Plasma display technologies for large area screen and cost reduction

Article *in* IEEE Transactions on Plasma Science · May 2006

DOI: 10.1109/TPS.2006.872453 · Source: IEEE Xplore

Tsutae Shinoda
Shinoda plasma co.Ltd.,Japan,Awaji

Plasma Dispaly Technologies for Large Area Screen and Cost Reduction

Tsutae Shinoda and Kenji Awamoto

***Abstract*—In this paper, the basic technologies of alternating current (ac) plasma display panel (PDP) and the next-generation technologies are described. The panel structure of reflective type and three electrodes with surface discharge, and the basic operation of address display-period separation (ADS) subfield method have been developed for PDP products, and these basic technologies have the capabilities which can respond to next-generation development, such as high luminous efficacy, low cost, and enlargement of the screen size. In the recent research, the technologies that provide three times the luminous efficacy comparing with that of latest PDP products and innovative manufacturing process technologies for drastic cost reduction have already been developed. How we install the new technologies in the products is an important subject. PDPs will keep advantages in a large screen flat panel display market by the technical development for the next-generation in each field.**

***Index Terms*—Address display-period separation (ADS) subfield method, alternating current plasma display panel (ac PDP), luminous efficacy, three-electrode with surface discharge.**

I. Introduction

PLASMA display panels (PDPs) have produced a new market of large-area-screen flat panel television (TV) featuring real and impressive image expression and have gone into the stage of continuous spread. PDPs have extended the market share steadily in the public display field, taking advantage of the flat panel, large-screen, and extensive viewing angle since the 42-in diagonal PDPs had been put into the large-area-display market for the first time in 1996. A 32-in diagonal PDP-TV had received attention in the market in 2001, which was the first year of broadcasting satellite (BS) digital high-definition television broadcasting started in Japan. The number of products for home use exceeded the business use in that year, and that is called the first year of the plasma television era. The number of sales has doubled every year, reaching around 2 700 000 sets all over the world in the 2004 fiscal year. In such a market situation, development of technology toward a next-generation product has been powerfully promoted, and promising new technologies have begun to be reported.

In the recent product development, enlargement of the screen size has attracted attention. The prototype PDPs of 80-in diagonal was announced in January 2004 and that of 102-in diagonal, which was the world's largest screen size, was announced in December 2004. Although the products of screen size between 40-in and 50-in are expected to take the lead in PDP-TV, demand is being extended in the larger-screen-size direction.

On the other hand, many technologies for improving luminous efficacy and the results of installing these technologies in the product application have recently been proposed. Many manufacturing process technologies for the reduction in cost have also been announced.

In this paper, the basic technology used for the PDPs product and the next-generation technologies proposed recently are described.

Manuscript received June 16, 2005; revised November 13, 2005.

T. Shinoda is with the Fujitsu Laboratories, Ltd., 674-8555 Akashi, Japan. He is also with the Institute of Industrial Science, University of Tokyo, 106-0032 Tokyo, Japan (e-mail: shinoda@fujitsu.com).

K. Awamoto is with the Shinoda Fellow Group, Fujitsu Laboratories, Ltd., 674-8555 Akashi, Japan (e-mail: awamoto.kenji@jp.fujitsu.com).

Digital Object Identifier 10.1109/TPS.2006.872453

II. Basic Technologies for Color ac PDPs

The basic technologies of color ac PDPs were established by the first half of the 1990s when the 21-in diagonal color PDP was developed [1]. Then, a large-screen, high-definition, and high-quality picture technologies have been developed for the plasma television product. In this section, the basic structure and the driving method are introduced first, and then the advantages of these basic technologies are reverified.

A. Basic Structure

The ac PDP was invented in the 1960s and the monochrome displays were put into the practical use with the opposed discharge technologies [2]. However, at the early stage of development, color ac PDPs had difficulty achieving a long lifetime due to the degradation of color phosphors caused by the ion bombardment with the opposed discharge [Fig. 1(a)].

In the 1970s, a surface discharge PDP with phosphor system for a segment display was researched [3], and also a single substrate PDP of matrix structure for a monochrome display was proposed [4]. A color PDP of matrix structure by using the surface discharge technology was investigated, and it was confirmed that the phosphor's life was prolonged greatly [5]. Furthermore, the life of the electrode caused by sputtering at the intersection of the electrode matrix has also been improved by developing a three-electrode structure invented by one of authors in the early 1980s [Fig. 1(b)]. There was no electric field concentration between two parallel electrodes compared with that between rectangular electrodes, so the three electrodes were introduced as parallel electrodes for sustain discharge on one substrate and address electrodes on the opposite substrate in perpendicular direction to the sustain electrodes [6].

Since the number of the electrodes for a unit cell increased from the conventional two to three, the three-electrode structure seemed to be complicated. However, by separating address discharge and sustain discharge clearly, the display system including drive circuit became simple.

