Invited: Development of High-Definition PDP TV with High-Efficient Hexagonal Array Structure

Byung Hak Lee, Eun Gi Heo, Cha Keun Yoon, and Kwang Sik Lee
R&D Team, PDP Division, Samsung SDI Co. Ltd., Chungchongnam-Do 330-300, KOREA
Yoon Hyoung Cho, and Min Sun Yoo
PDP Team, Corporate R&D Center, Samsung SDI Co. Ltd., Gyonggi-Do 449-902, KOREA

Abstract
Optimization of the luminance, luminous efficiency, and address voltage margin characteristics has been made on the delta color array PDP with various hexagonal shape subpixels. The optimal subpixel and electrode designs are obtained for the 42-inch high-definition PDP (1,366×768) with the fine pixel pitch - less than 0.7 mm. The hexagonal delta array structure shows more improved characteristics than that of the normal delta array structure with rectangular shape subpixels.

1. Introduction
Presently, a 42-inch SD (standard-definition) PDP with 852×480 pixel array is a dominant model in the world PDP market. But, within a few years, it must be replaced with HD (high-definition) models, which has more than 768 lines vertical resolutions. This change is not a matter of choice, but the essential needs for surviving in the competition with fast-growing large-sized LCD TV technology [1]. The screen resolutions of the commercial 42-inch HD PDP are 1,024×768 (progressive scan) or 1,024×1,024 (interlaced scan), but the horizontal resolution of them is not increased proportionally to their vertical resolution. This is mainly caused by parallel color array of the pixels. It is very difficult to obtain a sufficient volume for discharge with three barriers within 0.675 mm pixel pitch in stripe array 42-inch PDP. But, the resolution of 42-inch LCD TV is mainly 1,280×768, and this is probably the most important difference for the general consumers.

There are many research reports that delta color array plasma display panel showing the better luminance and luminous efficiency characteristics [2-4]. It also has an advantage for easy increase of the horizontal resolution. Generally, pixel pitch of 42-inch SD PDP is 1.08 mm, while that of the same size HD PDP with the horizontal resolution of 1,366 is 0.675 mm, only 62.5% of SD's pixel pitch. Because the top-width of barrier by sand blasting method, about 60 ~ 70 μm, is not changed in both cases, the decrease of discharge volume in 42-inch HD is more severe than that of pixel pitch itself. This problem can be partially solved with the adoption of the delta color array structure.

In the hexagonal delta array structure, barriers are connected to each other and organized in a hexagonal grid structure (like honeycomb), which enable us to obtain the higher productivity in the barrier rib fabrication process for its physical stability than that of the stripe structure. Figure 1 shows the schematic diagram of hexagonal delta color arrayed subpixels. In normal case, a color pixel with three elementary subpixels must be a square, so horizontal pixel pitch equals to the vertical pixel pitch, p in Figure 1. A horizontal subpixel size a is always 2/3 of p and the subpixel shape can be continuously changed from rectangle ($b = c = p/2$) to diamond ($b = 0$, $c = p$). But, the equation, $b + c = p$, must be satisfied always for their periodicity. When b is smaller than c, subpixels become hexagon and we define the shape of them with the parameter b/c or b:c.

