Progress in plasma technologies for Extra-large Screen Displays

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Abstract: *A 42-inch plasma display was developed by Fujitsu Ltd. in 1995, which opened the door to the new world of large screen flat-panel displays. For these ten years, plasma displays have won on the great success story from both the business and technical points of view. The latest development enabled us to build a 100-in. plasma display, and some of the new technical approaches are going to achieve a new plasma display with a screen size of as large as over 200 inches. Especially, plasma tube arrays are to be noticed as the new technology that goes to achieve ultra-thin, light-weight, flexible displays. Prototype display of 0.5 x 1-m screen size was fabricated and its weight was measured at 0.6 kg.*

Keywords: PDP; FPD; Flat-panel TV; Large screen; Wall-TV; Plasma tube array; PTA; Flexible display.

1. Introduction

Plasma display panels (PDPs) have produced a new market of large-screen flat panel television (TV) featuring real and impressive image expression and have gone into the stage of continuous progress. The world's first full-color 21-in. diagonal PDP was developed in 1992 by Fujitsu [1] and the developed basic technologies of the color ac PDPs with that had several advantages that lead to future development for higher definition and larger screen. Based on the practical structure of PDPs which were suitable for large screen, the 42-in. diagonal color PDP was developed in 1995 [2], and the world of a new flat-panel large screen display was opened. PDPs have extended the market share steadily in the commercial display field by taking advantage of the flat panel, large-screen, and wide viewing angle in the 1990s. A 32-in diagonal PDP-TV had received attention in the market in 2001, which was the first year of broadcasting satellite (BS) digital HDTV broadcasting started in Japan. The number of products for consumer use exceeded the comercial use in that year, and that is called the first year of the plasma television era. Fig. 1 shows recent world market of PDP-TV. The number of sales has been doubled year by year, reaching around 5.9 million sets in 2005. The prediction for PDP-TV market has been often revised upward, because PDPs have been producing new application and new market in addition to replacing large CRT. In the situation, development for next-generation products has been powerfully promoted.

In the recent development, enlargement of the screen size has attracted attention. Fig. 2 shows progress in screen size of color PDPs since first 21-in. diagonal PDP was produced. The prototype PDPs of 80-in diagonal was announced in January 2004, and that of 103-in diagonal, which is the world's largest size, was announced in January 2006. Although the current main screen size of PDP-TV for home-use is between 40-in to

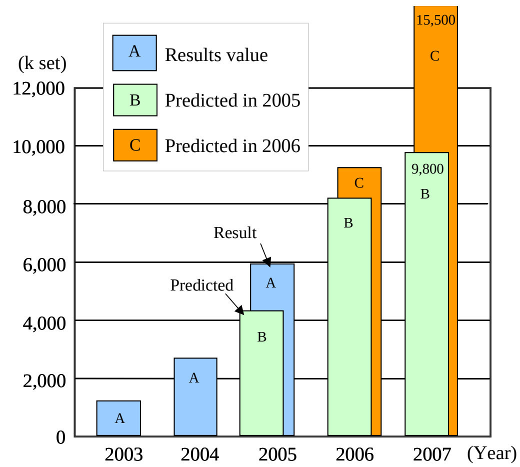


Figure 1. Market seize of PDP-TV

50-in, demand for larger screen-size increase gradually.

On the other hand, network services with digital video imaging are progressing toward ubiquitous with the spread of broadband and wireless networks. As flat panel displays will be the most important user interfaces in the ubiquitous network era, large-screen public displays which are set up in anywhere required places are receiving a great attention. A large-screen public display in several screen sizes from 40 to 300 inches diagonals such as extra-large wall-to-wall systems is required. Several technologies of over 100-in. diagonal were announced in these several years. Although PDPs

