The Realization of Affordable Full-HD PDP in 42-inch: How soon will it come true?

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Abstract
We have studied the needs for developing plasma displays with 1080p quality and the possibilities to construct an affordable 42-inch full HD PDP. It seems impossible to get a prototype unless we overcome technical difficulties. First, we should find a way to innovatively improve luminous-efficacy and interconnection problems. At the same time, we should find a way to overcome image quality degradation in single scan.

1. Introduction
The market for large screen televisions above 40-inch is changing. The rapid growth of market will soon change ordinary people's life style and generate need of various surrounding devices creating new secondary market. By the year of 2008, total television market size above 40-inch will reach 25 million units earning 25 billion US dollars. CAGR from 2004 to 2008 will be about 13 %[1]. Major large FPD manufacturers are practicing top quality strategies on business, technology and marketing seeking for a new advantageous ground.

In this paper, we will discuss present status and potential value of PDP's in such environment, in the meanwhile we will mention technical obstacles to overcome in order to become a leader in this massive market.

2. Customer requirements
2.1 Diverging needs of digital contents
Considering the data compression type designated by ATSC (Advanced Television System Committee)[2], 1920 x 1080 format is advisable for HDTV and high fidelity film and 1280 x 720 is advisable for sports game relay and animation movies. When HDTV standard was established, both 1080i and 720p formats were considered initially, but gradually 1080i is becoming a main stream according to the standard practiced by broadcasting companies. Table 1 shows an example of terrestrial digital broadcasting programs globally operated.

IT business is also working hard to play leadership in this field. In 1997, 3 major IT companies formed a 'Digital TV team' and they proposed three introduction stages for digital broadcasting as in Table 2[3]. They made important technical breakthrough. The development of high-density storage media such as Blu-ray disc and HD-DVD can allow us to enjoy high fidelity films with 1080p quality even without having to install a HD-TV receiver.

Now let us talk about Internet. Thanks to the ultra-high speed data transferring system, we will soon be able to receive movies with 1080p quality from web sites. Ten million pixel quality digital cameras and two million pixel quality cam-coders are by now ready to provide high-resolution images. In another word, as long as display devices are ready, we are able to receive, save and play 1080p quality image data without having to install a HDTV receiver.

Table 1. Terrestrial digital broadcasting programs from major broadcasting companies in 2003.

Nation	A/R	Reso-lution	Scan type	Broadcasting company	Schedule
Korea	16 : 9	HD	1080i	Major 3	10 hrs/week
GB	16 : 9	SD	480p	BBC, etc.	Full day
US	16 : 9	SD	480p	FOX	Partly
		HD	1080i (720p)	Major 4	Half of Prime time

Table 2. The correspondence from major IT companies in US.

Stage	Format
HD 0	720 / 24p, 480/ 60p
HD 1	1080/ 24p, 720/ 60p
HD 2	1080/ 60p

Technology is not simply about digital broadcasting, but more intellectual. This trend is well illustrated in Figure 1 with the term, 'intelligent broadcasting'. At all circumstances, in order to digest various digital contents, there is a need for displays with 1080p. Sometimes this format is called full HD. However, this does not have any official origin. There is no certified limit for scan lines to define the term 'full'. In the future of intelligent broadcasting age, diverse digital contents will be mixed to each other and evolve without clear borderlines. For example, think about the situation that new customers ask for 4K class digital cinema in television[4]. How can you name the new display format with twice of scan lines in comparison with that for 1080p? One of the most important points is again that various customers will soon want a display with 1080p over the counter, so to speak a full HDTV.

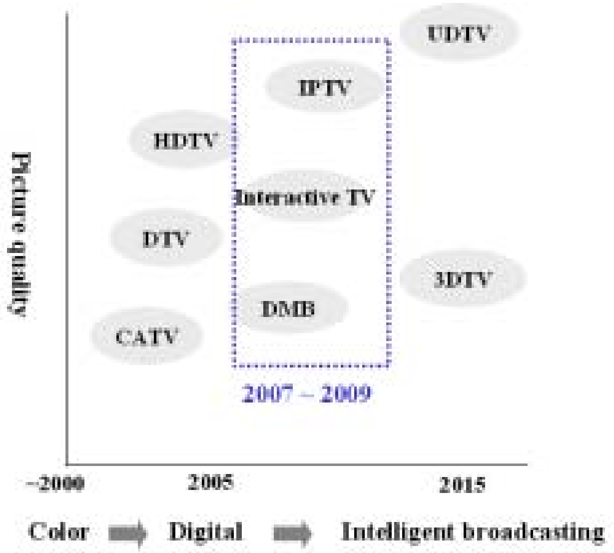

Figure 1. The evolution of television broadcasting type.