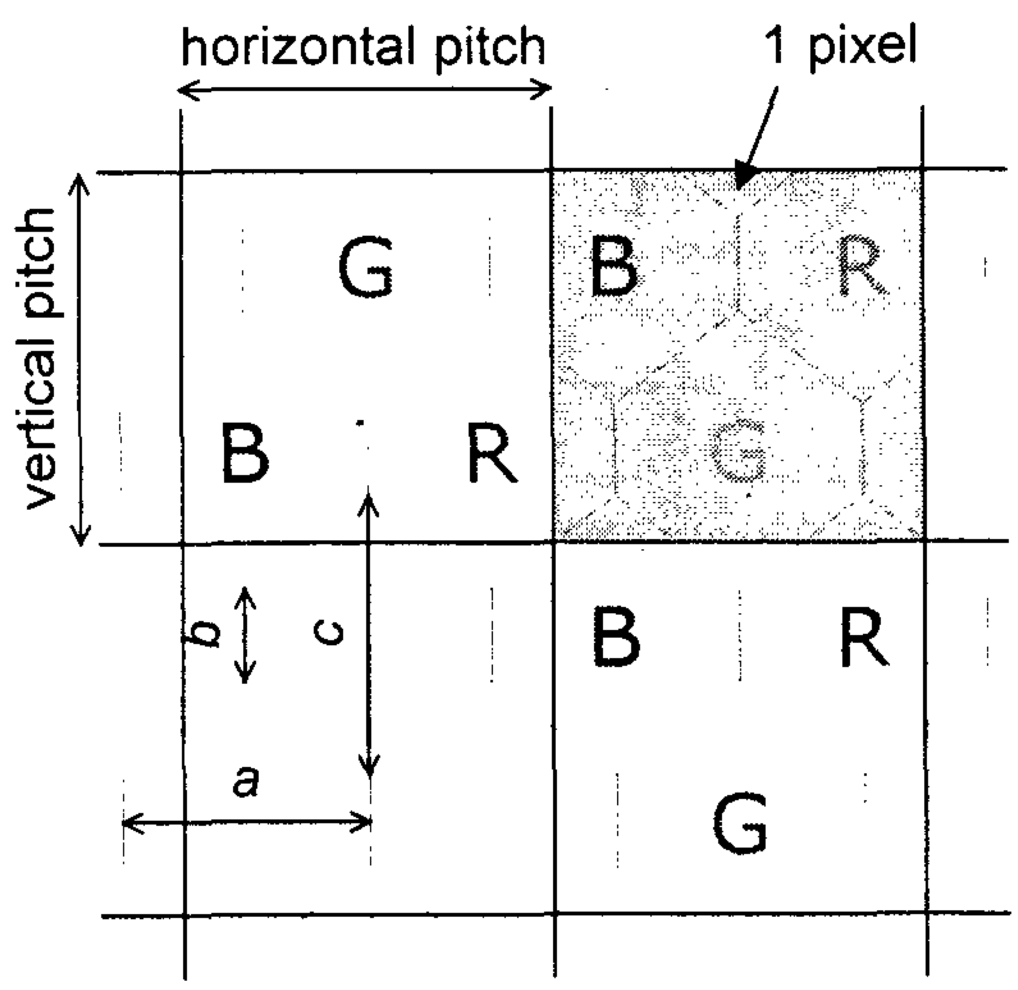


Figure 1. Schematic diagram of hexagonal delta color arrayed subpixels.

2. Test Panel Experiment

We have accomplished various test panel experiments with the hexagonal subpixels for optimizing their discharge characteristics. Figure 2 shows schematic panels design of HEXA (High Efficient heXagonal Array) structure. ITO electrodes are segmented and electrically connected to BUS electrodes, which show zigzag pattern along subpixel boundaries. And, each hexagonal subpixel is completely closed by barriers.

