United States Patent [19]

Fukushima et al.

[11] **3,873,870**

[45] **Mar. 25, 1975**

[54] **FLAT DISPLAY PANEL**

[75] Inventors: **Masakazu Fukushima; Seiichi Murayama,** both of Kokubunji, Japan

[73] Assignee: **Hitachi, Ltd.,** Tokyo, Japan

[22] Filed: **June 28, 1973**

[21] Appl. No.: **374,328**

[30] **Foreign Application Priority Data**

July 7, 1972 Japan 47-67478

Nov. 17, 1972 Japan 47-114683

[52] **U.S. Cl.** ..... **313/217,** 313/220, 315/169 TV, 340/336

[51] **Int. Cl.** **H01j 17/04**

[58] **Field of Search** ..... 313/217, 220; 315/169 TV, 315/169 R

[56] **References Cited**

UNITED STATES PATENTS

3,626,245 12/1971 Rosenberg et al. ..... 315/169 R X

3,673,451 6/1972 Tackett ..... 313/220 X

Primary Examiner—Rudolph V. Rolinec

Assistant Examiner—Lawrence J. Dahl

Attorney, Agent, or Firm—Craig & Antonelli

[57] **ABSTRACT**

A flat display panel comprising one or more first electrodes, one or more second electrodes each surrounding at least one of the first electrodes to form therewith a discharge space, and two insulating substrates sandwiching the first and second electrodes and hermetically sealing the discharge space, at least one of the insulating substrates being made of a transparent material such as glass, the direction of discharge between the first and second electrodes being parallel to the transparent insulating substrate.

