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Kamegaya et al.

[11] **3,882,342**

[45] **May 6, 1975**

[54] **GAS DISCHARGE DISPLAY PANEL FOR COLOR PICTURE REPRODUCTION**

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[52] **U.S. Cl.** **313/188;** 313/209; 313/217; 313/419

[51] **Int. Cl.** **H01j 61/06**

[58] **Field of Search** ..... 313/188, 485, 491, 217, 313/209, 220; 315/169 TV

[56] **References Cited**

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Primary Examiner—Palmer C. Demeo

Attorney, Agent, or Firm—Stevens, Davis, Miller & Mosher

[57] **ABSTRACT**

A gas discharge display panel for efficiently reproducing a color picture having high brightness and high definition. The display panel comprises a plurality of picture elements arranged in matrix. Each picture element is formed by a set of three discharge units reproducing red, green and blue light respectively. Each discharge unit is coupled to a hollow cathode. The hollow cathode of a suitable size is divided into two portions, i.e., a set of display hollow cathodes each of which forms main part of the discharge unit, and a scanning hollow cathode which couples the set of display hollow cathodes and operates for obtaining preparatory discharge. Said two portions of the hollow cathode are jointly operated so as to obtain a large discharge current supply at low voltage and in a small surface area. Thus a practical gas discharge display panel having high density discharge unit arrangement is realized and which is able to increase the luminance by about several tens of per cent more than the conventional one and also being able to be assembled in a simple manner by simplifying the panel construction with unified parts.