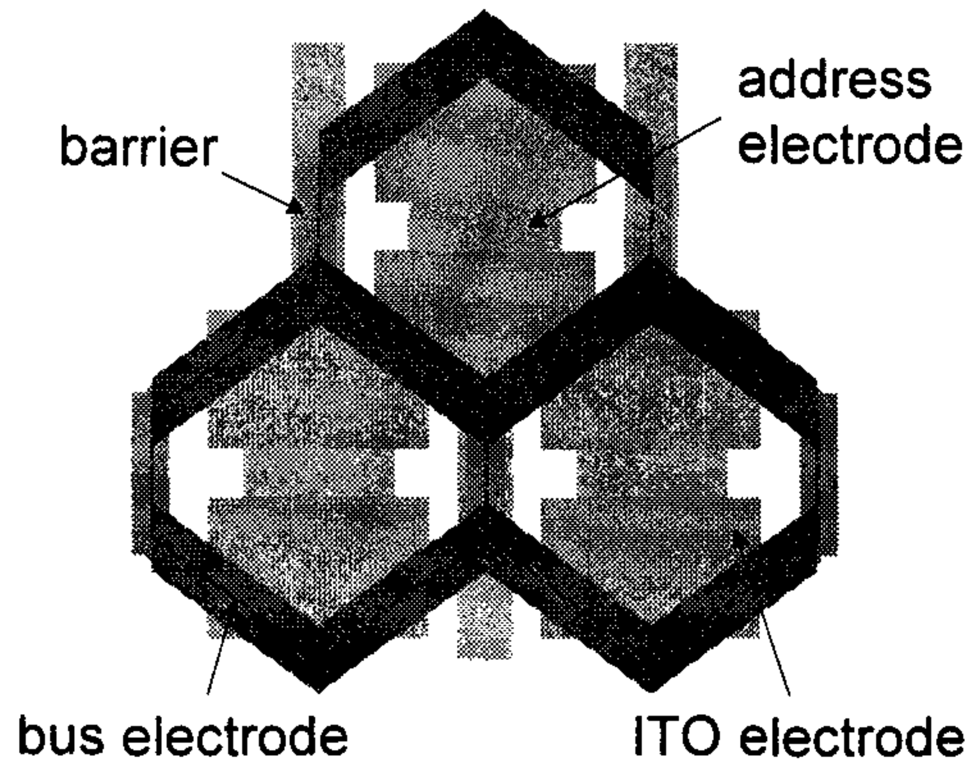


Figure 2. Panel design of HEXA structure.

The experimental conditions for deciding the optimal hexagonal subpixel shape are shown in Table 1. All experiments were accomplished with a test panel. Other experimental conditions, such as barrier height and thickness of dielectric and phosphor layers, are maintained as same in all cases. Although the pixel pitches of four test panel experiments in Table 1 are slightly different, we were able to compare their relative variations of luminance, luminous efficiency, and addressing voltage margin characteristics with those of the delta color array with the rectangular subpixel structure, namely 'SDR' structure that is introduced at elsewhere [2].

Table 1. Experimental conditions.

	Number	1	2	3	4
Experiments	Resolution	50"HD (1,366)	50"HD (1,366)	42"HD (1,280)	42"HD (1,366)
	Pitch [mm]	0.81	0.81	0.729	0.681
Subpixel Shapes	Rectangular	O	O	O	-
	HEXA 1:1.4	-	O	-	-
	HEXA 1:2	-	O	-	O
	HEXA 1:2.6	O	-	-	-
	HEXA 1:3	-	O	O	O
	Diamond	-	-	O	-

3. Experimental Results

In Figure 3 (a) ~ (c), the incremental ratio of panel luminance, luminous efficiency, and relative variation of addressing voltage margin are shown respectively. The *x*-axis in Figure 3 represents subpixel shapes with *b*/*c*, which is pre-defined in Figure 1, and the *y*-axis is the relative changes of each characteristics. The added lines in graphs are mathematically fitted curves with consideration of each characteristics.

