Color Plasma Displays

HEIJU UCHIIKE AND TAKAYOSHI HIRAKAWA

Invited Paper

After decades of research and development, plasma displays are finally beginning to appear in the commercial and consumer markets. Following a short review on the basic principles of direct and alternating current plasma displays, we present a summary of the status of color plasma displays. Plasma display panels (PDPs) have finally achieved luminance and efficiency values on par with hi-definition cathode ray tube monitors. Additional improvements in performance will open up a new world of large PDP displays. Ultimately, what will drive the PDP market will be continued improvements in the performance of color PDPs themselves. PDP makers are working on reducing power consumption through improved luminous efficiency and improved component materials and manufacturing methods of color PDPs. With improvements in the cell structure and driving methods, there is a good prospect of achieving a luminous efficiency of 2–3 lm/W and a power consumption of about 200 W for 50-in diagonal size.

Keywords*—*AC plasma displays, flat-panel displays, gas plasmas, PDPs, plasma displays.

I. Introduction

It is well known that monochrome plasma display panels (PDPs) were the flat-panel displays that were used in the early laptop computers at the end of 1980. However, with rapid advances and improvements in active-matrix-addressed thin-film transistor liquid-crystal displays (LCDs), LCDs became the de facto standard for displays in portable computers and hand held devices in the early 1990s. Despite this, research continued in the development of plasma displays as PDPs have all the essential advantages for large area displays. When compared to cathode ray tube (CRT) displays, PDPs do not require thick glass plates as their little difference in the pressure between the inside and outside of the panel. CRTs and field emission displays need a high vacuum for their operation and this requires the use of thicker glass plates. Another advantage of PDPs is that the capacitance between the electrodes of PDPs is not large, which makes driving a large display area less difficult. Because organic and inorganic electroluminescent display devices have large capacitance, they have the essential disadvantage of driving large display area. After 30 years of research and development, PDPs are still relatively expensive compared to other flat-panel displays. However, with the advent of high-definition television, color PDPs started to appear in volume quantities in consumer electronics. This is expected to reduce unit prices in the near future.

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II. Monochrome Plamsma Displays

A. General Principles of Plasma Displays

Light emission from gases occurs when an electron transits from a higher energy level to a lower energy level and the gas is in the ionized state when a sufficiently large number of the atoms have lost one or more electrons. This process leads to a flow discharge and the gas is then referred to as plasma. In this condition, it is most likely to emit radiation and all plasma displays are based on this gas discharge mechanism.

The color of gas discharge is characteristic of the atom. For example, orange is the characteristic color of neon and this is the basic color of the majority of monochrome PDPs, as they use neon gas. In a discharge column, there are two regions that exhibit light output, namely, the negative glow region and the positive discharge column. The negative glow is close to the cathode and is more intense than the positive column-light output. Majority of monochrome PDPs use the negative glow as the light source, whereas the positive column has been used to excite phosphors in fluorescent lamps and in color PDPs.

In a discharge column, along with the primary noble gas, other gases can be mixed to improve discharge characteristics. The purpose of this mixture is to form what is known as a Penning mixture, in which the metastable energy level of the noble gas is greater than the ionization energy of the added gas [1]. This leads to lower breakdown voltages, as illustrated in Fig. 1 for a mixture of neon and argon. It can be seen from Fig. 1 that very small amounts of added gas lead to considerable reductions in the breakdown voltage and all color PDPs use mixtures of this type, such as Ne + Xe (4%).

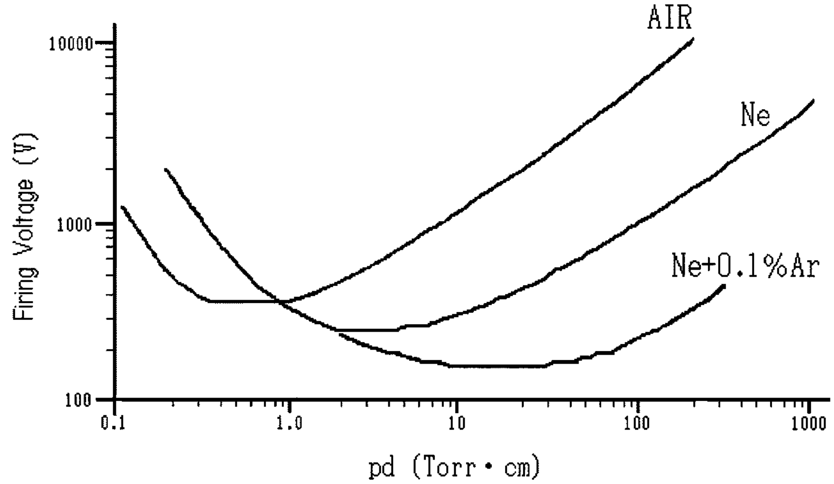

Fig. 1. Examples of Paschen curves.