10 Claims, 12 Drawing Figures

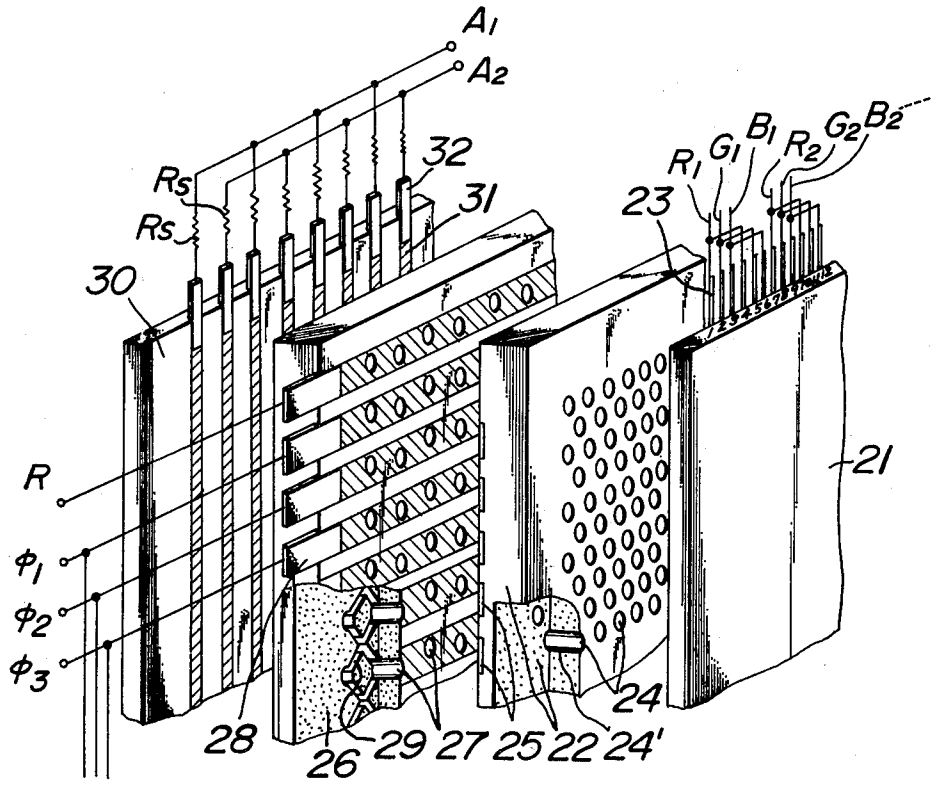


FIG_1 PRIOR ART

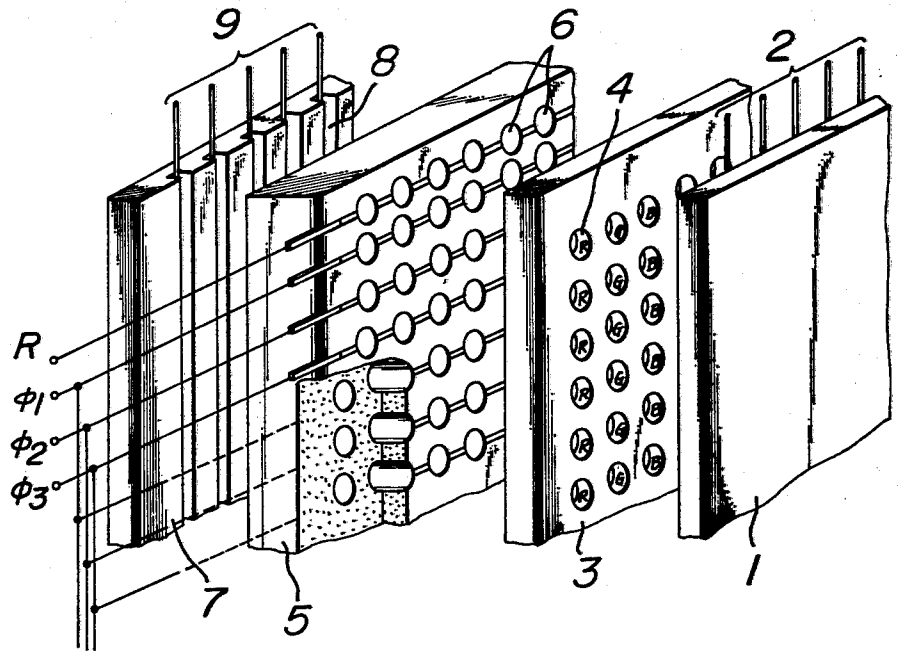


FIG_2

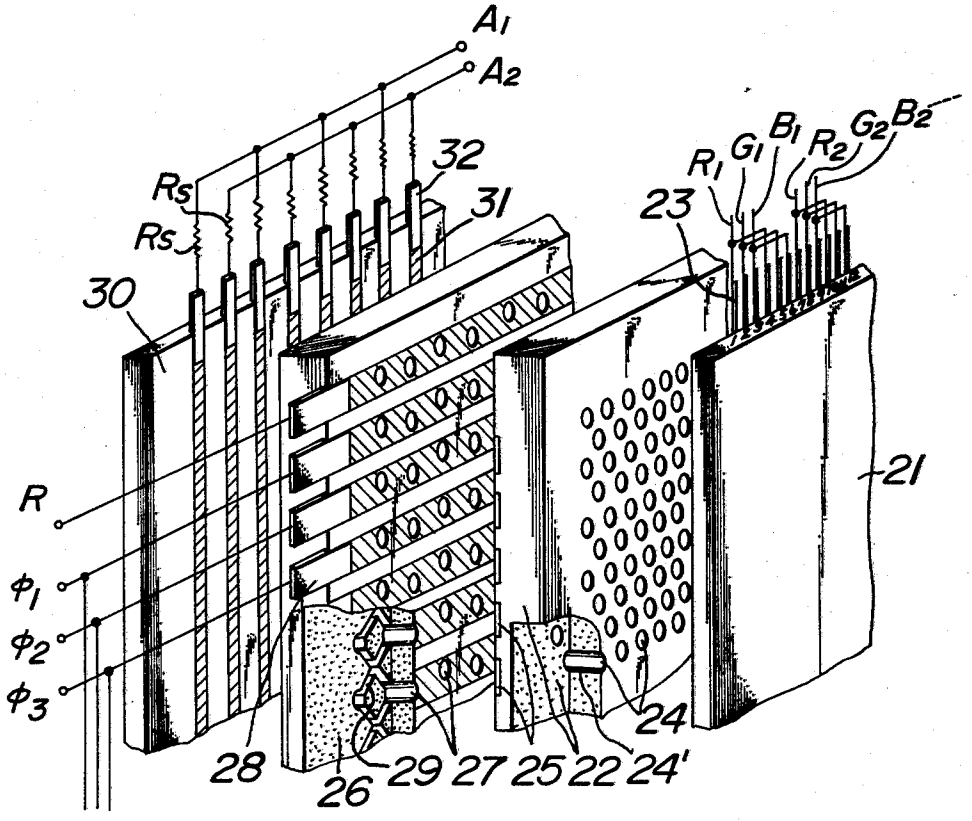


FIG_3

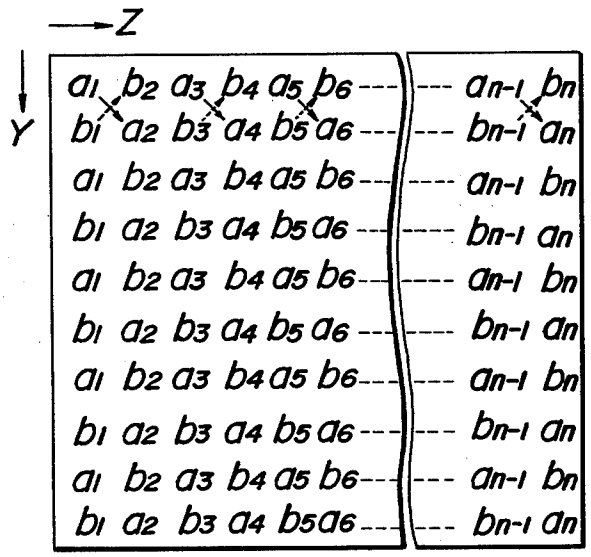

Z
Y
a1 b2 a3 b4 a5 b6 --- --- an-1 bn
b1 a2 b3 a4 b5 a6 --- --- bn-1 an
a1 b2 a3 b4 a5 b6 --- --- an-1 bn
b1 a2 b3 a4 b5 a6 --- --- bn-1 an
a1 b2 a3 b4 a5 b6 --- --- an-1 bn
b1 a2 b3 a4 b5 a6 --- --- bn-1 an
a1 b2 a3 b4 a5 b6 --- --- an-1 bn
b1 a2 b3 a4 b5 a6 --- --- bn-1 an
a1 b2 a3 b4 a5 b6 --- --- an-1 bn
b1 a2 b3 a4 b5 a6 --- --- bn-1 an

FIG_4

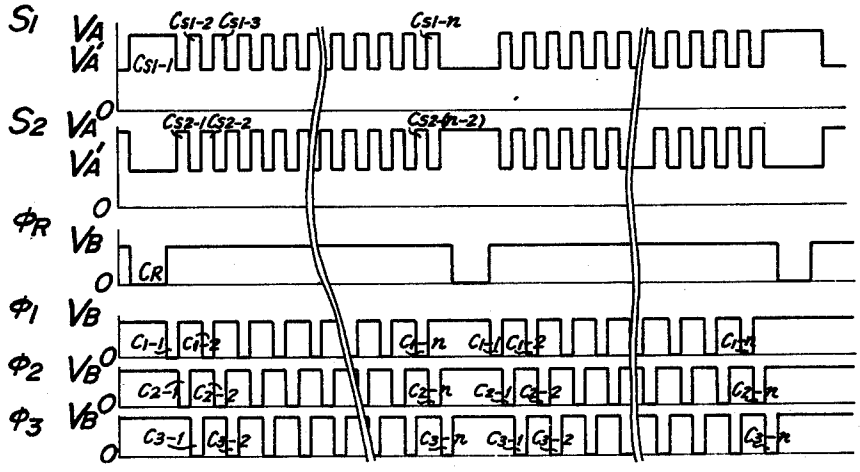

S1
VA
VA'
Cs1-2 Cs1-3
Cs1-n
Cs1-1
S2
VA
0
VA'
Cs2-1 Cs2-2
Cs2-(n-2)
0
ΦR
VB
0
CR
Φ1
VB
C1-1 C1-2
C1-n
Φ2
VB
0
C2-1 C2-2
C2-n
Φ3
VB
0
C3-1 C3-2
C3-n
0