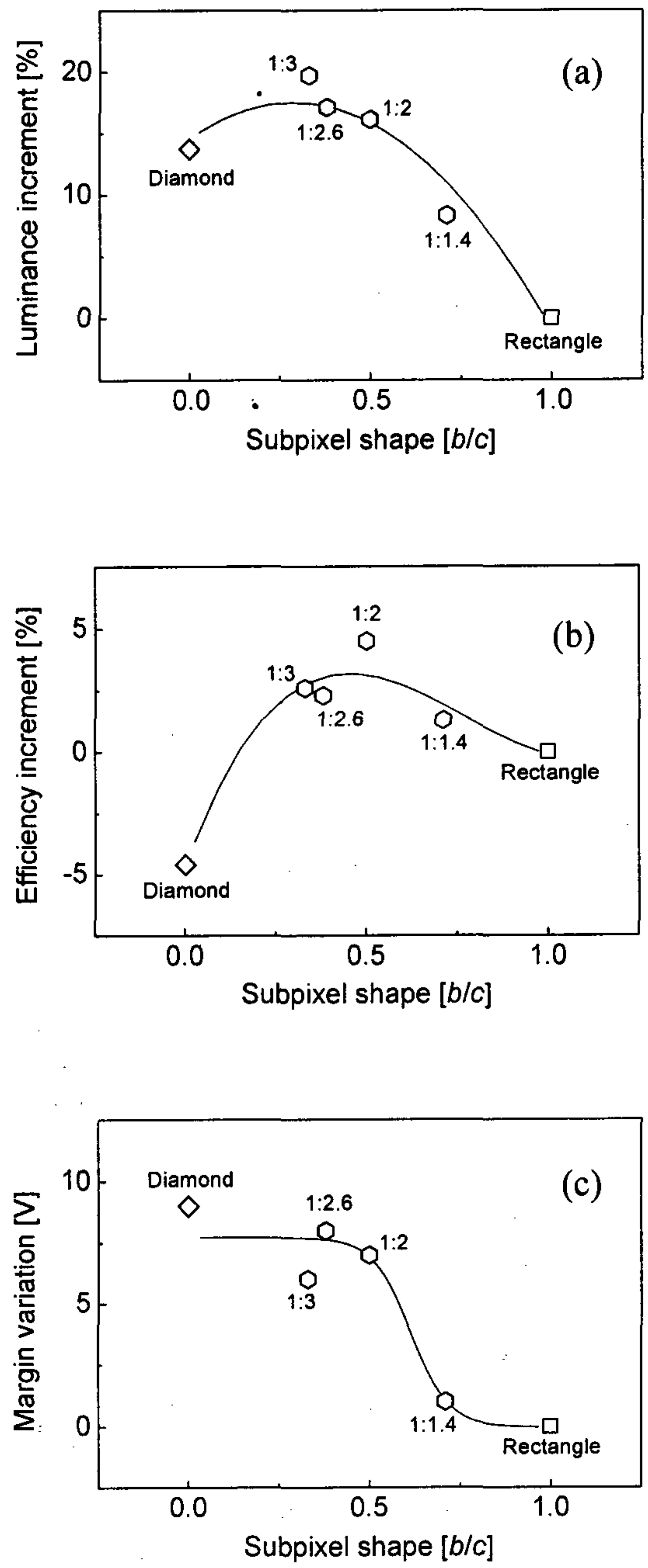


Figure 3. Characteristics of subpixel shapes.

Figure 3 (a) shows the luminance increase more than 10% in hexagonal subpixel to that of the rectangular subpixel. Especially, luminance graph shows about 15% increase between 1:2 ~ 1:3 hexagonal subpixel, and small decrease with diamond subpixel (b = 0) to its maximum point. A fitted line in this graph is a 2[nd] order polynomial curve, so we can speculate that there can be an optimal hexagonal subpixel shape, which has the maximum luminance value, between diamond shape and 1:2 hexagon shape subpixel structure.

A luminous efficiency is measured with sustain-only driving circuit (f = 10 kHz) and the result is shown in Figure 3 (b). Despite of the luminance increase over 10% to rectangular subpixel in all hexagonal shapes, only 5% of efficiency increase is observed in them to rectangular subpixel structure. This is mainly due to the enlargement of total sustain electrode area, and its resultant increase of discharge current.

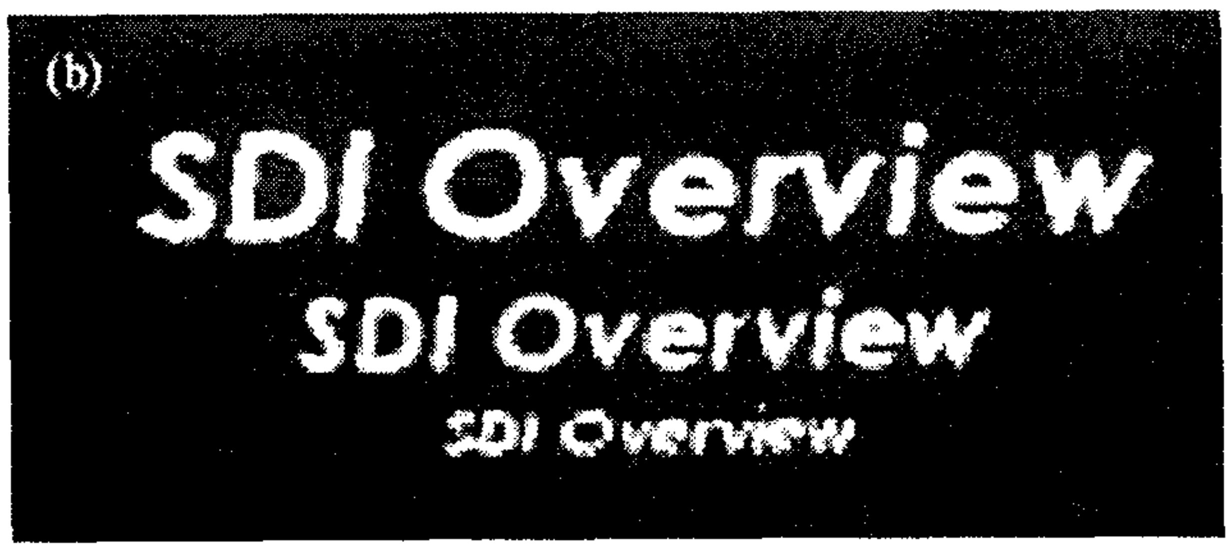
For addressing voltage margin variation, in Figure 3 (c), the diamond subpixel shows the best result. We can see that subpixel shapes from diamond to 1:2 hexagon exhibit 6 ~ 9 V voltage margin improvement compared with the rectangular subpixel. This can be easily explained with sustain electrode's projected vertical length. A longer vertical length of projected ITO is more beneficial to address voltage margin, and this characteristic is one of the main reasons for the start of this research.

