Development of Panel Structure for a High-Resolution 21-in-Diagonal Full-Color Surface-Discharge Plasma Display Panel

Tsutae Shinoda, Masayuki Wakitani, Toshiyuko Nanto, Noriyuki Awaji, *Member, IEEE*, and Shinji Kanagu

Abstract—**Plasma display panel (PDP) structure has been investigated to develop a 21-in-diagonal color plasma display with a high-resolution of 0.22-mm subpixel pitch. To realize a high-resolution display, a stripe alignment of three primary color elements such as red, blue, and green, was introduced. Four kinds of panel structures are compared and finally stripe rib and stripe phosphor structures were introduced for the three electrode surface discharge plasma display. The 21-in-plasma display developed with the structure has firstly been put into the market with sufficient performance, such as a wide operating voltage margin, a high luminance, and a wide viewing angle of more than 60 V, 200 cd/m2, and 160°, respectively.**

Index Terms—**Flat panel displays, gas discharge display.**

I. Introduction

DEVELOPMENT of a large-area color flat panel display which can display image and information is expected to be used for a wall-hanging television and a multimedia displays. Plasma display is a most promising candidate for large-area wall-hanging displays because of the features of a simple panel structure, simple processes appropriate for large-area displays, a good display quality, and high-speed addressing ability. Since the world first practical three-color plasma display development in 1990 with surface-discharge technologies [1]–[3], a realization of a full-color plasma display has been expected.

The authors have first developed a 21-in-diagonal full-color plasma display which has good features of high peak luminance of 200 cd/m2 and a wide viewing angle more than 160° in 1992 [4]. The plasma display is the world's first production of color plasma displays with 260 000 colors.

The first important issue was a new structure introduction for the three electrode surface discharge plasma display [5], [6]. The three-color plasma display employed two phosphors and realized three colors such as red, green, and yellow which is realized with mixing the red and green colors. The plasma display was used for display large characters, so that the resolution was as low as 0.8 mm pixel pitch between red and green color phosphors comparing to 0.22–mm pitch of the 21-in-diagonal plasma display to be developed. We investigated some structures and finally developed a simple structure with striped ribs and stripe phosphors.

This paper will discuss the structural technologies and features of the final simple structure developed for a 21-in-diagonal color plasma display panel (PDP).

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II. Target Specification of a 21-in-Diagonal Color Plasma Display

Table I shows the target specification of a 21-in-diagonal panel to be developed. The number of pixels are 640 horizontally × 480 vertically. A pixel has been composed of three primary colors of blue, red, and green which are arranged horizontally, so that 1920 × 480 subpixels are in the panel. The subpixel pitch of 0.22 × 0.66 mm was the highest level of conventional color plasma displays at the stage. The luminous target was higher than 150 cd/m2 which is sufficient to use for information and image displays.

The color plasma display previously developed was three-color display for financial display. Fig. 1 compares the color arrangement between the three-color and a 21-in-diagonal panel. The difference between them was pixel resolution as that the resolution of the 21-in-diagonal plasma display is about four times higher than that of the three-color plasma display. The red- and green-color pixels were alternatively arranged in the vertical direction and a pixel was made with 4 × 3 subpixel matrix for the three-color PDP. The subpixel pitch between red and green was 0.8 mm. In the case of 21-in-PDP, a pixel is made with a combination of three subpixels , such as red, blue, and green colors, as shown in the figure. The subpixel pitch between neighboring colors is 0.22 mm.

Fig. 2 shows the panel structure of the three-color PDP. The panel is one of the three-electrode surface-discharge plasma displays which will be explained more detail later. The barrier ribs were formed on both substrates in the panel which was called as double rib structure. A mesh type rib structure was introduced on the front glass plate and stripe rib was on the rear substrate. The red and green phosphors were deposited alternately along the stripe rib as shown in the figure. The address electrodes were not covered by phosphors to prevent an accumulation of wall charges on the address portion of the cell. It was thought that a high-resolution 21-in-diagonal plasma display should not be able to be developed by the complex structure. The idea of simple arrangement of stripe color, as shown Fig. 1(b) was investigated to solve the resolution problem.