It was originally hoped that alternating-current (ac) arrangement would protect the electrodes from sputtering due to ion bombardment, since the electrodes are protected from the gas by the combination of dielectric layer and MgO [2]. However, when a discharge is initiated, the charge particles flow to the cell walls and build up a surface charge that leads to quenching the discharge. In an ac type of cell, there is no need for current-limiting resistors, since the discharge current is limited by the capacitive reactance in series with the cell. This is one advantage of the ac cell to which can be added the ability to operate in a memory mode by using a voltage below the discharge voltage but large enough to sustain the discharge once it has been initiated. This essential characteristic of ac-type PDPs have an advantage of high production yield compared to direct-current (dc) type plasma displays.

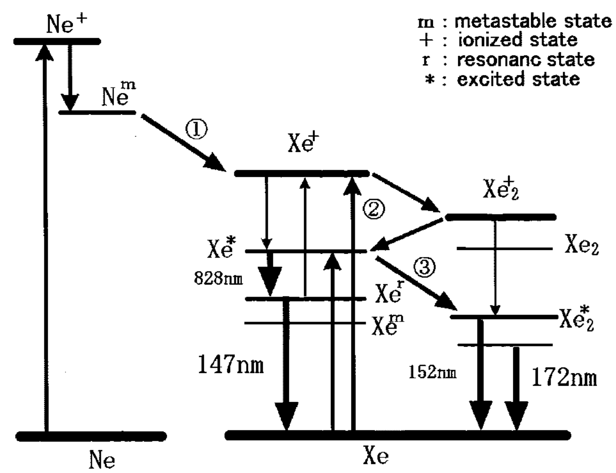

Fig. 2. Energy level of transition for Ne + Xe gas mixture.

III. Research and Development of Color Plasma Displays

A. Early Stage of dc Color Plasma Displays

There are many ways to achieve color in PDPs, but the two principal methods are the following. The simplest method is to use the "primary color" of the discharge. The second method is to excite inorganic phosphors by ultraviolet rays or electrons created by the discharge process. Among the two methods, ultraviolet ray excitation has been applied to recent color PDPs. Excitation by ultraviolet rays provides high luminance and color purification is provided by the selection of appropriate phosphor materials. In particular, Ne with 4%–5% of Xe showed excellent results to achieving high luminance and luminous efficiency. Vacuum ultraviolet rays of 147, 152, and 172 nm are radiated from Xe and Xe-dimers as illustrated in Fig. 2.

At the early stage of development on ac and dc PDPs, achievement of color was carried out to for their application in computer monitors and color televisions. Of the color PDPs to achieve the qualities of a color television were dc PDPs. Color ac PDPs had difficulty in achieving the required display lifetime due to the degradation of color phosphors caused by ion sputtering [3]. As phosphors of dc color PDPs are deposited around the anodes, color dc PDPs at this stage have the advantage of longer lifetime compared to the ac plasma displays.

Color dc PDPs for television were made practical use by the application of discharge at positive column region. Even though color dc PDPs using positive column had good results compared to those of negative glow region, the luminance and luminous efficiency were are not yet sufficient for consumer applications. In 1983, NHK developed a 16-in diagonal color dc PDPs whose luminance and luminous efficiency were 21 cd/m^2 and 0.05 lm/W, respectively [4]. However, these devices did not provide luminance and efficiency values beyond 150 cd/m^2 and 0.4 lm/W, respectively [5].