4. Subpixel Rendering Method

A display system with delta color array has serious image deterioration problem as itself. We found that this problem was caused by the subpixel arrangement. The lack of symmetry between the delta (Δ) arranged subpixels of one pixel and the nabla (∇) arranged subpixels of adjacent pixel caused the problem. We were able to solve it by using an image processing method – a subpixel rendering (SpR) method, which treats three kinds of subpixels as an independent display cell and compensate relative position among the subpixel. In addition, we were able to achieve improved image quality by using more image information than the number of physical display cells [5].

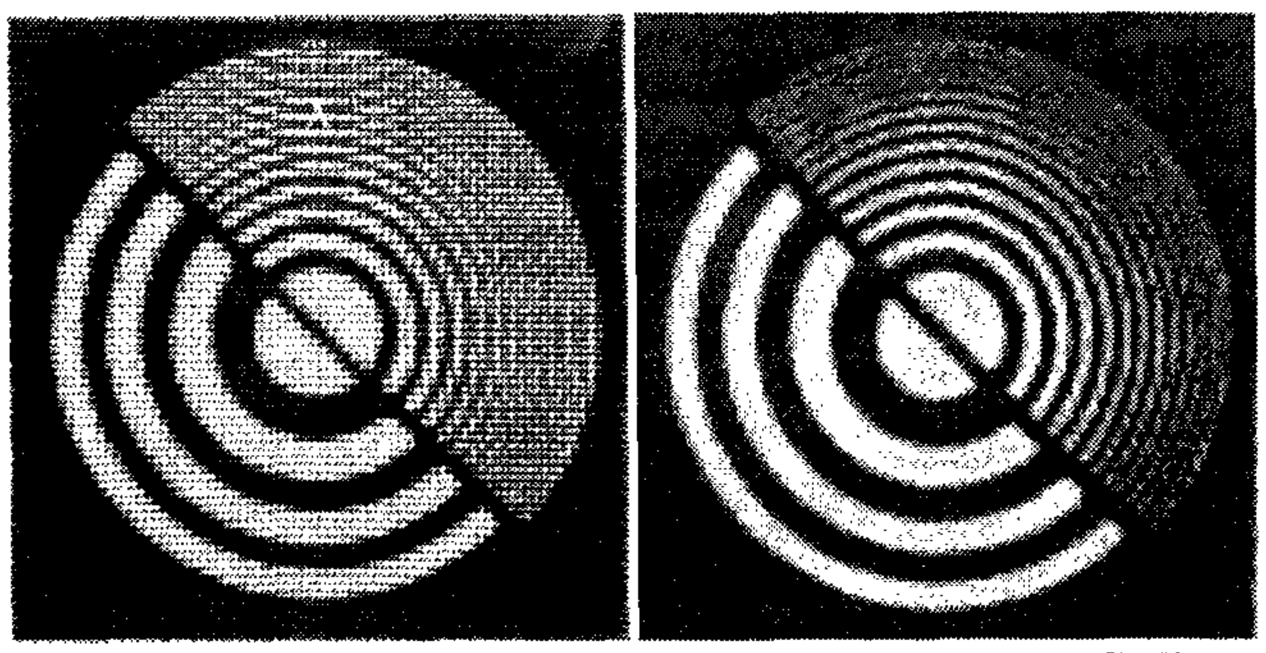
Figure 4 is one of the resulting images. Figure 4 (a) is displaying image on the HEXA structure PDP before SpR is applied, and Figure 4 (b) is displaying image on the HEXA structure PDP with SpR image process. A character readability, which is a kind of resolution function, was much enhanced by the developed SpR method.

