14.1: *Invited Address:* Development of Technologies for Large-Area Color ac Plasma Displays

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1.Introduction

Large area flat panel displays which can display both images and information, promise to capture the multi-media market of the 21st century. Plasma displays thought to be the most appropriate devices for HDTV have seen significant innovations in color technologies since 1990[1],[2],[3]. In 1992, NHK demonstrated the feasibility of dc plasma displays when they presented a 40-inch diagonal color HDTV [4] with an impressive high display quality. Fujitsu began production of a 21-inch diagonal ac plasma display in 1993, introducing the full color plasma display. Plasma displays are appropriate for large-area images because of their simple fabrication process, and good quality self emitting display. The flat display is likely to be shared, however, because LCDs may be for displays of less than 20-inches . We have been developing manufacturing technologies for monochrome ac-plasma displays, as well as doing research and development into color plasma devices. In particular, we introduced surface discharge technologies, inventing and developing both the three-electrode and reflection-type surface discharge structures, and applying them to practical use. The plasma display features a white peak area luminance of 200 cd/m^2. a viewing angle of 140 degrees, and a 256-level gray scale. The 21-inch full color plasma display panel was first introduced in the public information market and it will be extended next to NTSC-TV. We think that there is a sufficiently large market for flat displays, although the high-quality low-cost CRT is likely to remain in the up to 20-inch display market.

In applications requiring more than 30-inch displays, the thickness and weight of CRTs become serious problems ,leaving a extremely large market for plasma displays. Wide TV, HDTV, and multi-media display markets are all targets for plasma displays.

In this paper, we discuss the history of full-color ac-plasma display research at Fujitsu, the technologies and features of our 21-inch full-color plasma display, and the goals to realize large area plasma displays in the future.

2. History of Color ac-Plasma Displays

Color plasma displays have a 20-years research history. The principle of the color plasma display is that a gas discharge radiates ultra-violet which excites phosphor, producing visible light. In conventional black and orange monochrome plasma displays, visible light from Ne gas discharge is used. The first structure in color plasma research was an opposed twin substrate type, as is used in conventional monochrome plasma devices. Such color plasma displays were not successful, however, due to problems such as the short period luminous degradation of phosphor due to ion bombardment in the structure. Fujitsu therefore studied the surface discharge structure for a color plasma display [5],[6]. Table 1 summarizes progression of color plasma display research at Fujitsu.

Figure 1 shows both twin substrate and surface discharge panel structures. Although surface discharge was suggested in the early stages of research into a color segmented plasma display, the structure was not thought appropriate for high resolution devices, and full-color dot matrix plasma display research did not continue. The research into full color dot plasma displays using surface discharge techniques, started in 1979 for the multi-layered cross electrode structure as shown in fig.2. Fig.3 shows a display example. Although luminance and life were improved, they were not good enough for practical use, also fabrication was difficult. Three electrode surface discharge was invented in 1986 and it lengthened life and reduced process complexity, but not to the desired levels. There was no convincing practical example of color plasma display technology until the reflection structure was invented in 1989 [7]. Figure 4 shows the panel structure of the first commercial three color plasma display. The unique three electrode structure separates the functions of electrodes for display and addressing. Using a pair of display electrodes to maintain the discharge for display reduced the electric field on the dielectric layer and extended the display`s life. The initial three electrode structure is the transmitting type with discharge behind the phosphor, so the visible light passes through the phosphor. The reflecting type improved luminance, the discharge is in front of the phosphor and the visible light is seen directly, as you can see from the figure. There are a pair of parallel display electrodes on the glass plate. The display electrode is a multi-layered transparent electrode. The opaque metal auxiliary electrode is adopted to prevent the driving voltage from dropping by the resistance of the transparent electrode. The display electrode is covered with a dielectric layer. The latticed ribs on the dielectric layer prevent adjacent cells suffering from optical and electrical crosstalk. The dielectric layer is covered with an MgO protecting layer. The other glass plate carries an address electrode with a separator on one side of it. Green and red color phosphors are printed between the address electrodes and separators to avoid obscuring the address electrodes. The display spot is seen through the transparent electrode. This panel structure gave a high-luminance display with a low driving frequency.