B. Early Stage of ac Color Plasma Displays

From early on, surface-discharge color ac PDPs showed extremely good performance with luminous efficiencies greater than 0.75 lm/W, 0.4 lm/W, and 0.15 lm/W for green, red, and blue phosphors, respectively [6]. Initial research and development work on surface-discharge color PDPs based on single-substrate ac PDPs was started by Dick [7]. Phosphors were deposited on the front cover glass substrate

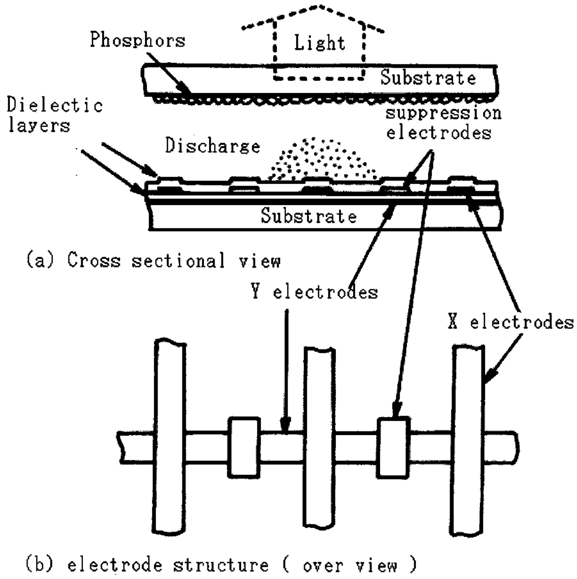

Fig. 3. Primitive electrode structure of surface-discharge ac PDPs.

placed away from the discharge area as show in Fig. 3. Therefore, surface-discharge color PDPs have the advantage of long life because phosphors deposited on the front cover glass are not degraded by ion sputtering.

The original electrode configuration of the surface-discharge color plasma displays was much improved. A more recent device structure is shown in Fig. 3, where pairs of the sustaining electrodes are placed on the rear glass substrate and phosphors are deposited on the front cover glass substrate. Visible light is transmitted through the phosphor layer and this type of device is, therefore, called transmissive phosphor type. With this type of structure, performance of luminance and luminous efficiency improved significantly and early laboratory results reported in 1989 had luminance and luminous efficiency values of 400 cd/m^2 and 1.6 lm/W, respectively [8]. Similar results were accomplished in commercial color PDPs within two to three years. Detailed studies on the basic mechanisms of surface-discharge ac PDPs revealed that the cathode fall region moves from the center of the electrodes outward during one cycle of the operation [9].

IV. Commercialization of Color Plamsa Displays—The Early Years

Fujitsu developed the early prototype of surface-discharge color PDPs based on the reflective phosphor geometry. The basic electrode configuration in this case was same as the recent commercial ones. The configuration consists of pairs of sustaining electrodes made of indium–tin–oxide, which are placed on the front glass substrate, whereas the phosphors and addressing electrodes are placed on the rear glass substrate. These colors PDPs also are called three-electrode surface-discharge color PDPs.

On the rear glass substrate, striped type barrier ribs are fabricated to prevent crosstalk from the neighboring discharge cells. By applying the reflective phosphor type of the surface-discharge color PDPs, the performance of luminance

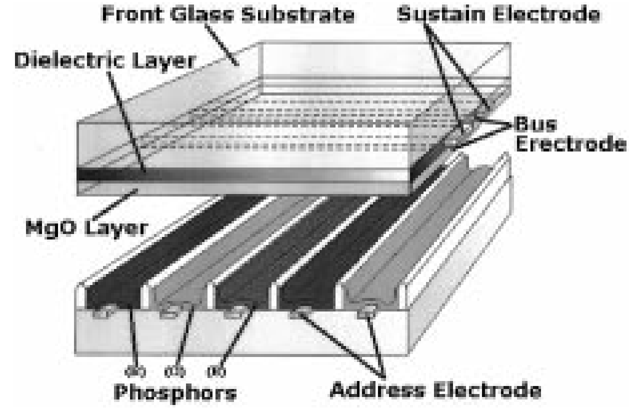

Fig. 4. Electrode structure of conventional type of surface-discharge ac PDPs.

and luminous efficiency were improved by almost one half of the previous transmissive type of ones.

The first color PDP were VGA-class products with a resolution of 680×480 pixels. The first color PDP that were introduced by Fujitsu were 21–in diagonal size (see Fig. 4) and had luminance of 200 cd/m^2 and luminous efficiency of 0.8 lm/W [10]. Later, Fujitsu introduced displays 42-in diagonal PDPs, but with much improved luminance and luminous efficiency figures of 350 cd/m^2 and 1.2 lm/W.

