Development of a 25-in. SVGA SMPDP

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Abstract — A newly developed 25-in. SVGA ACPDP containing a shadow mask (SMPDP) is presented. Some modifications have been introduced into the fabrication technique. Instead of using conventional Ag in a thick-film process, an aluminum bus electrode without ITO was fabricated on the front substrate, which was made by using a thin-film process. Due to this improvement, excellent uniformity of the dielectric layer has been achieved. Only five necessary process steps are required during the manufacturing process of the front/rear substrates for the SMPDP. The panel capacitance was reduced by over 20% by adopting an ITO-less structure, which enables high-speed addressing for large-capacity displays. The color purity was improved by applying a high Xe content.

Keywords — *SMPDP, ITO-less bus structure, discharge.*

1 Introduction

The plasma-display panel (PDP) is one of the promising candidates for high-definition large-area flat-panel display. PDPs have been recognized to have many advantages, such as high brightness, high contrast, wide viewing angle, and a rather long lifetime. Whereas some properties, such as cost, power consumption, and luminous efficacy, still need to be improved. Most of the work has focused on the structural optimization, gas mixture, phosphor material, and driving scheme.[1–5]

The novel SMPDP invented by Southeast University is a possible solution for low-cost PDPs.[6] The main difference between the structure of an SMPDP and a coplanar PDP is that a conductive shadow mask is used to separate the substrates instead of conventional barrier ribs. This results in many benefits such as lower firing voltage, high-speed discharge, good uniformity, lower cost, and longer lifetime. Furthermore, high resolution can be easily realized for the SMPDP structure, which is due to the availability of the high-resolution shadow mask and the single-electrode structure in the front substrate.

Because 40–50-in. PDP-TV products have the most suitable screen size and price for common consumer applications, it is recommended that high-definition (HD) resolution be included in order to compete with LCDs. Now, more and more companies are paying attention to how to realize a 42-in. HD PDP for which a fine-pitch specification of less than 0.5 mm is required. In this paper, a 25-in. SMPDP with a pitch size of 0.66 mm and SVGA resolution was investigated for future HDTV application. The discharge cell structure for a 25-in. SMPDP has been optimized, which can provide a larger discharge volume and facilitate panel fabrication. A peak luminance of 500 cd/m^2 and a total power consumption of 100 W has been achieved in a 25-in. SMPDP prototype.[7]

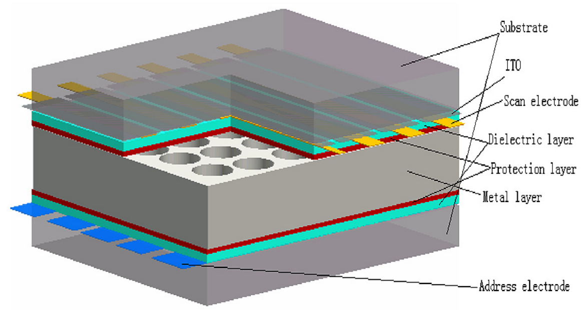

FIGURE 1 — Panel structure of the SMPDP.

Besides the optimization of cell structure, more improvements in the fabrication technology are needed. The manufacturing procedure of SMPDPs was further simplified for mass-production purposes. Detailed information about the fabrication processes for a 25-in. SVGA SMPDP panel is introduced.

To realize low power consumption and fast addressing, the discharge characteristics were studied by capturing the discharge process by using an ICCD camera.

2 Production of 25-in. SMPDP

The structure of a SMPDP is shown in Fig. 1. The front and rear substrates are almost identical to that of a conventional coplanar-structured PDP. To reduce the capacitance and fabrication costs, parallel scan electrodes without ITO are applied to the front glass substrate. Address electrodes, placed orthogonally to the scan electrodes, are applied to the rear substrate. A dielectric layer is formed on these electrodes and a MgO protecting layer is evaporated on the dielectric layer. Tri-primary color phosphors (red, green, and blue) are formed on the inner surfaces of the shadow-mask cell.