FIG_5

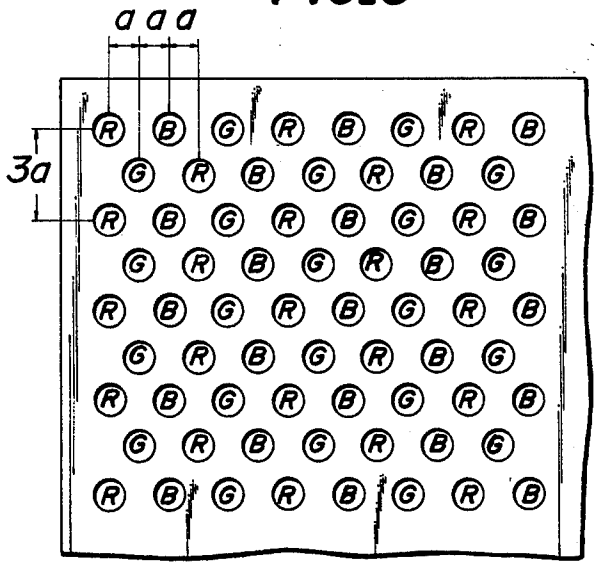


FIG_6

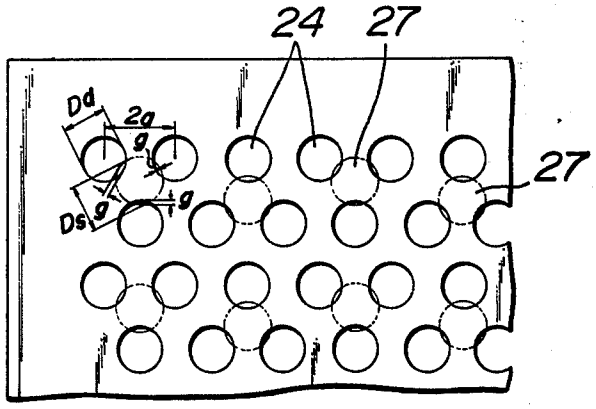


FIG_9

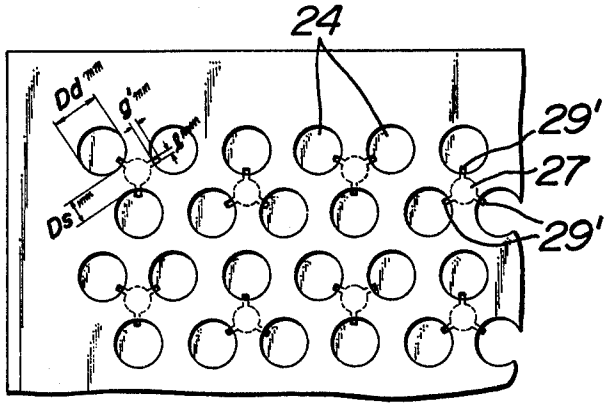


FIG_7a

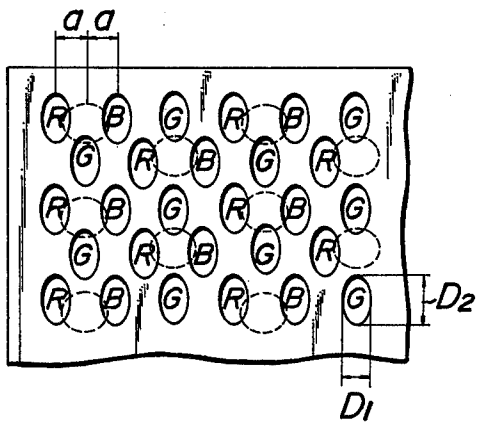


FIG_7b

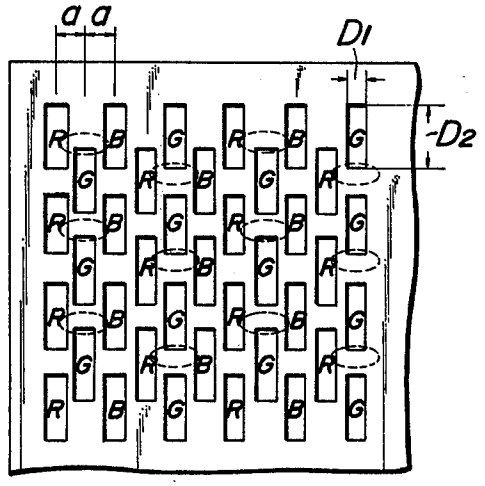


FIG_11

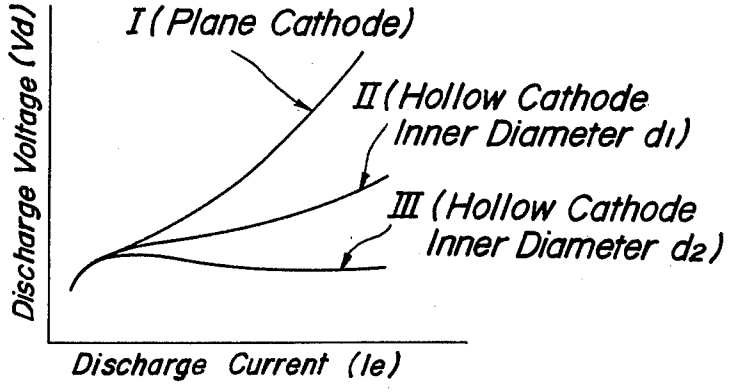


FIG_8

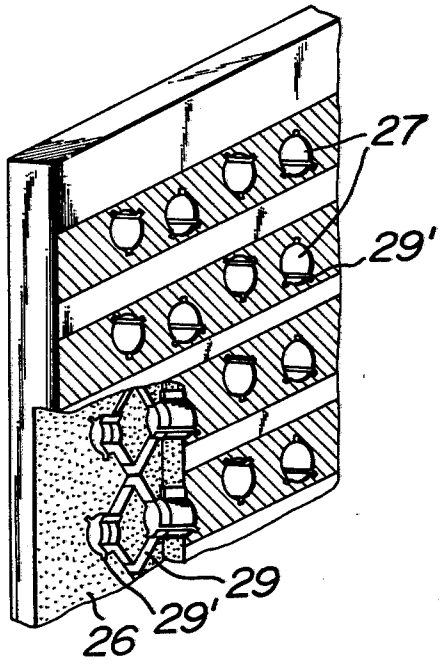
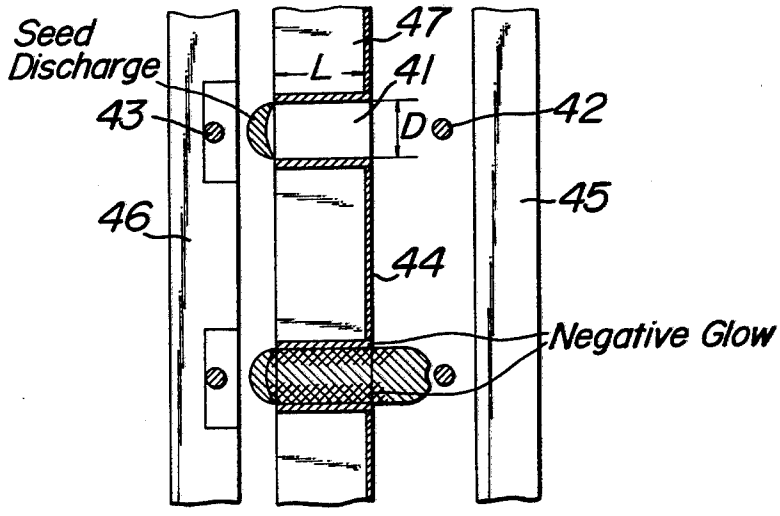

