High Efficient Structure of Plasma Tubes

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Abstract
The plasma tube array display is expected to realize the wall size display with very high luminous efficacy. The cell design for high luminous efficacy was investigated. Also discharging in plasma tube was observed to investigate the structure for high luminous efficacy. As the result, high luminous efficacy of 5.4 lm/W was achieved.

1. Introduction
In the broadband network era, the interacted communication between two distinct places with realistic picture will be very common. This kind of system can display the real scale image and people can see as if they are really there (Figure 1).
For this kind of display, we have proposed a new full color emissive display with plasma tube array technology [1] based on the principle of the Plasma Display.
High luminous efficacy is needed for this display because of its power consumption for large screen size. Higher than 5 lm /W is our target for this system [1].

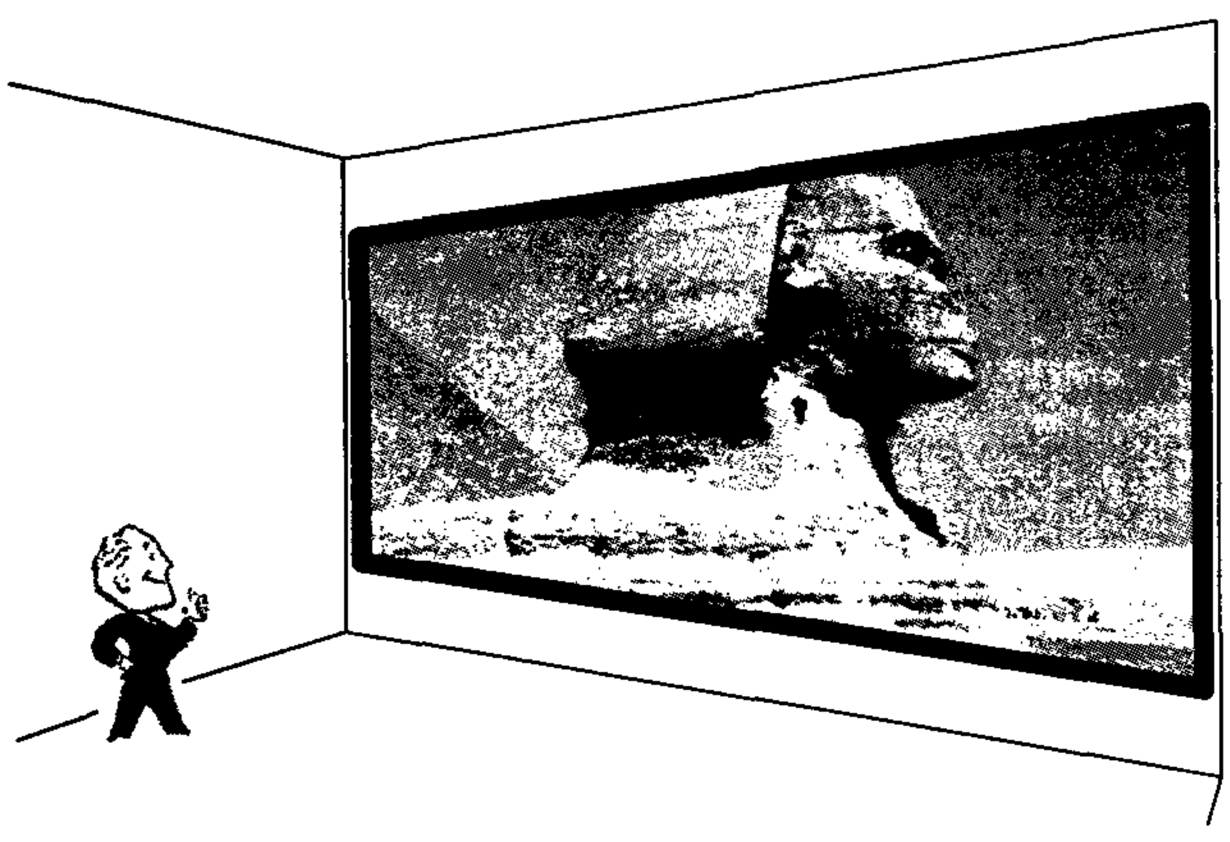


Figure 1 Concept of Wall Display

2. Structure of the Plasma Tube
Figure 2 shows the basic structure of this display. The basic idea is to realize the display by arraying many fine and long emissive fluorescent tubes (plasma tubes). The size of each tube is, for instance, 1 mm diagonal and 2 m long [2]. Each tube emits red, green or blue color light to make full-color display. Also each tube is divided into small pixel that can be selectively driven by applying the signals externally.
The oblique perspective figure of the cell is shown in Fig.3. The structure is similar to that of the conventional plasma display.