2.2 Display market consideration

In case of plasma displays that have a forte in large screen size from 37-inch up to over 100-inch, there is a demand for living room or public applications.

For the last three years major applications for plasma displays have been in the field of indoor venue, conference room application and financial exchange. Proper display size ranges from 40-inch to 60-inch. Although the largest revenue is coming from 40-inch class panels currently, the center of mass of profit will be slowly switched to larger sized group such as 50-inch.

The large screen display market has not experienced a new trend of intelligent broadcasting yet, but for coming three years, major FPD's will compete each other to embrace a new display concept dealing with various digital contents. Whichever display wins, it should satisfy fastidious customers in performance and cost. As display provider, releasing right products at perfect time is very important. But more importantly providers should secure material cost efficiency of such product in order to overcome sales price drop that goes up to over 20 % annually.

2.3 Psychophysical consideration deciding display format suitable to HDTV

Above all applications, the most attractive one is living room use, because every household has at least one television in his or her living room.

Previously we have mentioned that there is a new trend calling for the displays with 1080p. But can those displays impress people psychophysically? Or is it all about over-developed technology?

Japan Broadcasting Corporation (NHK) has performed psychophysical experiment emulating an average sized living room with watching distance of 2 meters. Recommended display conditions for super reality were shown in Table 3[5]. It says that displays should be larger than 50-inch and they should have at least 1080 scan lines. Therefore, if manufacturers can provide displays with 1080 scan lines near 50-inch, general consumers can enjoy various digital contents with family with deep impression in living room.

Table 3. Recommended conditions for Hi-vision.

Horizontal viewing angle	Near 33 degrees
Aspect ratio	16 : 9
Relative viewing distance	3H (H: picture height)
Active pixels	1920 x 1080
Preferred display size	53.5-inch diagonal

3 Comparison among large FPD's

It is worthwhile to search for commercially available FPD's with 1080p capability. Table 4 shows products with various display types available in market.

Table 4. Commercially available displays with 1080p.

Display type	Size
LCD	37-in, 45-in, 46-in, 55-in
PDP	71-in
Rear projection	70-in (SXRD)

LCD's are taking up the most positive attitude from 37-inch up to 55-inch. Other displays such as PDP's and rear projection displays have difficulties in positioning screen size below 70-inch due to technical difficulties.

DLP's have applied 'Wobulation' to displays with the physical resolution of 720p to provide enhanced image quality. Although this does not provide information compatible to 1080p, improved picture quality has powers of persuasions in the size range between 40-inch and 60-inch. Plasma displays are also making an aggressive move in the range between 50-inch and 60-inch by releasing business plans in press at the beginning of the year.

4. Plasma display panel requirements

So far, we have discussed necessities of 1080p capability for plasma displays of 50-inch in diagonal. From now on we will discuss the significance of developing a full HD 42-inch PDP.

Figure 3 shows dimensions of unit image element for 42-inch and 50-inch full HD. At a glance, it is difficult to see the difference between two. But In case of plasma displays, we believe there exists a technical turning point between two sizes. In other words, between two sizes, there is a borderline beyond which conventional technologies cannot reach. Within this border, we can use concurrent engineering to achieve what we want by maximizing our knowledge. Outside the boarder, some of conventional technologies no longer work and therefore, we should shift our paradigm by introducing alternatives to overcome obstacles. This is a good opportunity to innovate cost reduction strategy, because new paradigm can also create a large changing factor in material cost structure in either good or bad way. Keeping this in mind, we believe that the ability of being able to develop an affordable 42-inch full HD PDP will bring PDP manufactures to the gateway for success in intelligent broadcasting age.

Undoubtedly, above points at issue are disputable, because we are mentioning that it is impossible to build a 42-inch full HD PDP technically. From now on we will discuss related technical hurdles and desirable approaches to jump over them.

4.1 Fabrication issues

As for an upper substrate, whichever structure it has, as long as it utilizes surface discharge in moderate modifications, there is no significant difficulty in fabricating 42-inch full HD plasma panels. However, in ultra-fine discharge cells with space limitation, we won't have many degrees of freedom in designing parameters to improve performance.

Not like upper substrates, we have several serious difficulties in fabricating lower substrates. The reason is because lower substrates have three-dimensional structure composed of tall barrier ribs while upper substrates are flat.