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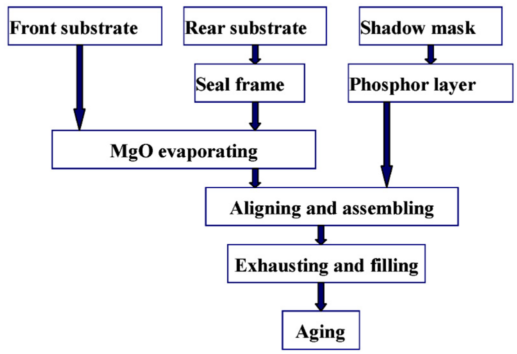


FIGURE 2 — Fabrication process of 25-in. SVA SMPDP.

The fabrication process of a 25-in. SVGA SMPDP panel is shown in Fig. 2. Parallel with the manufacture of the front/rear substrate, the phosphor layer is formed on the shadow-mask cell. The shadow mask, which is one of the mature technologies for CRTs, is made of pure Fe or invar steel. The thickness of the shadow mask used in the 25-in. panel is 0.15 mm. The uniform RGB color phosphor layers are sprayed on the inner surface of the shadow-mask cell separately by shielding with a special mask.[8] A seal frame is placed on the rear substrate. The MgO film is vaporized on both the front and rear substrates by an e-beam evaporator, respectively. The panel is sealed after the front substrate, the rear substrate, and the shadow mask are accurately aligned. After baking and exhausting, mixed gas of Ne + 20% Xe with a 450-torr pressure is filled.

3 Improvement of fabrication process

In order to further decrease the cost, substrates with normal soda-lime glass instead of PD200 glass is adopted. The fabrication technology for the front substrate is the same as that for the rear surface, which is shown in Fig. 3. There are only a total of five processes left, which require less equipment and fabrication time. The Al film, with a thickness of less than 2 μm, is evaporated on glass substrates by a sputtering method. The electrode pattern is formed by photolithography and wet etching. The width of the bus electrode in the front substrate is about several tens of micrometers, and the width of the data electrode in the rear substrate is about 2 times larger than the width of bus electrode. The dry film dielectric is laminated and fired to form a transparent dielectric layer with a thickness of about 30 μm.

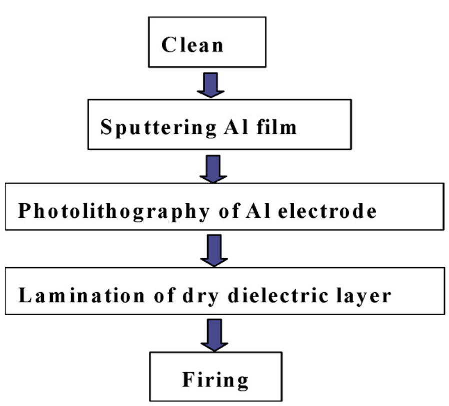


FIGURE 3 — Fabrication process of the substrate.

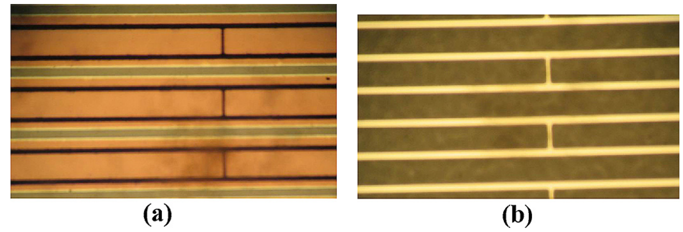


FIGURE 4 — Bus electrode in the front substrate. (a) With ITO, (b) without ITO.

