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[54] **METHOD OF FABRICATING A GAS DISCHARGE DISPLAY DEVICE HAVING AN ALKALI METAL ATOMIC LAYER**

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[58] **Field of Search** .... 316/3, 4, 5, 6, 7, 8, 9, 316/11, 12, 17, 19, 20, 24, 18; 313/182, 210, 188; 315/169 R; 117/225

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[57] **ABSTRACT**

A pair of insulating substrates, at least one of which provides a group of electrodes on the inside surface, are positioned in spaced parallel relation having inside surfaces opposite each other with a gap filled with ionizable gas. The surface of the group of electrodes is covered with a dielectric layer, and this dielectric layer is covered with a material having a high secondary electron emissivity by introducing a fluid which includes alkali metal into the above-mentioned gap. Further, the dielectric layer is composed of a material having small activity with alkali metal.

2 Claims, 5 Drawing Figures

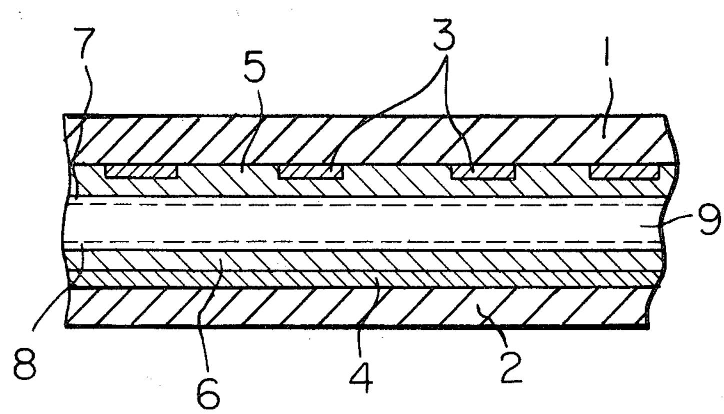


Fig. 1

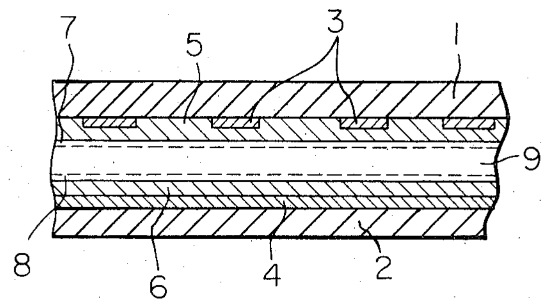


Fig. 1A

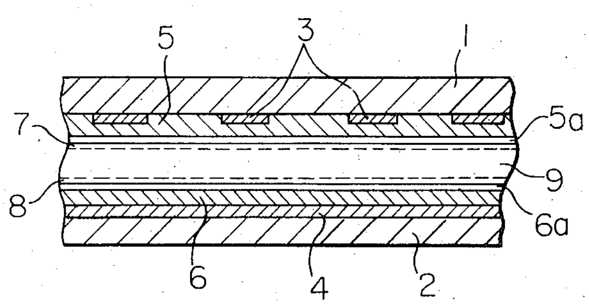


Fig. 3

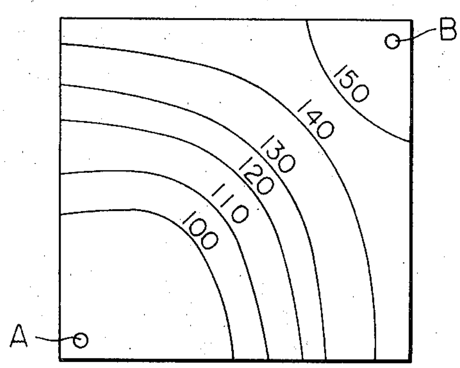


Fig. 4

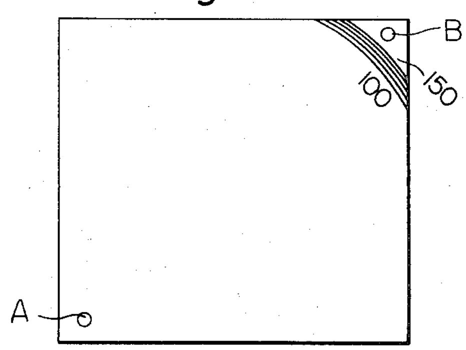
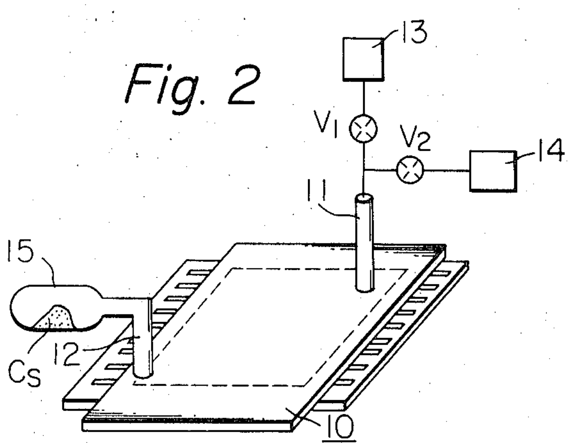


Fig. 2



METHOD OF FABRICATING A GAS DISCHARGE DISPLAY DEVICE HAVING AN ALKALI METAL ATOMIC LAYER

The present invention relates to a display device utilizing gas discharge known as a plasma display panel, and the method for manufacturing the same. More particularly, this invention relates to a novel display device utilizing gas discharge, which is improved so as to discharge with a relatively low firing voltage.

One of the characteristics features of such a plasma display panel is the fact that the electrodes for gas discharge are insulated from the gas cell. This display device can thus effect a memory function and has a great range of application. However, because the driving voltage for this device is too high for some applications which can be considered, it becomes necessary to decrease the firing voltage of this kind of device.

Generally, in the above-mentioned plasma display panel, the voltage applied to the electrodes is divided into a voltage across the dielectric layers and a voltage across the gas cell medium. When the voltage across the gas cell medium becomes larger than the minimum voltage which can produce a discharge in the gas cell medium (this minimum voltage is hereinafter called the firing voltage V_f), a gas discharge is produced in the gaseous medium. The main factors determining the firing voltage in the plasma display panel are the composition of ionizable gas, and the dielectric layer which covers the