Over the last five years, most of the PDP manufacturers have started to adopt ac surface-discharge electrode configuration for the following reasons. First, compared to the dc configuration, the ac PDP devices had lifetimes reaching more than 30 000 h. In addition, the extremely wide memory margin of 40–50 V allowed for improvements in the uniformity of luminance across the entire screen surface. This in turn translates into a high production yield. Accordingly, prospects have opened up for much higher manufacturing yield. Furthermore, the ac surface-discharge made it possible to achieve luminance and luminous efficiency several times higher than the dc system. Because of its simple electrode structure, the color ac PDPs can be manufactured with relative ease.

V. Color Plamsa Display Televisions

A. Second-Generation of Mass Production in Color Plasma Displays

At the end of 1990, Fujitsu and Hitachi merged their PDP activities into a new company named Fujitsu Hitachi Plasma Display Limited (FHP). At the same, Mitsubishi discontinued their PDP operations and transferred their technology to Chungwa Picture Tube Company in Taiwan. By the end of the 1990s, FHP, NEC, Pioneer, and Matsushita in Japan and LG and Samsung in Korea were the only remaining players in the business and all these companies established second-generation factories for the mass production of PDPs. In addition to improvements in luminance and luminous efficiency, the last few years saw a substantial improvement in the picture quality of color PDPs to a level sufficient for commercial TV displays. With further

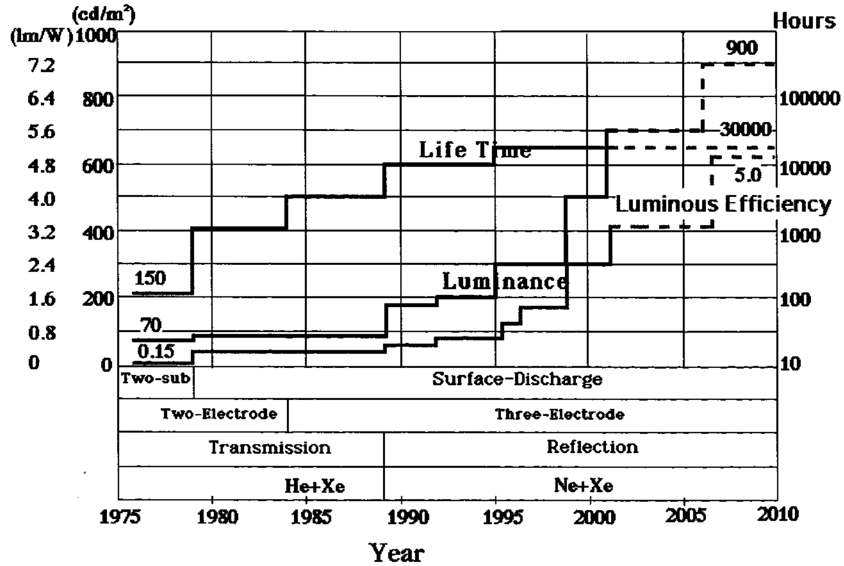

Fig. 5. Change of performance—luminance, luminous efficiency, and lifetime.

refinements and improved drivers, PDPs have can finally compete with CRTs in picture quality.

After Hitachi introduced the color PDP television ahead of the competition in 2001, Pioneer, Matsushita, Sony, Sharp, Sanyo, and Toshiba entered the color PDP television market. However, except for Pioneer and Matsushita, these companies buy PDP units from color PDP manufacturers. Meanwhile, the manufacture of color PDPs has also expanded in volume. In Japan, FHP and NEC have structured their production lines for the second-generation PDPs, while Pioneer has built a new production line for a new PDP model with improved performance that was introduced to the market in October 2001. With expanding production volumes, a number of new ventures for supplying components for the PDP market were established. At the end of 2001, Matsushita established a joint venture with Torey to manufacture components of color PDPs. Asahi Glass, one of the largest flat-panel glass manufacturers, entered into a joint venture with Dai Nippon Printing to manufacture rear plates for color PDPs.

In Korea, LG Electronics and Samsung Electronics have started construction of plasma-display production plants capable of manufacturing 30 000 PDP units monthly, a rate similar to the production capacity as FHP. Meanwhile, a joint venture by Orion and Daewoo is slated to begin PDP production in China. In Taiwan, Acer developed demonstrated a 42-in diagonal PDP product in early 2001. Chungwa Picture Tube Co is constructing a full-scale PDP production line based on technology from Mitsubishi.