24 Claims, 29 Drawing Figures

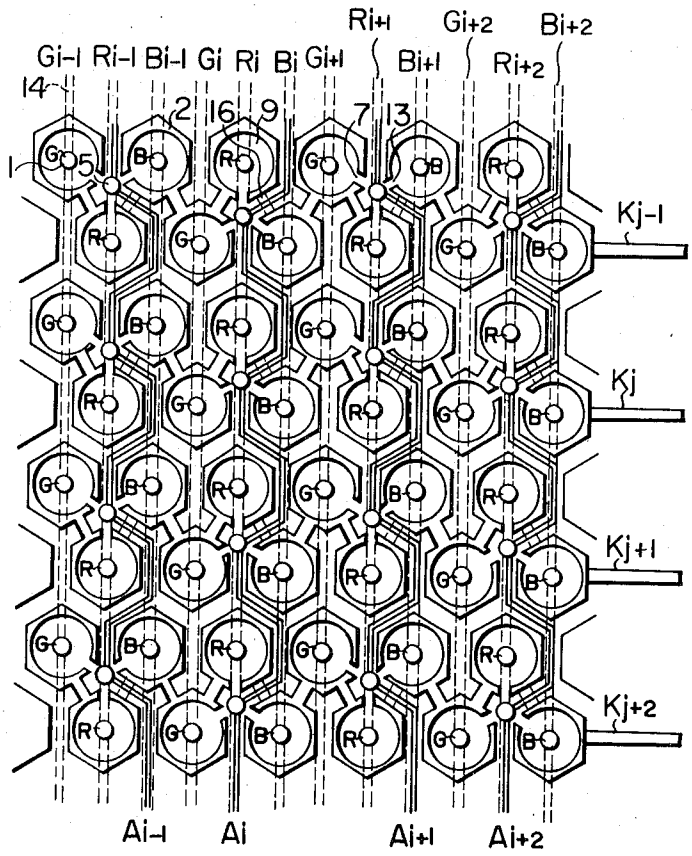


FIG. 1 PRIOR ART

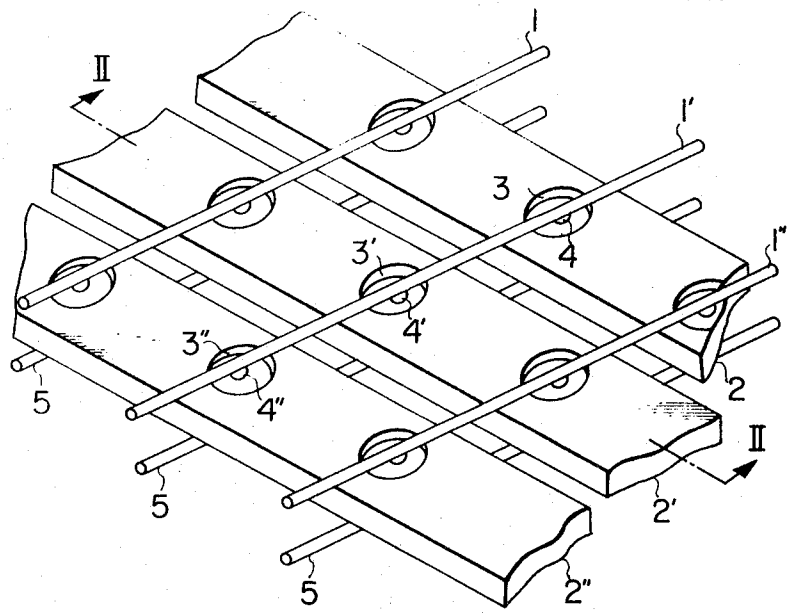


FIG. 2

PRIOR ART

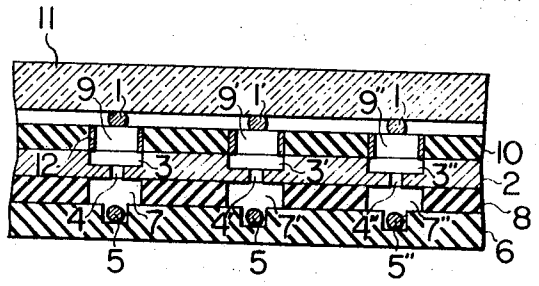


FIG. 3a

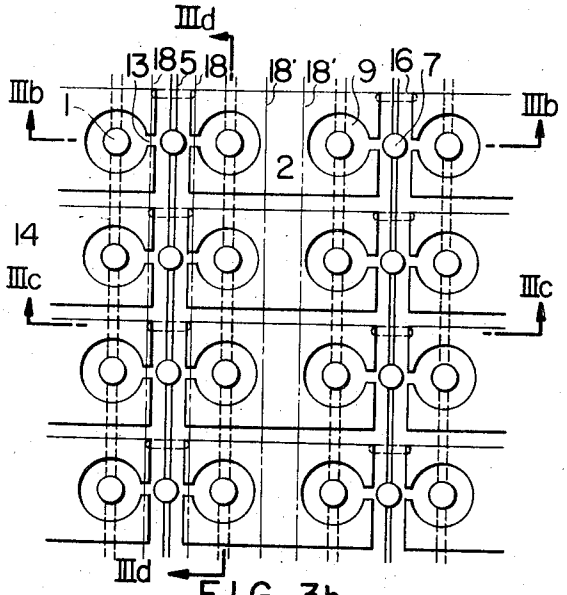


FIG. 3b

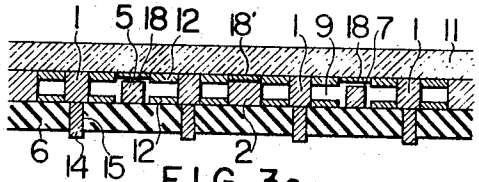


FIG. 3c

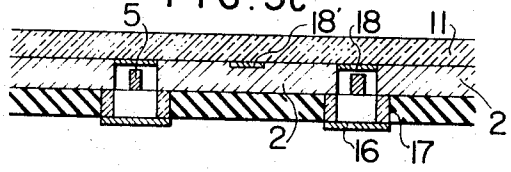


FIG. 3d

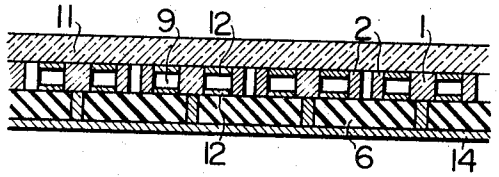


FIG. 4

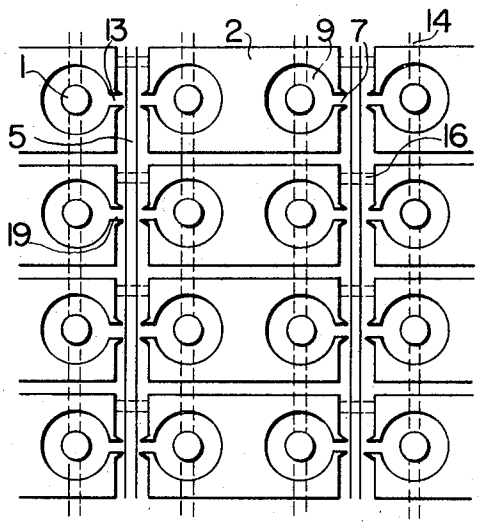


FIG. 5

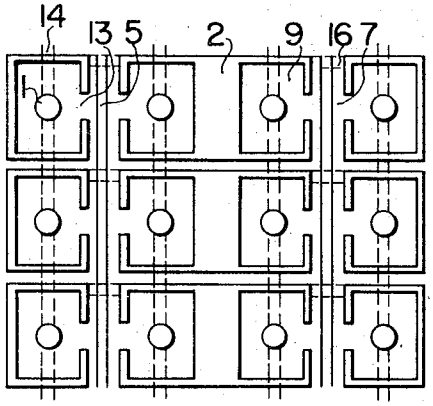


FIG. 6

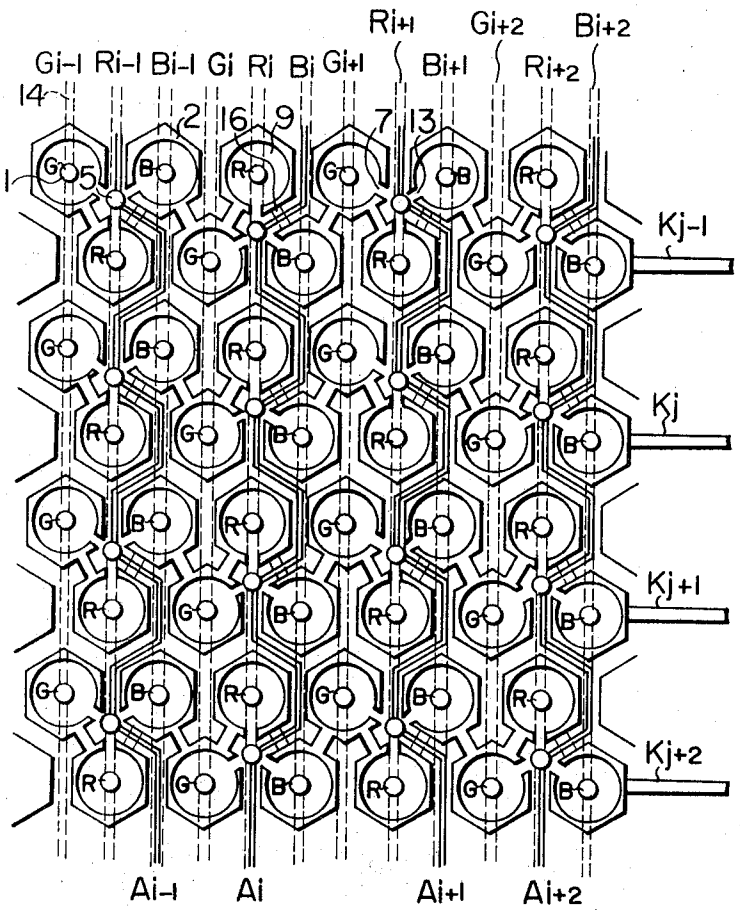

Ri+1
Gi+2
Bi+2
Gi-1
Ri-1
Bi-1
Gi
Ri
Bi
Gi+1
Bi+1
Ri+2
14
2
16
9
7
13
1
5
Kj-1
Kj
Kj+1
Kj+2
Ai-1
Ai
Ai+1
Ai+2

FIG. 7

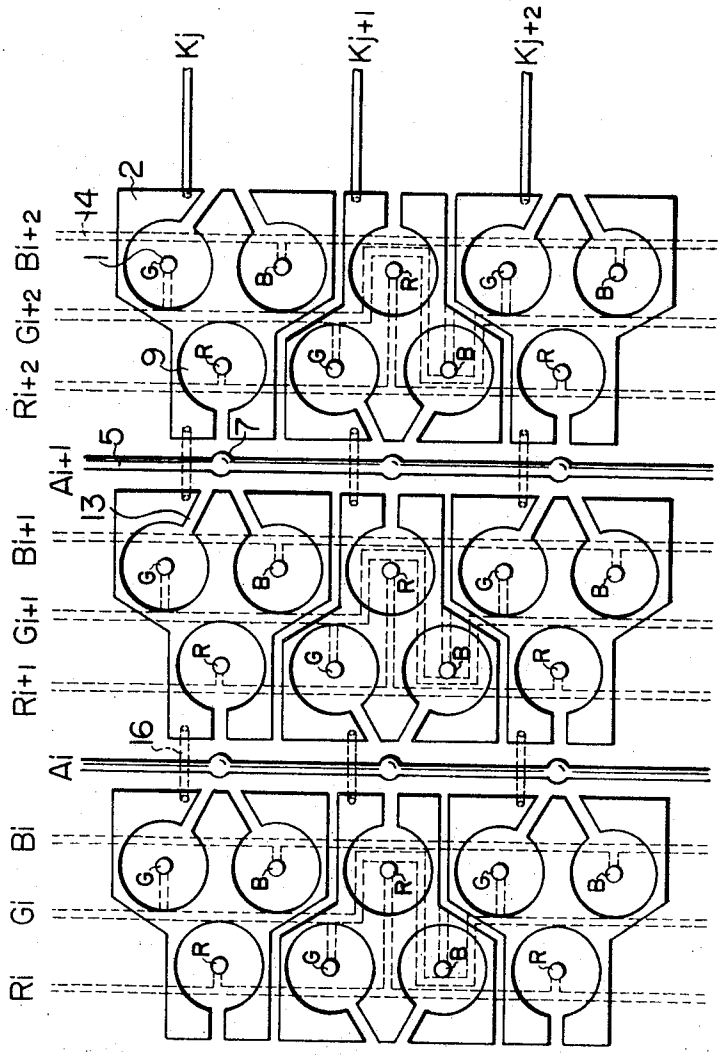

Kj
Kj+1
Kj+2
12
14
1
Ri+2
Gi+2
Bi+2
9
5
Ai+1
7
13
Ri+1
Gi+1
Bi+1
16
Ai
Ri
Gi
Bi
R
G
B