TABLE I
TARGET SPECIFICATION OF A DEVELOPED PANEL

Items	Specification
Active display area	21-in.-diagonal
Display capacity	640 horizontal x 480 vertical
Pixel pitch	0.66 x 0.66 mm
Sub pixel-pitch	0.22 x 0.66 mm
Luminance	> 150 cd/m^2

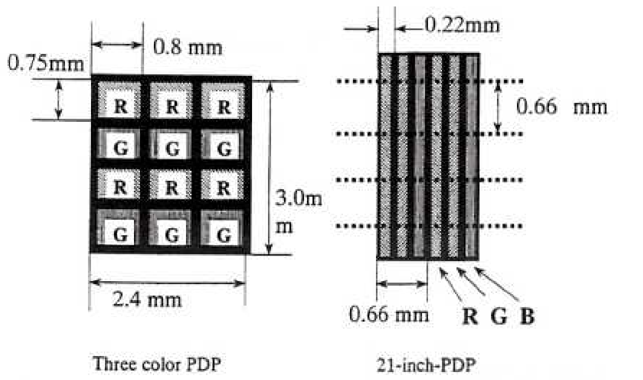


Fig. 1. Comparison of color arrangements between three-color and 21-in-diagonal plasma displays.

We investigated four kinds of panel structures in terms of rib and phosphor structures. Fig. 3 shows the cross section of the structures. Fig. 3(a) shows a transmission type panel with single rib structure in which ribs were deposited on only rear glass substrate and phosphor was only on front substrate. A luminance was not sufficiently high because we observed the visible light through the phosphor layers which absorbs emitted light. The visible light is excited only on the surface due to the short wavelength ultraviolet and absorbed in the phosphor layers. We investigated three kinds of reflection panel structure in which phosphors were deposited only on the back plate. It was expected to have a feasibility to realize high luminance because we could observe both the emitted light on the phosphor surface and the reflected light by the phosphor layer. Fig. 3(b) shows one of the reflective type panel with double rib structures in which the phosphors are deposited only on the dielectric layer and side wall of the rib on the back plate. The panel however has a disadvantage of requiring highly accurate alignment when assembling the two substrate. Fig. 3(c) shows another reflection and single rib structure in which the phosphor is deposited only on the dielectric layer of the rear plate. Fig. 3(d) shows the other reflective and single rib structures in which the phosphors are deposited on both the side wall of the rib and the dielectric layer.

The structure of Fig. 3(d) has advantages over other structures in terms of luminance and viewing angle which are most important features for large-area color plasma displays. The detail performances will be discussed later.

III. PANEL TECHNOLOGIES

A. Panel Structure and Fabrication Process

Figs. 4 and 5 show the practically developed panel structure and fabrication processes developed for the 21-in-diagonal color

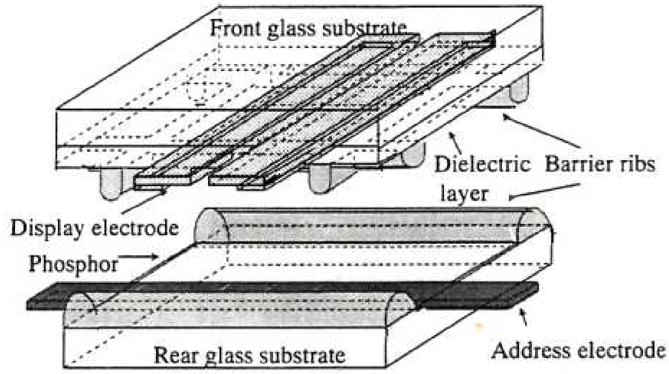


Fig. 2. Panel structure of a three-color PDP. The phosphors did not cover the address electrodes and barrier ribs were formed on both substrates.

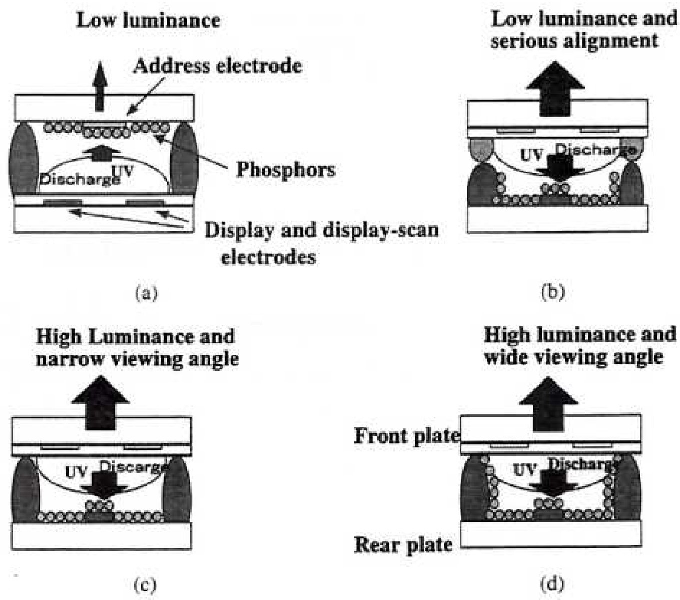


Fig. 3. Panel structures investigated in the developing process of the 21-in PDP. (a) Transmission and single rib type structure. (b) Reflection and double rib type structure. (c) Reflection and single rib type structure, without phosphors on barrier rib. (d) Reflection and single rib type structure.