27
29'
29
29'
26

FIG_10


Seed
Discharge
43
46
47
L
41
D
42
45
44
Negative Glow

GAS DISCHARGE DISPLAY PANEL FOR COLOR PICTURE REPRODUCTION

BACKGROUND OF THE INVENTION

The present invention relates to a gas discharge display panel for reproducing color picture, of which panel comprising a display anode and a scanning anode respectively arranged at front and rear side of its cathode so that the cathode is interposed between these two anodes. More particularly, the present invention relates to an improvement of a gas discharge display panel comprising a hollow cathode being suitable for color picture reproduction.

Various types of display panels using gas discharge have been suggested heretofore. A gas discharge display panel of the type comprising discharge electrodes made of conductive stripes arranged on a surface of an insulator plate, such as a glass plate, has a drawback in that it is difficult to obtain a stabilized normal glow discharge in the operation mode of the cathode forming the discharge cell or unit due to its narrow operation surface emitting the electrons. Furthermore, it tends to cause an abnormal glow discharge condition at small discharge current range and as the result the discharge voltage tends to rise so that misoperation of the discharge cell or fluctuation of the same might occur and blackening of inner surface of the panel and loss of the cathode material might result.

Whereas a discharge cell formed by using so-called hollow cathode, which is made from intermediate insulating plate provided with small holes of for instance cylindrical shape and applied with conductive materials at inner wall surface of the holes to form hollow cathode, is suitable for use as a gas discharge display panel for color picture reproduction since it has larger discharge current when compared with its smaller cathode surface and accordingly a higher luminance can be obtained.

For the display of color picture using this type of gas discharge display panel, a known construction as shown in FIG. 1 has been used. In FIG. 1, a front panel 1 made of a transparent insulating material such as a glass is provided with a plurality of display anodes 2 made of stripe or belt shaped conductive body arranged vertically and in parallel on the inner surface thereof. A first intermediate insulating plate 3 made of insulating material such as glass or ceramics is provided adjacent to the front panel 1. The first intermediate insulating plate 3 comprises a plurality of matrix shaped discharge spaces 4 each located at a position oppositely facing to one of the display anodes 2. A second intermediate insulating plate 5 made of insulating materials such as glass or ceramics is arranged next to said first insulting plate 3. The second insulating plate 5 comprises a plurality of holes 6 also arranged in matrix at a location to face one of respective discharge spaces 4. The inner surface of the holes 6 is made conductive and such holes 6 are connected in parallel by conductive stripes in a direction normal to the direction of the display anode 2. The conductive stripes are arranged horizontally in this case. A rear panel 7 made of like insulating material is arranged at the back side of the second intermediate insulating plate 5. The panel 7 is provided with a plurality of slots 8 running in parallel with the display anodes 2 and a plurality of scanning anodes 9 each arranged in the slot 8.

The above-mentioned front panel 1, first intermediate insulating plate 3, second intermediate insulating plate 5 and the rear panel 7 are stacked in this order and are jointed to form a panel. The edges of the stack are sealed and usually a rare gas is filled inside. The panel construction thus formed is excited by applying for instance three phase ac voltage between the scanning anodes 9 and the hollow cathodes 6 to produce gas discharge plasma. The gas discharge plasma is successively transferred along the slots 8 and at the respective transferred positions a seed discharge is formed in front of the hollow cathode 6 to prepare excitation for the discharge between the hollow cathode 6 and the display anode 2. By this seed discharge, a gas discharge between the display anode 2 and the hollow cathode 6 is formed. Namely a gas discharge is formed near the side of the front panel 1. An ultraviolet radiation emitted by the gas discharge near the front panel 1 energizes fluorescent materials R, G, B applied, for instance, on the inner wall surface of the discharge space 4 provided in the first intermediate plate 3 or on the inner surface of the front panel 1 which emit red light, green light, blue light, respectively. The light in the three primary colors thus produced can be seen through the front panel 1. As can be seen from FIG. 1, phosphorescent materials each emitting light in one of the three primary colors are applied at suitable positions of the discharge spaces 4. The three phosphorescent coatings forming a group of the three primary colors are arranged to form one picture element, and a color picture can be reproduced by separately controlling the luminous intensity of each coating.

In color television picture reproduction by using a conventional color television receiver, there is a close relation between the picture quality and the size, pitch, and disposition of the picture elements, and the size of the scanning beam and others. The same relation can be applied to the gas discharge display panel. Therefore, the size, pitch and allocation of the picture elements should carefully be selected so as to obtain an excellent picture quality.

The conventional construction of the gas discharge display panel as shown in FIG. 1 is not satisfactory for use as a display of color picture because of the allocation of the phosphorescent materials of the three primary colors is not suited for the sight of viewers. More particularly, the pitch of one picture element formed by a set of the three primary colors differs nearly three times in the horizontal direction and in the vertical direction which greatly deteriorates the picture quality. Furthermore, if the scanning is to be made under line at a time display system for the groups of picture elements in one line each of which consisting of the three primary colors, the driving circuit arrangement may become very much complicated since each of the hollow cathode 6 and the scanning anode 9 must correspond to one discharge space 4 and the display anode. Also visible irradiation of the scanning side by the gas discharge may directly be seen from the display side and moreover, the ultraviolet irradiation produced by the gas discharge of the scanning side may excite phosphorescent material provided in the discharge space 4 to cause luminescence so that luminance at dark image portion of a picture may increase and which further deteriorates the contrast ratio of the reproduced picture.

SUMMARY OF THE INVENTION

The object of the present invention is to mitigate above-mentioned disadvantages of the conventional gas discharge display panel and is to obtain an excellent construction being able to reproduce a high quality color picture.

