cross-sectional view of an image intensifier embodying this invention,

Figure 2 is an enlarged cross-sectional view of a part of an input screen for an image intensifier according to one embodiment of this invention,

Figures 3 and 4 are enlarged sectional views showing steps in the manufacture of the input screen of Figure 2,

Figure 5 and 6 are enlarged sectional views showing steps in the manufacture of an input screen of an image intensifier according to another embodiment of this invention,

Figure 7 is an enlarged cross-sectional view of part of an input screen for an image intensifier according to another embodiment of this invention, and

Figures 8, 9, 10 and 11 are enlarged sectional views showing steps in the manufacture of an output screen for an image intensifier.

Referring to Figure 1 schematically showing the whole of an X-ray image intensifier, a glass envelope 12 contains an input screen 13 so shaped as to conform to the convex front end face of the glass envelope 12 and an output screen 14 lying near the rear end face of the glass envelope 12. Positioned between the input screen 13 and output screen 14, as is well known, are a focussing electrode 15 to focus electron beams from the input screen 13 and an acceleration electrode 16 to accelerate said electron beams. The input screen 13 comprises a substrate 19 in the form of an aluminium sheet permeable to X-rays; a phosphor layer 20 formed on the inner surface of the substrate 19 and excited by X-rays passing through the substrate to emit visible light; a barrier layer 21 formed on the phosphor layer 20 of a material chemically stable and permeable to light excited in the phosphor layer 20; and a photocathode 22 deposited on the barrier layer 21. Reference numeral 17 denotes X-rays and numeral 18 denotes an object exposed to X-rays.

Now will be described the detailed construction of the phosphor layer of an input screen of an image intensifier according to the present invention together with the method of manufacturing the same with reference to Figures 2 - 4. An auxiliary layer comprising electrically insulating material of mosaic form 302 is provided on at least one surface of an electrically conductive substrate 301, for example an aluminium sheet of about 0.5 mm thickness. It may be that only the surface of the mosaic 302 is electrically insulating. In a plurality of grooves 307 dividing the parts of the mosaic 302, dividing members 303 such as metal are deposited electrochemically in the form of a net. On this auxiliary layer a phosphor layer 320 is deposited and cracks 305 extend from the tops of the dividing members toward the surface of the phosphor layer.

The auxiliary layer 302 on the substrate surface can be formed by means of anodization of an aluminium sheet, a sealing process and a heat treatment. The surface of the mosaiced material must be electrically insulating. The auxiliary layer 302 can be composed of another material, for example chromium covered with thin oxide film thereof and cracked by heat treatment. The net members 303 can be deposited easily in the grooves 307 by an electrochemical method, because the bottoms of the grooves are electroconductive through the substrate. If the bottoms of the grooves are covered with electrically insulating films, these are removed by an etching method before the deposition of the net members.

Another embodiment of this invention has the structure in which the auxiliary layer is removed by an etching method leaving the members 303 as shown in Figure 5.

In this case, the phosphor layer adheres to the substrate because the surface of the substrate does not carry an auxiliary layer but only the dividing members.

Example 1

One side of an aluminium sheet 301, 0.5 micron thick was subjected to anodisation for about one hour in a 3% oxalic acid solution by introducing current of 1 A/dm^2, thereby rendering the surface of the aluminium sheet oxidized and porous. Thereafter, the aluminium sheet was washed with water and then dipped in boiling water for about one hour for the swelling with water of crystallization contained in the numerous pores, that is, the so-called "sealing process". The oxidized aluminium sheet containing water of crystallization was thermally treated for several minutes at a higher temperature of about 250°C to evaporate the water of crystallization from the surface. As a result, the aluminium sheet forming the substrate 301 presented a surface of mosaic form. As microscopically measured, the mosaic surface of the substrate 301 surrounded by narrow grooves 307 has a width of about 3 to 7 microns and a depth of about 10 microns and, most of the individual parts of the mosaic have an average diameter of 50 to 100 microns (Figure 3).

Thereafter, nickel was electrochemically plated on the substrate treated as mentioned above. Nickel metal was deposited preferentially in the narrow grooves whose bottoms were electrically connected to the substrate 301 to form the members 303 (Figure 4). The description of the method of electrochemical plating of nickel is abbreviated because it is well known in the field of electrochemical engineering.

Next, a phosphor layer 320 was formed in such a manner that cesium iodide was thermally deposited in vacuum with a thickness of about 150 microns on the above mentioned surface of the substrate 301 maintained at about 80°C. The phosphor layer 320 included a large number of columnar blocks 321-326 about 50 to 100 microns in diameter which were defined by cracks 305 extending from the tops of the members 303.