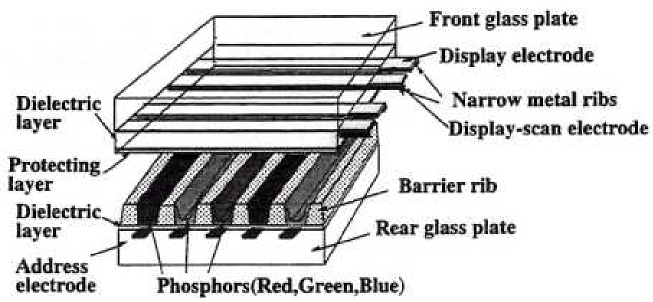


Fig. 4. Panel structure developed for the 21-in-diagonal color plasma display.

plasma display, respectively. The panel structure is called as the reflection type three-electrode surface-discharge color plasma displays. Paired parallel display electrode X and display scan electrode Y are formed on the front glass substrate. Each display electrode and display electrode is composed of a transparent SnO_2 and a narrow bus electrode of multilayered Cr, Cu, and Cr, to emit a luminance effectively through the transparent electrode and reduce the electrode resistance. These electrodes are covered by a dielectric layer which is made of low melting

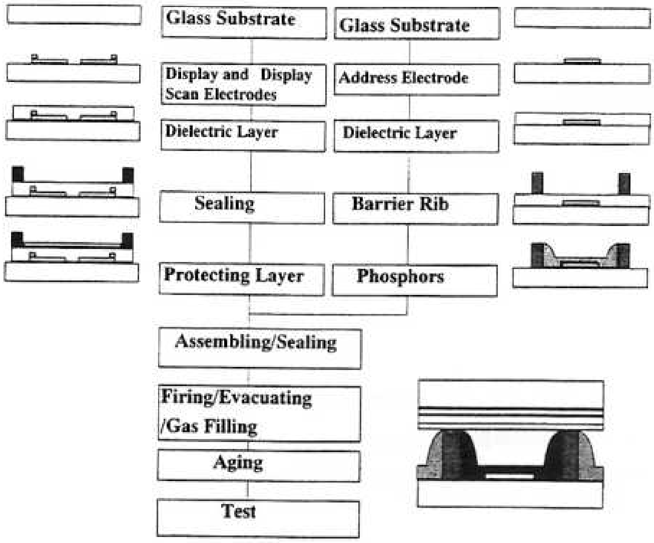


Fig. 5. Fabrication process for color plasma display.

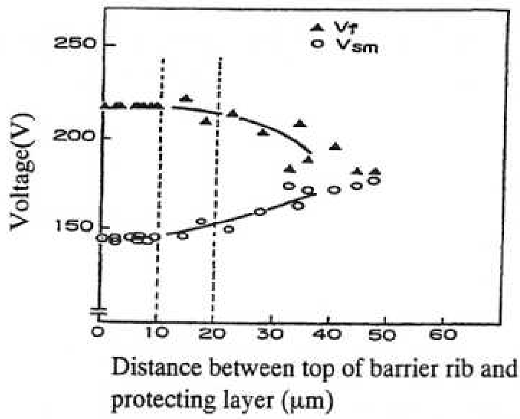


Fig. 6. Relationship between operating voltage range and uniformity of the top of the rib.

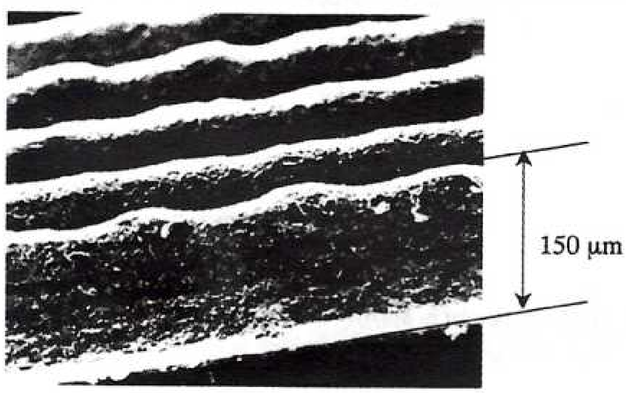


Fig. 7. Photograph of the top shape of the printing rib before polishing.