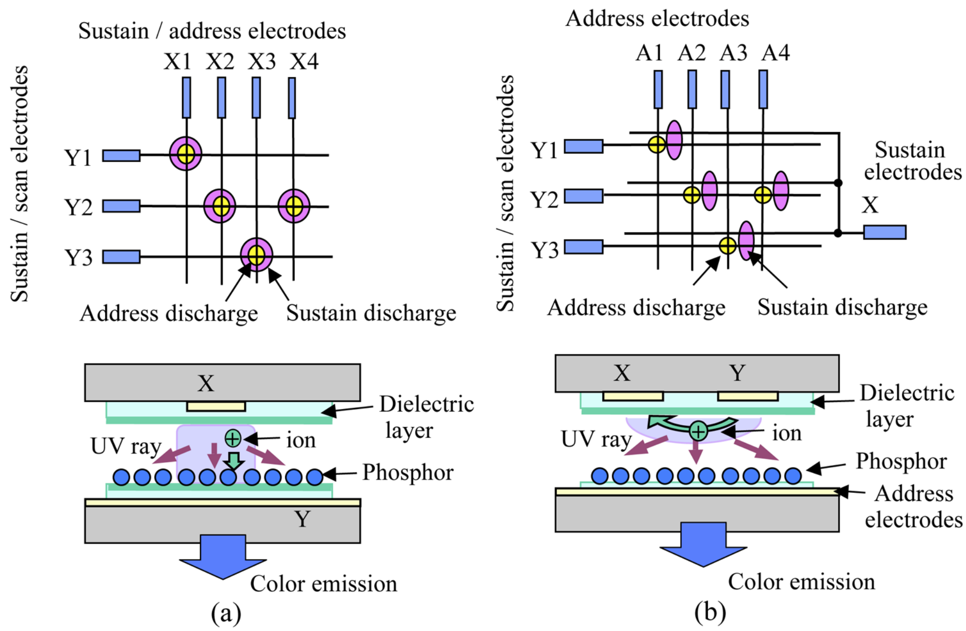

Fig. 1. Progress of the electrode configuration in color ac-PDP. (a) Two electrodes opposed discharge type. (b) Three electrodes surface discharge type.

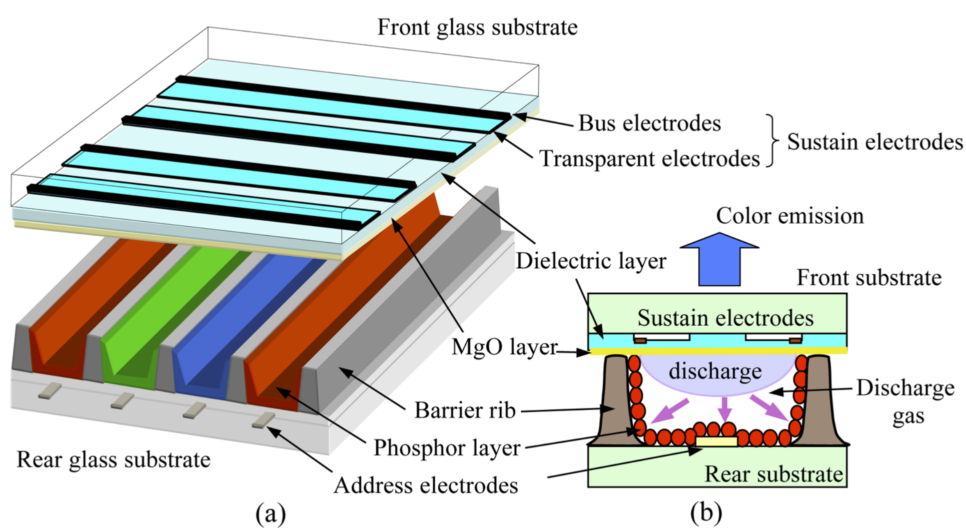

Fig. 2. Practical structure of the three-electrode ac PDP. (a) Panel structure with the stripe rib. (b) Unit cell of reflective structure.

The development of the three-electrode structure was continued mainly for the improvement of the luminance. The cell structure, as shown in Fig. 1(b), was called "transmitting type" because the emitted light from the phosphor was transmitted through the phosphor layer. In this structure, the luminance was reduced so much because of the absorption in the phosphor layer. To resolve this issue, the structure, as shown in Fig. 2, the so-called "reflecting type," was developed [7]. In this structure, the discharge occurs on the surface of the dielectric layer between a pair of display electrodes formed on the front plate by supplying alternating voltage pulse to them. The barrier ribs are formed on the back plate to separate 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. The phosphor layer on the back plate is stimulated by the ultraviolet ray that emitted from the discharge and emits the red, green, and blue visible lights depending on the phosphor materials. The lights that reflect from the phosphor layer are used for the display image. Due to the increment of the area of the phosphor layer and the lack of the absorption of emitted light by the phosphor layer, the luminance increases largely. Moreover, this phosphor layer formed on the sidewall of the barrier rib achieves wide-viewing angle. High accuracy aliment is not needed when the front and back plates are assembled because the cell is determined automatically by the pair of the display electrodes and the barrier ribs. Therefore, this structure is good for the manufacturing of the large-area display.

B. Basic Fabrication Process

The manufacturing processes have been developed for the structure. The panel manufacturing process is shown in Fig. 3. The processes ware divided into (a) the front plate processes and (b) the back plate processes. After these processes, two