3.1 Bus electrode without ITO

Scan and common electrodes with ITO film are widely used in conventional PDPs. The ITO electrode pattern is fabricated by photolithography and wet etching. The lateral pixel structure electrode without an ITO film was discussed at SID 2001.[9] In the new SMPDP panel, the bus electrode without an ITO film is applied to the front substrate. Figures 4(a) and 4(b) compares the bus electrode with ITO and one without ITO. The sputtering, photolithography, and etching process are omitted, which means less equipment is needed and the cost is significantly reduced. The pitch of the scan electrode line is 0.333 mm. The width of the ITO electrode in Fig. 4(a) is about 3.5 times larger than the width of the bus electrode on it. The same width for the bus electrode is used in Fig. 4(b). The capacitance is also reduced by over 20% by adopting a ITO-less structure, and higher luminance efficacy is achieved. The discharge performance will be discussed in the following section.

3.2 Ag electrode replaced by Al electrode

Today, the patterned data/bus electrodes for most PDPs are formed by screen printing with Ag paste or photolithography of photo-sensitive Ag paste. The surface of the Ag electrode is rather rough and even some sharp tips will be introduced as shown in Fig. 5. It is one of the main reasons why the dielectric layer is easily electrically broken down and defects could result in the panel. In the new scheme, the Al electrode is formed by using thin-film technology. The surface of the Al electrode is smooth and uniform. The high-quality Al-electrode pattern is shown in Fig. 6. The breakdown of the dielectric layer will not occur again.

3.3 Improvement in dielectric layer

The conventional dielectric layer is fabricated by screen printing. Multi-processes are required, such as screen printing and drying three times or more and at least two firings.

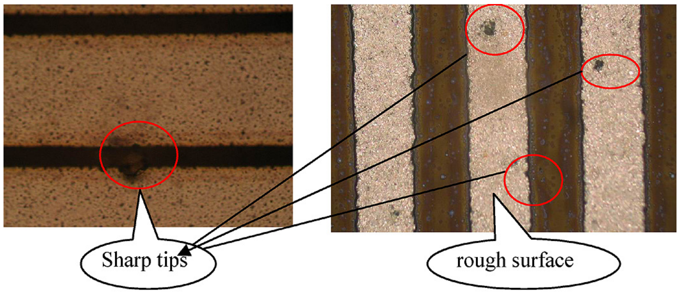


FIGURE 5 — Bus/date electrode made of Ag.

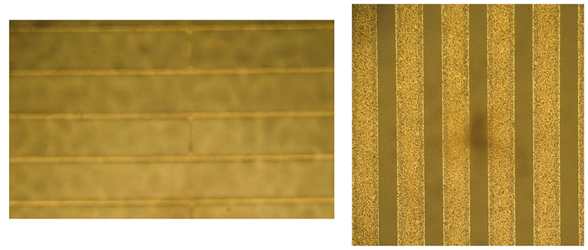


FIGURE 7 — Dielectric layer made of dry film on the front/rear substrates.

More equipment and process time is needed. However, poor uniformity of the dielectric layer thickness resulted because of frequent printing and firing. For a 30-μm dielectric layer thickness for a 25-in. substrate area, the uneven thickness is normally 7–10 μm. Moreover, some defects can still result in the dielectric layer which are introduced by dust during the long process time.

Lamination of the dry film of the dielectric layer is applied in the new SMPDP. Less processes and equipment are required. There is only one laminating and firing remaining. Because the uneven thickness of the dry film of the dielectric layer is less than 0.5 μm, the dielectric layer formed has good uniformity. The dielectric layer made of dry film for the front/rear substrate is shown in Fig. 7. The breakdown voltage of the dielectric layer determines the insulation performance of the dielectric layer. When the voltage is applied to the two electrodes, top and bottom until the dielectric layer is broken down, the breakdown voltage can be tested. This value is over 1000 V for a dielectric layer with a thickness of 30-μm.