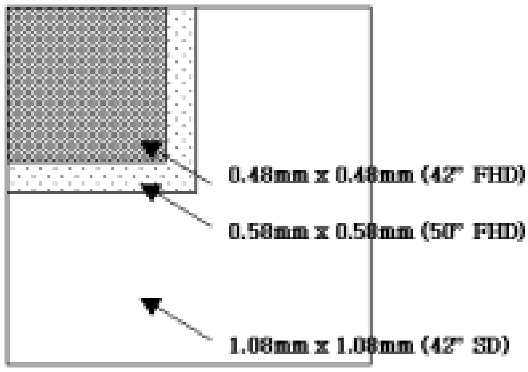

Figure 2. Dimensions of a unit image element of 42-inch and 50-inch full HD in comparison with 42-inch SD.

From Figure 3 we can compare typical discharge space between full HD and SD panels in case of 42-inch PDP with stripe structure. Dim light in green, blue and red represents visible light emission from phosphor. In comparison with the SD case, the internal space of full HD panels defined by barrier ribs is drastically reduced. In case of 42-inch full HD using HEXA structure, even though the barrier width is reduced to ideal zero, there is no way to spare the same space as in 42-inch HD panels with 768 scan lines. On the other hand, in case of 50-inch full HD PDP using the same HEXA structure, situation is different. If we half the barrier width, we are able to obtain the same discharge space as in 42-inch HD[6].

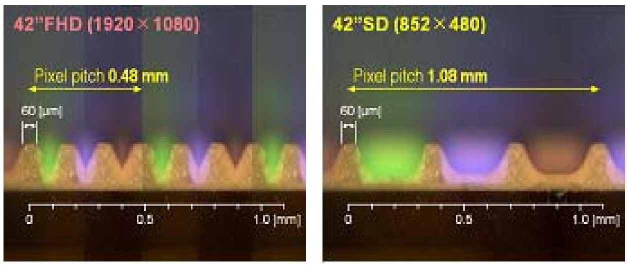

Figure 3. The comparison of discharge space between full HD and SD in case of 42-inch PDP.

There is a reason why we want to ensure discharge space as large as in 42" HD PDP. From the experimental test with MARI and HEXA structures in 42-inch HD, we have proved that there is no technical difficulty to achieve 2.0 lm/W in luminous-efficacy. If it is true that we loose efficacy because of reduced discharge space, it should be important to retain the same level of discharge space as in 42-inch HD panels, even though cell pitch is reduced.

We made a comment that there is not enough discharge space in 42-inch full HD panels. However, if we find a way to improve luminous-efficacy with reasonable discharge control, the problem may be mitigated. If such is the case, the best cell shape should be a circle with discharge space leveled in all directions. In figure 4 we introduced the photographs of lower substrates with two different barrier shapes designed for 42-inch full HD with 0.48 mm in pitch. Sandblasting was used to form barriers. Instead of circles, hexagonal shape was used.

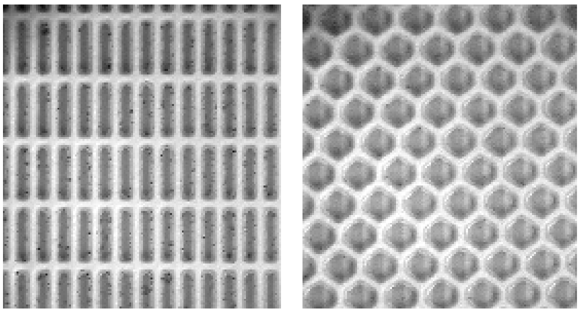

Figure 4. Barrier ribs with stripe and delta sub-pixel arrays applied to 42-inch full HD application.

Other than this, there are more problems to solve. Above all, we want to mention of discharge gas filling. While liquid crystal is active material for LCD, discharge gas is active material in PDP. For both devices active media should be filled into the narrow gap between two assembled substrates in vacuum. In case of PDP, barrier ribs with small halls isolate each discharge cell, and therefore vacuum conductivity is very poor and even lower than as in LCD that uses coarsely positioned spacers. For HD PDP, this problem gets worse. For example, 42-inch SD PDP has 1.2 million discharges cells and 42-inch full HD PDP has 6.2 million cells. We should evacuate all the cells and fill them with discharge gas through tiny halls made at barrier ribs. This cannot be a good vacuum system we can think of. LCD has found a clever way to fill liquid crystal and it is called direct falling with which there is no need of using vacuum line. Likewise, PDP can use the similar concept. Two substrates may be sealed in an environment of discharge gas or vacuum. Research and development in several institutes have made some fruitful result[7].