electrodes. With regard to the former factor, every possible known means have already been tried and a decrease of the firing voltage by improving the composition of ionizable gas, cannot be anticipated. With respect to the latter factor, various improvements have been tried, and a recent device using a low melting temperature glass can operate with a voltage of 250 – 300 volts. However, the conventional device using a glass seat requires 300 – 700 volts for its operation.

When we assume that the composition of gas in the gaseous medium is constant, the main factors determining the firing voltage (V_f) are (*a*) the product of the pressure of the gas and the length of the discharge gap and (b) the secondary electron emissivity (γ) on the surface of the dielectric layer. And when this secondary electron emissivity (γ) on the surface of the dielectric layer increases, the firing voltage (V_f) decreases.

Accordingly, a material having a high dielectric constant and at the same time a large secondary electron emissivity is recommended as the dielectric layer covering the electrodes. This dielectric layer requires excellent characteristics in its softening temperature, fluidity, mutual diffusion characteristics with the electrode material, its thermal expansion, thermal resistivity, and optical transparency. Some type of low melting temperature glass was used conventionally, because such glass satisfied the above-mentioned characteristics. As a result of this, the firing voltage of the display device, using such low melting temperature glass, could be decreased to about 250 – 300 V. The reason for this decrease of the firing voltage in a device using low melting temperature glass is that the large lead (Pb) component included in such glass presents a relatively high secondary electron emissivity.

However, the above-mentioned improvement, concerning the decrease of the firing voltage, does not satisfy the newest requirement. That is, an integrated circuit technique introduced in the driving circuit requires that the display device utilizing gas discharge operate at a lower voltage than that mentioned above.

As noted above, it has been confirmed that the utilization of glass having a high secondary emissivity can decrease the firing voltage of the display device utilizing gas discharge.

It is realized that the alkali component of the low melting temperature glass, used as the dielectric layer, is an important factor. However, when the component of alkali metal is increased the thermal expansion coefficient increases. And then the difference in the expansion coefficient between a substrate and a dielectric layer including alkali-metal increases, the mechanical and electrical characteristics of the displaying device deteriorate.