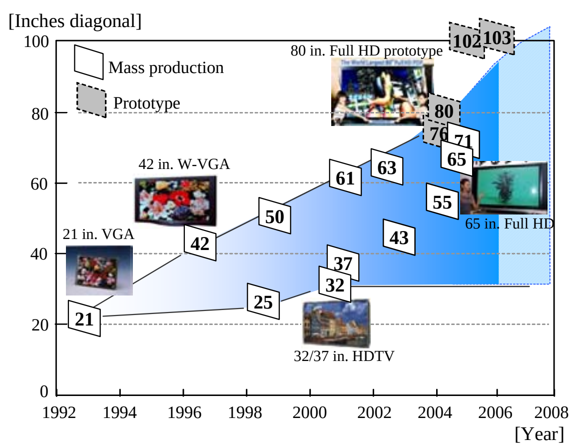


Figure 2. Progress in screen size of color PDPs

are gradually becoming larger because of advantages with enlargement based on their emissive and simple structure, fabrication of displays with over 100-in.

diagonals has two serious problems with the handling of large glass plates and the huge investments. We have been trying to solve both these problems and proposed plasma tubes arrays (PTAs) in 2002 [3] that provide a unique structure and fabrication process. PTA succeeds the basic advantages for large screen that PDP has essentially.

In this paper, the basic structures of conventional PDPs are reviewed and advantages for larger screen in PDPs and PTA are discussed. Then, progress in recent development of PTA is described. And a new world produced by extra-large screen PTA display is shown.

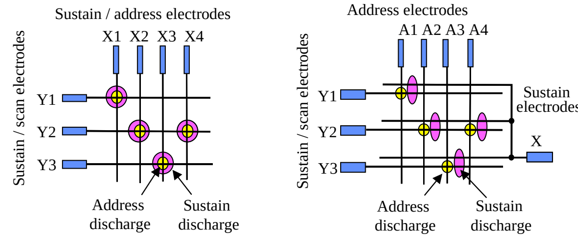
2. Progress in Plasma Display

2.1 Basic technologies for PDP Products

The principle of an ac PDP was invented in 1960s and the monochrome PDPs were put into the practical use with the opposed discharge technologies [4]. Fig. 3 (a) shows the two-electrodes opposed discharge configuration used for early stage color PDPs. At the development in 1970s, color ac PDPs had difficulty of achieving enough lifetimes due to the degradation of color phosphors caused by the ion bombardment with the opposed discharge.

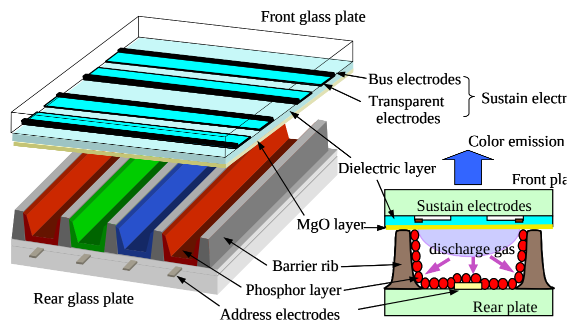
Fig. 3 (b) shows a three-electrode surface discharge invented by author in Fujitsu. The life problem was solved by developing the structure in the early 1980s [5]. In the structure, the parallel electrodes for sustain discharge were introduced on one glass plate and the address electrodes were arranged on the opposite glass plate in perpendicular direction to the sustain electrodes. With these separation, the address electrodes were released from the role of the power transmission and the sustain electrodes were able to be concentrated on the discharge power transmission. Therefore, the display system including drive circuit became simple.