(a) HEXA without subpixel rendering



(b) HEXA with subpixel rendering

Figure 4. Character readability test images.



(a) Striped subpixel (b) HEXA with SpR

Figure 5. Fresnel zone plate test images.

To test the effective resolution, we used Fresnel zone plate (FZP) test, and the results are shown in Figure 5. FZP in a conventional striped subpixel PDP without subpixel rendering showed a weak false pattern in the A (upper center) region of Figure 5 (a). But, subpixel rendering was applied to the HEXA structure PDP, the false patterns on A region disappeared in Figure 5 (b). In the HEXA structure PDP to which subpixel rendering was applied, each subpixel performed its role not only as a color-representing factor but also as a resolution-representing factor.

5. Conclusions

Figure 6 shows the region of adaptable hexagonal subpixel shapes according to the pixel pitch for delta color array PDP. It shows that optimized hexagonal subpixel is essential for the smaller pixel pitch PDP, and the effects of them also increase.

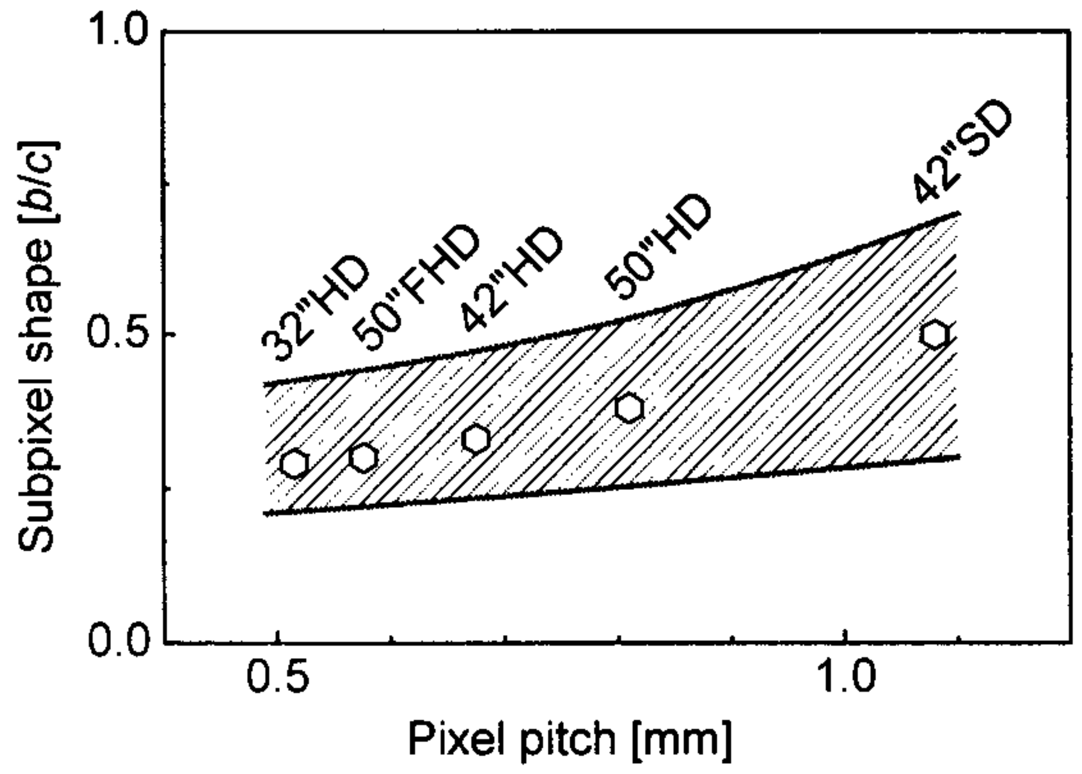


Figure 6. Best subpixel shape *vs.* pixel pitch.