4 Results

4.1 Pixel design of 25-in. SVGA SMPDP

To realize an SVGA resolution on a 25-in. SMPDP, the pixel pitch should be about 0.66 and 0.22 mm, respectively, for each subpixel. The pitch decreases, so does the discharge cell space compared to a conventional VGA SMPDP. Obviously, it will introduce more wall loss during discharge. To maintain a high luminance efficacy, the discharge cells have to be carefully designed and optimized. In the previous VGA SMPDP, the shape of the subpixels is rectangular, as shown in Fig. 8(a). The narrow width of the cell, which is about 0.32 mm, causes the main wall-charge loss. In the 25-in. SVGA SMPDP, the subpixels are arranged in triangular arrays and the shape of the subpixel is a small circle, as shown in Fig. 8(b). The diameter of each cell is 0.36 mm, which is almost the same as the narrow width of the previous rectangular cell. Furthermore, the new round design of the discharge cell introduces more phosphor area than that of a rectangular type, which means more visible light will be generated. Figure 8(c) shows the phosphor layer formed by spray method before discharge. The phosphor solution is a mixture of phosphor powders and some organic solvent. The average grain diameter of the powders is about 3 μm. The atomized phosphor solution is sprayed on the shadow mask by using special equipment. A uniform R, G, B phosphor layer is formed on the inner surface of the shadow-mask holes through the corresponding mask. The thickness of the phosphor layer is controlled to be about 10 μm. No blind-holes occurred, as shown in Fig. 8(c).

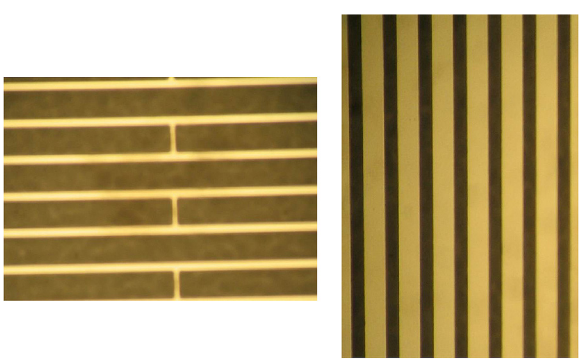


FIGURE 6 — High-quality Al-electrode pattern for bus/date electrode.

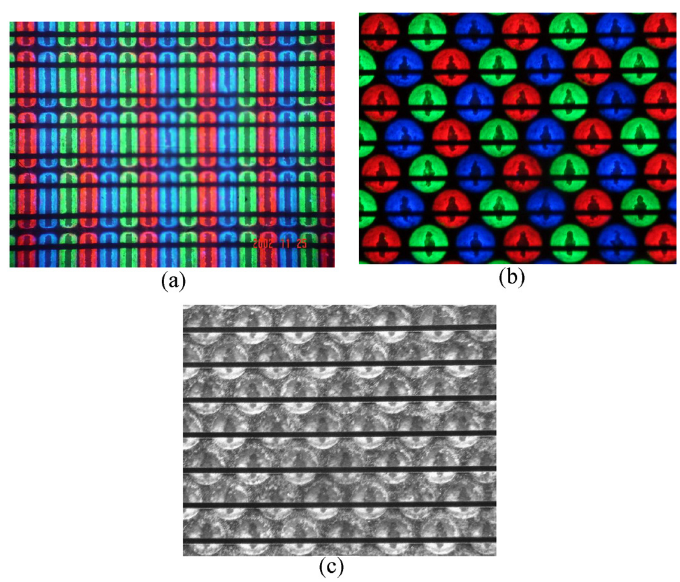


FIGURE 8 — Comparison between rectangular- and round-type subpixels in an SMPDP. Comparison between phosphor and discharge. (a) Rectangular subpixel, (b) round subpixels, and (c) phosphor layer before discharge of (b).

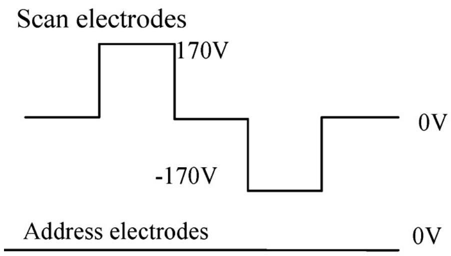


FIGURE 9 — Sustain pulse waveform on the electrodes.