The present invention provides a means for forming an element which raises the secondary electron emissivity on the dielectric layer without the above-mentioned drawback. That is, a sufficient amount of this element, which raises the secondary electron emissivity, is formed on the surface of the dielectric layer and decreases toward the inside of the dielectric layer. As a result of this, the firing voltage of the display device can be considerably decreased and the drawback, due to the difference in the expansion coefficient between the substrate and the dielectric layer, can be completely overcome.

In the fabrication of the plasma display panel, the substrates are first prepared. A group of electrodes are then disposed on the substrates and then the dielectric layers are provided so as to cover the electrodes. Two substrates thus fabricated are assembled on each other so that the di-electric layers face each other with a small gap between them, and the peripheral portions of these panels are sealed hermetically. This hermetic sealing must be carried out in the air at a temperature of about 400°C. The element which raises the secondary electron emissivity, for example alkali metal, has a strong chemical activity and reacts with oxygen in the air which results in the deterioration of its secondary electron emissivity. Accordingly, the treatment of a dielectric layer composed of an alkali metal and the assembly of the panel must be carried out in a vacuum or in a non reactive gas. This, of course, complicates the manufacturing process and the cost of the manufacturing equipment becomes high. Further, the qualities of some kinds of material require that the assembly and the sealing be carried out in the air, which would eliminate the possibility of forming alkali metal layers.

Accordingly, one object of the present invention is to provide a display device utilizing gas discharge, which is preferable to the demand of decreasing the firing voltage, and a method for fabricating the same.

Another object of the present invention is to provide a display device, utilizing gas discharge, wherein the dielectric material used for covering the electrodes of the display device is improved and the method for fabricating the same.

A further object of the present invention is to provide a display device, utilizing gas discharge, which is operable at a firing voltage lower than 100 volts, and a method for fabricating the same.

One characteristic of the present invention is that a pair of substrates, providing the dielectric layer which covers the electrodes, are disposed face to face with a very small gap between them; the peripheral portion of the substrates is sealed; a fluid, which includes alkali metal for raising the secondary electron emissivity, is introduced in a gaseous or liquid state into the above-mentioned gap, and thus the surface treatment of the dielectric layer is carried out. With this fabricating method, an alkali metal layer can be easily formed and the firing voltage can be considerably decreased.

Another characteristic of the present invention is that an alkali metal atomic layer, for example cesium, having a thickness of less than 100 A is formed on the gas discharge surface of the dielectric layer which covers the electrode. A gas discharge panel is completed in such a manner that the alkali metal layer is exposed to the ionizable gas medium.

A further characteristic of the present invention is that a material is used which has very little reactive activity with the alkali metal, which raises the secondary electron emissivity. When the area of the display panel increases, it is very difficult to introduce and deposit the alkali metal vapour via the small gap between the surface of the dielectric layers of the panel. This is due to the strong activity of the alkali metal. Namely, the alkali metal near the inlet of the vapour rapidly reacts with the dielectric layer and is absorbed near the inlet. Consequently, the amount of the alkali metal which diffuses over the dielectric layer farther from the inlet becomes insufficient and the raising of the secondary electron emissivity can not be anticipated near the exhaust point. It is believed that decreasing the temperature of the treatment will slow the reaction with the dielectric layer. However, this is not practical because it also decreases the vapour pressure of the metal element and, therefore, increases the time required for a sufficient deposit to accumulate. This problem can be solved by forming the dielectric layer with materials, such as soda-lime glass, almina, or a silicon compound, which have small activity with the alkali metal. Thus, the alkali metal vapour can easily diffuse homogeneously all over the small gap of the sealed panel, repeating the collision and the re-evaporation with the surface of the dielectric layer, and can form the layer having the secondary electron emissivity.

A still further feature of the present invention is that it is proposed to form a second dielectric layer from material which has small activity with the element forming the secondary electron emission layer on the dielectric layer. After coating the surface of the dielectric layer with the second dielectric layer of a thin film, for example of almina or silica, and mounting and sealing the panel, the vapour of alkali metal is introduced into the gap between the second dielectric layers. By this treatment, a surface having a uniform secondary electron emissivity can be obtained even in a panel having a large area. Thus the plasma display panel will have a uniform firing voltage. An additional characteristic of this method, is the low melting temperature of glass, which has easy workability and can be used as the material of the first dielectric layer.