On the phosphor layer, a barrier layer 308 of aluminium oxide about 500 Å in thickness was deposited and a photocathode layer 309 was formed on the barrier layer. When an image intensifier was fabricated using such an image screen, it had the characteristic of high resolution. The block structure of the phosphor layer can be reproduced consistently.

Example 2

As an alternative to Example 1, the aluminium oxide was removed by etching in an aqueous caustic solution after the formation of the members 303. This state is shown in Figure 5. On such a substrate 361 (see Figure 6) a phosphor layer 360 was formed by an evaporation method. Then cracks 365 were generated in the phosphor layer from the tops of the member 363 toward the surface of said phosphor layer, to form the phosphor blocks 371-376 in said phosphor layer. After that, a barrier layer 368 and a photocathode 369 were deposited on the phosphor layer as described in Example 1. The obtained characteristics were the same as the case of Example 1. Additionally the adhesion between the phosphor layer and the substrate was so strong that accidental peeling of the phosphor from the substrate hardly occured.

Example 3

As an alternative to the Examples 1 and 2, the thin oxide films covering the bottoms of the narrow grooves were removed by etching before the electrochemical plating of the nickel. The the metal members were deposited in the form of a net very smoothly and adhered strongly to the substrate.

Example 4

The material for electrochemical plating in the narrow grooves was selected from gold, copper, chromium and other metals. Electrically non-conductive materials could also be deposited by electrophoretic method. The results of these materials were similar to the Example 1.

Example 5

In a screen manufactured as previously described, a reflective layer of aluminium was deposited on the substrate having a mosaic structure defined by the members arranged in the form of a net. The thickness of the reflective layer was 2000 Å. Then the excited light directed to the substrate was reflected from said substrate to the photocathode so that the characteristic of brightness was improved by about 20-25% relative to the screen of Example 1.

Example 6

On one side of an aluminium sheet 0.5 mm thick, chromium was plated electrochemically as an auxiliary layer by subjecting the aluminium sheet to electrochemical plating of chromium in a plating bath comprising chromium oxide 200-500 g/l and sulphuric acid 0.5-2 g/l, keeping the temperature 30-70°C and introducing current of 10-50 A/dm^2. The thickness of the chromium was ten microns. The formed chromium layer had fine grooves. After sufficient washing, said substrate was subjected to heat treatment in an oxidizing atmosphere. Then a mosaic layer was formed on the auxiliary layer by growing of the fine grooves and the surfaces of the mosaics were covered with oxide films which are electrically non-conductive. The average size of the parts of the mosaic were 20-50 μ, the thickness were about 10 μ and the width of the narrow grooves were about 1-2 μ. Then after the oxide films on the bottoms of the narrow grooves were removed by chemical etching, gold was electroplated into the grooves. Gold plating was deposited preferentially in the grooves in the form of net members. The height of the members was such that they protruded about 10 μ from the level of the auxiliary layer, and the average pitch of the members was about 20-50 μ. A phosphor layer of cesium iodide was then deposited on such a substrate under the conditions as mentioned in Example 1.

An image intensifier using the above mentioned input screen showed a characteristic of 43 lp/cm in resolution.

Example 7

In a screen of Example 6, after the gold members were deposited in the grooves, the auxiliary layer of chromium was removed electrochemically in a bath of phosphor acid 500-1,000cc/1 and triethanol amine 100-500 cc/l and at a temperature of 65-95°C, by introducing current wherein the substrate was anodic. Then the height of the members 363 was about 20 μ and the average pitch was about 20-50 μ. On such a substrate, a phosphor layer of cesium iodide was deposited by evaporation method. An image intensifier using such an input screen showed an improved characteristic of resolution as Example 6. And additionally the adhesion between the phosphor layer and the substrate was improved.

Example 8

Nickel or magnanese was deposited electrochemically as the auxiliary layer in place of the chromium used in Example 6 or 7. The achieved characteristics of the image intensifier were the same as the Example 6 or 7.

Example 9

In the Example 5, zirconium was deposited before the chromium was deposited. The chromium deposition was then easier and a smooth layer resulted.

Example 10

As an auxiliary layer, silicon oxide was deposited by an evaporation method about 1 μ thick on a substrate of aluminium through meshes place on the surface of the substrate. On removing the meshes a part of the substrate was exposed in the form of a net. Thereafter members of nickel were deposited by electrochemical plating method on the exposed part of the substrate in 5 μ thickness. An image intensifier having an input screen using such substrate showed an improved resolutional characteric as mentioned in Example 6.