The reflection type three electrode surface discharge structure made possible the first commercial three color plasma display for public information market (Fig.5). Luminance was high at 400 cd/m^2 for green and 200 cd/m^2 for red with a sustaining frequency of only 15 kHz. Life was more than 10,000 hours, long enough for practical use. The first display was the 20-inch and displayed green, red , and mixed yellow brightly enough to be seen from a few meters . This was a clear demonstration that plasma displays are suitable for large display equipment.

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3. A 21-inch Full Color Plasma Display

Research into a full-color ac-Plasma display began with a 31-inch plasma display[8]. The aim was to develop a large plasma display and implement a 64 gray level scale. Resolution was 640 by 480 pixels and pixel pitch was 1 mm. Each pixel consisted of four sub-pixels. A new technique provided a 64-level gray scale and the panel successfully displayed TV image. White peak luminance was 65 cd/m^2 with a sustaining frequency of 30 kHz. Figure 6 shows a sample display of the 31-inch diagonal panel. 64 gray levels were realized using 16 gray levels for each sub-pixel and dither.

The results from this display were used to develop the 21-inch full color plasma display. The aim was the public information display market, and the display resolution was designed to be compatible with IBM`s VGA standard. This full-color display had a resolution of 640 x 480 pixels, 256 gray levels and improved color purity. Figure 7 shows the panel structure . There is a pair of parallel display electrodes on the front glass plate. The display electrodes are multi-layered transparent and auxiliary electrodes. The display electrodes have a dielectric layer and MgO protecting layer. The address electrodes are on the rear glass plate. The striped ribs are between the address electrodes to prevent electrical and optical crosstalk between adjacent cells. The red, blue, and green phosphors are formed inside cells and on the address electrode alternately. The wide phosphor area increases luminance and improves the viewing angle. Phosphor materials used were: $BaMgAl_2O_3$:Eu for blue , $(Y.Ga)BO_3$:Eu for red, and Zn_2SiO_4:Mn for green . The front and rear glass plates were assembled with a cavity gap of about 100 µm, and the Ne + Xe gas mixture was introduced into this cavity. This panel structure is the simplest so far developed for color plasma displays and uses mostly conventional thick and thin film technologies, so it is easy to make a large panel.

The driving technique was ADS sub-filed to give a 256-level gray scale[9]. Figure 8 shows a sample display of the 21-inch full color plasma display. The panel has good characteristics including a white peak area luminance of 200 cd/m2, a wide viewing angle of 140 degrees, and 256 gray levels.

Table 2 lists the characteristics of the three color plasma display , the 31 inch plasma display, and the 21- inch plasma display.

4.Future Topics and Prospects for Large Area Displays

Plasma display can be large and are very promising as HDTV displays. Some ,however, remain to be solved. Table 3 compares the specifications for HDTV 40- to 60-inch panels and the commercial 21-inch diagonal full color plasma display specifications. There are 4 area for development.

4.1. Large area panel

Target HDTV display size is 40 to 60-inch diagonal. The largest plasma display is the 60-inch monochrome panel developed by Photonix Inc. The color plasma display is fabricated using a printing and thin film technologies which are used for the conventional plasma display panels. Tolerance becomes more important as the display gets bigger. The process with thin-films and photolithography meets requirements, but printing technology does not. The glass substrate is fired near to its the softening point causing thermal shrinkage , so a new glass is needed.