An important feature in the method of fabricating the plasma display device of the present invention is that the fluid which includes the alkali metal element is introduced into the small gap between the dielectric layers of the panel, the mounting of which is completed by sealing. At this juncture, inlet and exhaust tubes can then be utilized for the purposes of introduction and the exhaustion of the discharge gas. By this method, the alkali metal is insulated from the atmosphere and a better surface treatment for raising the secondary electron emissivity can be achieved. Further, the alkali metal distributes itself with high density onto the surface of the dielectric layer and the density of the alkali metal decreases toward the interior of the dielectric layer. Consequently, the effect due to the increase of the heat expansion coefficient, based on the high density of the alkali metal, can be decreased.

Further features and advantages of the present invention will be apparent from the ensuing description, with reference to the accompanying drawings to which, however, the scope of the invention is in no way limited.

FIGS. **1** and **1A** are partial cross-sectional views of two embodiments of a display device, utilizing gas discharge, of the present invention;

FIG. **2** is a schematic diagram explaining the method of manufacturing the display device of the present invention;

FIGS. **3** and **4** are graphic presentations showing the distribution of the firing voltage of the display device of the present invention.

Referring to FIG. **1**, a pair of glass substrates, **1** and **2**, provide respectively groups of column electrodes **3** and row electrodes **4** on the inside of their surfaces. The plurality of parallel electrodes **3** and **4** are composed of gold or oxide tin and are transversally positioned relative to each other. Dielectric layers **5** and **6** are provided on the surfaces of the above-mentioned electrodes. Dielectric layers **5** and **6** are composed of almina or silicon compound and the thickness of said dielectric layers are limited to $0.1 - 20\mu$. On the surface of dielectric layers **5** and **6**, alkali metal atomic layers **7** and **8**, particularly cesium atomic layers less than 100 A, are disposed. A gaseous medium **9** is composed between the above-mentioned alkali metal atomic layers **7** and **8.** When the electrical signals are selectively supplied to some of the above-mentioned electrodes, pulsive glow discharges are produced at the crossing portions between the electrodes **3** and **4,** and these glow discharges are maintained by alternate sustaining voltages.

Replacing the low melting temperature glass used in the conventional dielectric layer, almina, silicon dioxide or silicon nitride are preferably used as the material of dielectric layers **5** and **6.** The reason for this is understood on the assumption that alkali metal atomic layers **7** and **8** are disposed on dielectric layers **5** and **6.** The display device utilizing gas discharge with the dielectric layer including only almina, clearly requires a firing voltage higher than that of the usual display device with a dielectric layer of low melting temperature glass. However, when a thin atomic layer, for example Cs is disposed homogeneously on the surface of the dielectric layer of almina, the firing voltage of said dielectric layer decreases to about 80 V, which is a wonderful value. Generally, it is very difficult to dispose an atomic layer such as Cs on the low melting temperature glass. This is because the lead (Pb) component included in the low melting temperature glass is very reactive to the cesium (Cs) in the atomic layer. However, since the almina or silicon compound used in the present invention has only small reactivity with the alkali metal, particularly Cs, the alkali metal atom layer can be disposed on the surface of the dielectric layer even after assembling the display device. Many other materials could be considered for the insulating material. However, the above-mentioned almina, silicon dioxide or silicon nitride are the most preferable materials because they satisfy all the demands of manufacturing technology, expansion coefficient, thermal flow properties and dielectric constant; can withstand voltage etc., and fits to the alkali metals.

It is preferable to make the dielectric layers **5** and **6** thin, so as to decrease the unuseful voltage participated thereon. However, using the materials in the present application, when the dielectric layers **5** and **6** become less than 0.1μ, there is a possibility of producing a dielectric breakdown. When the thickness of the dielectric layers **5** and **6** exceed 20μ, the firing voltage increases, the construction of the surface of the dielectric layer becomes complex and the manufacturing technology becomes difficult. Accordingly, it is preferable to limit the thickness of the dielectric layers to a value between 0.1 – 20μ.