In the late of 1980s, a new structure of reflective type was developed [6] to improve the luminance. And a new structure of the stripe rib and the stripe phosphor arrangement were developed for the practical structure used in full-color 21-in. diagonal PDPs production in 1992 [2]. These structures are shown in the fig. 4. In the reflective structure, the discharge occurs on the surface of the dielectric layer between a pair of transparent electrodes formed on the front glass plate. The phosphor layer on the rear glass plate is stimulated by the ultraviolet ray that emitted from the discharge and emits the color visible light. The emitted lights that reflect by the phosphor layer are also used in this structure. This stripe barrier ribs that are formed on the rear plate separates the discharge and the different color emission from the phosphor layer to avoid the color mixing. The phosphor layer is formed both on the bottom between the barrier ribs and on the sidewall of them. Due to the phosphor layer formed on the sidewall, wide-viewing angle were achieved. High accuracy aliment is not needed when the front and rear plates are assembled because the cell is determined automatically by the display electrodes and the barrier ribs. Therefore, this structure is good for the manufacturing of the large-area display. The basic process used in the production



(a) Two-electrodes configuration (b) Three-electrodes configuration

Figure 3. Progress in structure of color ac PDPs in 1980s



(a) Pane with the reflective stripe rib structure (b) Unit cell

Figure 4. Practical structure of the three-electrode ac PDP

consists of the common thick-film printing method and thin-film formation method. Therefore, the process is very suitable for the mass production of large screen. By comparison with the LCD technology, the process time is shorter and easier to produce the large area display since the PDP does not have the active device like TFT in the panel and also it has the simple structure, that has the barrier ribs, electrodes, phosphors, and so on, inside.

Because of pulse discharge in ac PDPs, the luminance has only the two states of ON and OFF. The luminance gradation depends on the number of discharge pulses. As for grayscale driving, the address-display period separation (ADS) subfield method shown in fig. 5 is

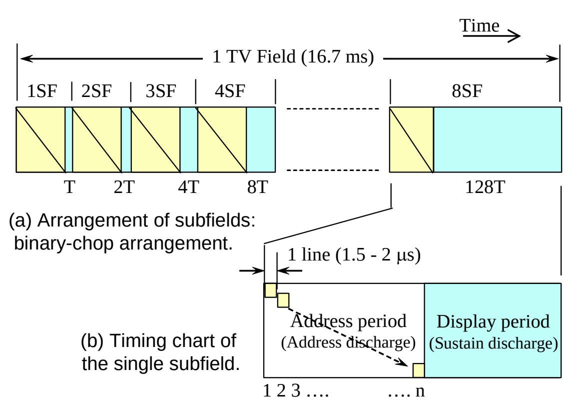


Figure 5. ADS subfield driving method

adopted for operating the ac PDP to meet the requirement and realizes a TV image with 256 grayscales [7]. Fig. 4(a) shows an example of subfield arrangement called a binary-chop arrangement type used in the early system. As shown in (b), the address period to select the pixel to be lit and the display period to provide a luminance are separated exactly. In the ADS method, as the display period can be configured without limitation by the other period, the various arrangements of display pulses in every subfield are proposed for improving image quality [8]. Since various control of operation is applicable, power-saving by controlling luminance according to image source is possible.

2.2 Advantages in PDPs for large screen

Advantages in PDPs for larger screen size are summarized in table 1. With surface discharge structure, intensity and firing voltage of discharge are stable even if in larger screen by controlling the gap and the area value of the parallel electrodes. With three-electrode structure and ADS driving method, as providing for discharge power and that for image data are separated by different electrodes and different sequence as shown in fig. 3 and fig. 5, driving control is easy even if in larger screen. With reflective strip rib structure, extra-wide view angle and high luminance are possible, which are great advantages for large-screen commercial system.

Table 1. Advantages in PDPs for larger screen size

Basic technologies	Function in PDPs	Advantages in large screen
Surface discharge	Discharge and emission	Stable pulse discharge and emission life
Three-electrodes	Control of address and display electrodes	Easy control for power and driving
ADS driving	Gray scale control	Easy control for image quality and power
Reflective stripe rib	Separation of color and discharge	High luminance, wide view angle and wide process margin,

3. Approaches for Extra-large Screen

3.1 Display system in the current and future market

As shown in fig. 2, the first 21-in. PDP product was produced in 1993 and the first 42-in. color PDP product was produced in 1996 by Fujitsu. They had resolutions of 640 x 480 and 852 x 480 pixels respectively, and had peak luminance of 250 cd/m^2 that was one fifth of latest products. Although the performance of them seemed not to be enough, they were accepted in new market of large public flat-panel display (FPD). The screen size has been increasing in these 10 years, and the maximum screen size of the current PDP product for consumer-use is 65-in. diagonal, and is enough large as home television. However, development for further large-screen is continued like the 103-in. model.