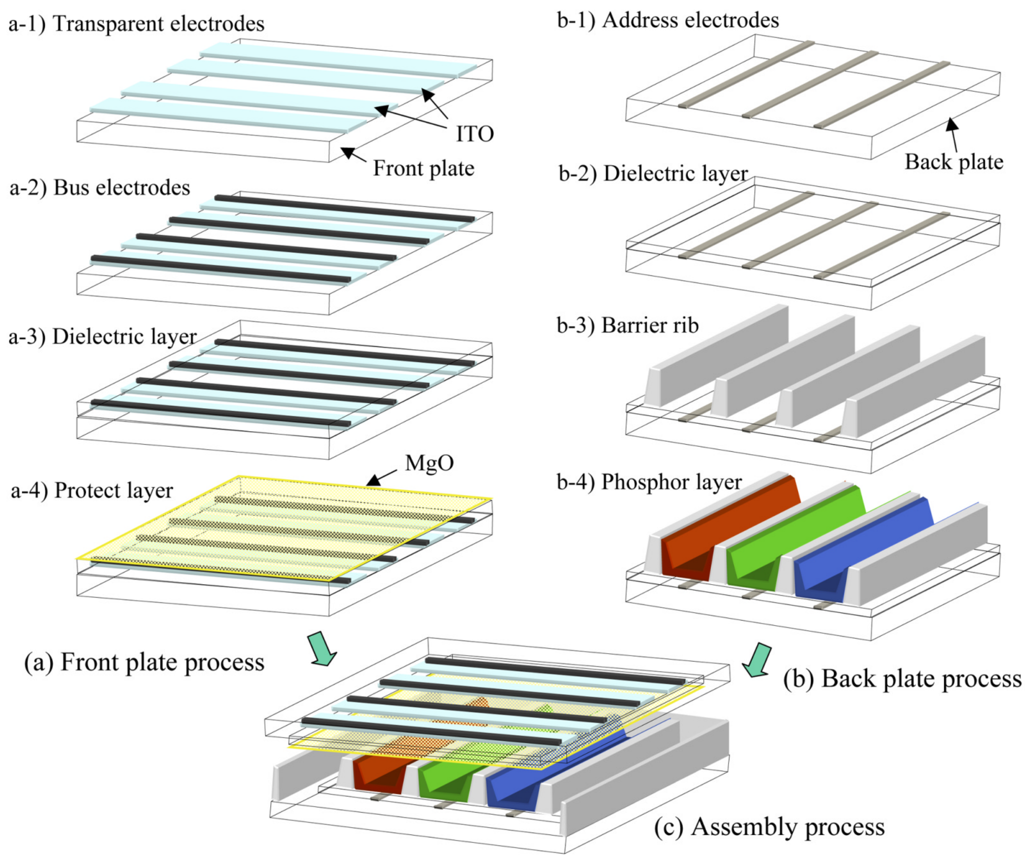

Fig. 3. Basic fabrication process for panel.

plates are assembled and discharge gas is introduced between the plates, as shown in Fig. 3(c), and then the PDP panel is completed. The driving circuit and the chassis are assembled to the panel and the PDP module is completed. The principal manufacturing technologies in each process are outlined as follows.

Indium–tin–oxide (ITO) thin film is used for the transparent electrodes [Fig. 3, (a-1)]. The film is formed by the vacuum deposition method and it is shaped as a pair of electrodes by the photolithography technology. Then a narrow metal electrode (bus electrode) is formed on the transparent electrode to avoid the voltage drop due to the high resistance of the transparent electrode [Fig. 3 (a-2)]. Silver paste that is an application material consisted of silver particles, organic binder, and solvents used for forming the bus electrode, and it is also shaped by the photolithography technology. The address electrode [Fig. 3 (b-1)] is formed in same way. The dielectric layer [Fig. 3 (a-3) and (b-2)] is very important for the ac PDP, and it contains much know-how. The glass paste that is a mixed low-melting glass powder with organic binder and solvents is coated on the front plate with display electrodes by screen printing or sheet laminate method. Then it is burned out in about 600 °C and the transparent glass dielectric layer is formed on the front plate. It is very important to control the thickness of the dielectric layer and the dielectric constant because the layer achieves the function as the capacitor, and it also affects the strength of the electrical field. The protecting layer [Fig. 3 (a-4)] is MgO thin film, and it is formed by the vacuum deposition method. The protecting layer not only has the function of the protection for the dielectric layer but also has the function to stabilize the firing voltage of the discharge. Therefore, the uniformity of its characteristics is very important. The material of the barrier rib [Fig. 3 (b-3)] is low-melting glass, and it was formed by the screen printing method in the early period of the development. However, the sand blasting method was developed for higher accuracy and fine resolution. So, many shape variations become possible with this method. In Addition, the photolithographic method with photosensitive rib paste material has been developed for practical manufacturer. The phosphor layer [Fig. 3 (b-4)] is formed by the printing method. The red, green, and blue phosphors are printed separately on the back plate with the barrier ribs. Then it is dried and baked to form the phosphor layer. The front and back plates are assembled to each other with a plate gap of about 150 um. An Ne + Xe gas mixture is introduced between two plates.

The PDP process uses the common thick-film printing method and thin-film formation method. Therefore, the process is very suitable for the mass production of large-area 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.

C. Basic Operation

A picture display is performed by controlling the two states of ON and OFF in ac PDP. The luminance depends on the number

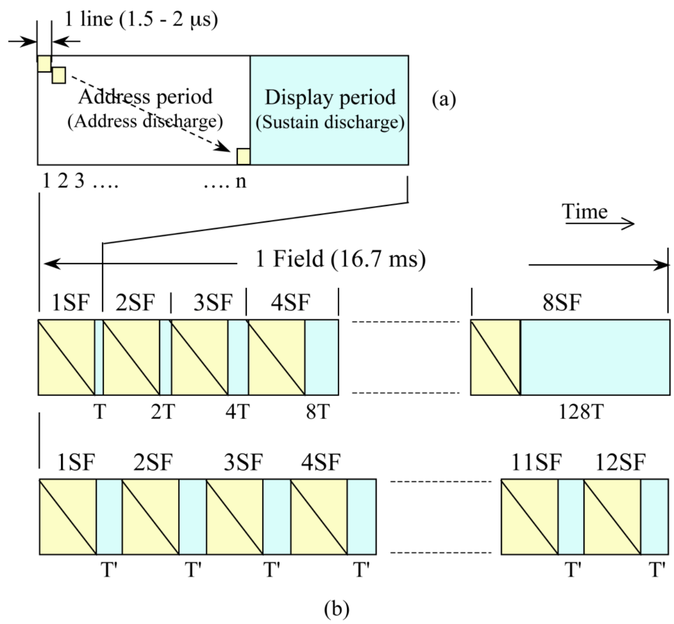

Fig. 4. ADS subfield method. (a) Timing chart of the single subfield. (b) Arrangement of subfields: binary-chop (upper) and equal (lower) arrangement).