Alkali metal atomic layers **7** and **8** should not decrease the surface resistance of the dielectric layers **5** and **6.** To maintain the memory function obtained by the wall charge, in this kind of display device, the wall surface exposed to gaseous medium **9** should have a high insulation resistance whether alkali metal atomic layers **7** and **8** exist or not. According to the present invention, the thickness of the above-mentioned alkali metal atomic layers **7** and **8** are maintained at less than 100 A. A high secondary electron emissivity is, therefore, obtained on the wall surface, thus maintaining the surface resistance of the wall surface in the best condition. This is due to the fact that, when the alkali atomic layers are maintained at less than 100 A, a discontinuous condition appears on the layer and they become non conductive to the surface direction.

According to another embodiment of the present invention, shown in FIG. **1**A, it is proposed to previously form second dielectric layers, *5a* and *6a*, on the dielectric layers **5** and **6** when layers **5** and **6** are composed of low melting temperature glass. The second dielectric layers, *5a* and *6a*, are composed of a material, such as almina or silica, which have a low reactivity with the alkali metal. These second dielectric layers are coated with the above-mentioned alkali metal layers having a homogeneous and high secondary emissivity over a wide range.

The next explanation will concern a preferable method for manufacturing the display device utilizing gas discharge.

Referring to FIG. **1**, the groups of electrodes **3** and **4** are first formed by using a well-known method, for example, a vacuum evaporating coating of gold or screen printing method. Then the dielectric layers **5** and **6**, composed of silicon compound or almina, are provided, except for the portions connected to its terminals, by using a sputtering means. After that the substrates **1** and **2** are disposed face to face with a gap of about 300μ therebetween, and the peripheral portion of the substrates is sealed with the low melting temperature glass. Next, tip tubes **11** and **12**, which are connected to the above-mentioned air gap, are provided for forming the alkali metal atomic layers as shown in FIG. **2.** Tip tubes **11** and **12** are connected to two corner portions on panel **10.** Tip tube **11** is connected, via valves V_1 and V_2 respectively, to an exhaust device **13** and a gas supply device **14.** Tip tube **12** is connected to a vessel **15** reserving, for example, cesium (Cs). In the system connected as shown in FIG. **2**, the gap **9** of panel **10** is exhausted to about 10^{-6} Torr and the entire panel **10** is heated to 100° – 300°C.

Then, operating exhaust device **13**, another heater not shown in the figure heats vessel **15**, reserving cesium (Cs), and the cesium reserved in vessel **15** is evaporated. After this the cesium vapour penetrates to the above-mentioned gap **9** and deposits on dielectric layers **5** and **6**, which are preheated. By continuing the above-mentioned process over a period of one to several hours, thin cesium atomic layer are obtained over all the surface. After finishing this process, valve V_1, connected to exhaust device **13**, is closed, and then valve V_2, provided for introducing ionizable gas, is opened. After adjusting the gas pressure in gap **9**, tip tube **11** is sealed and cut and the device **10** is completed.

The display device, utilizing gas discharge, which is fabricated by the above-mentioned method operates at a voltage lower than 100 V. For example, we fabricated the panel by substrates disposed almina layer having the thickness of about 3μ, for covering the electrodes, preheated to 130°C while exhausting, heated the cesium vessel to 150°C, carried out the abovementioned process for 5 hours, and obtained the cesium atomic layers having a thickness less than 100 A on the almina layers. We then completed the display device by using the above-mentioned panel. This completed display device could discharge at a firing voltage of 80 V $\pm$ **10** V over all portions which the the cells at crossing points between the column and row electrodes included in a display area of about 10 cm × 10 cm, and no inconvenience was found in its memory function. This reason is that the alkali metal atomic layer, particularly the cesium atomic layer, of the present invention is diffused homogeneously over all the dielectric layer, and enhances the secondary electron emissivity of the surface.