Fig. 6 shows the market of direct-view display and entry of devices and the subsequent growth that were accepted in the market until now. In this figure, the market is roughly divided into three segments of usage by the horizontal axis, and is divides into screen size by the vertical axis.

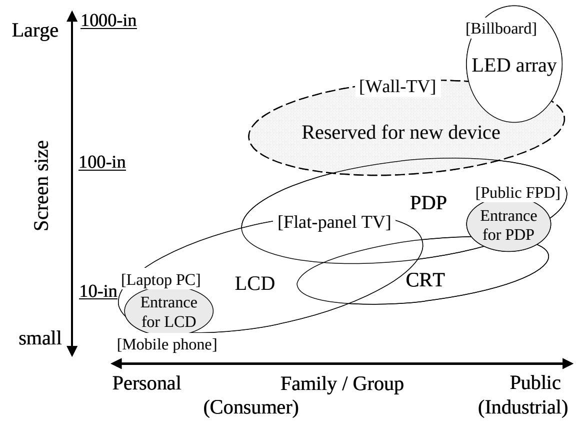


Figure 6. Market area of direct-view displays

In the CRT era of until 1980s, there were no competitive devices for CRTs in the direct-view display market, and the display system had developed within the limits of the size and performance which CRTs had. Although CRTs had great advantage of cost and quality, in the 1990s, PDPs and LCDs came into the entry market by taking the advantage of their screen size and thickness that was unrealizable for CRTs. PDPs got new market of commercial FPD that was entrance for PDPs to establish their position in the market. PDPs had improved their performance and reduced costs gradually, and had succeeded in creating a new consumer market of flat-panel TV in the start year of 21st century. Since this market is very big, LCDs also extended their screen size rapidly and entered into the market. On the other hand, LED array display was accepted in outdoor extra-large display by taking the advantage of high luminance against for the daylight.

In the fig. 6, we can find the market area for extra-large screen over 100-in. is still remained. A new display device which has ability of not only screen size but also thin, light weight, low power consumption, and high resolution will be able to enter the new market for a wall-TV in near future. Plasma technologies have sufficient potential to get the new market.

3.2 Advantages in Plasma Tube Array Structure

The projector is most popular to get large-screen, however, there are some restrictions such as long distance for projection and low luminance. Therefore, direct-view type large-screen FPDs are strongly desired.

Basic structures of three types of array technologies for large-screen and one plate type technology are examined as direct-view type displays in fig. 7. When the number of the production volume is not so much, the array method is effective to obtain an extra-large screen. In the case of the array by panels like PDP and LCD, since there are sealing areas around the panel, the seam will remain and the weight is heavy. In the case of the array