Example 11

After the surface of an aluminium sheet of about 0.5 mm thickness had been subjected to degreasing and cleaning, molybdenum oxide was deposited thereon electrophoretically as an auxiliary layer. The electrophoretic deposition was undertaken in the bath of molybdenum oxide ammonium 5-30 g/l and sodium nitrate 10-30 g/l. Molybdenum oxide was deposited 2μ thick. The auxiliary layer was black in colour and was divided by fine cracks. Further the substrate was washed in flowing water and subject to heat treatment of 100-500°C. causing the fine cracks to grow until their width became 1-2μ. Gold was deposited in the cracks by an electrochemical plating method, and thereafter the auxiliary layer of molybdenum oxide was removed by nitric acid. A phosphor layer, a barrier layer, and a photocathode were formed successively and thus an input screen of an image intensifier was obtained. This showed an improved characteristic of resolution as mentioned in Example 1.

Example 12

On the concave surface of an aluminium substrate 71 having a certain curvature, was poured an epoxy mixed resin comprising epoxy resin, benzoyl peroxide as a hardening agent and dimethyl aniline as an auxiliary reagent. The mixing rate was 100: 0.5 4 : 0.5 3. The mixed resin was extended on the substrate about 10 μ thick by rotating the substrate. The substrate with such resin layer was heated quickly to 100-250°C, then the condensation reaction of the resin layer took place, and a mosaic structure was formed. Thereafter, a metal such as gold, nickel or copper was electrochemically plated on the substrate and into the plurality of narrow grooves dividing the mosaics of the epoxy resin. After that, the resin layer was removed by acetone and the members 72 in the form of a net were revealed on the substrate. To complete the removal of the resin a heat treatment in air was added. On such a substrate, a reflective layer 73 of aluminium was deposited in 0.3 - 1 μ thickness. Next, cesium iodide phosphor 75 was deposited about 150 μ thick. Then cracks 74 extending to the tops of the members 72 in the phosphor layer and mosaic structure were formed. Each block is preferred to be connected with each other near the surface. As the result the photocathode 77 can be formed smoothly on a barrier layer 76 covering the phosphor layer. This was achieved in this example.

An image intensifier using an input screen fabricated to have above mentioned structure showed the improvement of the value of modulation by about 50%, and the increase of brightness by about 20%, which was thought to be because of the elevation of reflection and the prevention of reaction between the phosphor and the impurities on the substrate. According to this example image intensifiers having such improved characteristics could be regularly reproduced.

Example 13

In the Example 12, the auxiliary layer was built up to 100 mm in thickness by repeating the application of resin and heat treatment. The height of the members 72 was about 100 μ and the average size of the phosphor blocks was about 50-100 μ. The phosphor layer was deposited in 150 μ thickness. As a result of the high members 72, they intercepted completely the excited light trying to diffuse transversely. That is, they operated as interception walls for the light.

An image intensifier using such phosphor layer showed very high resolution of about 43 1p/cm.

Example 14

Adding to the Example 13, repetition of the process comprising applying resin, heat-treating and depositing electrochemically in narrow grooves was preferred to obtain high members 72. Thereafter the resin was finally removed.

Example 15

This is an example of the present invention applied to an output screen of an image intensifier. There will now be described the detailed construction and the method of manufacturing the output screen according to this invention with reference to Figures 8 to 11.

On one side of the transparent glass 81 a transparent electroconductive layer 82, for example indium oxide, was deposited 1,000-2,000 Å in thickness and on the electroconductive layer 82 aluminium film of 3 μ thickness was deposited by a vacuum evaporation method. Said aluminium film was subjected to anodizing in oxalic acid solution and changed to aluminium oxide film. Said aluminium oxide film was subjected to a "sealing process" and heat treatment. As the result of these successive processes, fine grooves 84 were formed in the aluminium oxide film. Thereafter similarly to the Example 1 metal, for example nickel, was electrochemically deposited in the grooves 84 and the mosaics of aluminium oxide film was removed by etching. Then the interceptive walls 85 of nickel and a plurality of spaces surrounded by the interceptive walls 85 remain. The height of the interceptive walls was about 4 μ.

On the above mentioned glass substrate, a phosphor layer comprising phosphor particles of zinc sulfide and a small quantity of water glass as binder was deposited in 7 μ thickness by means of sedimentation method. This phosphor layer 87 was covered with aluminium film 88.

The output screen according to this example showed a 15% improvement of MTF at 40 lp/mm resolution as compared with a conventional one.