of sustain pulses. As for grayscale driving, the address–display period separation (ADS) subfield method shown in Fig. 4(a) is adopted for operating the ac PDP to meet the requirement and realizes a TV image with 256 grayscales [8]. 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 [9], [10]. Fig. 4(b) shows two examples of subfield arrangement. One is a binary-chop arrangement type in early system that has a false contour problem, and another is an equal arrangement type in which grayscale is interpolated with signal processing and canceled the false contour. The features brought from the basic operation that the address operation and the display operation were separated clearly are as follows.

1) Various waveform and a drive systems are possible for an address electrode and a display electrode, respectively.
2) Since various control of operation is applicable, power-saving by controlling luminance according to image source is possible.
3) High peak luminance and a delicate gradation expression are possible.

These features brought by the basic operation, the basic structure, and a manufacture process described above will also cause technical advantages such as high flexibility of the structure and the driving method, in future development on PDPs.

III. Technologies for the Next-Generation PDPs

A. Directive for the Development

The development issues and the technologies for the next-generation PDPs are shown in Fig. 5. As picture quality has progressed, the main requirements of the market are low power consumption and low cost. To enlarge the screen size further, the subject of power consumption should be solved first.

Reduction of power consumption used by the manufacturing and development of a component with low environmental load are also furthered. The technologies for the reduction of environmental load are important to push the PDPs to the next stage. Although it may increase the cost of the manufacturing process in factory, it may enhance the cost competitiveness in the end. In terms of the screen size, 40–50-in diagonal will be still main products in the market; however, larger size products are also in demand. So, the developments for larger screen size and for higher resolution are important.

In the case of PDPs, using larger substrate is not only the way to bring lower costs because the panel production cost does not have big ratio in total cost not like liquid-crystal displays (LCDs). Since the technologies of PDP are not completed yet, many new manufacturing processes exist. It is very important to select the effective process technologies for future production.

The luminous efficacy of the PDP product is currently almost 1.5 lm/W and the maximum power consumption of 42-in diagonal TV set is about 300 W. As shown in Fig. 6, the maximum power consumption of direct view displays depends on the display area size and that of LCD and PDP is almost same. In the case of PDPs, the actual power consumption depends on the display image and is usually 20%–30% lower than the maximum power consumption. So, there is no difference in power consumption between PDP and LCD. But the power consumption should be low even if the size becomes large. The next target of luminous efficacy is 3 lm/W. In this case, the power consumption of 42-in diagonal TV set will be about 200 W. This is lower than that of 32-in diagonal CRT TV set, which is popular for consumers now, so replacement from CRT will progress. Also, this is lower than that of the same size LCDs in displaying the normal TV program.

B. Technologies for High Luminous Efficacy

In recent technical development, not only improvement techniques in luminous efficacy but also techniques that address speed improvement and drive voltage reduction are proposed for installing in products. Improving the aperture ratio and vacuum ultraviolet (VUV) radiation are very important to get a high luminous efficacy. The delta cell arrangement is proposed to maintain a high aperture ratio. PDP using meander ribs that produce over 3 lm/W of luminous efficacy [11], using a high efficiency rib and its optimized electrodes (HERO) structure [12], and segmented electrode in delta color arrayed enclosed subpixel (SDE) structure [13] are reported.

The various experiments are reported to improve the VUV radiation efficiency. The luminous efficacy is increased as the Xe content of discharge gas is increased. Fig. 7 shows a relation between Xe content in discharge gas and luminous efficacy collected from several research reports.

Pioneer has adopted high Xe content discharge gas in the product shipped in the end of 2001 [9]. Samsung SDI has also announced the prototype experimental model of high Xe content [14]. These are summarized as a product level and as a prototype production level in Fig. 7. Phillips Research Laboratory reported 5 lm/W of luminous efficacy using a small panel set to 50% of Xe content on the experiment level [15]. Seoul National University has reported the effect that applied high Xe content