FIG. 8a

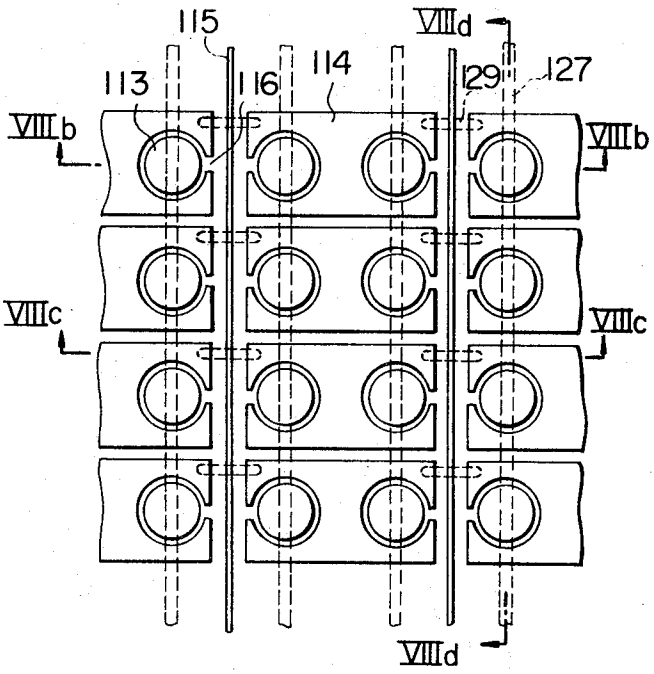


FIG. 8b

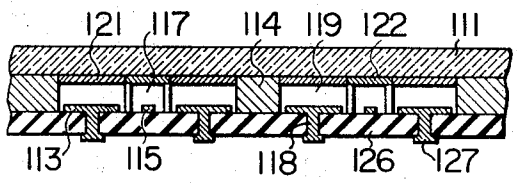


FIG. 8c

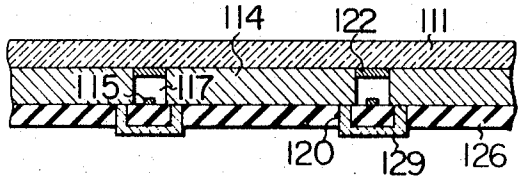


FIG. 8d

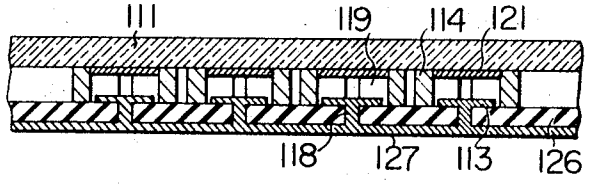


FIG. 9

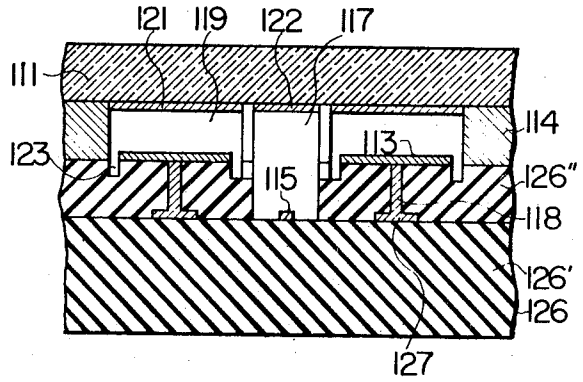


FIG. 10a

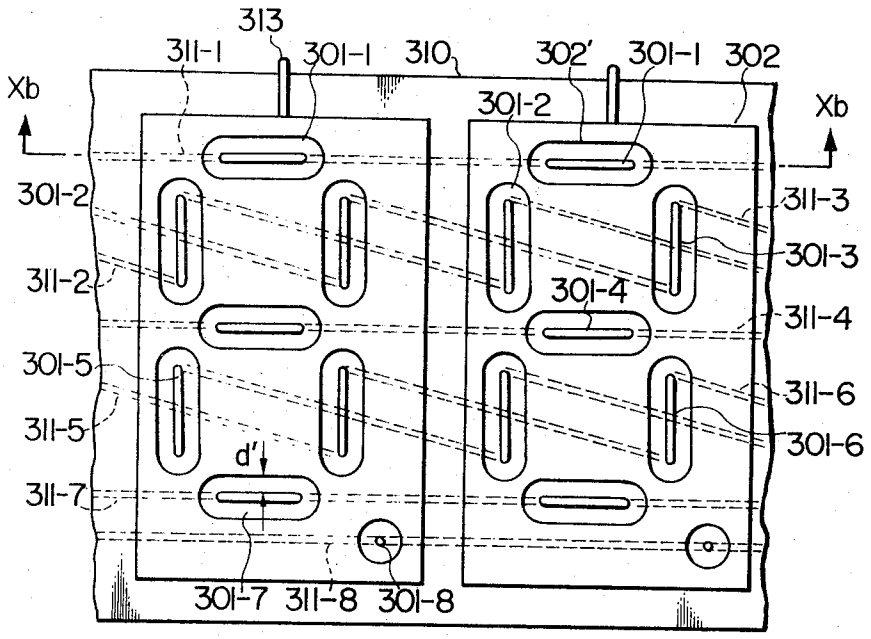


FIG. 10b

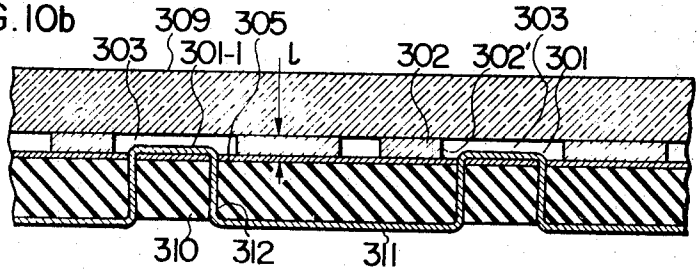


FIG. 11a

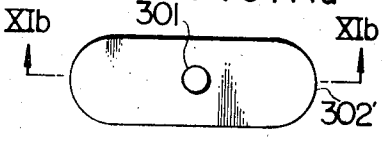


FIG. 12a

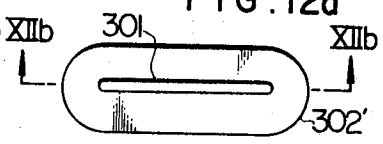


FIG. 11b

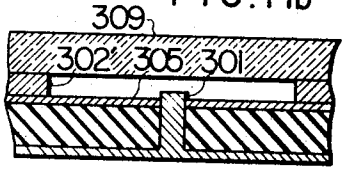


FIG. 12b

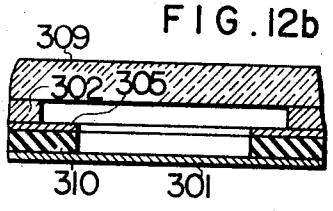


FIG. 13

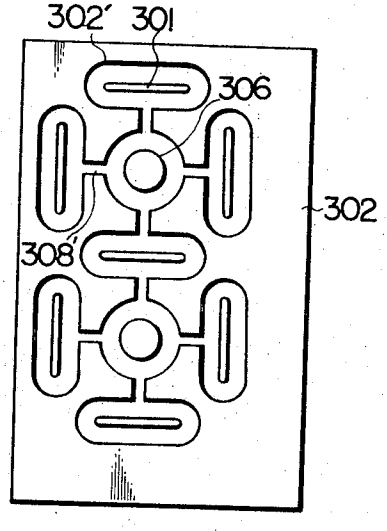


FIG. 14a

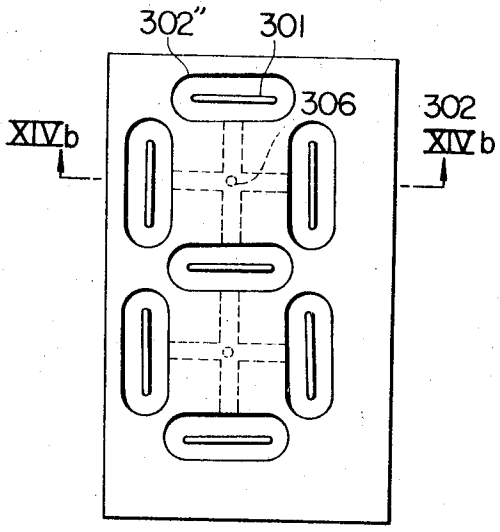


FIG. 14b

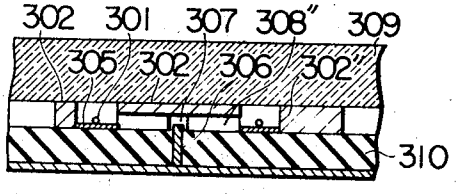


FIG. 15

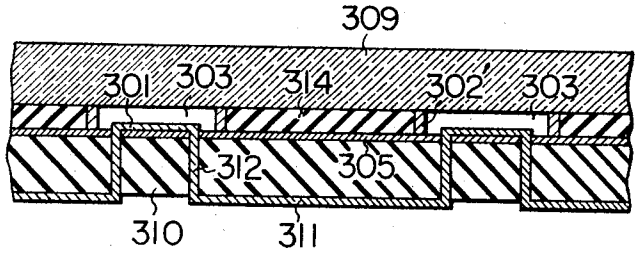

309
301
303
314
302
303
312
305
310
311

FIG. 16

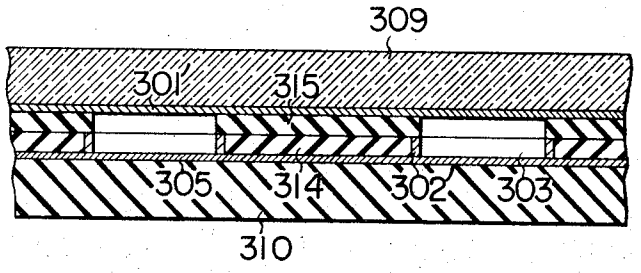

309
301
315
305
314
302
303
310

FIG. 17

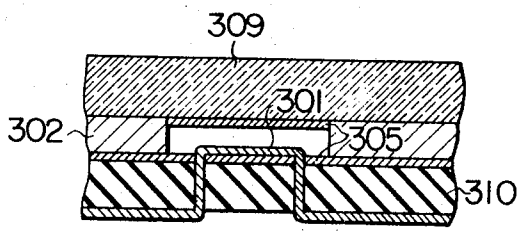


FIG. 18

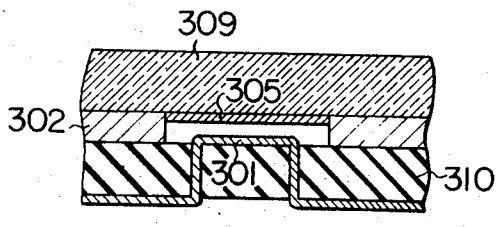
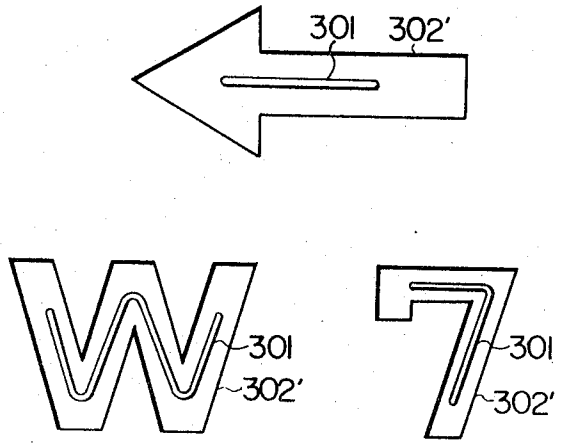


FIG. 19



FLAT DISPLAY PANEL

The present invention relates to a device for displaying letters, figures, numerals and the like by means of DC discharge in a gas, and more in particular to the construction of a display portion (hereinafter referred to as "flat display panel") of such a device.

A conventional flat display panel using DC discharge is shown in FIGS. **1** and **2**. For convenience of explanation, FIG. **1** illustrates only the construction of the electrodes of the flat display panel in which main discharge is facilitated by the use of subsidiary or auxiliary discharge.

In FIG. **1**, reference numerals **1**, **1'** and **1''** show anodes for main discharge, numerals **2**, **2'** and **2''** cathodes, numerals **3**, **3'** and **3''** openings bored in the cathodes **2**, **2'** and **2''** respectively, numerals **4**, **4'** and **4''** through-holes bored in the bottoms of the openings **3**, **3'** and **3''** respectively and numerals **5**, **5'** and **5''** anodes for subsidiary discharge. A sectional view of the flat display panel having the above-described electrode arrangement is shown in FIG. **2**. In this drawing, reference numeral **6** shows a ceramic substrate supporting the subsidiary anodes **5**, **5'** and **5''**, numerals **7**, **7'** and **7''** ribbon-shaped spaces for subsidiary discharge in parallel with the subsidiary anodes **5**, **5'** and **5''**, numeral **8** a ceramic plate having the ribbon-shaped through-holes forming the subsidiary discharge spaces **7**, **7'** and **7''**, numerals **9**, **9'** and **9''** main discharge spaces having circular cross sections, numeral **10** a ceramic plate having circular through-holes constituting the main discharge spaces **9**, **9'** and **9''**numeral **11** a transparent insulating substrate, and numeral **12** a phosphor material coated on the inner wall of the through-holes of the ceramic plate **10**.

The subsidiary discharge is provided for the purpose of facilitating the starting of the main discharge. Occurrence of the subsidiary discharge causes electrons, metastable atoms and the like to reach the main discharge spaces by way of the through-holes **4**, **4'** and **4''**. Since the metastable atoms generate secondary electrons when impinging upon the side walls of the main discharge spaces, the electron density in the main discharge spaces is increased so that the discharge starting voltage in the main discharge spaces behind which subsidiary discharge occurs can be decreased. This phenomenon is utilized to simplify the driving circuit. In other words, by utilizing the operation principle of the well-known step discharge tube, transfer (or scanning) of the subsidiary discharge can be effected by pulse wave of three or several phases. For example, the subsidiary discharges aligned in the direction of a row are scanned in line sequence, and in sychronism with this scanning, a video signal voltage of such a magnitude that main discharge occurs only in the presence of the subsidiary discharge is applied to the main discharge anodes extending in the direction of a column, thereby accomplishing the display of a desired image. In this driving method, only several circuits are required in the direction of a row.

However, a first disadvantage of the above-mentione conventional flat display panel lies in that the display with high-brightness and therefore the display of numerals, letters, figures and the like on a large area is impossible due to the fact that the discharge between the anodes (or the main discharge anodes in the example of FIG. **1**) and the cathodes in the discharge space (or

the main discharge space in the example of FIG. **1**) occurs substantially at right angles to the transparent insulating substrate at the sacrifice of discharge over the whole area of the discharge space.