Recently, we also developed the world largest PDP with the size of 70-inch, and it also realized the full HD resolution (1,920×1,080) in plasma display for the first time. A photo of 70-inch Full HD PDP is shown in Figure 7. This state-of-art prototype has adopted another improved panel structure, and it shows 800 cd/m^2 of peak white luminance and 1,200:1 of dark room contrast.

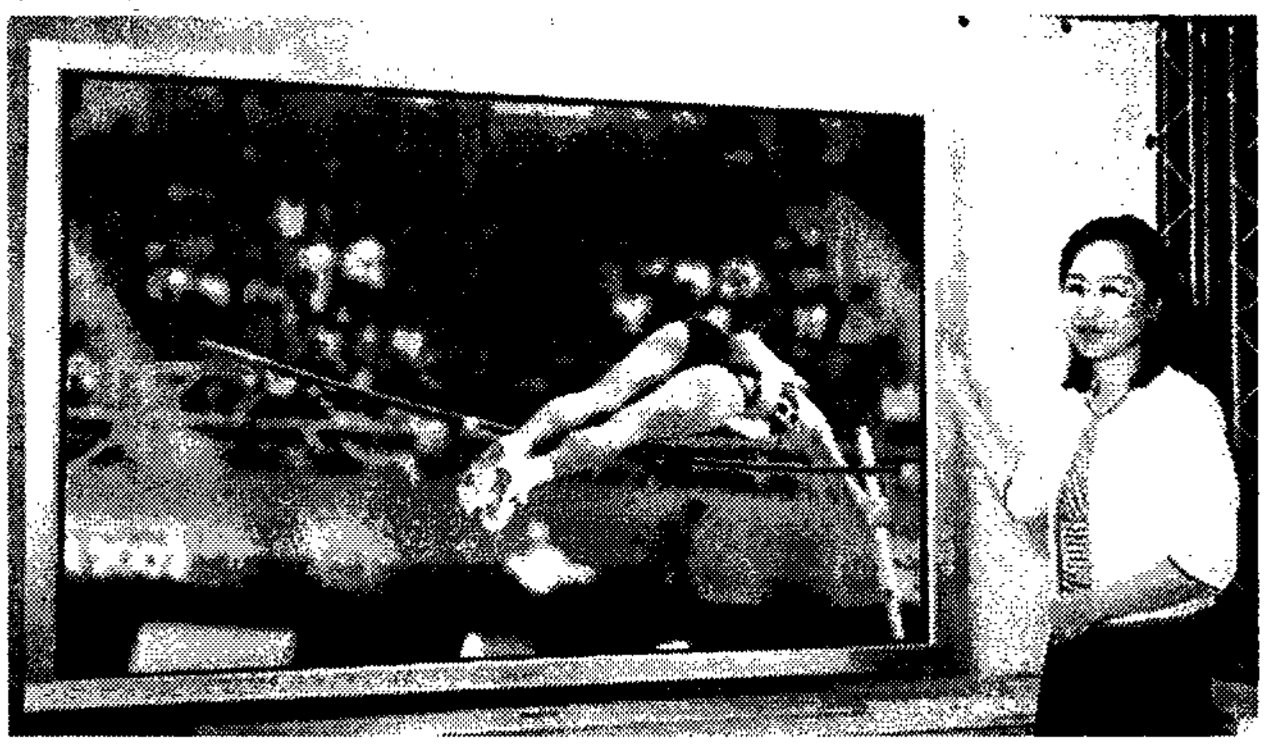


Figure 7. Photo of 70"FHD (1,920×1,080) PDP.

The factory for plasma display panel fabrication does not need very high-class clean room facilities as semiconductor or LCD module industry does. Except a few process, most fabrication processes are thick film process. This thick film process is a source of price-competition power for making large-size TV, but at the same time, it can be a hindrance to making a high-definition product. In this reason, the effective use of small discharge area is very important in PDP.