B. Improvements in Performance of Color Plasma Displays

Over the last few years, color PDPs have improved tremendously in luminance, luminous efficiency, and life (see Fig. 5). A look at the course of these improvements shows the results of the introduction of three-electrode surface-discharge system. Japanese PDP manufacturers attained basic performance levels of color PDPs with luminance and luminous efficiency of 350 cd/m^2 and 1.2 lm/W, respectively, a few years ago and have since been making technical efforts to improve production yields.

Most Japanese manufacturers followed almost the same course of development in improving the performance of their color PDPs. However, recently, they have started to pursue different directions in their development activities. Noteworthy among them is the efforts made by Pioneer. Among the technical improvements so far are Pioneer's waffle structures and CLEAR drive system, NEC's CCF system, Matsushita Electric Industrial's plasma AI and its high color temperature system by an asymmetrical cell structure, and FHP's alternate lighting of surfaces (ALIS). Improvements from developers outside Japan include demonstration of 60-in diagonal color PDPs from both LG Electronics and Plasmaco, a subsidiary of Matsushita. These systems and products attain advanced performance levels through improvements in the cell structures and drive systems. In the spring of 2001, NEC introduced a 61-in diagonal color PDP in the market.

C. Improvement of the Cell Structure

FHP reported on ALIS technology, as shown in Fig. 6 [11]. The ALIS method does not have a nonluminous area. Discharge takes place between adjacent display electrodes, instead of scanning display electrode pairs one by one. This system, however, does not permit line progressive scanning by upper and lower discharge cells with the use of shared cells. This interlaced scanning can be operated by the drive circuits, which are the same as those in existing PDPs with 80 scanning lines. It does not require special high-speed addressing technology or dual scanning, which requires twice the usual number of driver integrated circuits. With this technology, it is possible to double the pixel definition by using the same manufacturing and driving technology as that for the conventional method. In other words, they can apply conventional methods to turn a VGA color PDP into an SXGA

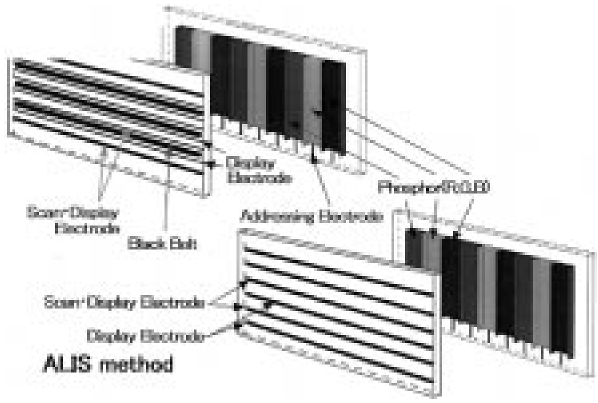

Fig. 6. Electrode structure of ALIS and conventional surface-discharge color PDPs.

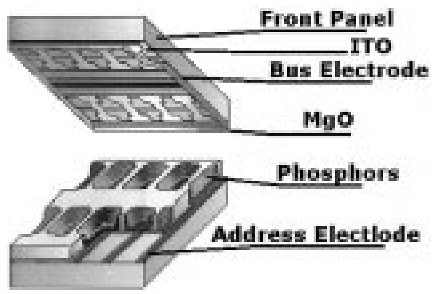

Fig. 7. Electrode structure of Pioneer's T-shaped electrodes are placed on the front panel. Waffle ribs are fabricated on the rear substrate.

PDP. But, the ALIS system itself does not improve luminance or luminous efficiency. However, the adoption of the method makes a nonluminous area unnecessary and raises the aperture rate to 65%. Furthermore, ALIS improved the luminance 50% from that of the conventional method by improving the phosphor material. By adopting the ALIS system, FHP made its 852×1024-pixel color PDP capable of displaying high definition pictures.