4.2. High resolution

The 21-inch full-color plasma display has a pixel pitch 0.66 mm sufficient for a 60-inch HDTV. A 40-inch HDTV, however, needs a 0.45 mm pixel pitch. Resolution is related to characteristics and process. First, we need a sufficient dynamic margin. Although some believe that the three electrode surface discharge plasma display cannot be high resolution [10], we believe that the simple structure of the 21-inch color panel refutes this. We must also fabricate a fine rib over the entire 1.5 m^2 area requiring new fine printing or fabrication techniques.

4.3.High driving speed and many-level gray scale

The new ADS-subfield driving technique presented at the `92 SID meeting was used with the 21-inch color panel with 480 scan lines and gave 256 gray levels with an addressing speed of 3 µs/line. This addressing speed is high enough to drive an HDTV display with 1035 scan lines with interlaced scanning. Display quality is better, however, with non-interlaced scanning. Then, higher addressing speed of 2 µs/line or a panel structure in which the address electrode is divided in two areas have to be developed.

4.4. High luminance and high luminous efficiency

The luminance of the 21-inch color panel is 200 cd/m^2 above the target luminance of 150 cd/m^2 for HDTV. Although the luminous efficiency has been greatly improved clearly to the practical level, the present 0.7 lm/W is not enough. High luminance and high luminous efficiency are always barrier. Research into the phosphor materials , discharge cell structure, and discharge mechanism is expected to improve the luminous efficiency to nearly match a fluorescent lamp which produces more than 10 lm/W and works on the same discharge principle [11].

5.Conclusion

We have reviewed full-color plasma display development as far as practical devices , the technologies used for the 21-inch full-color plasma display, and further topics and prospects for large area displays , such as HDTV. The plasma display panel has demonstrated its suitability for large area displays. There will be large display markets for HDTV and large multi-media displays which use HDTV technologies. Digital devices have an advantage over CRTs because they are compatible with computers , and plasma displays are the only direct view displays of more than 40-inches. Full-color plasma displays are in their infancy, and we expect that many researchers and entrepreneurs to enter this fast growing and promising business field.

6. References

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1979	Start to study a full color dot surface-discharge plasma display panel
1984	Three-electrode surface-discharge plasma display panel (TSD-PDP)
1989	Reflection type three-electrode surface-discharge plasma (RTSD-PDP)
	Demonstration of a 15-in. multi color plasma display panel
1990	Production of a three color plasma display
1991	Demonstration of a 31-in. full color plasma display panel
1992	Demonstration of a 21-in. full color plasma display panel
1993	Production of a 21-in. full color plasma display panel

Table 1 History of color plasma display research at Fujitsu.

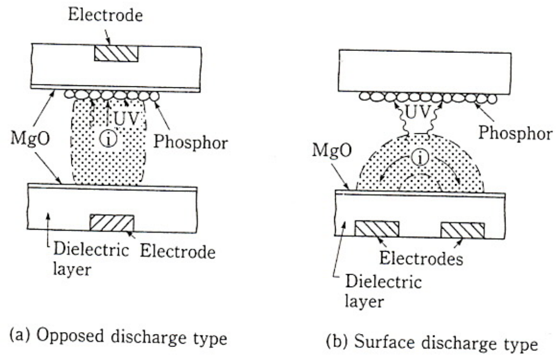

Fig.1 Principal panel structures of color AC-PDPs.

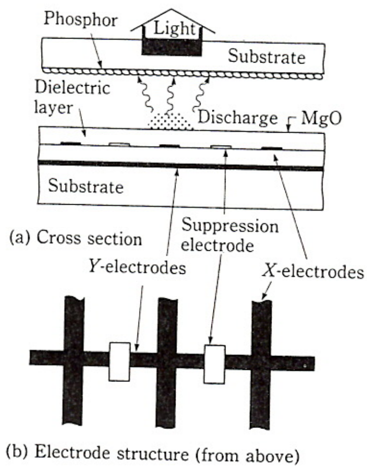

Fig.2 Structure of experimental surface discharge color AC-PDP.