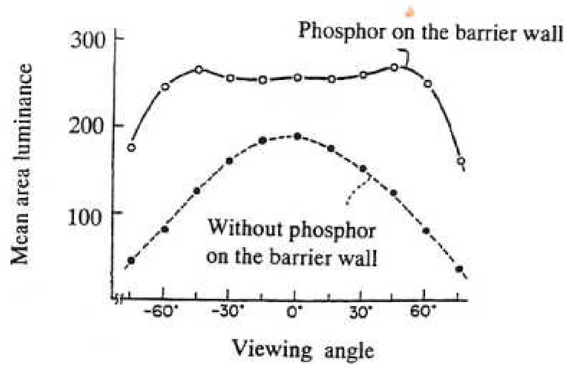


Fig. 8. Dependence of the mean area luminance on viewing angles.

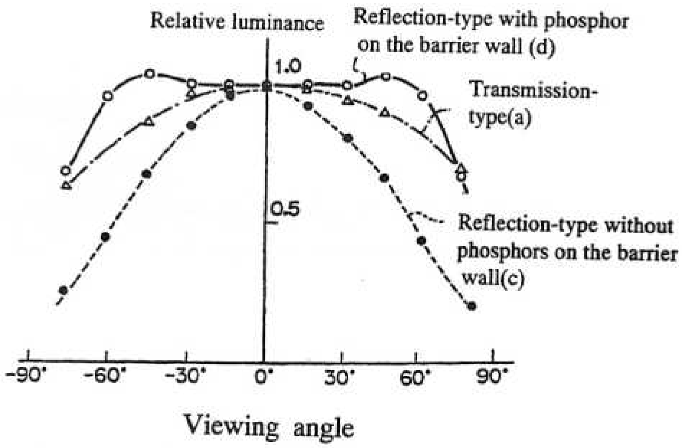


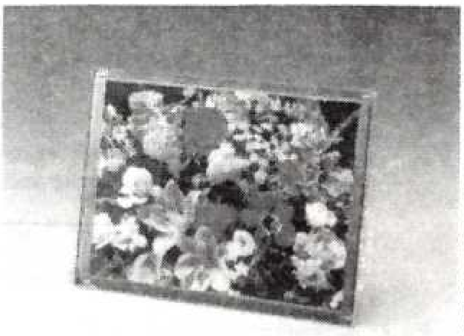
Fig. 9. Dependence of the normalized luminance on viewing angles for three kinds of panel structures. Relative luminance is normalized by the luminance of normal direction.

glass materials. These are also covered by a thin MgO layer. On the other rear substrate, striped address electrodes A are arranged. Striped barrier ribs are on both sides of the address electrodes to separate the adjacent discharge cells and to eliminate the optical crosstalk between them. Three primary color phosphor materials for red, blue, and green colors are deposited in the neighboring channels made by the ribs to cover both of the side wall of the ribs and the dielectric layer. The structure has realized good performances such as a high luminance, a high luminous efficacy, and a wide viewing angle. Phosphor materials are $BaMgAl_{14}O_{23}:Eu$ for blue, $(Y.Ga)BO_3:Eu$ for red, and $Zn_2SiO_4:Mn$ for green. The substrates are assembled onto each other with about 120 μm gap. A Ne and Xe gas mixture is introduced between the gap. The panel structure developed for the 21-in-diagonal color PDP is the simplest one of conventionally developed color PDP's and the fabrication process is simple enough to mass produce, so it has advantages such as a low-cost process and easiness to manufacture large-area panels and high-resolution panels.

B. New Rib Structures for Stable Operation in a High-Resolution Panel

To develop the high-resolution 21-in-diagonal PDP with a 0.66 × 0.66 mm pixel pitch, the striped rib and phosphor structure has been firstly introduced which is currently a popular structure for color ac plasma displays [7]. The uniformity of the top of the ribs was one of the most important issues to isolate between adjacent subpixels to have a stable operation.