In another embodiment of the present invention, the secondary electron emission layer are formed by introducing the liquid which includes the alkali metal element. Alkali, for example, makes a liquid compound which is not reactive to the dielectric layer at ordinary temperature; can be introduced to the gap which is composed between the dielectric layers of the panel after mounting; is reberated by the heat treatment; and allows formation of the secondary electron emission layers on the surfaces of the dielectric layers. For example, a solution of alkali-metal alcoholate in alcohol is introduced into the panel, then the solvent is removed out of the panel and a homogeneous layer of alcoholate is formed on the surfaces. After decomposition by heating, homogeneous secondary electron emission layers of alkali metal can be obtained. When this occurs the by-product of the heat decomposition is exhausted as a hydrocarbon. By using the above-mentioned method, the material forming the secondary electron emission layers can be previously distributed on the surface of the dielectric layer.

In the above-mentioned device, alkali metal is used as a substance forming the secondary electron emission layers. The other material, such as alkali earth metal and lead (Pb), can also be used as the substance forming the secondary electron emission layers.

As mentioned above, the method for fabricating the plasma display device of the present invention comprises the process of forming a layer having a high secondary electron emissivity on the dielectric layer. This is done by introducing the fluid, in liquid including alkali metal into the panel after assembling. We will now compare the distribution of the firing voltage of a panel having dielectric layer composed of low melting temperature glass with that of almina.

FIG. 3 is a diagram showing the distribution of the equi-firing voltage curves when the above-mentioned process is performed directly on the dielectric layer composed of low melting temperature glass. Referring to FIG. 3, the inlet of the alkali metal is shown as A and the exhaust is shown as B.

FIG. 3 shows that the firing voltage decreases by forming the secondary electron emission layer of the present invention. That is, when the secondary electron emission layer is not formed, a firing voltage greater than 150 V is required all over the panel surface. When the secondary electron emission layer exists, the firing voltage can be decreased, to less than 100 V, near the cesium gas inlets. The phenomena shown in FIG. 3 is applicable to a panel having a relatively small area. However, in a large area panel having the dielectric layer of low melting temperature glass which easily absorbs the cesium, it is very difficult to homogeneously decrease the firing voltage all over the surface. Then, as mentioned above, the second dielectric layers are provided, as shown in FIG. 1A. FIG. 4 shows the distribution of the equi-firing voltage in the case of providing the second dielectric layer. When the second dielectric layer is provided, the decrease of the firing voltage is realized homogeneously at 80 – 90 V all over the surface, as shown in FIG. 4. The portion having a variation of the firing voltage is limited to that near the outlet, which is not used as a display portion.

According to the present invention, the firing voltage can be decreased by 50 – 60% by forming the secondary electron emission layers. Further a homogeneous decrease of the firing voltage can be realized all over a large area surface by providing the second dielectric layer on the surface of the first.

As mentioned above, the present invention relates to a display device, utilizing gas discharge, whose firing voltage can be surprisingly decreased, and the method for fabricating the same. A firing voltage lower than 100 V can at low cost of device be used as the driving circuit through an integrated circuit. It, therefore, develops the field of application of this kind of display device. Application of the methods used is not limited to above-mentioned device. Rather they can be applied to any display device in which groups of gas discharge electrodes are disposed in a condition insulated from the ionizable gas medium.

What is claimed is:

1. A method for fabricating a display device utilizing gas discharge comprising the steps of:
   - forming a pair of insulating substrates, at least one of which providing a group of electrodes on an inside surface;
   - coating a dielectric substance on said group of electrodes;
   - forming a panel by positioning said pair of insulating substrates in spaced parallel relation having inside surfaces opposite each other with a gap therebetween;
   - forming an hermetic seal at a periphery of said panel;
   - exhausting said gap;
   - introducing a gas including an alkali metal element into said gap while said panel is heated to form an alkali metal atomic layer on said dielectric substance; and,
   - filling said gap with an ionizable gas.

2. A method for fabricating a display device utilizing gas discharge comprising the steps of:
   - forming a pair of insulating substrates, at least one of which providing a group of electrodes on an inside surface;
   - coating a dielectric substance on said group of electrodes;
   - forming a panel by positioning said pair of insulating substrates in spaced parallel relation having inside surfaces opposite each other with a gap therebetween;
   - forming an hermetic seal at a periphery of said panel;
   - introducing a liquid including an alkali metal element into said gap;
   - removing the solvent of said liquid to form an alkali metal atomic layer on said dielectric substance during heating of said panel; and,
   - filling an ionizable gas into said gap.

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