4.2 Discharge process

To study the discharge of a high-resolution round-type cell, the sustain discharge process was recorded by a ICCD camera. The IR distribution was continuously captured, which reveals the detailed discharge information on the ignition, spread, propagation, and extinguishment. With the help of conductive shadow mask inside the discharge volume, an opposite discharge shows some special characteristics compared to an opposite discharge with a traditional barrier rib.

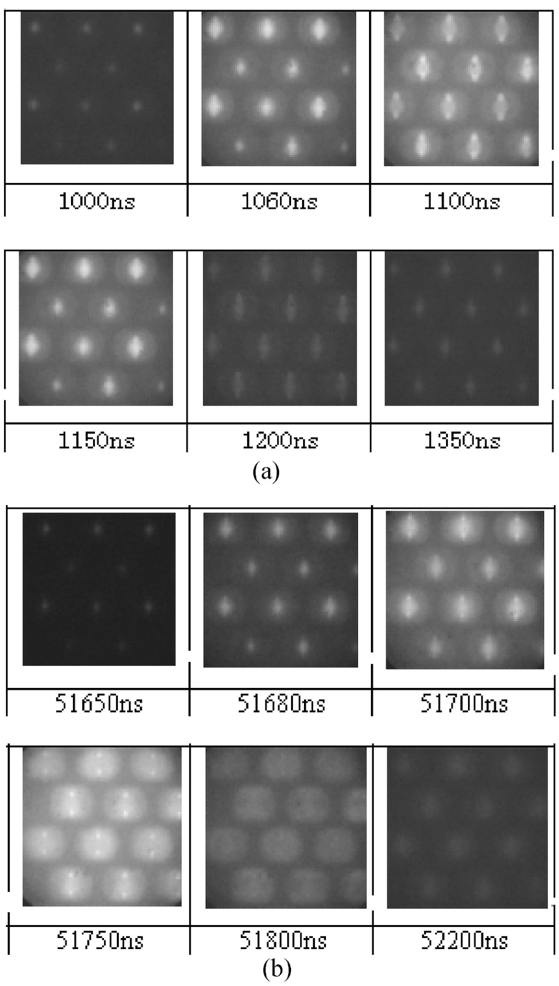


FIGURE 10 — Sustain discharge process photographed by an ICCD. (a) Positive sustain pulse on scan electrodes. (b) Negative sustain pulse on scan electrodes.

The waveform of the sustain pulses applied to the electrodes is shown in Fig. 9. The frequency of the sustain pulse is 10 kHz. Figure 10(a) shows the discharge process for a 25-μsec-pulse-width positive sustain pulse applied to the scan electrodes. Figure 10(b) shows the discharge process during the negative sustain pulse applied to the scan electrodes. The addressing electrodes on the rear substrate in the column direction are kept at ground during the entire sustain period.

We can see that a sustain discharge starts in the center and increases in intensity, after 51,680 nsec the other mode that is broader takes over until that mode also dies. Here the discharge starts at 1000 and 51,650 nsec.[10]