A second disadvantage of the cooventional flat display panel is that in the display panel utilizing subsidiary discharge the arrangement of the main discharge space and the subsidiary discharge space in two upper and lower layers requires two ceramic plates **8** and **10** as thin as 0.3 mm to 2 mm and perforated with numerous holes as shown in FIG. **2**, thereby making the manufacture of the display panel very difficult. Therefore, it is almost impossible to manufacture a flat display panel of large area (for example, of 1 m^2) for the reason that a thin large insulating substrate is weak in mechanical strength and is very hard to handle.

A third disadvantage of the conventional flat display panel is that ultraviolet rays generated by the discharge are absorbed in the gas existing in the wide space between the surface of the cathodes for generating negative glow and the phosphor material **12** to be excited by the ultraviolet rays, resulting in a lower efficiency and hence lower brightness.

A fourth disadvantage of the conventional flat display panel is the small effective luminescent area of the phosphor material in view of the fact that the plane coated with the phosphor material is parallel to the line of vision of viewers, leading to a lower efficiency and brightness.

Therefore, an object of the present invention is to provide a flat display panel which has a high brightness and high efficiency and can display numerals, letters, figures and the like over a large area.

Another object of the present invention is to provide a flat display panel which has a large display area and can be easily manufactured.

According to one aspect of the present invention, there is provided a flat display panel comprising at least one first electrode, at least one second electrode each surrounding at least one of said at least one first electrode to form therewith a main discharge space for gas discharge, and two insulating substrates for hermetically sealing said main discharge spaces, at least one of said insulating substrates being transparent, the direction of discharge between said first and second electrodes being parallel to said one insulating substrate.

The above and other objects, features and advantages of the present invention will be apparent when reading the detailed description taken in conjunction with the accompanying drawings in which:

FIG. **1** is a diagram showing the arrangement of electrodes in part of the conventional flat display panel;

FIG. **2** is a sectional view taken in line II — II of FIG. **1**,

FIG. **3***a* is a plan view showing part of an embodiment of the present invention;

FIGS. **3***b*, **3***c* and **3***d* are sectional views taken in lines III*b* — III*b*, III*c* — III*c* and III*d* — III*d* of FIG. **3***a* respectively;

FIGS. **4** to **7** are front views respectively showing parts of the flat display panels according to another embodiments of the invention;

FIGS. **8** and **9** are diagrams respectively showing further embodiments of the invention; and

FIGS. **10** to **19** are plan views and sectional views showing the constructions of still other embodiments of the invention.

The construction of the flat display panel according to the present invention which obviates the above-mentioned disadvantages of the conventional flat display panel and in which discharge occurs between anodes and cathodes in parallel with a transparent insulating substrate will be explained below with reference to a flat display panel utilizing subsidiary discharge.

A partial front view of a flat display panel embodying the present invention utilizing subsidiary discharge is shown in FIG. 3*a*. FIGS. 3*b*, 3*c* and 3*d* are sectional views thereof taken in line IIIb — IIIb, IIIc — IIIc and IIId — IIId of FIG. 3*a* respectively. In the drawings, reference numeral **1** shows main discharge anodes, numeral **2** cathodes arranged surrounding the main discharge anodes **1**, and numeral **9** main discharge spaces separated from each other by the cathodes **2**. The face of the cathode **2** that faces each main discharge space **9** may be of any configuration depending on the desired display form, the face being of a circular cylindrical surface configuration in the embodiment under consideration. Reference numeral **5** shows subsidiary discharge anodes, numeral **7** subsidiary discharge spaces in the same plane as the main discharge spaces **9**, and numeral **13** openings coupling the main discharge spaces **9** with the subsidiary discharge spaces **7**. Through the opening **13**, electrons, metastable atoms and light quanta generated in the subsidiary discharge spaces **7** are passed to the main discharge spaces **9**. As a result, the discharge starting voltage of the main discharge spaces is reduced as already mentioned, and the starting of discharge is expedited. Reference numeral **6** shows an insulating substrate, numeral **14** conductors connecting the main discharge anodes, numeral **15** through-holes provided in the insulating substrate for electrically connecting the main discharge anodes **1** and the conductors **14**, numeral **16** conductors connecting the cathodes **2** to each other, and numeral **17** through-holes provided in the insulating substrate **6** for electrically connecting the cathodes **2** and the conductors **16**. Thus, wirings of the main discharge anodes **1** and cathodes **2** are effected in one layer on the back side of the insulating substrate **6** by means of the through-holes **17**. Numeral **11** shows a transparent insulating substrate and numeral **12** a phosphor material coated on those surfaces of the insulating substrates **6** and **11** which face the cylindrical main discharge spaces **9**.

In this construction, as will be seen from FIG. **3**, the direction of the discharge occurring between the anodes **1** and cathodes **2** is parallel to the transparent insulating substrate **11**, thus enabling the display with a high brightness and therefore the display over a large area. Further, the above-described arrangement not only eliminates the need for a thin insulating substrate with openings but makes it possible to shorten the distance between the phosphor material and the negative glow generated on the faces of the cathodes facing the main discharge spaces by making such faces of cylindrical or annular surface configuration, thus reducing the amount of ultraviolet rays absorbed in the gas. Furthermore, power consumption due to subsidiary discharge is reduced by providing a single subsidiary discharge space for a plurality of main discharge spaces.

The above-described arrangement facilitates the manufacture of a flat display panel which has a high efficiency and high brightness and in which the display over a large flat area is possible.

One-dot chain lines **18** in FIG. 3*a* illustrate portions provided with black paint arranged in stripes for shading or shutting the light from the subsidiary discharge in order to prevent any light generated by other than the main discharge from leaking outside. A similar paint may be provided at such portions as defined by one-dot chain lines **18'** where no main discharge occurs, in order to improve the contrast of the display panel. Another possible way to improve the contrast is to arrange the paint in strips. According to the present invention, a sufficiently high mechanical strength to assure the display over a large area is realized by the provision of the insulating substrate **6** consisting of a ceramic plate, for example, several millimeters to 1 cm thick and the transparent insulating substrate **11** of glass, for example, 3 mm to 2 cm thick. The isolation or separation of the main discharge spaces **9** and the subsidiary discharge spaces **7** from each other are effected by the cathodes **2**, and the main discharge spaces **9** are in the same plane as the subsidiary discharge spaces **7**. For this reason, it is possible to form the main discharge spaces **9** and the subsidiary discharge spaces **7** of a predetermined shape by removing by etching or otherwise the predetermined portions of a metal layer 0.1 mm to 0.5 mm thick which is formed by appropriate means on the whole surface of the insulating substrate **6** in advance for this purpose. Also, the wiring of the electrodes is accomodated in a single layer on the back surface of the insulating substrate **6**.

It will be noted from the above description that according to the present invention, a flat display panel which is manufactured very easily and in which the display over a large area is possible is obtained.