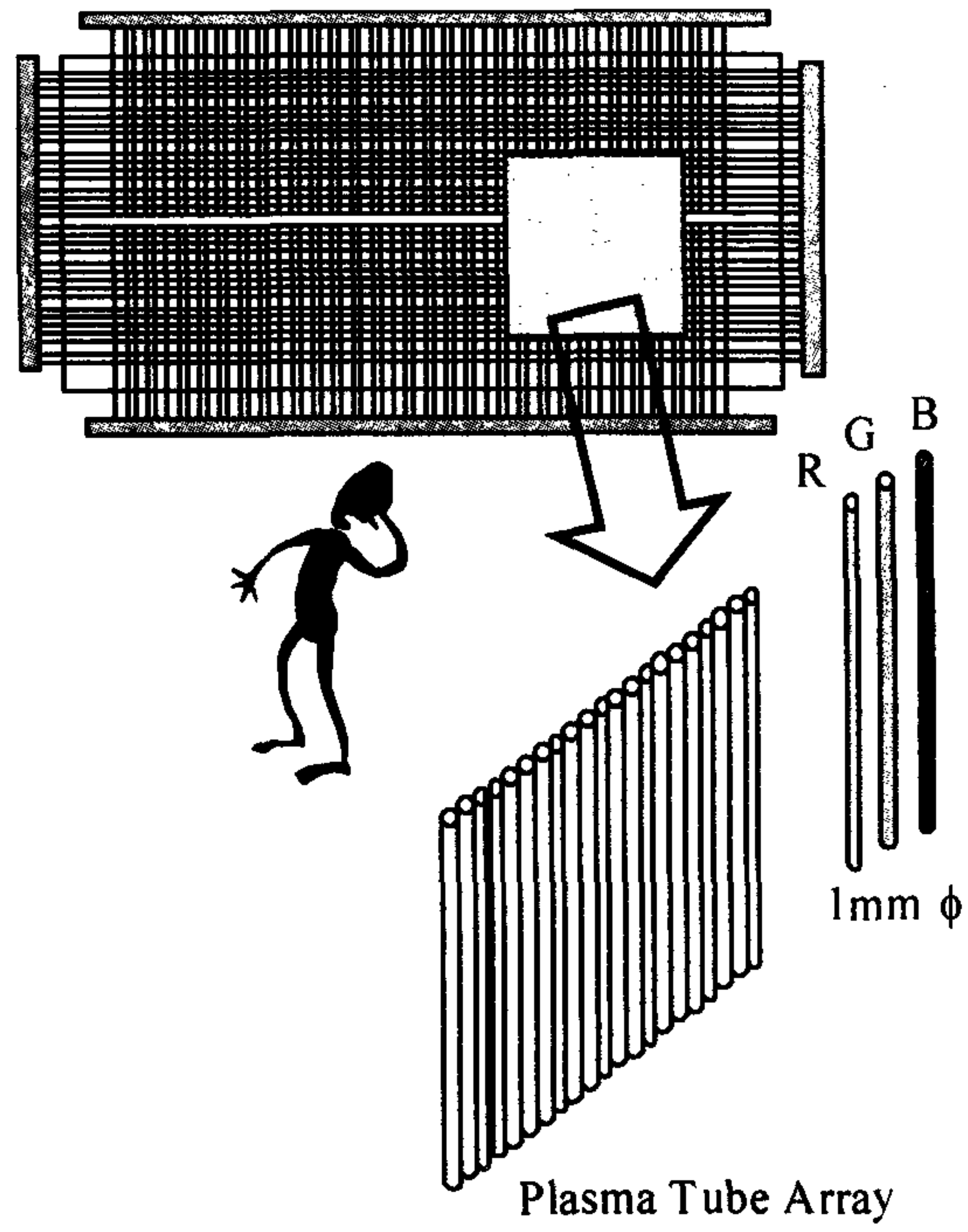


Figure 2 Concept of Plasma Tube Array Display

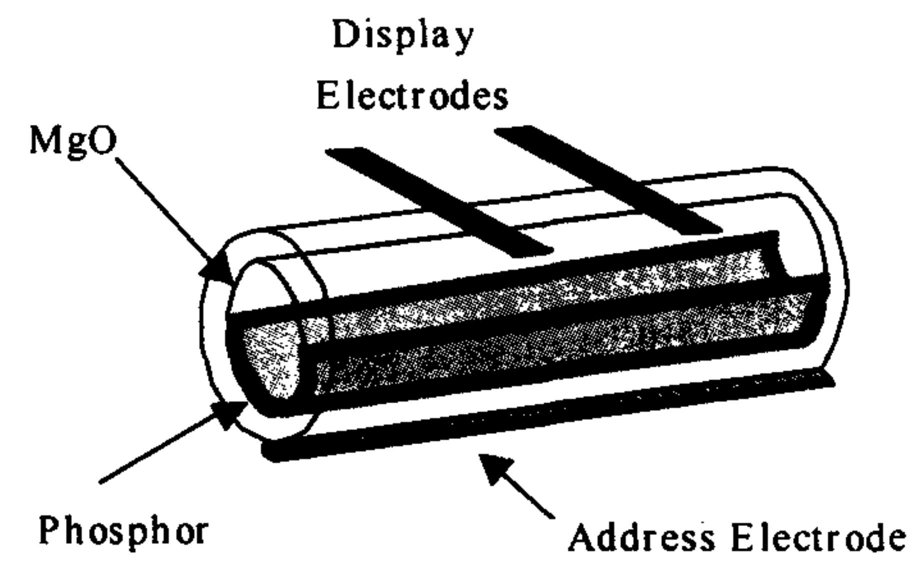


Figure 3 Cell Structure of Plasma Tube

3. Luminous Efficacy of Plasma Tubes
We have reported the cell design of the tube for 3 m x 2 m display [2]. According to this design, the sub pixel size is about 1 mm x 3 mm for HDTV resolution (1000 x 700) and the discharge gap is 0.4 mm to 0.8 mm due to the operation voltage limitation (<400 V) for the conventional driving circuit of conventional PDPs. Because of this large cell size and long discharge gap, high luminous efficacy is expected. However not only the cell size and the discharge gap but also other tube design parameter strongly affect to the

luminous efficacy as we have reported [3]. In this paper the design of the plasma tube for high luminance efficacy is discussed and the high luminous test tube is shown.

4. Experiments and Results

4.1 Discharge Gap and Shape of the Tube

First of all the effect of the discharge gap and the shape of the tube to the luminous efficacy was investigated. The shapes of the test tube are shown in figure 4 and Figure 5 and figure 6 show the luminous efficacy of test tubes with various discharge gaps.