Example 16

In this example, the phosphor layer was deposited by means of an evaporation method, instead of a sedimentation method. The material of phosphor was zinc sulfide containing a little of chlorine and copper. The brightness of this output screen was only one-third of conventional type using phosphor particles but the resolution was improved by 30% of MTF at 40 lp/mm resolution. As additional description, the brightness was about two times larger than a conventional evaporated phosphor screen.

Further, the phosphor layer of this example was used as an output screen of an image intensifier for observing a dark scene, which comprises a photocathode and an output phosphor screen. The improvement of the characteristics was achieved similarly as expected from the above mentioned characteristics.

WHAT WE CLAIM IS:-

1. An image intensifier comprising
an input screen for converting a radiation image into an electron image,
an electro-optical system for accelerating and focusing the electron image, and
an output screen for converting the accelerated and focused electron image into a visible light image and wherein the input screen comprises
a substrate,
electro-chemically deposted members in the form of a net on one surface of the substrate, and
a phosphor layer interposed between said one surface and a photocathode, said phosphor layer having cracks therein extending from the deposited members towards the photocathode thereby dividing the layers into a multiplicity of columns or blocks.

2. An image intensifier as claimed in claim 1, in which a barrier layer of a material permeable to light generated in the phosphor layer is disposed between the phosphor layer and the photocathode.

3. An image intensifier as claimed in claim 2, in which the barrier layer is of aluminium oxide.

4. An image intensifier as claimed in any preceding claim in which the substrate is of aluminium.

5. An image intensifier as claimed in claim 1, 2 or 3, in which material is provided on said one surface in the form of a mosaic between said electro-chemically deposited members.

6. An image intensifier as claimed in claim 5, wherein the substrate is of aluminium and the material is aluminium oxide.

7. An image intensifier as claimed in claim 5, wherein said one surface of the substrate is provided with a metallic layer and the material is an oxide of the metal.

8. An image intensifier as claimed in claim 7, wherein said metallic layer is of chromium and the material is chromium oxide.

9. An image intensifier as claimed in claim 8, wherein a layer of zirconium is interposed between the substrate and the chromium layer.

10. An image intensifier as claimed in any preceding claim, wherein the electro-chemically deposited members are of material selected from a group consisting of nickel, gold, copper and chromium.

11. An image intensifier as claimed in any preceding claim, in which the phosphor is an alkali halide.

12. An image intensifier as claimed in claim 11, in which the phosphor is cesium iodide.

13. An image intensifier as claimed in any preceding claim, having a reflective layer disposed between the substrate and the phosphor layer.

14. An image intensifier as claimed in claim 13, in which the reflective layer is of aluminium.

15. An image intensifier as claimed in any preceding claim, in which the height of each electro-chemically deposited member is substantially equal to or greater than one fifth of the thickness of the phosphor layer and the thickness of each deposited member is substantially one quarter of the average diameter of each column or block.

16. An image intensifier as claimed in any preceding claim, wherein the output screen comprises

a substrate,

electro-chemically deposited members in the form of a net on one surface of the substrate, and

a phosphor layer supported on said one surface of the substrate, said phosphor layer having cracks therein extending from the deposited members and dividing the layer into a multiplicity of columns or blocks.

17. An image intensifier as claimed in claim 16, wherein the substrate of the output screen is of transparent glass and the said one surface is electrically conductive.

18. An image intensifier as claimed in claim 16 or 17, wherein the phosphor layer of the output screen is of zinc sulphide.

19. An image intensifier substantially as hereinbefore described with reference to the accompanying drawings.

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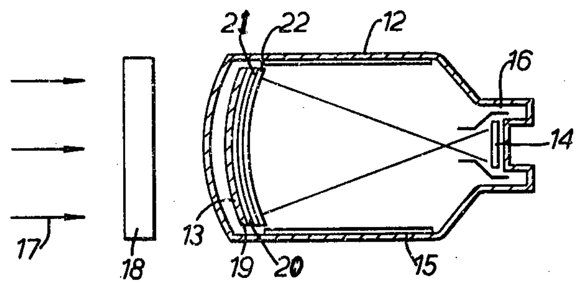
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FIG.1.