Pioneer devised PDPs with a high luminous efficiency and a high contrast ratio by adopting a T-shaped electrode structure, as shown in Fig. 7 [12]. The T-shaped electrode structure has proved effective for expanding the memory margin. Furthermore, it produces a favorable effect on luminous efficiency and contrast ratio. This has become known as Pioneer's own electrode structure. In the conventional system, the ribs on the rear plate side to which the RGB phosphors are applied, adopted a stripe structure. The waffle structure arranges these ribs in parallel crosses [13]. The waffle rib structure eliminates light leakage along the vertical direction and makes it possible to reproduce sharp image contours. At the same time, the arrangement can widen the per cell area of applied phosphors. The adoption of the T-shaped electrode structure and the waffle rib structure enabled PDPs with a luminance of 560 cd/m^2 (which is approximately 60% higher than that of the conventional system) and raises the luminous efficiency 40% and produces a color PDP with optimum high resolution.

D. Improvement of Drive Systems

Characteristically, many color PDPs now adopt software-based improvements, as well as hardware-based improvements such as the improvement of cell structures. Pioneer achieved a high contrast ratio of 560:1 and solved the problem of false contours by adopting the hi-contrast and low energy address and reduction of false contour sequence (CLEAR) system to achieve a hi-definition progressive display with excellent picture quality [14]. False contours occur because PDPs adopt the subfield method for gray scale. False contours always have been one of the most serious problems with PDPs. To diminish false contours, engineers previously resorted to methods that made false contours as invisible as possible. The CLEAR method resolved this problem by preventing the generation of false contours. Furthermore, the CLEAR system yields a color PDP with the same gamma characteristic as that of CRTs because it weighs the number of light emissions of each subfield.

The CLEAR system handles gray scale by using 12 subfields instead of the conventional method's eight subfields. With 12 subfields, the driving system is capable of supporting 13 gray scale levels. The interfield offset turn method adds another 25 levels of gray scale. With the addition of the dithering system and the error diffusion method, it is possible to form more than 300 levels of gray scale per color. The color quality of Pioneer's PDP has won favorable appraisal by color experts.

E. Future Prospects of Color PDPs

Laboratory research to improve the luminance, efficiency, and color quality of PDPs continues in a number of research laboratories around the world. One of the most recent innovative developments was the Meander structure reported by Betsui of Fujitsu Laboratories, a development akin to the waffle structure [15]. However, it is not clear whether this structure merely improves luminance and luminous efficiency by increasing the area of phosphor application (as shown in Fig. 8) or it is an inherent property. Nevertheless, the luminance and luminous efficiency of this structure are about double those of the conventional method.

Another approaches that are being studied to improve the performance were the idea of raising the concentration of Xe in the display. This method did not attract much attention earlier, as it did not solve the problem of the extra cost for the driver integrated circuits that must handle the additional driving voltage. Nevertheless, it certainly was effective in improving the luminous efficiency and luminance of PDPs. In a recent experiment, Yoshioka demonstrated that it is possible to prevent a rise in the driving voltage because of a high concentration of Xe by introducing a floating electrode that operated independently of the sustaining electrode, as shown in Fig. 9 [16]. Studies on the introduction of this electrode showed that the sustaining voltage rose to some extent but not as high as in the previous system. This method solved the problem of high voltage, while nearly doubling the luminance and luminous efficiency. It is interesting to note that