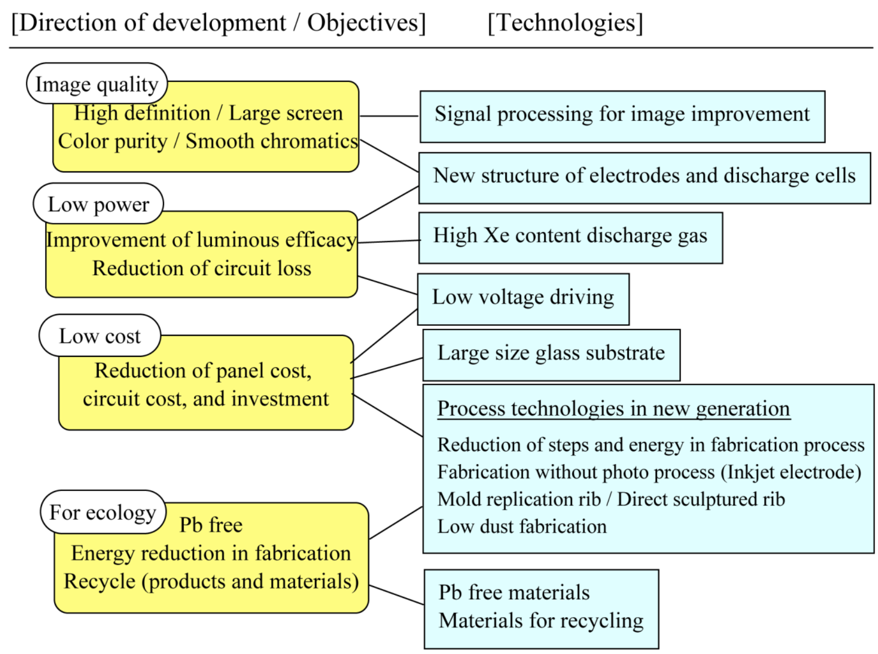

Fig. 5. Direction of development, objectives, and technologies for PDPs.

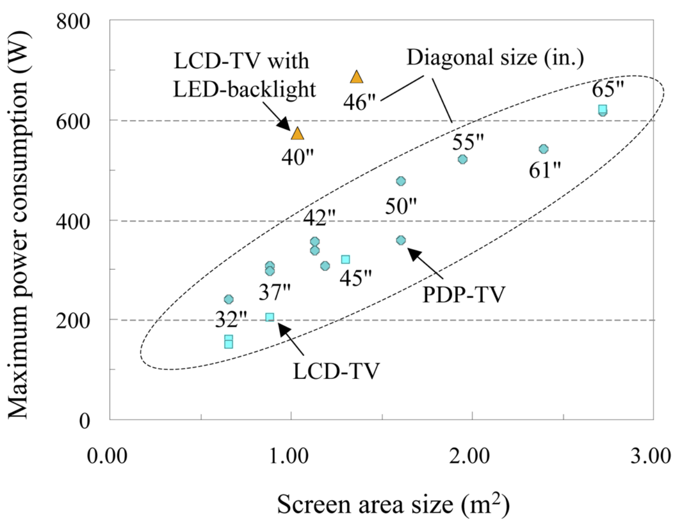

Fig. 6. Power consumption of the direct view displays.

discharge gas to SDE structure [13]. Although these cannot be simply compared since the detailed setup and evaluation conditions differ from each other, the luminous efficacy of 2 lm/W in product level still has distance from that of 5 lm/W in the small panel experimental level. This is because that sustain voltage, address speed, and drive margin should be taken into account in the production level.

Fig. 7(b) shows the relation between luminous efficacy and sustain voltage for some panel designs. The experimental values by different high luminous efficacy techniques were compared. At Fujitsu Laboratories, the luminous efficacy of 3.7 lm/W has been obtained by adding a high-voltage part in the front edge of sustain pulse [16]. Fujitsu Laboratories also reported 4.7 lm/W in the plasma tube which has three times the cell size of conventional PDPs and the design of sustain gap 0.4 mm [17], [18].

As shown in the figure, luminous efficacy and sustain voltage have a proportional relation roughly no matter what technology may be adopted. This fact causes a barrier of product application of techniques for high luminous efficacy. Both the high-voltage driving technique for circuit, lowering the discharge voltage technique, and low capacitance design for panel become important in order to suppress a circuit cost.

C. *Next-generation Process Technology*

As the continuous effort to improve the main manufacturing processes in PDP production factory was done almost ten years since the mass production started, it became very stable. It, however, is still important to develop competitive new technologies in manufacturing process to bring the cost reduction and the environment load reduction. From the cost and environment load view, the next-generation technologies will be reviewed below.

For the electrode forming process, the inkjet printing technology without photolithography process has been investigated in 2002 [Fig. 8(a)] [19]. In this case, the electrodes are formed by the inkjet printing method on the back plate with meander ribs that were formed by the direct glass sculpting method [20]. The plating method was also investigated to form the electrodes in 2003 [Fig. 8(b)] [21].

The inkjet printing method does not use the photolithography process resulting in low cost. In the case of the plating technology, the photolithography process still remains, but the cost of the materials and the facilities will be greatly reduced. Also, it can realize thicker electrodes than the conventional one, and the lower electric resistance can be realized. The thickness of the conventional electrode is about 1–2 m but with this plating technology, it can be more than 5 μm, as shown in Fig. 8(b). With this low-resistance electrode, the width of bus electrode can be narrower so larger cell aperture ratio and the more controllable discharge will be expected.