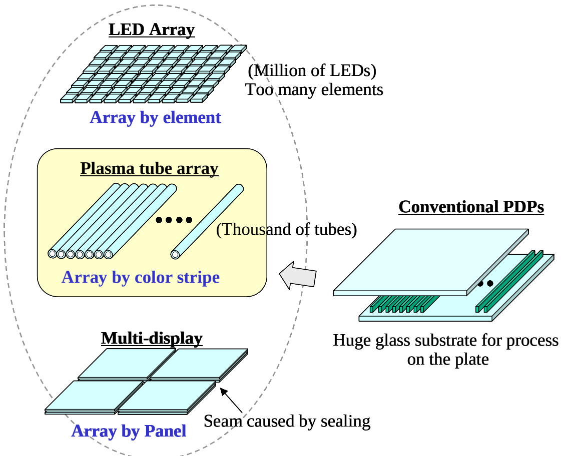


Figure7. Evaluation of basic structures for large screen

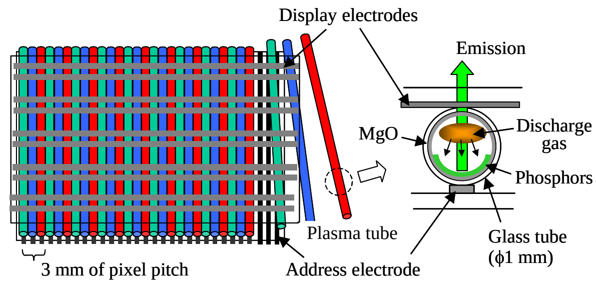
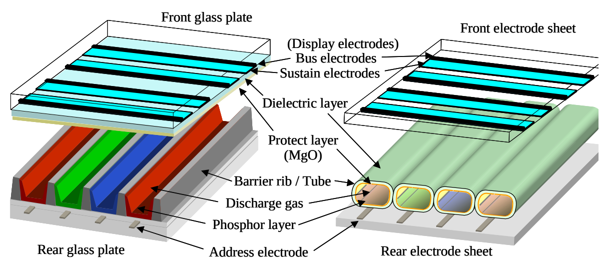


Figure 8. Basic structure of PTA



(a) PDP (b) PTA

Figure 9. Comparison of each element in panel structures

by small element like LED, the seam is not a problem. However, to put million of elements, cost is high, and the system is very huge and heavy. If an emissive structure as in a color PDP can be formed in a fine glass tube, an extra-large screen can be formed by arranging them in order. And the problem of seam can be solved and the number of the elements can be reduced.

As shown in Fig.8, the entire structure for the PTA we developed was composed by arranging plasma tubes in RGB order according to phosphor emissions. The plasma tube has the same emission structure consist of phosphor layer, MgO protection layer, and discharge gas inside the thin glass tube as PDPs. The display electrodes are formed on the sheet, and they are contacted to the tube surface outside the tubes array. The diameter of the glass tube is designed to be 1 mm to make the pixel pitch of the display to be 3 mm that is match for the image format of 720p in 150-inches class and that of 1080p in 250-inches class diagonal.

Since this display consists of small tubes, it has many advantages. Screen size is expandable without seam. The luminous efficacy is higher than plasma display because of the large cell size. Clean room is not needed for the production because of the cavity structure. Also only small facility is needed for the production to make such a small tube structure. Therefore investments for production can be much cheaper than other large-screen display.

4. Development of Plasma Tube Array

4.1 Basic Design of PTA

Figure 9 compares each element in the structures for PDPs and PTAs. The dielectric layer in PDPs is equivalent to the glass tube in a PTA. The shape of the sustain electrode determined by the ITO pattern in PDPs is determined by the contact area of the electrodes and the glass tube surface in PTAs.

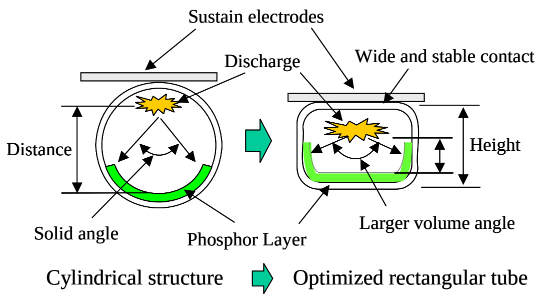
Adapting to the tube structure and dimensions for PTAs, the sustain gap, discharge gas, and gas pressure was optimized. To raise luminous efficacy using advantage of large space for discharge, the wall thickness of glass tube and discharge gap was optimized to be 100 μm and 400 μm respectively. Although some glass tube parameters caused increase of firing voltage, reducing discharge current by thickening the dielectric layer, luminous efficacy can be rise much. Current density in PTAs decreases to one sixth that of PDPs. Gas pressure was determined to be 450 hPa according to discharge gap expansion and firing voltage reduction.