Another object of the present invention is to provide a gas discharge display panel using hollow cathodes being able to convey much larger discharge current per unit surface area compared with the conventional display panel so that the luminance of the displayed color picture can materially be increased.

Further object of the present invention is to realize a gas discharge display panel using hollow cathodes being able to operate at a low voltage and thus to display a large size color picture in high efficiency.

Still further object of the present invention is to simplify the construction of the gas discharge display panel for color picture display and to simplify machining of the parts or assembling of the panel so that utilization of the display panel may be improved.

More particularly, the present invention has for its one object to arrange the hollow cathode used in the gas discharge display panel to be suitably dimensioned so that a high luminance gas discharge display picture can be reproduced at low voltage.

The gas discharge display panel using hollow cathodes according to the present invention has a construction in that three discharge units for representing three primary colors red, green, blue and forming one picture element are arranged to couple against one scanning hollow cathode as one set of the units, that the hollow cathode is so arranged to operate partly as a discharge display unit and partly as a scanning unit for initiating the display discharge, and that slots are provided at back side of the intermediate insulating panel provided with the hollow cathode so as to connect said hollow cathodes in order to transmit the scanning discharge and to obtain a definite zigzag shaped interlacing scanning and thus to produce a large size color picture of high quality.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view in detached form of a conventional gas discharge display panel;

FIG. **2** is a detached perspective view of a gas discharge display panel according to the present invention;

FIG. **3** is a diagram for showing the scheme of transition of plasma positions in zigzag form interlaced scanning;

FIG. **4** shows waveform diagrams for showing various driving voltages for effecting said interlaced scanning;

FIG. **5** is a diagram for explaining disposition of red, green, blue units forming one picture element in the display panel according to the present invention;

FIG. **6** is a diagram for explaining relative position between the hollow display cathode and the hollow scanning cathode;

FIG. **7** is a diagram for explaining a different relative positions between said two cathodes;

FIG. **8** is a perspective view showing construction of a hollow scanning cathode provided with slots for supplying seed discharge;

FIG. **9** is an explanatory view for showing relative position of the hollow scanning cathode shown in FIG. **8** and the hollow display cathode;

FIG. **10** is a diagrammatic cross-sectional view of the hollow cathode used in a gas discharge display panel of the present invention; and

FIG. **11** shows characteristic curves for showing discharge current (*Ie*) to discharge voltage (*Vd*) characteristics in comparison between a known discharge cell (I) and two discharge cells according to the present invention (II and III).

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention will now be explained in more detail be referring to the accompanied drawings. One embodiment of the gas discharge display panel for color picture reproduction according to the present invention is shown in FIG. **2** in detached form. Referring to FIG. **2**, the gas discharge display panel comprises a front panel **21** formed by transparent insulating material such as glass and a first intermediate insulating plate **22** made of insulating material such as glass or ceramic. On the inner surface of the front panel **21** a number of display anode stripes **23** are provided in parallel. In the present embodiment the stripes **23** are provided vertically. These stripes **23** may alternatively be provided on the front surface of the first intermediate insulating plate **22.** A great number of small holes **24** are provided in the first intermediate insulating plate **22** in matrix form. The holes **24** and the display anode stripes **23** are arranged to face oppositely each other. On the wall surface of the small holes **24** conductive materials are applied by means of printing, vaporization, metallization or soldering or the like to form hollow display cathode **24'** having front opening. Each two lateral rows of these hollow display cathodes **24'** are connected together by a conductive stripe **25** provided on the back surface of the first intermediate insulating plate **22** in a direction normal to the direction of the display anodes **23.**

The gas discharge display panel further comprises a second intermediate insulating plate **26** made of insulating materials such as glass or ceramics and a rear panel **30** also made of insulating materials such as glass or ceramics. The second intermediate insulating plate **26** comprises a plurality of hollow scanning cathodes **27** each formed by a small hole and provided at a position facing against a set of three hollow display cathodes **24'**. The hollow scanning cathodes **27** are connected by conductive stripes **28** being provided in parallel on the front surface of the second intermediate insulating plate **26** at positions against respective conductive stripes **25** connecting said hollow display cathodes **24** for each two rows. The hollow scanning cathodes **27** are arranged in a form of substantially regular matrix shaped at a pitch corelated to the allocation of the hollow display cathodes **24** as has been described briefly in above and will more fully be described hereinafter. Inner surface of the hole forming the hollow scanning cathode **27** and peripheries of its front opening are coated by conductive material by means of printing, vaporization, metallization or electroplating, etc. The front openings of the scanning cathodes **27** in one column are connected by a conductive stripe **28** as mentioned above. Rear sides of the hollow scanning cathodes **27** are connected together by scanning slots **29**

running curved shaped or zigzag shaped and generally normal to the direction of said conductive stripes **28.** On the front surface of the rear panel **30,** a plurality of scanning anodes **31** are provided in parallel and in a direction normal to the conductive stripes **28** connecting the hollow scanning cathodes **27** by means of printing, vaporization, metallization or electroplating, etc. The scanning anodes **31** are formed in stripe shaped or belt shaped by applying conductive material. To each of the scanning anode **31,** there is provided with connecting wire **32.**

The front panel **21,** the first intermediate insulating plate **22,** the second intermediate insulating plate **26** and the rear panel **30** are stacked together in this sequence to form a united display panel in the same manner as of the conventional type. Peripheries of the panel are sealed air tightly, and rare gas, such as, helium, neon, argon, xenon or the like or mixture with nitrogen or hydrogen thereof is introduced after evacuation. The pressure of the sealed gas is for example several tens to several hundreds Torr and the composition of the sealing gas is so selected as to produce maximum ultraviolet ray irradiation. On the inner surface of the front panel **21,** phosphorescent material is coated at respective positions opposite to the hollow display cathodes.