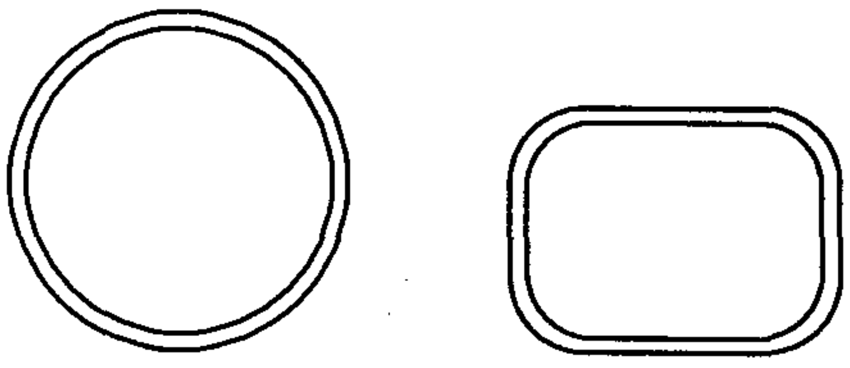


Figure 4 Cross section of Test Tube

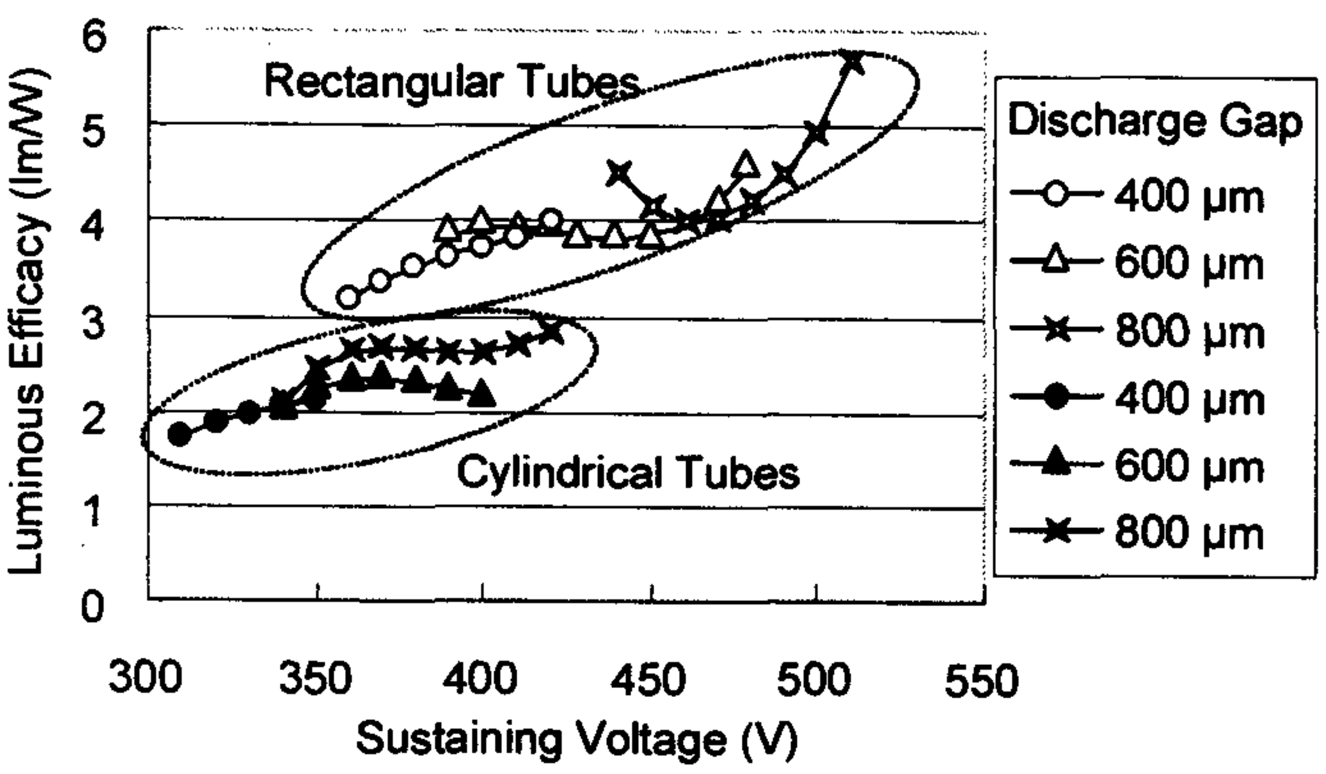


Figure 5 Luminous Efficacies of Plasma Tubes

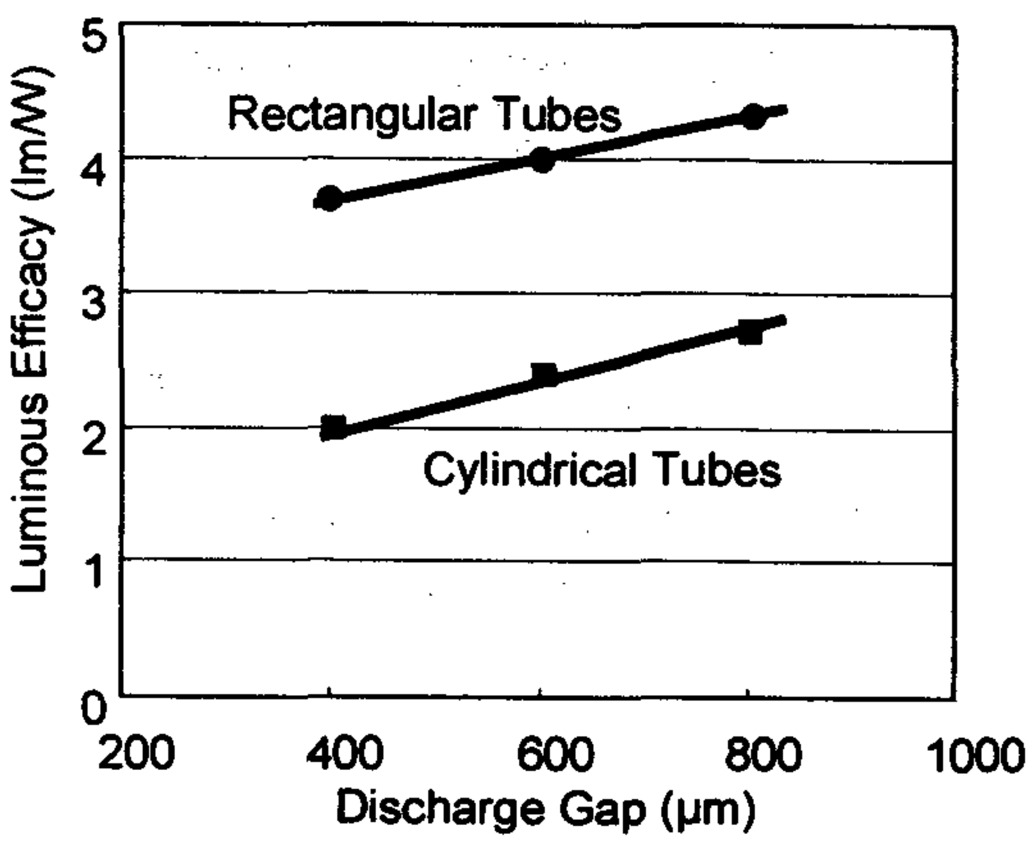


Figure 6 Luminous Efficacies of Plasma Tubes with Various Discharge Gap

The luminous efficacy is proportional to the discharge gap in both cases. Rectangular tube showed the almost 1.8 times higher luminous efficacy than cylindrical tube and the luminous efficacy with margin center voltage was 4.3 lm/W when the gap is 800 um. Even when the driving voltage is less than 400 V, with which same circuit design as conventional PDPs' can be used, the luminous efficacy is 3.7 lm/W [3].