In a screen with a 200-in. diagonal, the display electrode length is several times that of PDPs. Consequently, increased voltage drop due to resistance and inductance of the electrode and power loss due to capacitance between electrodes are problems. The problem with electrode resistance can be solved by increasing the bus electrode thickness. Although bus electrodes in conventional PDPs are a few micrometers thick, in PTAs, ones over 10 micrometers are available [9]. The dielectric constant of the substrate were designed to reduce the capacitance between the sustain electrodes, and the capacitance per unit length was aimed at about 1/5 of that in PDPs.

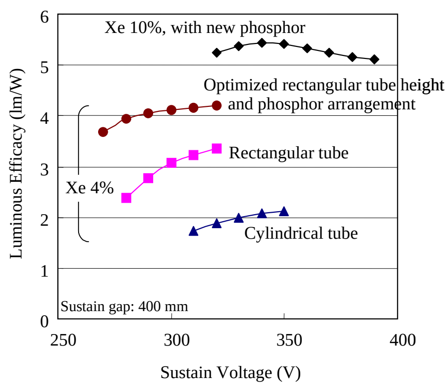
4.2 Technique for High Luminous Efficacy

High luminous efficacy is needed for PTA because of its power consumption for large screen size. Higher than 5 lm/W is our target for the PTA system. A cylindrical tube was used in the early stage of development, and as its luminous efficacy was 2.3 lm/W [2]. In plasma tube, the discharge can be observed easily from side and top at the same timing, so we investigated the discharge and optimized the tube figure and the phosphor layer figure.

The shapes of improved tubes are shown in Fig. 10 (a). The rectangular tube was introduced [10]. The height



(a) Improved tube structures



(b) Measured luminous efficacy

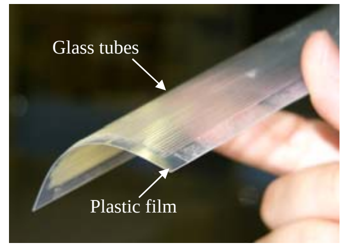
Figure 10. Development of device structure of PTAs for high luminous efficacy

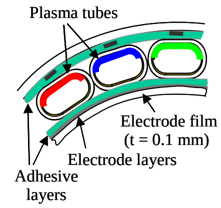
and shape of the rectangular tube were optimized. Fig. 10 (b) plots several stages of progress with luminous efficacy with test arrays using a 20-cm-long tube. With the rectangular tube, the distance between discharge and the phosphor were closer and the solid angle from discharge to the phosphor layer is larger. The rectangular tube had 1.8 times higher luminous efficacy than that of cylindrical tube. Even with plasma tubes, high luminous efficacy can be expected with high Xe content as well known in PDPs. With a 10% Xe discharge gas mixture and a gas pressure of 450 hPa, high luminous efficacy of 4.9 lm/W was achieved. We also tested a new phosphor material and very high luminous efficacy of 5.4 lm/W was achieved with sufficient memory margin [10].

4.3 Technique for Flexible Screen

PTAs are possible to curve a display screen depending on how the glass tubes are placed in order; however, a flexible substrate is needed to achieve a curved screen. As PTAs has the electrodes outside the tubes, the plastic film can be applied to the electrodes plate as shown in fig. 11(a). A stable fixing method is needed to prevent gaps between the tube and the sheet. A technique of fixing these with adhesives on both sides of the plasma tube between the front and back electrode sheets has been developed as shown in fig. 11(b) [11].

The 0.5 x 1 m experimental array using 1-m-long tubes was fabricated. The array shown in Fig. 12(a) was flexible and less than 1-mm thick and its weight was 0.6 kg with the plastic film electrode and glass tubes. Fig.