The allocation of the phosphorescent coating films R, G and B irradiating three primary colors, red, green, blue, respectively, and forming one picture element is selected for instance as shown in FIG. **5.** In this arrangement, each picture element is arranged at location having equidistant pitch both in vertical and in horizontal directions. The phosphorescent film of each color is arranged at a pitch of 3:2 in vertical and in horizontal directions. The relative position of the hollow display cathodes **24,** each of which corresponds to one of a set of three primary color phosphorescent films forming one picture element, against the hollow scanning cathode **27** is as shown in FIG. **6.** Namely, one hollow scanning cathode and three hollow display cathodes are overlapped to form three small through holes *g* which can be observed through the front panel **21.** In other words the three hollow display cathodes **27** forming one set of picture element are arranged in partly overlapping position with a hollow scanning cathode **27** which is provided commonly with the set of three cathodes **27.** The through holes *g* formed by said overlapping portions have been provided under an object to supply the seed discharge produced at the scanning anode side to the display anode side. A particular feature of the panel according to the present invention is the fact that the seed discharge is supplied from one hollow scanning cathode to the three hollow display cathodes simultaneously of which cathodes forming a set of three groups for red, green and blue luminance.

The seed discharge between the sanning anode **31** and the hollow scanning cathode **27** for causing the display discharge moves in zigzag form as shown in FIG. **2** by means of a combination of driving waveforms of scanning anode driving amplifier (not shown) and scanning cathode driving amplifier and also by a combination of scanning slot **29** and adjacent cathode. In this respect, at each location where the seed discharge had been transferred, the respective seed discharge is supplied to the side of hollow display cathode **24** via the respective through holes at the location of superposition for each of red, green and blue luminance as shown in FIG. **6.** The cross-sectional area $Sg\ \overline{mm}^2$ of the portion of one common through hole *g* must be so selected on one hand to be equal to or larger than $\pi/4(15\lambda e)\overline{mm}^2$ for easy establishment of the seed discharge, wherein λe is mean free path of electron in the sealed gas, and on the other hand to be less than one-third of the cross-sectional are $Sd\ \overline{mm}^2$ of the hollow display cathode **24** in order to minimize amount of ultraviolet ray radiation or visible light leaking from the display cathode **27** to the display panel side. If we assume the diameter of the hollow cathode **24** to be D*d*, when the cathode is a circular form, then *Sd* becomes as $Sd = \pi/4Dd^2$.

Under a condition that the seed discharge being supplied to the hollow display cathode **24** through the through holes *g* formed in a manner mentioned as above, and that an output of a display anode driving amplifier being supplied to the display anodes R_1, R_2, . . . R_n; G_1, G_2, . . . G_n; B_1, B_2 . . . B_n, and further that an output of a scanning driving amplifier being supplied to the cathode side, and the electrodes are excited by a combination of the driving waveform, picture elements in one row at positions at intersections between the sets of display anodes having suffixes 1, 2, 3; 4, 5, 6; 7, 8, 9; 10, 11, 12; . . . and respective column of the scanning cathodes are successively selected and scanned in zigzag form. In the succeeding frame, the rest of the picture elements are scanned also zigzag shaped and as the result a color picture of one frame is reproduced.

For example, as shown in FIG. **3,** by a first field scanning a zigzag shaped interlaced scanning in oblique direction with the scanning anodes a_1 to a_n as shown by full line arrows is made and by a successive field scanning the same for scanning anodes b_1 to b_n is made. The scanning will more fully be explained by referring also to FIG. **4,** in which waveforms of various driving voltages are shown. The scanning anodes **31** are divided into two groups as shown in FIG. **2** and the groups are connected to sources A_1 and A_2, respectively. To these groups a pulse wave signal C having binary value V_A and V_A' and having period corresponding to one picture element interval is applied. The voltage V_A in this case is so selected as a necessary value to produce plasma definitely between each of the scanning anode **31** and the scanning cathode **28** when the latter is at zero potential. This voltage V_A is for instance 250 V. On the other hand, the voltage V_A' is so selected as a voltage at which the aforementioned plasma extinguishes and further as a value at which a discharge is not produced between the groups of scanning anodes A_1 and A_2. This value V_A' is for instance 100 V for the value of V_A=250 V. In this manner, by alternatively switching the output voltages of the voltage sources A_1 and A_2 into values V_A and V_A', the discharge points move in a direction normal to the scanning anode, i.e., in Y-direction of FIG. **3.** On the other hand, as shown in FIG. **4,** the respective cathodes **28** are applied with three phase pulse waveform signals synchronized with each other at one picture element spacing and switching successively from three driving voltage sources ϕ_1, ϕ_2 and ϕ_3. By these driving voltages, the discharge points move in the direction of the scanning anodes, i.e., in Z-direction in FIG. **3.** Accordingly, in combination with the abovementioned displacement in Y-direction by the driving voltage sources A_1 and A_2, a zigzag shaped scanning in oblique direction with the

scanning anodes **31** is realized. The value of the pulse waveform voltage V_B applied with the cathodes **28** should be so chosen as to be sufficiently low to turn off the discharge plasma at the scanning anode **31** when the voltage V_A is applied thereto. A pulse waveform signal ϕ_R in FIG. **4** is reset pulse signal applied to a reset cathode R shown in FIG. **2.**

As for the disposition of the respective primary color discharge units in red, green, blue, besides of the embodiment shown in FIG. **5,** it is possible to dispose the respective discharge units at respective summits of a triangle and to arrange the ratio of vertical and horizontal pitches for each discharge unit to be $2\sqrt{3}$:3 or 1.155:1, or to dispose the three discharge units in a relation of vertical to horizontal pitch ratio in 1:4 or 1:2, respectively. The disposition shown in FIG. **5** has equal picture element pitches in vertical and horizontal directions, in which the pitch for both directions is $3a$, and an excellent picture quality is expected if compared with the abovementioned embodiments. In accordance with experiments made by the inventors, it has been confirmed that a most excellent result in the visual view point is obtained when the ratio between an interval in the scanning direction and an interval in a direction normal thereto for each picture element is defined in a range more than 0.87 and less than 1.15.