In exciting the phosphor material with ultraviolet rays, it is common practice to utilize resonance lines of gas atoms which are strongest. However, the resonance lines are very easily absorbed. For example, one absorption occurs on the average for each length of 0.01 mm to 1 mm depending on the type and pressure of the gas involved, with the result that negative glow present at a position more distant than the above-mentioned length from the phosphor material does not contribute to the excitation thereof. Therefore, assuming that the longest distance capable of being covered by ultraviolet rays is 0.1 mm, the provision of cathodes approximately 0.1 mm thick according to the present invention permits ultraviolet rays from the negative glow over the whole surface of the cathodes to be effectively utilized regardless of the inner diameter of the cathodes. In the conventional flat display panel, each cathode is in the form of a circle approximately 0.5 mm in diameter so that only the negative glow in the vicinity of the peripheral portion of the cathode functions to excite the phosphor material, thus wasting the electric power consumed by the negative glow at the center of the circular cathode, resulting in a lower efficiency. In some cases, it is the length of at most 0.01 mm which ultraviolet rays can cover depending on the composition and pressure of the gas uses. To prevent the occurrence of such cases, a cathode approximately 10 microns thick may be employed according to the present invention. Further, the present invention uses a single subsidiary discharge for controlling a couple of main discharges at a saving of electric power required for subsidiary discharge. It will be apparent from the above explanation that a flat display panel with high efficiency and high

brightness is obtained according to the present invention.

Another embodiment of the present invention in which the configuration of the face of the cathode facing the subsidiary discharge space **7** is different from that included in the embodiment of FIG. **3** is illustrated in FIG. **4**. Subsidiary discharge is required to occur at the front portion of the opening **13**, and the occurrence of subsidiary discharge should preferably be limited to the front portion of opening **13** from the viewpoint of power consumption and efficiency. In FIG. **4**, reference numeral **19** shows a projecting portion provided at the opening **13** of the cathode **2**. The projecting portion **19** enables the intensity of electric field at the front portion of the opening **13** to become higher than in the vicinity thereof and therefore subsidiary discharge is successfully limited to the projecting portion **19**.

The projecting portion **19** may take the configuration of a semicircle, half ellipse, equilateral triangle or various shapes other than the one shown in FIG. **4**.

Still another embodiment of the invention is shown in FIG. **5**. The configuration of the face of the cathode facing the main discharge spaces **9** is not limited to the circular cylindrical surface configuration as shown in FIGS. **3** and **4** but may take a square or rectangular pillar surface configuration as illustrated in FIG. **5**.

Still another embodiment of the present invention is shown in FIG. **6** which is applied to a color display. In the this embodiment, one picture element is made up of three main discharge spaces coated with phosphor materials of three colors of red, blue and green, and each picture element is provided with one subsidiary discharge. In other words, the three main discharge spaces share one subsidiary discharge space with each other. Wirings are accomodated in a single layer on the back surface in this embodiment, too. In other words, referring to FIG. **6**, symbols G_i, R_i and B_i respectively show back surface wiring conductors **14** on the *i*-th column (row) of the main discharge anodes for green, red and blue respectively, symbol K_j shows the cathode **2** on the *j*-th row (or column), and symbol A_i the subsidiary discharge anode **5** on the *i*-th column (or row). The discharge starting voltage of main discharge belonging to the picture element of the (*i*-1)th row and (*j*-1)th column [or (*j*-1)th row and (*i*-1) th column] can be reduced by utilizing the subsidiary discharge caused by the voltage applied between A_{i-1} and K_{j-1}. The back surface wirings in this case comprise conductors **14** and **16** arranged in a single layer.

A further embodiment of the present invention is illustrated in FIG. **7** which is applied to a color display. The color display panel according to this embodiment is different from the embodiment of FIG. **6** in that in the present embodiment the main discharge spaces **9** are differently arranged and the subsidiary discharge takes the form of a straight line. The embodiment of FIG. **7** is more efficient in the case where subsidiary discharge is to be scanned.

It will be seen from the above description that various modifications of arrangements of electrodes, discharge spaces and wirings in a single plane are possible also in the present invention.

The flat display panel according to the present invention may be economically driven on the operation principle of the above-mentioned step discharge tube with a fewer number of X circuits or Y circuits in an XY matrix by using several driving circuits to scan the subsidiary discharge in line sequence.

In the flat display panel according to the present invention, there are no special conditions attached to the composition and pressure of the gas used for discharge operation, except that such a gas preferably comprises a rare gas, a mixture of at least two rare gases, or a mixture of a rare gas and mercury vapor. More in detail, in the monochromatic display panel using no phosphor material, neon or a mixture of neon and 0.1 to 1% of argon is suitable. Desirable pressure in this case ranges from **100** Torr. to **300** Torr. depending on the inner diameter of the cathode, outer diameter of the anode and other dimensions. Further, in the event that ultraviolet rays are used to excite the phosphor material, xenon, a mixture of neon and xenon, or a mixture of argon and mercury vapor may be used.

The flat display panel shown in FIG. **3** is provided with the cathode around the anode, which the cathode functions as a partition wall for separating the discharge spaces from each other. The present invention is not limited to such an arrangement but may be applicable in a flat display panel which is constructed so that anodes each surrounding each main discharge cathodes are used to separate adjacent discharge spaces from each other and the phosphor material is coated opposite to the main discharge cathodes.

The diagram of FIG. **8***a* is a partial front view showing still another embodiment of the invention having such a construction, FIGS. **8***b*, **8***c* and **8***d* showing sectional views taken in lines VIII*b* — VIII*b*, VIII*c* — VIII*c* and VIII*d* *VIIId* respectively in FIG. **8***a*. In FIG. **8** reference numeral **113** shows main discharge cathodes, numeral **114** anodes arranged surrounding the main cathodes **113**, numeral **119** main discharge spaces isolated from each other by the anodes **114**, numeral **115** subsidiary discharge cathodes, numeral **117** subsidiary discharge spaces each arranged between and in parallel to the two main discharge spaces **119**, and numeral **116** openings connecting the main discharge spaces **119** to the subsidiary spaces **117** through which the electrodes, metastable atoms and light quanta generated in the subsidiary discharge spaces **117** reach the main discharge spaces **119**, whereby the discharge starting voltage of the main discharge spaces is reduced and the starting of discharge is expedited. Reference numeral **126** shows an insulating substrate, numeral **127** conductors each provided for connecting the main discharge cathodes **113** aligned in a column, numeral **118** through-holes provided in the insulating substrate **126** for the purpose of electrically connecting the main discharge cathodes **113** to the conductors **127**, numeral **129** conductors connecting the anodes aligned in a row, and numeral **120** through-holes bored in the insulating substrate **126** to electrically connect the anodes **114** to the conductors **129**.

Thus the wirings of the main discharge cathodes **113** and anodes **114** are accomplished on the back surface of the insulating substrate **126** by means of the through-holes **118** and **120**. Reference numeral **111** shows a transparent insulating substrate, numeral **121** a phosphor material coated on the transparent insulating substrate **111** oposite to the main discharge cathodes **113**, and numeral **122** black paint for preventing the subsidiary discharge light from leaking outside, the phosphor material and black paint being arranged in stripes in the

direction of columns (parallel to the conductors **127** and subsidiary discharge cathodes **115**).

The above-described arrangement eliminates the need of a thin perforated insulating substrate required in the conventional flat display panel for display of numerals, letters and figures by the use of subsidiary discharge. Also, according to the invention, a shorter length between the negative glow generated on the front portion of the main discharge cathode and the phosphor material reduces the amount of ultraviolet rays absorbed into the gas, with the result that it is possible to obtain a flat display panel which has a high brightness and high efficiency and in which the display over a large area is possible.