Elsewhere, we will mention interconnection issues. If pitch is reduced, there are more chances to have defects between electrodes due to impurities. In addition, when we display checkerboard pattern power consumption increases during addressing period of because of reduced gap between electrodes. Increased electric field between two electrodes at the terminal may cause more serious migration of conducting balls in ACF (An isotropic conduction film). Reduced electrode gap can interfere data signal of each line and cause signal deformation and EMI problems. To make things worse, if we drive panels using single scan, high speed switching can cause a serious reliability problem at TCP's.

In case of 50-inch full HD, depending on whether we use 96 or 192 pin type data IC's, approximately 120 to 150 microns of address electrode pitch is required at the terminals. In this scale, there are some ways to manage above problems previously discussed. However if we go with 42-inch full HD, we won't have such a chance. For example, let us consider a case illustrated in Figure 5. For TCP type interconnection, we need typical address electrode pitch of near 100 microns. Then the gap between two electrodes is about 50 microns. Considering the diameter of conducting balls of ACF to be 10 to 15 microns, there will be fewer contact points between two electrode surfaces from the panel and the circuit. Also the distance between electrodes are merely about three or four times of conducting ball diameter causing faster migration.

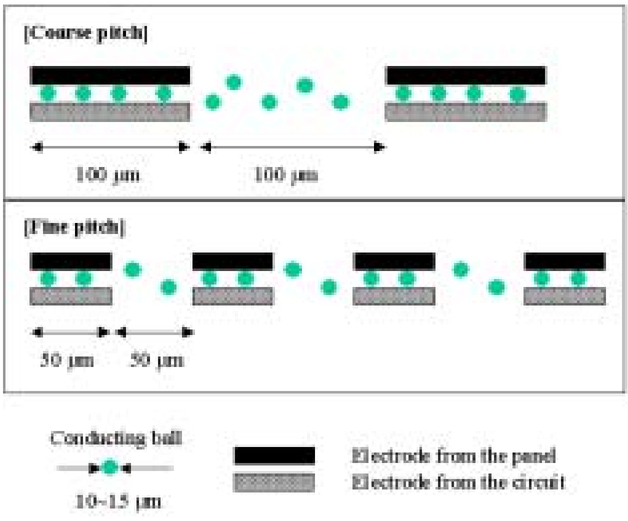

Figure 5. The interconnection of data-addressing electrodes for coarse and ultra-fine pitch.

An example of migration problem is illustrated in Figure 6. So far, we believe that the technical bottleneck for 42-inch full HD is interconnection problem. Although we may manage low efficacy problem associated from barrier ribs that are not sufficiently fine, there is no negotiable way to cover reliability problem related to interconnections in ultra-fine pitch. One way is to find improved solutions alternating interconnecting method of using conventional ACF. Clever designs of electrode terminals can allow us to stay with ACF technology. At the same time, we should develop methods how to address cells at lower voltage.

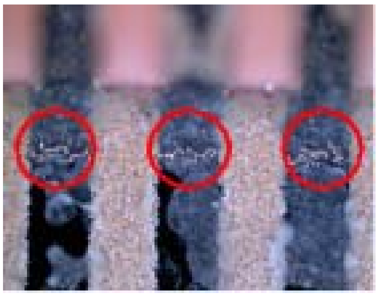

Figure 6. The migration of conducting balls in ACF at data-addressing electrodes.

4.2 Performance issues

Previously we have considered how to fabricate and construct a display module. From now on, we will be discussing how to take out satisfying performance from the device with the assumption that the module is perfectly fabricated. The level of performance for 42-inch full HD should be as good as or even better than 42-inch HD with 768 scan lines.

First, we should secure large enough driving margin. We need to deposit and erase wall charges at will, even though discharge space and electrode area is reduced significantly. We should learn how to avoid cross talk, although the distance between neighbors is reduced dramatically. We might modify three-dimensional electronic structure and driving waveforms to optimize condition for discharge without great success. Before we set up design rules, we should spend enough time in understanding discharge in ultra-fine discharge cells.

Second, we should make a break-through in improving luminous-efficacy to make brighter panels spending lower electronic power. We reported luminous efficacy tends to drop rapidly as image element size is reduced as in Figure 7. We suggested a mean to improve efficacy without having to modify patterning mask design by raising content of Xenon and driving frequency[8].