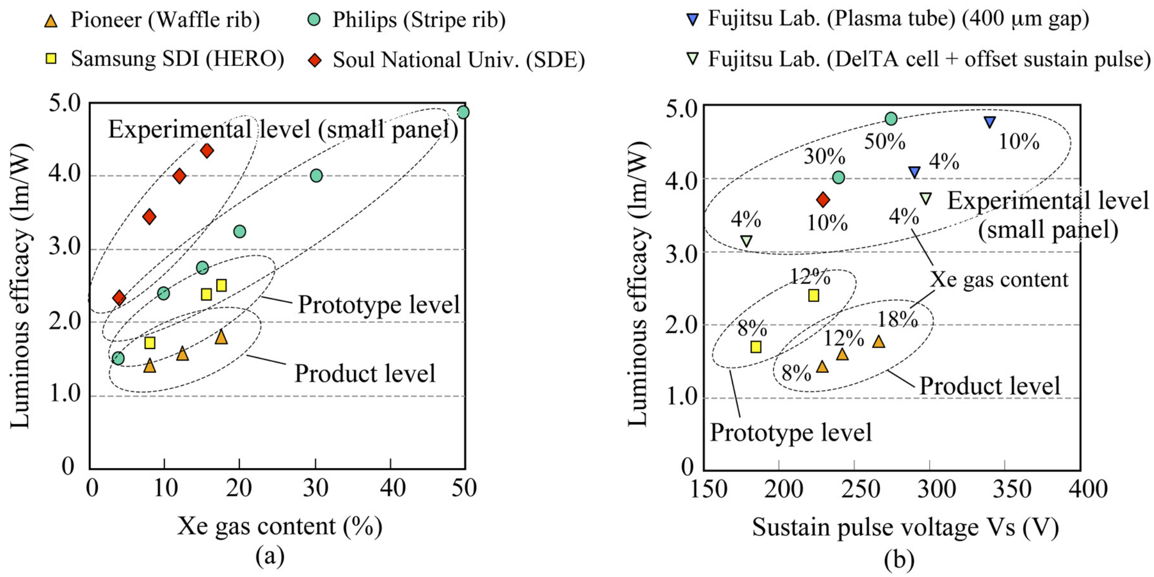

Fig. 7. Examples of development for high luminous efficacy. (a) Xe gas content and luminous efficacy. (b) Sustain pulse voltage and luminous efficacy.

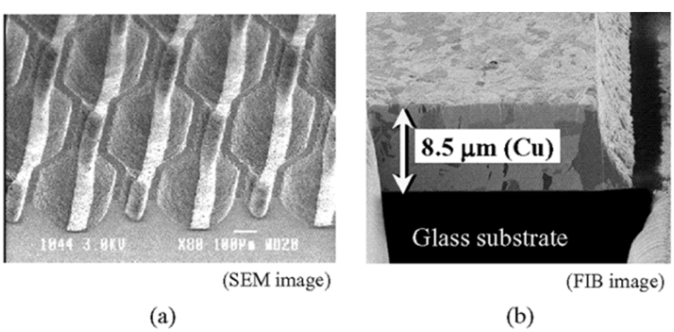

Fig. 8. New process techniques for electrode fabrication. (a) Inkjet electrodes on the meander ribs. (b) Full plated copper electrode by direct glass sculpting method.

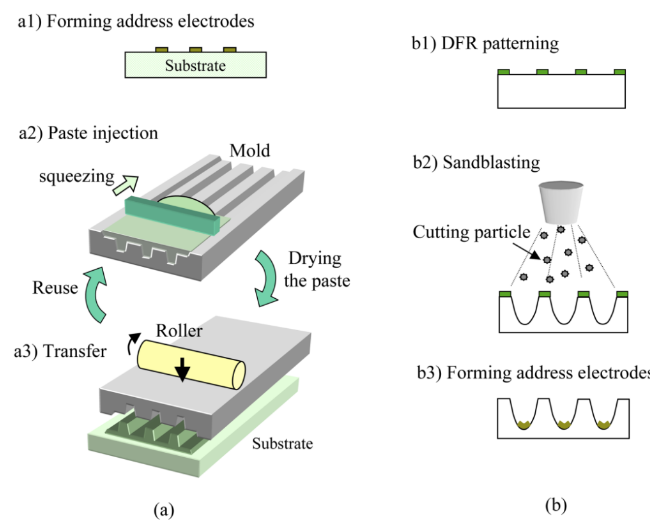

Fig. 9. Barrier rib process for next-generation fabrication. (a) Mold replication method. (b) Direct glass sculpting method.

In back plate manufacturing process development, the barrier rib formation process development is the main topic. The barrier ribs are currently formed by the sand blasting process or the photolithographic method with photosensitive rib paste material; however, they still have the issues. These processes are called as subtract methods and in these cases, a large amount of material is removed to form the rib shape. Therefore, the coefficient in material use is very low, resulting in high cost. Some of the wasted materials are reused, but it also costs, and the wasted material still becomes environment load. Consequentially, next-generation process should use the additive method that uses the materials only for the demanded part.

One of the typical additive methods is the transfer printing method [20]. As shown in Fig. 9(a), the rib material is filled in the mold that can be reused and then it transfer to the glass substrate. In this case, the filling process and the printing process run concurrently; therefore, the throughput will increase when the number of the printing mold increase.

If the low cost is a top priority, the direct glass sculpting method in Fig. 9(b) is most suitable [20]. In this case, the glass plate is graved directly by sand blasting after patterning by the photoresist. This method is very unique because it does not need the rib material and baking process. The issue of this method is the difficulty of the electrode formation on the bottoms of the rib groove. The inkjet printing method was demonstrated to make them in experimental level [Fig. 8(a)] and it showed the good performance, such as voltage characteristics.

The cost reduction process that is improved from the conventional manufacturing process is easy to apply the production in short time. However, the innovative new technologies as described above usually need the change of the production facilities and need the investigation of the compliance with the other manufacturing processes. Therefore, it needs a long time to apply to the production. In addition, the inspection processes will be affected when the panel production processes change, so these new processes may promote the development of the new inspection method and new appliances. These efforts, however, are important to realize a cost reduction and to keep PDPs as a promising position in the competitive display field.