Further, in the embodiment of FIG. **8**, as in the preceding embodiments, the arrangement of an insulating substrate **126** consisting of a ceramic plate several millimeters to 1 cm in combination with a transparent insulating substrate **111** of glass 3 mm to 2 cm thin provides a sufficient mechanical strength even if a large display area is involved. The separation of the main discharge spaces **119** and subsidiary discharge spaces **117** from each other is effected entirely by the anodes **114**, the main discharge spaces **119** being arranged in the same plane as the subsidiary discharge spaces **117**. Because of this single-layer arrangement, it is possible to form the main discharge spaces **119** and subsidiary discharge spaces **117** of predetermined configuration at the same time by etching off or otherwise removing predetermined portions of a metal layer 0.1 mm to 0.5 mm thick deposited in advance by evaporation or other appropriate means on the whole surface of the insulating substrate **126**. Also, the wiring of the electrodes are included in a single layer on the back surface of the insulating substrate **126**. It will be obvious from the above explanation that the present invention greatly facilitates the production of a flat display panel with a large display area.

The conventional flat display panel has the disadvantage that only the resonance lines generated by the negative glow in the vicinity of the circular openings **3** contribute to the excitation of the phosphor material, thereby wasting the electric power consumed by the negative glow in the central portion thereof for a lower efficiency of the panel, in view of the fact that the openings **3** making up the effective discharge surface of the cathodes take the form of circles as shown in FIG. **1**.

By contrast, the flat display panel according to the present invention is characterized in that the phosphor material **121** is coated on the upper faces of the cylindrical spaces bored in the anodes **114** and the main discharge cathodes **113** are arranged opposite to the phosphor material **121**, so that the distance between the second main discharge electrodes **113** and the phosphor material **121** is shortened to approximately 0.1 mm by maintaining the thickness of the anodes **114** at approximately 0.1 mm, thus making the best use of the resonance lines generated by the negative glow.

A partial sectional view of still another embodiment of the present invention is illustrated in FIG. **9** which is similar to the sectional view of FIG. **8***b*. This embodiment has grooves **123** between the main discharge cathodes **113** and the anodes **114** for preventing the electrical shortcircuiting between the main discharge cathodes **113** and the anodes **114** which otherwise would occur by spattering. Also, in the flat display panel of this embodiment, the bottom surface of the subsidiary space **117** provided with the subsidiary discharge cathode **115** is arranged at a lower level than the bottom surface of the main discharge space **119** having the main discharge cathode **113**, in order that transfer of subsidiary discharge may be facilitated by reducing the loss due to the diffusion of charged particles in the subsidiary discharge space **117**.

Another feature of the embodiment under consideration resides in the fact that the conductors **127** are disposed inside of the insulating substrate **126** divided into two layers **126'** and **126''**, so that the conductor **127** is first printed on the insulating substrate **126'** whereupon the insulating layer **126''** is printed. Then, the main discharge cathode **113** is printed thereby to connect the conductor **127** to the main discharge cathode **113** through the through-hole **118**. The anodes **114** can also be formed by printing. In this way, the length of the through-hole **118** can be shortened and as a result the reduction of product yield due to unsatisfactory connection can be prevented.

As will be apparent from the above explanation, the arrangement of electrodes, arrangement of discharge spaces, mode of wirings and method of production may be modified in various ways.

The embodiments shown in FIGS. **8** and **9** can also be driven economically on the operation principle of the previously-mentioned step discharge tube with a fewer number of X (or Y) circuits in an XY matrix by using several driving circuits to scan the subsidiary discharge in line sequence.

It was already mentioned that in the conventional flat display panel, as shown in Flg. **1**, the plane coated with the phosphor material is parallel to the line of vision of viewers and therefore the effective luminescent area of the phosphor material is reduced, resulting in a lower luminous efficiency and brightness. For example, the inventors are informed that not more than 900 fL of brightness is attained in the conventional flat display panel. As will be seen from the above description of the preceding embodiments, the present invention is characterized in that at least one of the upper and lower faces of the discharge spaces is coated with the phosphor material in a plane perpendicular to the line of vision and therefore the excitation of phosphor material is improved, thereby providing a flat display panel with a high brightness and high efficiency.

It will be also understood that the configurations of the faces of the anodes or cathodes facing the discharge spaces are not limited to those shown in the preceding embodiments.

The diagram of FIG. **10***a* is a plan view showing part of still another embodiment of the invention in which the face of the cathode facing the discharge space has an elliptical or elongated-elliptical or oval cylindrical surface configuration (hereinafter referred to as "the elliptical cylindrical surface configuration"), the diagram of FIG. **10***b* showing a sectional view taken in line X*b*—X*b* of FIG. **10***a*.

In this drawing reference numeral **301** shows anodes including electrodes **301–1** to **301–8** as shown in FIGS. **10***a* and **10***b*, numeral **302** conductor plates making up cathodes disposed on the insulating substrate **310**, and numeral **302'** faces of the cathodes bored in the conductor plates **302** and having the elliptical cylindrical surface configuration, the anodes being arranged within the faces of the cathodes. Reference numeral

305 shows a phosphor material deposited between the insulating substrate 310 and the conductor plates 302, numeral 303 discharge spaces within which the phosphor material is exposed, numeral 309 a transparent insulating substrate of glass or the like material which, together with the insulating substrate 310, hermetically seals the discharge spaces, numeral 311 lead wires for the anodes 301, numeral 312 through-holes in the insulating substrate 310 for connecting the anodes 301 to the lead wires 311 therefor, and numeral 313 lead wires for the cathodes.

The above-described arrangement permits the plane coated with the phosphor material to be directed perpendicular to the line of vision of viewers, thereby enlarging the effective lauminescent area of the phosphor material against viewers.

In this case, it is needless to say that discharge occurs in the direction parallel to the transparent insulating substrate and hence the phosphor material 305.

By reducing the thickness l of the cathode 302 as compared with the distance d' between the cathode 302 and anode 301, the ultraviolet rays generated by the negative glow functions effectively to excite the phosphor material for an improved efficiency.

It is especially desirable that the distance d' between the cathode and the anode be rendered substantially equal to the thickness of the negative glow. When argon or xenon is employed, the product pd' of distance d' between cathode and anode and pressure p is made approximately 1 cm · Torr. Thus, the discharge space 303 is completely filled with the negative glow thereby to achieve the most effective excitation of the phosphor material 305.

With reference to the embodiment of FIG. 10, as an example, the brightness of 6000 fL was obtained by employing Zn_2SiO_4 Mn and xenon 100 Torr. in pressure as the phosphor material and the gas respectively, when the distance between the anode and cathode and the thickness of the cathode 302 are 0.4 mm and 0.2 mm respectively. This brightness is much higher than that obtained by the conventional flat display panel.

By the way, the first electrodes 301, wirings 311 therefor and the through-holes 312 may be integrally constructed.

A plan view of a flat display panel according to still another embodiment of the present invention is shown in FIG. 11*a*. FIG. 11*b* is a sectional view taken in line XI*b* — XI*b* of FIG. 11*a*.

The configuration of the anode 301 is not necessarily similar to that of the cathode 302 which has a face of the elliptical cylindrical surface configuration as shown in FIG. 10. Instead, the anode 301 of a desired shape may be provided substantially at the center of the face of the cathode. For example, it is possible to employ a circular anode as shown in FIG. 11. The embodiment of FIG. 12*a* is one in which the anode 301 is arranged in the same plane as the wiring 311 therefor. FIG. 12*b* shows a sectional view taken in line XII*b* — XII*b* of FIG. 12*a*. The position of the anode in this embodiment is not limited to the one shown in FIGS. 10 and 12, but may be intermediate the two. Also, it is needless to say that the anode positioned so may be in any desired shape.