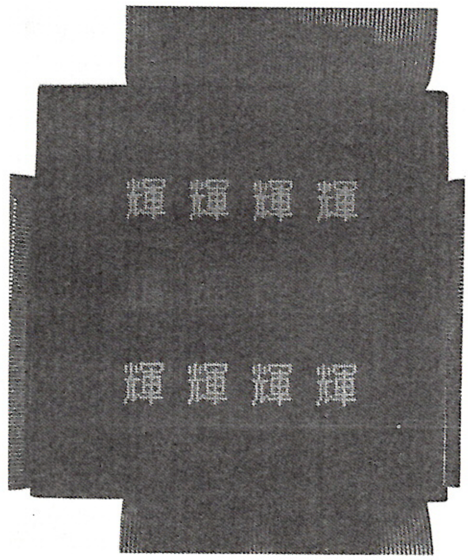

Fig.3 Display example on a initial experiment of surface discharge AC-PDP.

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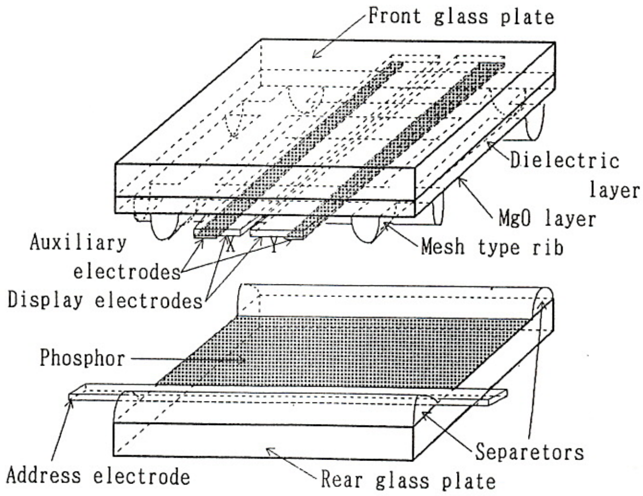

Fig.4 The practical reflection type three-electrode surface discharge color AC-PDP.

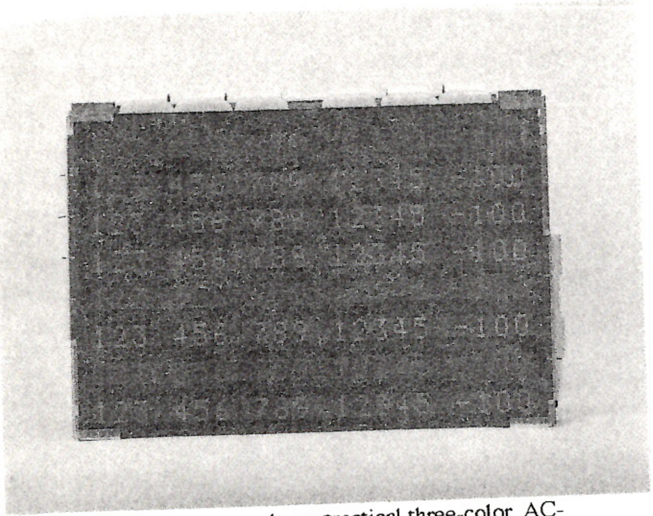

Fig.5 Display example on practical three-color AC-PDP.

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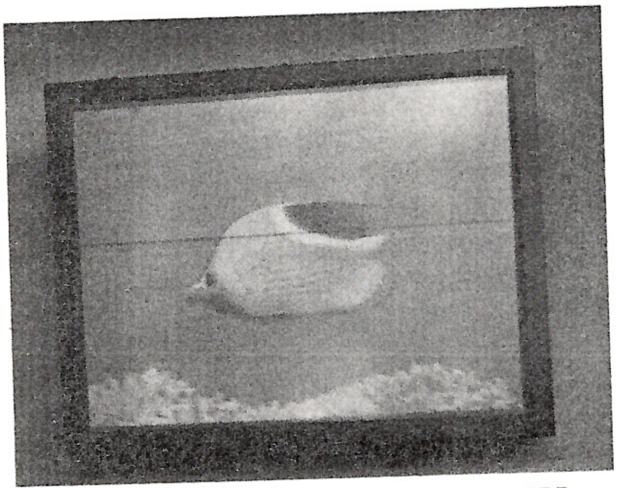

Fig.6 Display example on a 31-in. full color AC-PDP.