FIGS. **7***a* and **7***b* show different embodiments being applied minor modification of the configuration of the picture elements. The both arrangements have corresponding vertical and horizontal pitches with those shown in FIG. **5.** FIG. **7***a* shows an embodiment in which each unit coated at inside of the front panel is made in elliptic shape. FIG. **7***b* shows an embodiment in which each unit is made in square shape. The picture quality of these embodiments is equivalent to that shown in FIG. **5** and the size of the picture elements can be enlarged in the direction of the display anodes **23.**

In the foregoing explanation, the gas discharge display panel of the present invention has been described to comprise respective primary color display hollow cathodes **24** of red, green and blue for each scanning hollow cathode **27.** FIG. **8** shows a different embodiment from that shown in FIG. **2.** In the figure, only the second intermediate insulating plate **26** provided with the scanning hollow cathodes **27** is shown separately. In this embodiment, the display hollow cathodes **24** and the scanning hollow cathodes **27** are arranged in a relative position as can be seen from FIG. **9.** In FIGS. **8** and **9,** outwardly projecting grooves **29'** from the cylindrical scanning hollow cathode **27** are provided to form through holes for supplying the seed discharge from the scanning side to the display side. The cross-sectional area $Sg\ \overline{mm}^2$ of the through hole portion in the overlapped area of the hollow cathode between the scanning side and the display side is defined in the same manner with the foregoing embodiment as in the following range.

$$\pi/4(15\lambda e)^2 \leqq Sg \leqq Sd/3 \text{ (or } \pi/4Dd^2)$$

When defining the cross-sectional area of the through hole portion in the overlapped portion of the hollow cathode between the scanning side and the display side, the cross-sectional area of the hollow cathode being a base of such calculation is defined in a line of following consideration both for the scanning side and the display side.

FIG. **10** shows just a schematical cross-sectional view of such hollow cathode used in the gas discharge display panel. By referring to FIG. **10** the operation of the gas discharge display panel and that of the hollow cathode **41** will be explained. Generally, in a gas discharge display panel, a gas such as neon, helium, argon, cripton, xenon, hydrogen, nitrogen or mercury, etc., is sealed inside at a suitable gas pressure for maintaining a stable glow discharge. In the operation, two kinds of phenomena exist in combination. The one of them is to selectively transmit glow discharge to the scanning anode **43** arranged on the rear panel **46** adjacent to the cathode. The other one is to derive the glow discharge produced between the cathode **41** and the scanning anode **43** to the side of the display anode **42** arranged on the front panel **45** in accordance with the signal to be displayed and to obtain the display by causing the luminant discharge.

In the self-scanning type gas discharge display panel as shown in FIGS. **1** and **2,** at first the reset cathode R is earthed for a period for providing an ignition discharge thereof, then the cathode is earthed at a certain period corresponding to phase ϕ_1 and the reset cathode R is returned to the potential of voltage value $+V_B$. In this situation, the cathode in phase ϕ_1 located adjacent to the reset cathode R discharges at top priority and the glow discharge is transferred from the reset cathode R to the cathode in phase ϕ_1. During the period in which the discharge is maintained at the cathode of phase ϕ_1, the other cathodes will not cause discharge due to voltage drop by the discharge current so that the discharge is not transferred. At the next period cathode in phase ϕ_2 is earthed and phase ϕ_1 cathode is returned to the potential $+V_B$ and under the same selective condition as mentioned above, the glow discharge is now transferred to the cathode in phase ϕ_2. In the same manner, the successive cathode in phase ϕ_3 and so on will be earthed successively and the glow discharge will be transferred in turn.

The brightness obtained by the luminous discharge in the gas discharge display panel has been confirmed to increase in proportion to an increase of the discharge current. When the cathode is formed by a conductor stripe, only a weak discharge current can be supplied due to its small working surface and it may require to operate the discharge cell in a range of abnormal glow if a practical high brightness is desired. But in this case, as mentioned above, an inconvenience might occur by the increase of the discharge voltage, for instance, to cause an erroneous discharge to an adjacent discharge cell.

The cathode need not be made in plate shape as has been explained in the foregoing. As shown in FIG. **10,** an intermediate plate **47** is provided with regularly arranged matrix holes. The inner side of the holes may be coated with conductive materials, such as for instance, gold, platinum, nickel, iron, cobalt, molybdenum, tin, aluminum or iron-nickel alloy to form hollow cathodes **41.** A plurality of such hollow cathodes **41** are connected together by means of a conductive film **44** so as to form the cathode groups. The size of the hollow cathode **41** of this embodiment can be decided by the following manner.

Usually a gas discharge display panel operates in a normal glow discharge condition depending upon a certain pressure of the sealed gas and the current density J_K at the cathode surface is maintained constant. In

this condition, the current density J_K dominates the space charge density of the cathode dark space or the Crookes dark space located in front of the cathode. The mean number of collision between electrons and molecules in the cathode dark space under this condition is equal to $d/\lambda e$, wherein d is the thickness of the cathode dark space and λe is the mean free path of electrons. The value of $d/\lambda e$ is about 9 to 24. On the other hand, it is known that in case of such a cylindrical hollow cathode **41**, the best hollow cathode discharge effect or hollow effect can be obtained under the condition of $D=2d$, wherein D is the inner diameter of the cylindrical electrode **41** by taking into account the front portion of the cathode during the discharge condition. This condition $D=2d$ corresponds to a case in which the negative glow discharges produced along the inner surface of the hollow cylindrical cathode unit together as can be seen from FIG. **10.** In other words, it is possible to lower the discharge maintaining voltage and to increase the cathode current under this condition. Therefore by realizing this condition, it is possible to increase the brightness of the picture to be displayed and to decrease blackening of the panel.

The inventors of the present application had carried an extensive experiments for clarifying these phenomena by sealing neon gas in an experimental discharge panel provided with hollow cylindrical cathodes. The inventors had found that a remarkable hollow effect can be obtained under the following condition.

$D=(1-10)d$ or $D/\lambda e=(1-10)d/\lambda e$ and $2 < D/L < 15$

wherein,

D is the inner diameter of the hollow cathode **41**

L is the length of the hollow cathode **41**

By another experiments for varying the kind of sealing gases and the gas pressure, it has been found that a hollow cathode suitable for use as a gas discharge display panel can be realized under the following condition.

$$15 < D/\lambda e < 150$$

$$2 < D/L < 15$$

wherein,

λe is the means free path of an electron,

D is the inner diameter of the hollow electrode,

L is the length of the electrode.

The size of the hollow cathode in the gas discharge display panel according to the present invention is basically decided by the above equations based on the various experiments.

A comparison for discharge voltage to discharge current characteristics between gas discharge display panels according to the present invention and a conventional gas discharge display panel comprising a plate cathode is shown in FIG. **11.** In FIG. **11,** curve I represents a characteristic curve of a conventional panel having a plate cathode in which the discharge voltage Vd shows a remarkable increase according to an increase of the discharge current Ie. Curve II shows a characteristic curve of a display panel according to the present invention having hollow cathodes of inner diameter d_1 and curve III shows that of further embodiment of the present invention in which said inner diameter is d_2. As can be seen from the curves II and III, the display panels of the present invention show a very little increase of the discharge voltage Vd. More especially in the embodiment having the diameter d_2 shown in curve III shows an excellent characteristic in which the discharge voltage Vd is substantially constant at an increase of the discharge current Ie.