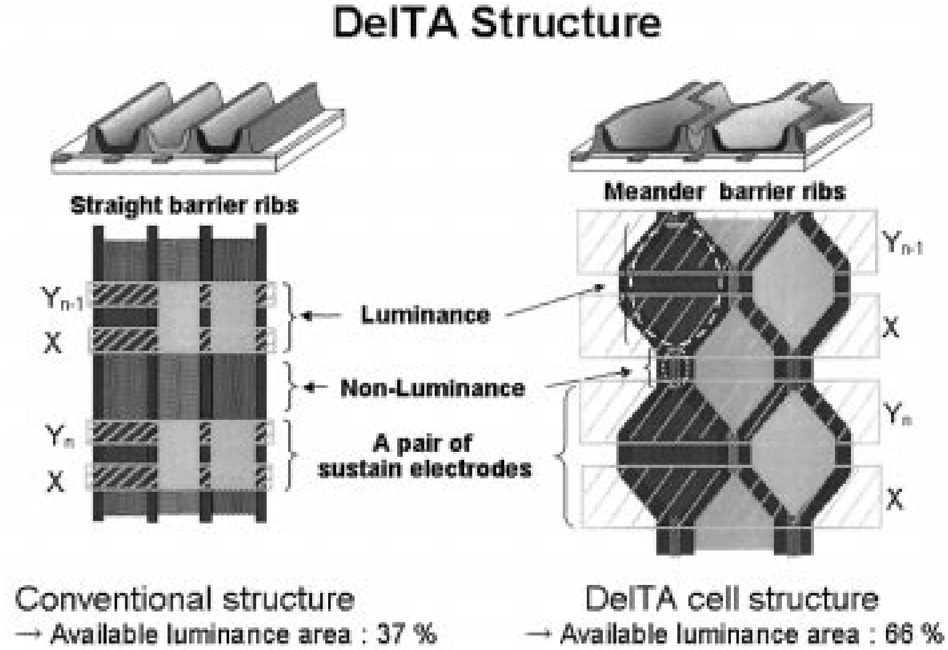

Fig. 8. Comparison between conventional and DelTA cell structure.

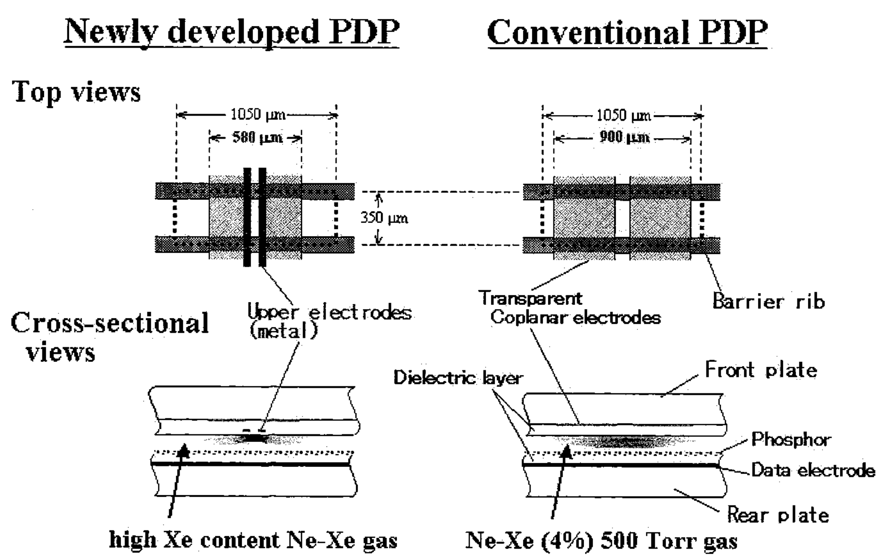

Fig. 9. Comparison between conventional and high Xe-concentrated color PDPs.

both the Meander structure and the high Xe concentration were effective in doubling the performance. Pioneer applied the concept of the high Xe concentration to their products by increasing Xe concentration from 4% to 10% in August of 2001 [17].

VI. Conclusion

It will take more than good luck for color PDPs to attain explosive growth. Ultimately, what will drive the PDP market will be continued improvements in the performance of color PDPs themselves. Every PDP makers is working on to reduce power consumption through improved luminous efficiency and improved component materials and manufacturing methods of color PDPs. With improvements in the cell structure and driving methods, there is a good prospect for achieving a luminous efficiency of 2–3 lm/W and a power consumption of about 200 W for 50-in diagonal size.

The levels of luminous efficiency and luminance that PDP makers have achieved are on par with performance levels of hi-definition CRTs. The achievement of a peak luminance of 1000 cd/m^2 without a nonglare filter or 400–500 cd/m^2 with a nonglare filter will give PDPs about the same values as those of color CRTs today. The addition of performance with 2–3 lm/W in luminous efficiency and at a power consumption of 200 W or less will open up a new world of large PDPs.

Those conducting research and development in color PDPs are not satisfied with a luminous efficiency of 2–3 lm/W, a peak luminance of 500 cd/m^2, and a power consumption of 200 W. The new targets for color PDP researchers are a peak luminance of 500 cd/m^2, power consumption of 50 W or less, and a color PDP thickness of 3 cm. Right now, these values are sheer fantasy. To attain these performance levels requires continued improvements in all areas and fundamental breakthroughs in discharge kinetics. Color PDP researchers and engineers at various manufacturing companies are beginning to explore possible directions for such a breakthrough. When will this fantastical color PDP become a reality? Everybody hopes that the development of such a color PDP will happen within five to six years.

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His current research interests include protecting materials for ac PDPs including, MgO.