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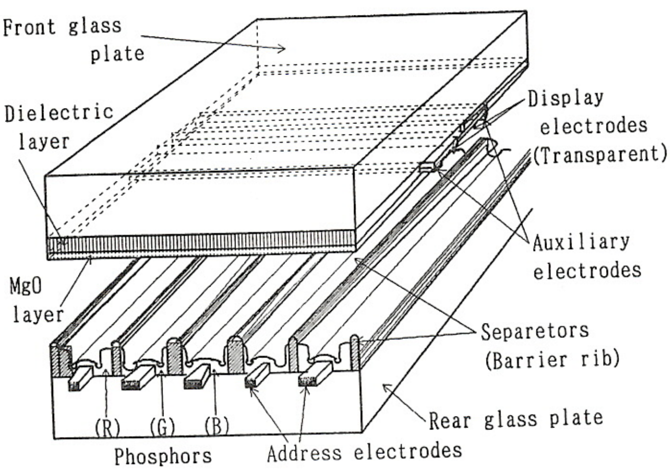

Fig.7 Panel structure of the 21-in. diagonal full color AC-PDP.

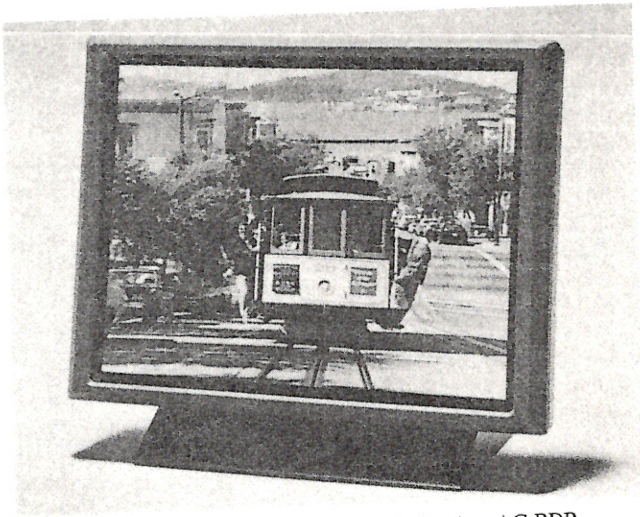

Fig.8 Example image on a 21-in. full color AC-PDP unit.

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Panel size (diagonal)	21-in. (3 color)	31-in.	21-in.
Number of pixels	100x56	640x480	640x480
Number of sub-pixels	330x224	1280x960	1920x480
Pixel pich (mm)	2.4x3.0	1.0x1.0	0.66x0.66
Sub-pixel pich (mm)	0.75x0.80	0.5x0.5	0.22x0.66
Area luminance (White, cd/m^2)	73 (12.5kHz)	65 (28 kHz)	200 (30kHz)
Luminous effi. (lm/W)	0.5	0.3	0.7

Table 2 Comparison of characteristics between the three-color plasma display, and the 31-in. and the 21-in. full color panels.

Size (inch)	40	50	60	21
Display area(mm)	864x466	1094x590	1325x714	422x317
Pixel pich (mm)	0.45	0.57	0.69	0.66
Peak area lumi. (cd/m^2)	150	150	150	200
Contrast	50:1	50:1	50:1	50:1
Luminous eff. (lm/W)	1.0	1.0	1.0	0.7
Power con. (APL. 1/3, W)	63	101	149	40

Table 3 Specifications for HDTV and the specifications of commercial 21-in. full color AC-PDP.