4.3 Comparison between the SMPDP and the ACCPDP

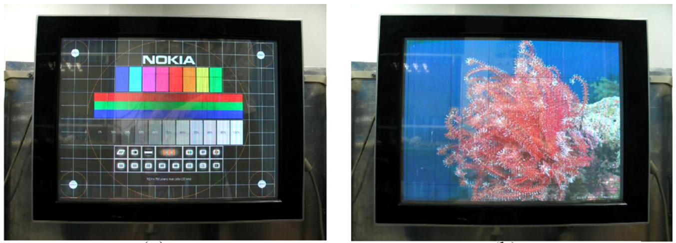
The process of radiation and the capture of the photo was simulated by using a combination of the fluid model and the Monte Carlo model. The photon distribution on the phosphor layer can be obtained. Table 1 shows the UV photons (%) hitting the phosphor layer in the SMPDP and ACCPDP (AC coplanar PDP) when changing the size of cell. It can be seen that as the size reduces, the photons hitting the phosphor layer increase for the SMPDP and decrease for the ACCPDP. This is mainly because a decrease in the area of the phosphor layer in the SMPDP is smaller than that in the ACCPDP, as the phosphor is formed on the inner surface of the shadow mask. And the phosphor layer is closer to the resonant photon when the size of the discharge cell is decreased. Hence, the efficacy will be better in an SMPDP than in an ACCPDP for high resolution. A high-definition SMPDP can be realized while maintaining high efficacy.

4.4 Results for a 25-in. SVGA SMPDP

Figures 11(a) and 11(b) show the standard test pattern and video image displayed on the newly developed 25-in. full-color SVGA SMPDP. A high xeon percentage of over 20% for a Ne–Xe gas mixture was applied and the pressure was increased to 450 Torr to obtain a higher luminance efficacy. A high addressing speed of 1.4 μsec/line has been achieved under an address voltage of 230 V and a data voltage of 60 V, which enables a single scan for a total of 600 lines. The orange-red background light produced by neon is greatly suppressed by adopting a high pressure and a high Xe content. The color temperature of the SMPDP has been improved

TABLE 1 — Comparison of the photons that hit the phosphor between the SMPDP and ACC PDPs.

Structure	SMPDP (%)	ACCPDP (%)
Original size	53.58	51.4
Original size/3	65.00	47.6



(a) (b)

FIGURE 11 — Images displayed on a 25-in. SVGA SMPDP. (a) Standard test pattern. (b) Video image.

by applying a non-saturated green phosphor. The color temperature of the SMPDP has been increased, which effectively improves the display quality.

The characteristics of a SMPDP panel sample are shown in Table 2.

5 Conclusions

The successful development of a 25-in. SVGA-resolution SMPDP has lead to the following fabrication technology improvements.

Firstly, a new electrode structure without ITO, which eliminates the sputtering of the ITO film and the photolithography for electrode patterning, has been introduced into the SMPDP. The Ag electrode formed by thick-film technology is also replaced by an Al electrode formed by thin-film technology. The use of thin-film technology improves the uniformity not only of the Al electrode array but also of the dielectric layer above it. Normal soda-lime glass substrates can be used without the yellowing problem caused by Ag.

Secondly, the screen-printing procedure is not necessary due to the utilization of thin-film technology and dry-film dielectric-layer technology, which means that the expensive screen-printing machine and large IR oven is no longer necessary. It is important for mass production; that is, the scheme of the fabrication line will be simplified and the investment scale will be decreased.

Finally, the process time is shortened and the fabrication complexity is reduced, which implies lower cost and large yield. Thus, a low-cost SMPDP with aluminum electrodes without ITO on a normal soda-lime glass substrate has been fabricated, which validates the mass production of SMPDPs.

TABLE 2 — Characteristics of a 25-in. SMPDP panel.

Diagonal size	25 in.
Resolution	800 × RGB × 600
Pitch size	0.22 mm × RGB × 0.66 mm
Gas mixture	Ne + 20% Xe 450 Torr
Address time	1.4 μsec/line
Luminance	500 cd/m^2

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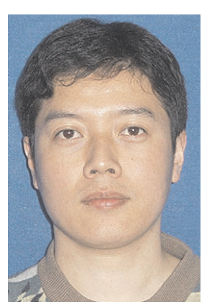

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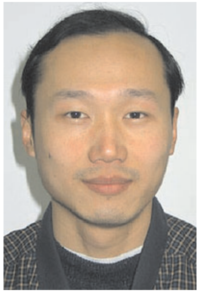

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