The difference of the luminous efficacy will occur because of the efficacy difference in using of the ultra violet ray from plasma. As it is shown in figure 7 the distance between the discharge and the phosphor layer is closer and the volume angle from discharge to phosphor layer is larger in the case of the rectangular tube. This is the reason of higher luminous efficacy of rectangular tube.

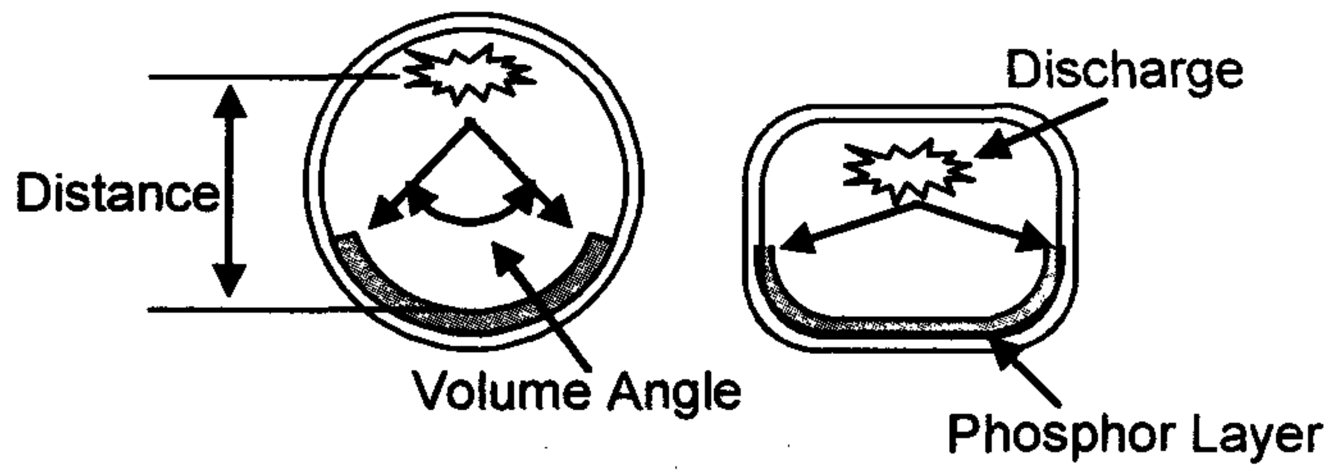


Figure 7 Efficacy Difference in Using of Ultra Violet Ray with Different Tube Shape

4.2 Shape of the Phosphor Layer

Next we investigated more efficient structure. As it is shown in figure 8, if the phosphor layer height is higher, the irradiation efficacy of ultra violet ray will be higher. So the test tube with higher phosphor layer height was fabricated and was measured. As shown in figure 9, the luminous efficacy was improved and it was almost 4.5 lm/W at operation margin center (270 V). The luminance of these test tubes is shown in figure 10. It is measured in static operation and the sustain frequency was 50 kHz. The luminance was also improved. It is almost 1.1 times higher than previous structure.