If the trend in Figure 7 stays the same at smaller pitch, the efficacy for 42-inch full HD with the pitch of 0.48 mm should be less than 1 lm/W. Probably we will face difficulties in improving efficacy using the same method previously proposed, because there should exist some limitation in broadening driving operational window. Unless we find innovative cell design, it should take for a while to make 42-inch full HD PDP with the efficacy near 2 lm/W.

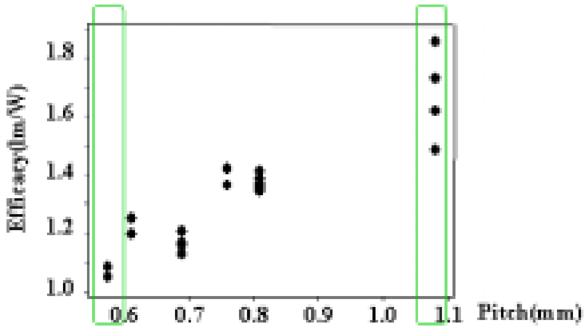

Figure 7. Luminous efficacy of 'HEXA' structure as a function of image element pitches in medium Xenon.

Third, we need to approach a power consumption issue in a different manner when we expand scan lines from 768 to 1080. In reality, it is not so simple to analyze an electronic power consuming mechanism.

Normally we measure power consumption at full white condition in which whole pixels are lit with every sub field is on. This is the case when power is consumed mainly by sustain discharge – so to speak, effective power consumption. In this case we can reduce power consumption by raising luminous efficacy. But in PDP with the resolution capable of full HD, we should not overlook the importance of ineffective power consumed in the circuit itself.

For example, if we set up the case where only 1 % of panel area is lit with every sub field is on, maximum number of sustain pulses are scheduled in time table. Effective power is minimized, because only 1 % of area is lit, conversely ineffective power is maximized, because every FET switch for sustain pulses is on. In this case capacitance of electrodes plays an important role. In full HD, we have more FET switches for sustain electrodes and higher cell capacitance and therefore, ineffective power increases.

Similar concern should be accounted for address power consumption. Modules driven by single scan should bring several secondary reliability problems resulted from fast switching. By all means, there is a limit in cutting capacitance between electrodes by changing cell-designing parameters because of space limitation. Presently there doesn't seem to exist smart ideas to cope with these troubles for both 42-inch and 50-inch full HD PDP.

4.3 Picture quality issues

In order to realize natural images, it is important to have a sufficiently long sustain-period to maximize gray levels. In comparison with panels with 768 scan lines; we need an about 40 % longer data-addressing period for those with 1080 lines. Since there is a limitation to spare it due to discharge time lag, we have to sacrifice the length of a sustain-period and number of sub-fields. We may loose abilities of low gray-level expression and false contour reduction consequently. In developing 102-inch full HD PDP, we have reached an acceptable level of picture quality. In this application we used dual scan. However if we challenge single scan for cost reduction, we will loose half of sub field number, only resulting 7 sub fields. In order to recover gray scales, one may want to use dithering at the expense of noise. This choice is not recommendable, because we will sense the loss of picture quality. In that case, displays with full HD resolution cannot realize sharp images contradictorily.

Certainly rapid addressing will solve this problem, but like it is difficult to reduce response time of liquid crystal, it is so challenging to reduce discharge time lag. Conceptual innovation is desired to solve such dilemma.

5. Conclusion

We have discussed several obstacles in realizing an affordable 42-inch full HD PDP. Regardless to say, we should apply single scan method without sacrificing picture quality. Unless we achieve conceptual break-thorough in Efficacy improvement and interconnection, it won't have any commercial merit. We have also introduced some problems that are common for all sizes of full HD PDP's. It may be true that it is worthless to commercialize 42-inch full HD PDP's. But still it is worthwhile to develop them, because larger-sized full HD applications can take advantages from such efforts. In order to speed up such procedure, we would suggest that we practice following three designing philosophies.

First, stay with conventional infrastructures somehow. As much as we can find ways how to cleverly exploit them, it will cut down time of wandering to find alternatives.

Second, be ingenious in solving technical dilemmas and keeping out of technical obstacles. Simple compromise won't help.

Finally, collaborate with people in various fields for integrative researches. Building consortiums composed of design, fabrication, driving and evaluating functions as a unit. Not like LCD's, the performance of elementary technologies cannot be evaluated until whole unit is operated as a system. We believe this is the nature of plasma displays. Regardless how small the test-panel size is, this kind of working system should speed up the advancement of PDP technologies.

Finally, we would like to express our acknowledgement to those in the production division for helping us perform feasibility tests, receive production data and criticize potential difficulties in realizing full HD plasma displays.

6. References

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