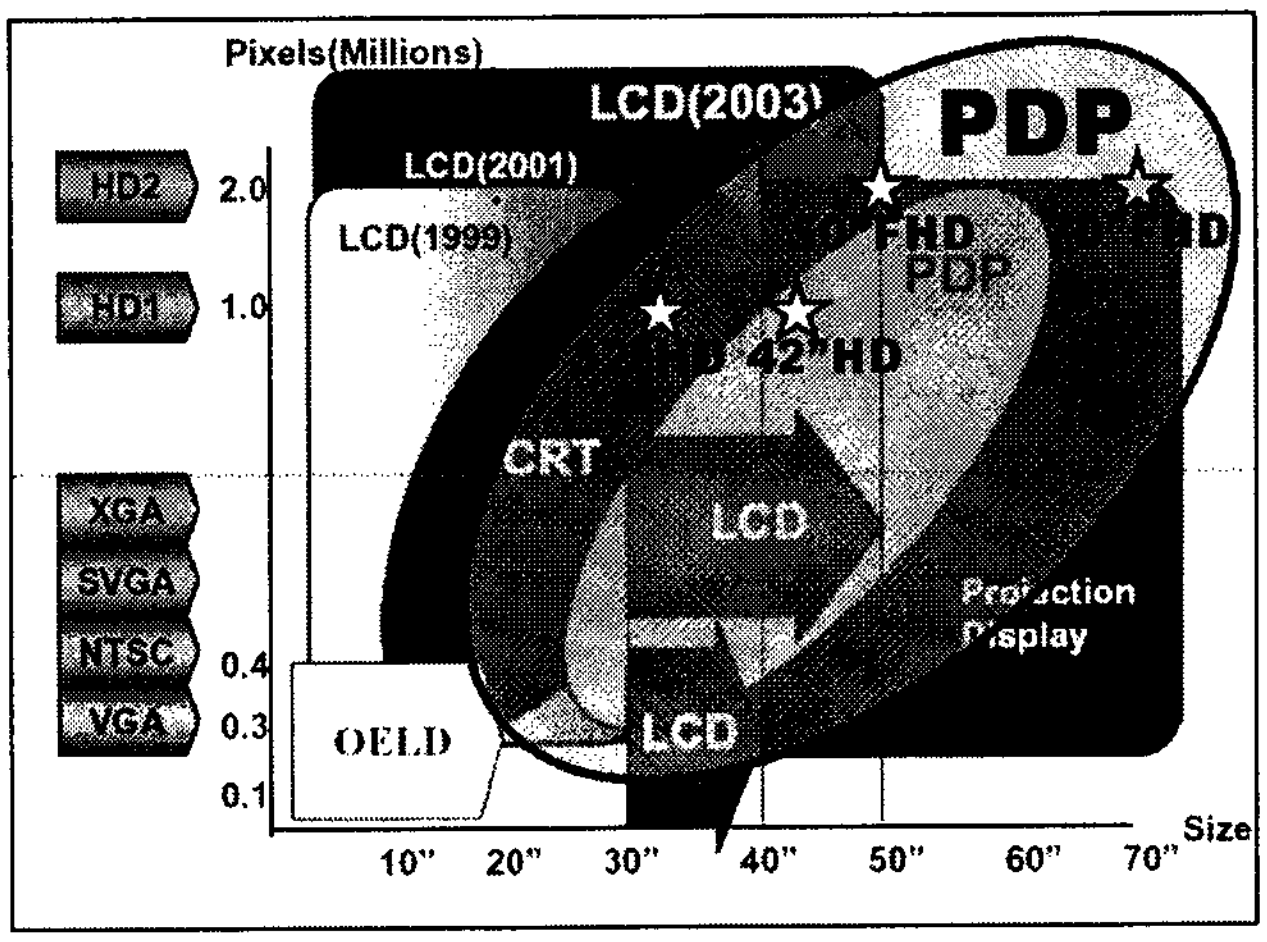


Figure 8. Market diagram – our hope.

We can see that the delta color array of hexagonal subpixel is more effective and essential in design of panel for high-definition PDP with relatively small pixel pitch. With this subpixel design scheme for high efficiency in small pixel pitch, we already made the 42-inch HD prototype, and try to make smaller size full HD (1,920×1,080) prototype. With the technology proposed in this paper combined with a new low cost manufacturing technology. We opened the way for PDP to compete in the area of larger size and higher resolution.

6. References

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