Still another embodiment of the invention in which actuation of main discharge is facilitated by subsidiary discharge is shown in FIG. 13. In this drawing, reference numeral 306 shows subsidiary discharge anodes, and numeral 308′ openings for supplying, from the subsidiary discharge space 307 to the space between the anode 301 and the cathode face 302′ of elliptical cylindrical surface configuration, the electrons, ions, metastable atoms, light quanta and the like generated by subsidiary discharge between the subsidiary discharge anode 306 and the cathode 302. The portions where the subsidiary discharge occurs may be covered with an opaque material to prevent light generated by the subsidiary discharge from leaking outside.

A plan view of a flat display panel according to still another embodiment of the invention in which the subsidiary discharge space 307 is located on the back side of the cathode plate 302 is shown in FIG. 14*a*. FIG. 14*b* shows a sectional view taken in line XIV*b* — XIV*b* of FIG. 14*a*.

In the this drawing, reference numeral 308″ shows grooves bored in the cathode plates 302 by way of which the electrons, ions, metastable atoms and the like reach the discharge spaces. In this arrangement, light generated by the subsidiary discharge is prevented from leaking outside and the actuation of main discharge is further facilitated by the extension of subsidiary discharge into the grooves 308″.

The phosphor material 305 in this embodiment is provided only on the cathode faces 302″ of the elliptical cylindrical surface configuration.

Reference is had to FIG. 15 showing a sectional view of part of still another embodiment of the invention in which the cathode face 302′ of the elliptical cylindrical surface configuration is located on the inner surface of the through-hole bored in the insulating plate 314.

A partial sectional view of still another embodiment of the invention is illustrated in FIG. 16, which is characterized in that the anode 301′ is provided on the inner surface of the glass plate 309. The anode 301′ preferably consists of a transparent NESA (a tradename) electrode or a thin metal wire not more than 100 microns in diameter. An insulating spacer 315 is inserted intermediate the anode 301′ and the cathode face 302′.

The insulating spacer 315 may be used also in the cases of FIGS. 10 and 15 in which the anode 301 is provided on the surface of the insulating substrate 316. This arrangement enables the cathode material to be prevented from being attached to the surface of the glass plate 309 due to spattering, resulting in long useful life of the display panel.

Still another embodiment of the invention is illustrated in FIG. 17, in which unlike the embodiment of FIG. 10 characterized by the phosphor material coated only on the lower face of the discharge space, the phosphor material is coated on both upper and lower faces of the discharge space to make the most of the ultraviolet rays generated by discharge.

The embodiment of FIG. 18 shows another case in which the phosphor material is coated only on the upper face of the discharge space, this is, only on the glass plate 309, thus facilitating the coating process, thereby contributing to the reduction in production cost.

Still another embodiment of the invention in which the configuration of the cathode face 302′ facing the discharge space makes up a numeral, letter, figure or the like is shown in FIG. 19. It is needless to say that not only the shown numeral, letter and figure but other

numerals, letters, figures and the like may be used in the applications of the invention.

As will be understood from the above explanation, there are various modifications, and all those discharge display panels in which each anode or cathode has a face facing the side of the discharge space and in which the phosphor material is coated on at least one of the upper and lower faces of the discharge space are included in the scope of the invention.

Thus, a flat display panel with high brightness and high efficiency is obtained according to the present invention.

What we claim is:

1. A flat display panel comprising at least one first electrode, at least one second electrode, each said second electrodes surrounding at least one of said at least one first electrode to form therewith a main discharge space for gas discharge, and two insulating substrates for hermetically sealing said main discharge spaces, at least one of said insulating substrates being transparent, and said first and second electrodes having at least a portion in a common plane between said two insulating substrates such that the direction of discharge between said first and second electrodes is parallel to said one transparent insulating substrate.

2. A flat display panel according to claim **1**, further comprising a phosphor material coated on the surfaces of said insulating substrates facing said main discharge space.

3. A flat display panel according to claim **1**, further comprising openings bored in said second electrode, and at least one third electrode each forming with said second electrode a subsidiary discharge space for facilitating the discharge in said main discharge space, said main discharge space being coupled with said subsidiary discharge space in the same plane through said opening.

4. A flat display panel according to claim **1**, further comprising a material for shading the light generated by the discharge in said subsidiary discharge space, said material being provided on the surface of said one insulating substrate facing said subsidiary discharge space.

5. A flat display panel comprising a plurality of main discharge cathodes, a plurality of anodes each surrounding at least one of said main cathodes at least partially in a common plane with said main cathodes to form therewith a main discharge space for gas discharge, a plurality of subsidiary discharge cathodes each forming with said anode a subsidiary discharge space for facilitating the discharge in said main discharge space, openings provided in said anodes for coupling said main discharge space with said subsidiary discharge space, two insulating substrates for hermetically sealing said main and subsidiary discharge spaces, at least one of said insulating substrates being transparent, a phosphor material coated on at least one surface of said two insulating substrates in facing relationship with said main discharge space, a plurality of conductors each passing through a plurality of through-holes in the other insulating substrate to apply a voltage to selected ones of said main discharge cathodes, and a plurality of conductors each provided on said other insulating substrate for interconnecting selected ones of said anodes.

6. A flat display panel according to claim **5**, further comprising grooves each provided on the portion of said other insulating substrate between said anode and said main discharge cathode.

7. A flat display panel according to claim **5**, further comprising an insulating substrate covering said conductors passing through said through-holes.

8. A flat display panel according to claim **1**, wherein said second electrodes surround said at least one first electrode with a surface having a predetermined geometrical configuration about said at least one first electrode.

9. A flat display panel according to claim **8**, wherein said predetermined geometrical configuration is a circular cylinder.

10. A flat display panel according to claim **8**, wherein said predetermined geometrical configuration is rectangular.

11. A flat display panel according to claim **10**, wherein said rectangular configuration is square.

12. A flat display panel according to claim **1**, wherein said at least one first electrode is in the form of a circular pillar.

13. A flat display panel according to claim **1**, wherein said at least one first electrode is in the form of a flat circular disc.

14. A flat display panel according to claim **2**, wherein said phosphor material is coated on only one surface of said insulating substrates.

15. A flat display panel according to claim **14**, wherein said phosphor material is disposed on the surface of said transparent insulating substrate.

16. A flat display panel according to claim **3**, wherein said second electrode includes a projecting portion at said openings.

17. A flat display panel according to claim **3**, wherein at least three main discharge spaces are formed by said second electrodes, each of said three main discharge spaces having a phosphor material corresponding to one of three different colors.

18. A flat display panel according to claim **17**, wherein said three main discharge spaces share one subsidiary discharge space.

19. A flat display panel according to claim **18**, wherein a plurality of subsidiary spaces are formed in a straight line, each of said subsidiary discharge spaces being shared by said three main discharge spaces.

20. A flat display panel according to claim **1**, wherein said at least one first electrode is an anode and said at least one second electrode is a cathode.

21. A flat display panel according to claim **1**, wherein said at least one first electrode is a cathode and said at least one second electrode is an anode.

22. A flat display panel according to claim **5**, wherein said phosphor material is coated on a surface of said insulating substrates opposite to said main discharge cathodes.

23. A flat display panel according to claim **5**, wherein the thickness of said plurality of anodes is a predetermined dimension selected to enhance the light output of said phosphor material.

24. A flat display panel according to claim **1**, wherein said first and second electrodes are separated at a predetermined distance substantially equal to the thickness of the negative glow of said gas discharge in said main discharge space.

* * * * *