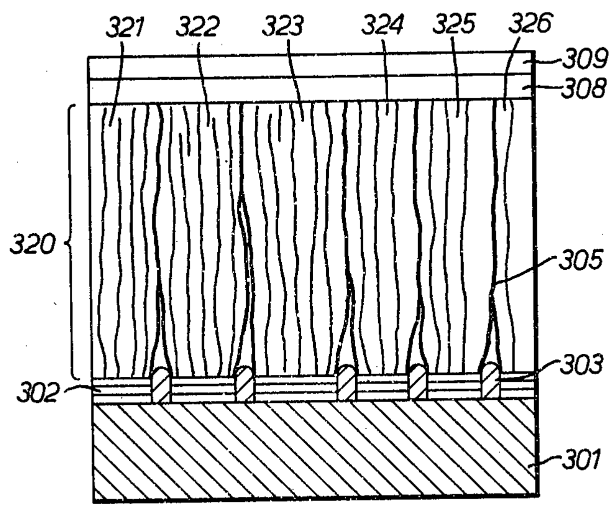
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FIG.2.

1586141 COMPLETE SPECIFICATION

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Sheet 2

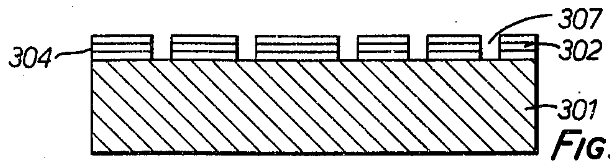

FIG. 3.

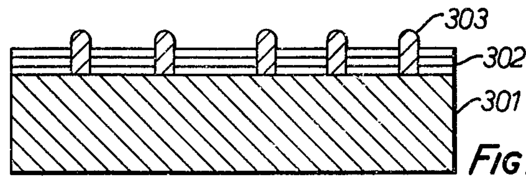

FIG. 4.

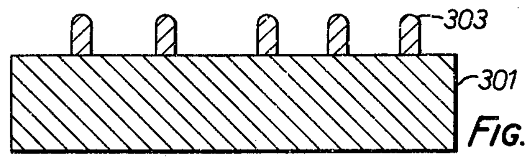

FIG. 5.

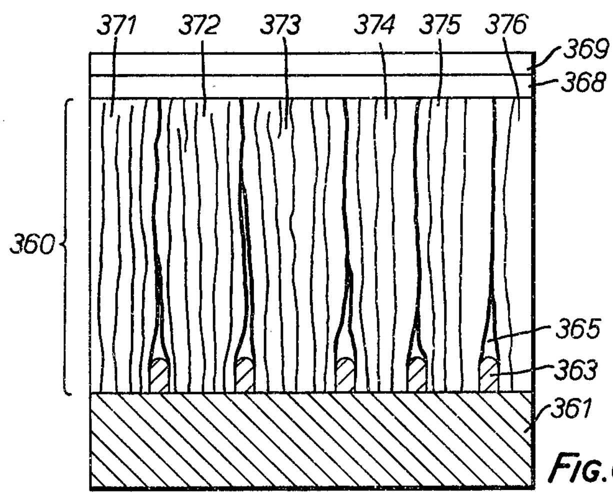

FIG. 6.

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3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 3

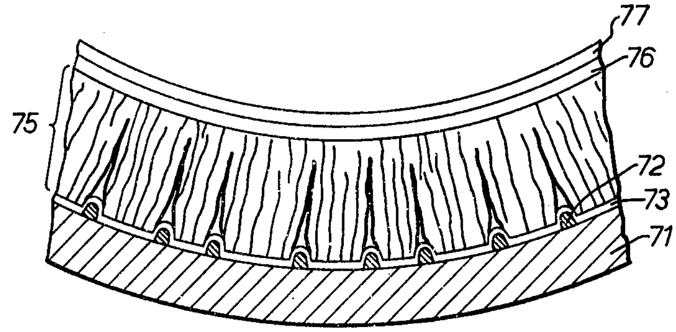

Fig. 7.

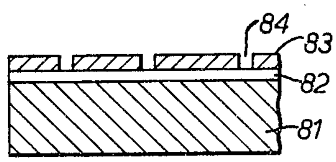

Fig. 8.

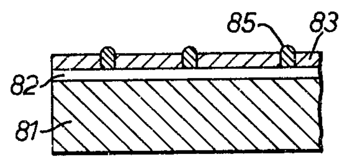

Fig. 9.

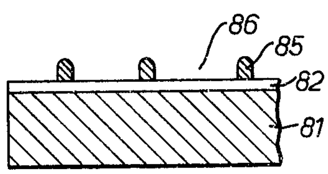

Fig. 10.

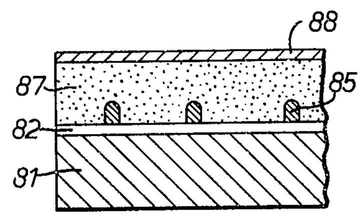

Fig. 11.