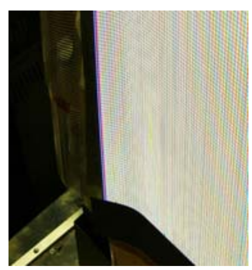


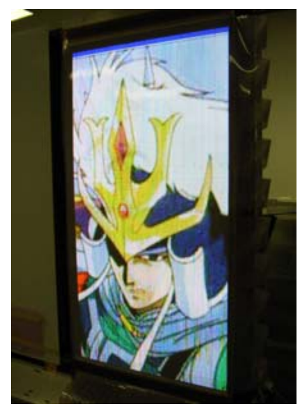


(a) Glass tube array with plastic film (b) Structure of adhesion

Figure 11. Flexible array with film electrode

(a) Flexible and light array





(b) Partially curved display (c) Display at dynamic operation

Figure 12. Test display of 0.5 x 1 m tube array

12(b) shows a partially curved display by the array. Fig. 12(c) shows a dynamic operation with 60Hz color video image. The luminance of the display was 600 cd/m2 at 60 kHz and 300 V of sustain pulse. The luminous efficacy was 3.7 lm/W at a Xe content of 4% [12].

In the next step, we aim at improving image quality and fabricating a larger size prototype. Stable manufacturing process technology is also needed to establish reliable arrays.

5. Future World of PTA Technology

In the next broadband network age, a large screen display is used as the tool of real communication, which connects people together in a visual space with life size

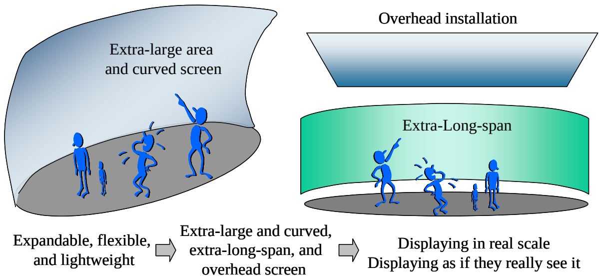
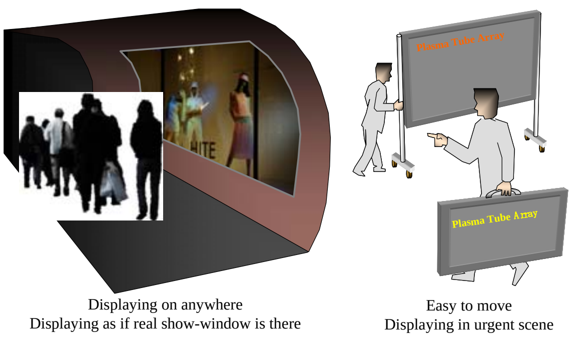


Figure 13. New world produced by PTA



(a) Thin and curved large array (b) Extra light-weight array

Figure 14. New applications with PTA

picture that helps them share information directly and participate in a shared environment, and a tool which advertises information to many people with emotional image in the public display field. As shown in Fig. 13, if the extra-large screen exceeding 150-in diagonal with a PTA system which cover a full of human view angle and the presence puts in practical use, a life-size display communication, a virtual experience service, will be attained. It is expected that the new market of transmitting information using an image with a reality will be created. Fig.14 shows some ideas of new applications with PTAs. Thin and curved large area PTAs will provide a real image in life size on anywhere such as inside building, shopping arcade and underpass. Light-weight is the most attractive feature of PTAs, so an extra-light weight array in 100-in. class will be produced for a portable large display that will be useful in the urgent scene.

6. Conclusion

The PDP has essential advantages, such as high-speed response with emissive, an extensive viewing angle, an easy manufacturing for making large screen over LCD in large-screen field. The new technologies of PTA for extra-large screen were developed and are progressing towards practical use. An experimental tube array display and its performance were demonstrated. With PTAs, plasma technologies will show the synergistic effect, and PDPs and PTAs will continue raising its advantages and providing a new applications and market of between from 30-in. to 300-in. class screen size.

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