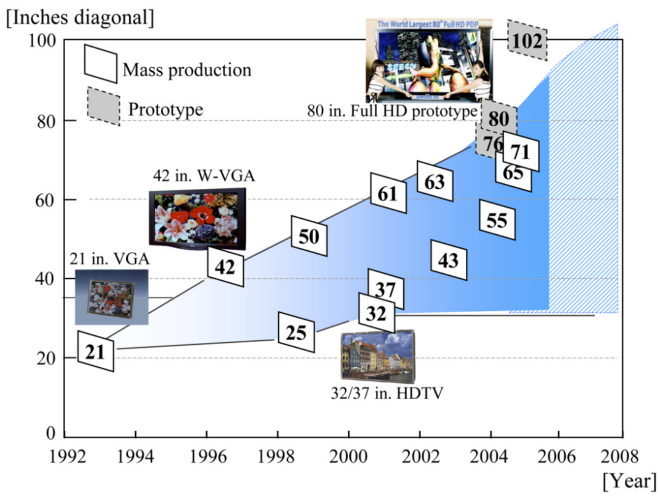

Fig. 10. Progress in screen size of PDPs.

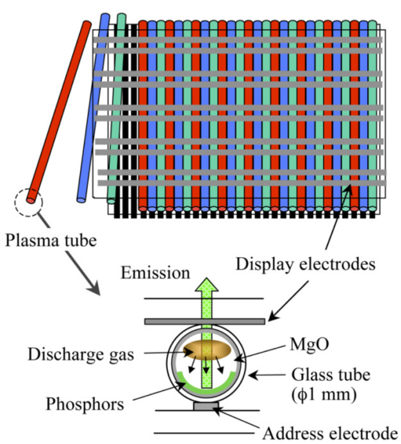

Fig. 11. Basic structure of PTA.

IV. Technical Trend of Enlargement of PDP

The 21-in diagonal PDP that was the first full-color PDP product was put on the market in 1993. Development of the screen size after it is shown in Fig. 10. The screen sizes of the PDP under mass production are currently 32–71-in diagonal. Although the maximum screen size had been enlarged gradually in several years until 2003, the large-sized prototype panel has reported using the advantages of their emissive and simple structure. The 80-in diagonal prototype panel was announced from Samsung SDI at the beginning of 2004. Moreover, the 102-in prototype panel was reported from them at the end of 2004. The 65-in diagonal full-HD panel was also announced from Matsushita in 2005.

Although one may think that commercial production will be possible to about 100-in diagonal by PDP, more than 100 in is not realistic since the large-scale equipment and the large factory treating a huge glass substrate are needed. On the other hand, a plasma tube array (PTA) that is not restricted to substrate size has been proposed in 2002 [17].

As shown in Fig. 11, a structure for discharge and emission are made in a glass tube with a diameter of 1 mm, and the extra-large screen exceeding 100-in diagonal can be realized by putting a large number of that in order. The drive electrodes are stuck from the outside. The shape of the display is very flexible because it depends on the arrangement of the tubes. Since the manufacturing unit is one glass tube, it can manufacture the small equipment and facilities for production. Since pixel size is large, about three times compared with the conventional PDPs, high luminous efficacy is theoretically expected [18]. So, even if it forms extra-large screen, the increase in power consumption can be suppressed.

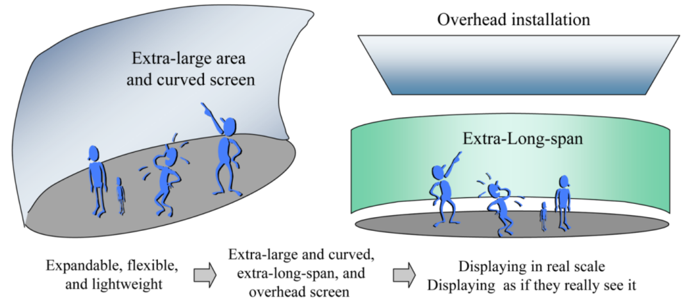

Fig. 12. New world produced by wall display using plasma tube technology.

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 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. 12, if the extra-large screen exceeding 100-in diagonal, like a PTA system puts in practical use, life-size display communication, the virtual experience service which covers human view angle, and is full of the presence will be attained. It is expected that the new market of transmitting information using an image with a reality will be created using an extra-large screen.

V. Conclusion

The basic technologies of color ac PDP and the development of the latest technologies were described. The basic structure of PDP has the foundation that can respond to next-generation technologies, such as high luminous efficacy, low cost, and enlargement of the screen size over the future, and has strong competitive power. PDP makers, such as those in Japan and in Korea, continue to compete for technical development, and a next-generation factory and a next-generation product will progress.

The PDP has essential advantages, such as high-speed response with emissive, an extensive viewing angle, an easy manufacturing, and its ease to make large screen over LCD in large area screen field. These advantages are further strengthened by developing low-power and low-cost techniques, and competitive power will become firm. The new technologies of a material, panel manufacturing, and set controlling will show the synergistic effect, and PDP will continue raising its advantages for a while from now on.

References

[1] S. Yoshikawa, Y. Kanazawa, M. Wakitani, T. Shinoda, and A. Ohtsuka, "Full color ac plasma display with 256 gray scale," *Proc. Jpn. Display*, pp. 605–608, Oct. 1992.

[2] H. G. Slottow, "Plasma display," *IEEE Trans. Electron Devices*, vol. ED-23, no. 7, pp. 760–772, Jul. 1976.

[3] K. Takashima *et al.*, “Surface discharge type plasma display panel,” in *SID Dig.*, 1973, p. 76.