There are two important factors of a firing voltage (V_f) and a minimum sustaining voltage (V_{sm}) in terms of an operating voltage. Alternative pulses are usually applied between the display and the display scan electrode to operate. When the applied pulse voltage is increased, discharges are ignited at a voltage



Item	Performance
Display Area	422 x 316 mm
Aspect Ratio	4 : 3
Number of Pixels	640(R,G,B) X 480
Pixel Pitch	0.66mm X 0.66mm
Number of Colors	260,000
Luminance	180 cd / m2
Viewing Angle	> 160 degree
Power Consumption	100 W max
Weight	4.8Kg

Fig. 10. Sample display and performances of 21-in-diagonal color plasma display.

which is called the firing voltage. After the ignition of the discharge, ions and electrons rapidly accumulate on the opposite dielectric layers resulting in reducing the electric field inside the subpixels to stop the discharge. So the discharge is usually pulse shaped. The accumulated charge called wall charge makes an important roll to reduce a following externally applied voltage to re-ignite the discharge, because the wall charge is superimposed to the following applied voltage. The effect is used for memory operation of ac plasma displays. The firing voltage (V_f) is the minimum voltage at which the subpixel can ignite a discharge without wall charge, and minimum sustaining voltage (V_{sm}) is the minimum voltage at which the subpixels can maintain the discharge with previously accumulated wall charges. These voltage are usually different for each subpixel, so that there are maximum V_f, minimum V_f, maximum V_{sm}, and minimum V_{sm} defined as V_{fn}, V_{f1}, V_{smn}, and V_{sm1}, respectively, for each subpixel group. The voltage range between V_{f1} and V_{smn} is an important factor for operation and defined as memory margin of the group. The memory margin should be large enough to operate the panel normally because the operating voltage is adjusted within this voltage margin range.

Fig. 6 shows the relationship between the memory margin and the distance between the top of the barrier and the surface of the protecting layer. The width of the top of the barrier rib was about 15 μm. The distance between the barrier and the surface of the protecting layer depends on the uniformity of the top of the rib in the actual device. This shows that firing voltage (V_f) reduces and minimum sustaining voltage (V_{sm}) increases with increasing the distance. The reduction of the firing voltage is due to the interaction between the adjacent cells through the space of top of the barrier ribs. The discharge previously ignited supplies charges through the space and then reduces the firing voltage of the adjacent cells. The difference between the V_f and V_{sm} is sufficiently wide when the distance is less than 10 μm. This shows that the uniformity of the top should be less than 10 μm to have a sufficient memory margin by isolating adjacent cells. Although the printing technologies were introduced to fabricate a high-resolution rib arrangement on the glass substrate, the top of the rib was not sufficiently flat. Fig. 7 shows the photograph of the top shape made by the printing technology in the early stage of the development. The roughness was so large that the polishing process was adopted to keep the flatness less than ±5 μm. As a result of the improvement, sufficiently large memory margin more than 60 V for each cell was obtained.

C. Optical Characteristics

The display characteristics such as luminance, luminous efficacy, and viewing angle are largely depend on the panel structure. The three structures as shown in Fig. 3(a), (c), and (d) are investigated in terms of luminous characteristics with 21-in-diagonal plasma displays. Fig. 8 compares the dependence of the luminance on the viewing angles between two structures with and without phosphors on the barrier rib. The vertical axis shows the mean area luminance. This means that the mean luminance of the structure with phosphors on the rib is almost 1.5 times higher than that of the structure without phosphors on the rib. Fig. 9 shows the dependence of the luminance which is normalized with respect to that of the normal direction. The higher luminance values than one of normal direction are kept within the ±60° and the higher luminance values than 50% of the normal direction are kept within ±80° in the reflection structure with phosphor on the rib. In the structure without phosphor on the rib, the distribution is narrow and close to cosine curve.

The luminous efficacy (η) is shown as the following equation:

$$\eta = \frac{\pi SB}{V(I - I_0)}$$

where

- S shows luminous area;
- B luminance;
- V applied voltage;
- I discharge current on the condition that all of pixels in the measured region are discharged;
- I_0 displacement current on the condition that all of pixels in the same region are not discharged.

The luminance and luminous efficacy were obtained from the experimental results at 200 cd/m^2 and 0.75 lm/W, respectively, which are sufficiently high to use for practical displays with the reflection panel structure with phosphors on the rib.

IV. Characteristics of a 21-In-Diagonal Plasma Display Panel

Fig. 10 shows the sample display and performances of the production of a 21-in-PDP in which the developed technologies mentioned above were introduced. The good features of high-luminance of 180 cd/m^2, a wide viewing angle more than 160° and full-color display of 260 000 colors has been realized.

V. Conclusion

This paper described the panel structural technologies developed for a high resolution 21-in-diagonal color PDP. Four kinds of panel structures were compared and finally a stripe rib and stripe phosphor structure is selected because the structure is simple enough to manufacture and has good features of high luminance, wide viewing angle, and high resolution.

The technologies enabled the 21-in-diagonal color plasma display to be put into practical use first in the world.

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