In case of the respective primary color discharge units are arranged in a shape as shown in FIG. **7,** the oblong formed hollow scanning cathode shown by dotted line or one as shown by **27** in FIG. **9** which comprises **3** projected corners may be used. The cross-sectional area of the abovementioned through holes g where the cross-section is not a circle can be defined in substantially same manner with that mentioned in the above. In this case, the cross-section of a hollow cathode is substituted in calculation with a circle having the same surface area. If the hollow cathode is formed in a frustconical shape in order to enlarge the area of phosphorescent film excited by the ultraviolet irradiation produced by the discharge plasma or to enlarge the apparent area of the phosphorescent coating viewed from the front side, the cross-sectional area of the through hole portion should be calculated against an effective area of the hollow cathode at as intersection of the scanning side and the display side of the hollow cathode.

The gas discharge display panel for color picture reproduction according to the present invention can realize a high fill factor arrangement of the primary color picture elements and is able to reproduce a high definition color picture. On the other hand, the panel, especially in the embodiments showns in FIG. *7a* or *7b*, which comprises oblong or elongated primary color discharge units closely arranged together at a very high fill factor, has at the same time a certain danger to cause erroneous discharge between a scanning hollow cathode and adjacent primary color discharge unit through gaps between intermediate insulating plates so as to result a cross-talk.

In order to avoid such malfunction in the gas discharge display panel according to the present invention, the whole area between layers where such erroneous discharge might cause, for instance, between the two intermediate insulating layers may be sealed except the portion forming the discharge path instead of sealing only the peripheries of the stacked layers forming a display panel. By such whole area sealing, the cross-talk due to erroneous discharge can be prevented. In case of insulating layers are made of glass, thin flit glass may be coated on the whole surface between such layers and the layers may be pressed together while heating.

As has been mentioned above, the gas discharge display panel according to the present invention is formed to operate the hollow cathode separately for the scanning anode side and for the display anode side. One scanning hollow cathode is combined with a set of display hollow cathodes. The seed discharge produced by one plasma occurring between a pair of discharge electrodes consisting of a scanning anode and a scanning cathode is divided so as to supply the excitation energy to the plurality of display anodes. Furthermore, the holes which supply the seed discharge from the scanning anode side to the display anode side are formed by very small through holes only to be viewed through by the viewer. Therefore the major portions of the hole are not throughly overlapped.

In the gas discharge display panel according to the present invention, the vertical and horizontal pitches of each primary color picture element for displaying the

three primary colors can more freely be selected in a suitable ratio if compared with the gas discharge display panel of the conventional type. Further it affords an improvement in the construction of the scanning hollow cathode itself and the arrangement of combination for the scanning hollow cathode and the display hollow cathode. Thus the display panel according to the present invention has an advantage to be able to display an excellent picture at a high contrast ratio in color. In the gas discharge display panel according to the present invention, one scanning hollow cathode is arranged oppositely with a set of three display hollow cathodes for reproducing the three primary colors so that the arrangement and construction of the scanning hollow cathodes becomes much more simpler if compared with the conventional arrangement, which may afford many practical advantages.

What we claim is:

1. A gas discharge display panel comprising in combination;

a front panel formed by transparent insulating material,

a first intermediate insulating plate provided with a plurality of picture elements arranged in matrix shape, in which each picture element is formed by a set of three display discharge units for displaying three primary colors, red, green and blue, respectively, and each of the display discharge unit comprises a hollow display cathode,

a number of display anode stripes extended in parallel and provided between the front panel and the first intermediate insulating plate, in which the display anode stripes are formed in groups for respective primary colors and each stripe being provided at a location to establish registration with respective row of said display discharge units for reproducing corresponding primary color,

a second intermediate insulating plate provided with a plurality of hollow scanning cathodes, in which each hollow scanning cathode is provided at a position facing against said set of hollow display cathodes representing a picture element and each column of the hollow scanning cathodes are connected by a conductive stripe,

a rear panel made of insulating material, and

a plurality of scanning anodes provided in parallel on the rear panel in a direction normal to said conductive stripes,

wherein the set of the hollow display cathodes and the hollow scanning cathode are so arranged as to overlap at through holes having small cross-sectional area so that a scanning discharge produced between the scanning cathode and the scanning anode can easily be transferred to the hollow display cathode forming the display discharge unit together with the display anode in a manner that the scanning discharge will not give substantial influence to a viewer located at the front panel side.

2. A gas discharge display panel according to claim **1**, wherein the display anode stripes are provided on inner surface of the front panel.

3. A gas discharge display panel according to claim **1**, wherein the display anode stripes are provided on front surface of the first intermediate insulating plate.

4. A gas discharge display panel according to claim **1**, wherein the hollow scanning cathodes are connected at part of its rear side by slots provided in said second intermediate insulating panel.

5. A gas discharge display panel according to claim **1**, wherein a cross-section of the scanning hollow cathode shows three outwardly projecting grooves and each groove overlaps with one of the hollow display cathode in its cross-section to form a through hole.

6. A gas discharge display panel according to claim **5**, wherein cross-sectional area Sg of the through holes of a hollow scanning cathode is selected with respect to mean free path of electron of sealed gas and cross-sectional area Sd of the hollow display cathode in a range of following equation,

$$\pi/4(15\lambda e)^2 \leqq Sg \leqq (Sd/3).$$

7. A gas discharge display panel according to claim **5**, wherein the cross-sectional area Sd of the hollow display cathode and length L of the same are selected with respect to diameter D of a circle having corresponding area Sd and with the electron mean free path λe in a range defined by the following equation,

$$15 < D/\lambda e < 150 \text{ and}$$

$$2 < D/L < 15.$$

8. A gas discharge display panel according to claim **1**, wherein said sets of hollow display cathodes are arranged in lateral to vertical pitch ratio between 0.87 to 1.15.

9. A gas discharge display panel according to claim **8**, wherein said hollow display cathodes are made in a form selected from circle, oblong circle, elongated square shape and being made in substantially same cross-sectional area.

10. A gas discharge display panel according to claim **9**, wherein said hollow scanning cathodes are obliquely connected in a group corresponding to even number row by said slot so as to cause zigzag shaped interlaced scanning.

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