[4] G. W. Dick and M. R. Biazzo, “Planar single-substrate ac plasma display,” *IEEE Trans. Electron Devices*, vol. ED-23, no. 4, pp. 429–437, Apr. 1976.

[5] T. Shinoda *et al.*, “Surface discharge color ac-plasma display panels,” presented at the Late News in Biennial Display Res. Conf., Cherry Hill, NJ, Oct. 1980.

[6] T. Shinoda *et al.*, “Logically addressable surface discharge ac plasma display panels with a new write electrode,” in *SID Dig.*, 1984, pp. 172–175.

[7] T. Shinoda, M. Wakitani, T. Nanto, T. Kurai, N. Awaji, and M. Suzuki, “Improvement of luminance and luminous efficiency of surface-discharge color ac PDP,” in *SID Dig.*, 1991, pp. 724–727.

[8] T. Shinoda, “Method and a circuit for gradationally driving a flat display device,” U.S. Patent 5 541 618, 1990.

[9] M. Uchidoi, “Technology for reducing power consumption of PDPs in pioneer,” in *ASIA-DISPLAY/IMID Dig.*, Aug. 2004, pp. 159–163.

[10] M. Kasahara, M. Ishikawa, T. Morita, and S. Inohara, “New drive system for PDPs with improved image quality: Plasma AI,” in *SID Dig.*, 1999, pp. 158–161.

[11] Y. Hashimoto, Y. Seo, O. Toyoda, and K. Betsui, “High-luminance and highly luminous efficient ac-PDP with DelTA cell structure,” in *SID Dig.*, 2001, pp. 1328–1331.

[12] K. D. Kang, J. I. Kwon, W. T. Kim, H. S. Yoo, S. G. Woo, E. Y. Jung, J. C. Ahn, S. J. Kim, E. G. Heo, and W. J. Yi, “Discharge characteristics of high efficiency rib and its optimized electrodes (HERO) using high xe gas mixture,” in *SID Dig.*, 2004, pp. 1030–1033.

[13] H. S. Bae, T. J. Kim, and K. W. Whang, “Mechanism of high luminous efficiency in delta color arrayed enclosed sub-pixel structured ac PDP with high xe content,” in *ASIA-Display/IMID Dig.*, 2004, pp. 59–62.

[14] J. D. Yi, J. Y. Kim, S. Y. Chae, T. W. Kim, S. C. Cho, B. M. Chun, J. N. Kim, and Y. H. Cho, “A new structure and driving scheme of PDP for high luminous efficacy,” in *ASIA-Display/IMID Dig.*, 2004, pp. 51–54.

[15] G. Oversluizen and T. Dekker, “High Xe-content PDP,” in *ASIA-Display/IMID Dig.*, 2004, pp. 55–58.

[16] Y. Seo, T. Kosaka, H. Inoue, N. Itokawa, and Y. Hashimoto, “High luminous-efficient ac-PDP with DelTA cell structure using new sustain waveform,” in *SID Dig.*, 2003, pp. 137–140.

[17] T. Shinoda, M. Ishimoto, A. Tokai, H. Yamada, and K. Awamoto, “New approach for wall display with fine plasma tube array technology,” in *SID Dig.*, 2002, pp. 1072–1075.

[18] M. Ishimoto, “High efficient structure of plasma tubes,” in *ASIA-Display/IMID Dig.*, 2004, pp. 103–108.

[19] M. Furusawa, T. Hashimoto, M. Ishida, T. Shimoda, H. Hasei, T. Hirai, H. Kiguchi, H. Aruga, M. Oda, N. Saito, H. Iwashige, N. Abe, S. Fukuta, and K. Betsu, “Inkjet-printed bus and address electrodes for plasma display,” in *SID Dig.*, 2002, pp. 753–755.

[20] O. Toyoda, A. Tokai, M. Kifune, K. Inoue, K. Sakita, and K. Betsui, “Low cost barrier rib formation technologies for high efficiency PDPs,” in *SID Dig.*, 2003, pp. 1002–1005.

[21] S. Fukuta *et al.*, “Full plated metal electrodes for PDPs,” in *Proc. IDW*, 2003, pp. 893–896.

Tsutae Shinoda received the B.E. and M.S. degrees from Hiroshima University, Hiroshima, Japan, in 1971 and 1973, respectively, and the Ph.D. degree in physics from Tohoku University, Sendai, Japan, in 1999.

He joined Fujitsu Laboratories, Akashi, Japan, in 1973, where he has been developing plasma display panel technologies. In particular, he started color surface discharge ac plasma display panels for development of full color plasma displays in 1979. He is currently a Fellow of Fujitsu Laboratories. He is also a Visiting Professor of the Institute of Industrial Science, University of Tokyo, Tokyo, Japan.

Dr. Shinoda is a winner of the Braun Prize from the Society for Information Display (SID) for his outstanding contribution for developing a color plasma display technologies in 2003. He received the Purple Ribbon Medal from the Japanese government in 2004. He is a Fellow of SID and is a member of the Institute of Image Information and Television Engineers in Japan.

Kenji Awamoto graduated in electrical engineering from Okayama University, Okayama-city, Japan, where he received the M.E. degree in electrical engineering, in 1986.

He joined Fujitsu Laboratories, Akashi, Japan, in 1986 as a Research Staff Member of the Infrared Sensor Group. He has been engaged in research for infrared sensor and for plasma displays. His current research interests are plasma tube technology and the driving technology for high efficacy plasma displays.

Mr. Awamoto is a member of the Society for Information Display (SID) and the Institute of Electronics, Information and Communication Engineers (IEICE) in Japan.