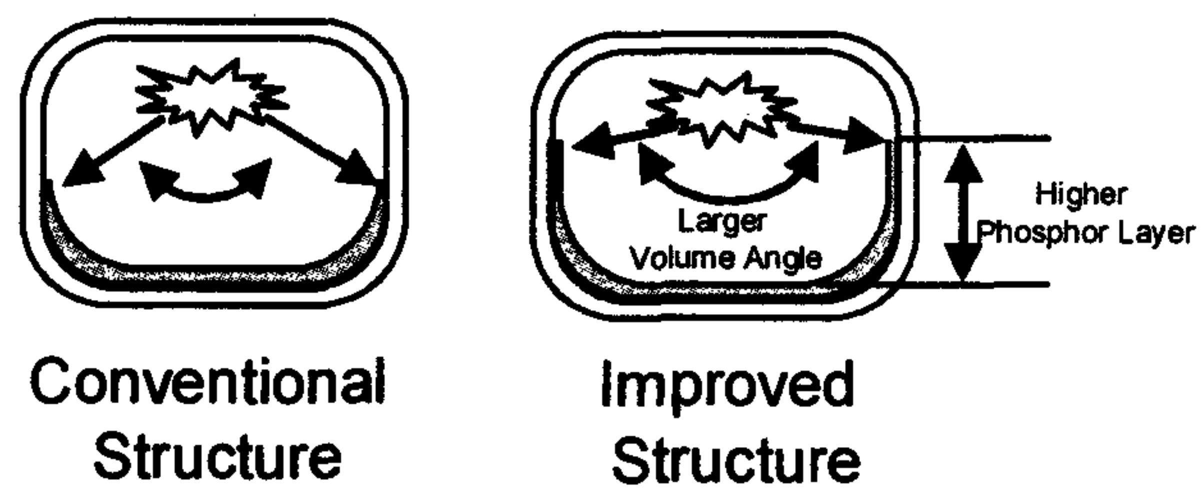


Figure 8 Higher Phosphor Layer Height Tube

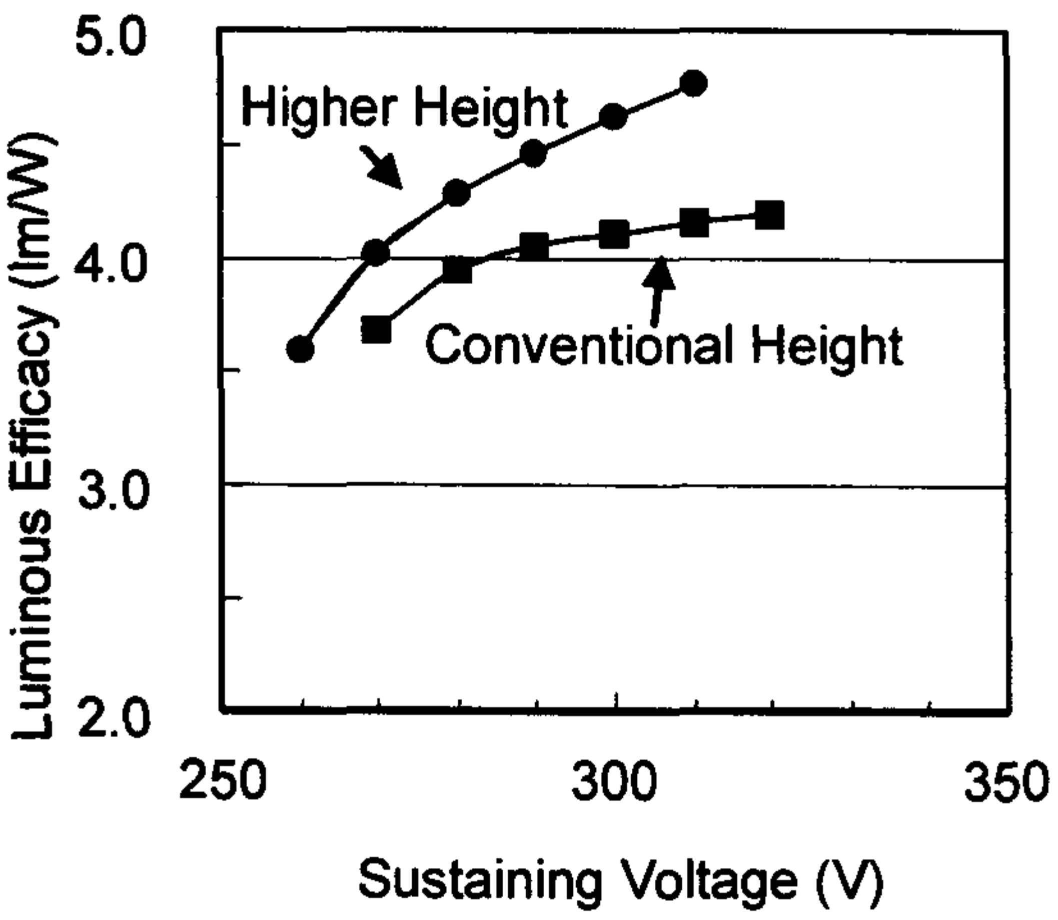


Figure 9 Luminous Efficacy with High Phosphor Layer Structure

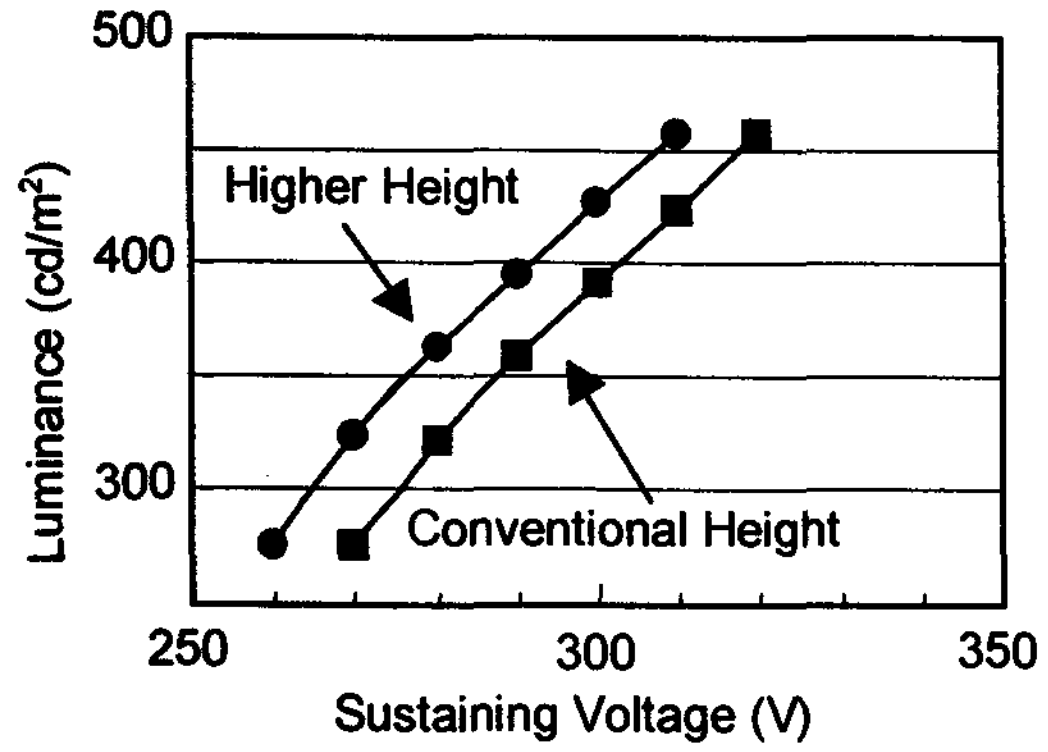


Figure 10 Luminance with High Phosphor Layer Structure

4.3 Xe Contents

It is well known that higher Xe contents discharge gas realizes higher luminous efficacy. Even in the case of plasma tubes, high luminous efficacy can be expected with high Xe content because of the same operation principle.
First, the operation voltage of high Xe contained tubes was investigated because high operation voltage was concerned. Figure 11 shows the results of Ne-Xe 10 % gas. For driving with the conventional driving circuit, the firing voltage should be lower than 400 V. So, this time the discharge gas pressure of 200 Torr, 250 Torr and 300 Torr were chosen for the test tubes. In these cases, the partial pressure of the Xe gas is 20 Torr, 25 Torr and 30 Torr respectively. In the case of the conventional gas mixture it is 14 Torr. Therefore, these are higher than that of conventional gas mixture. Figure 12 shows the luminous efficacy of these tubes.
In the case of gas pressure of 300 Torr, high luminous efficacy of 4.9 lm/W (@350 V) was achieved.

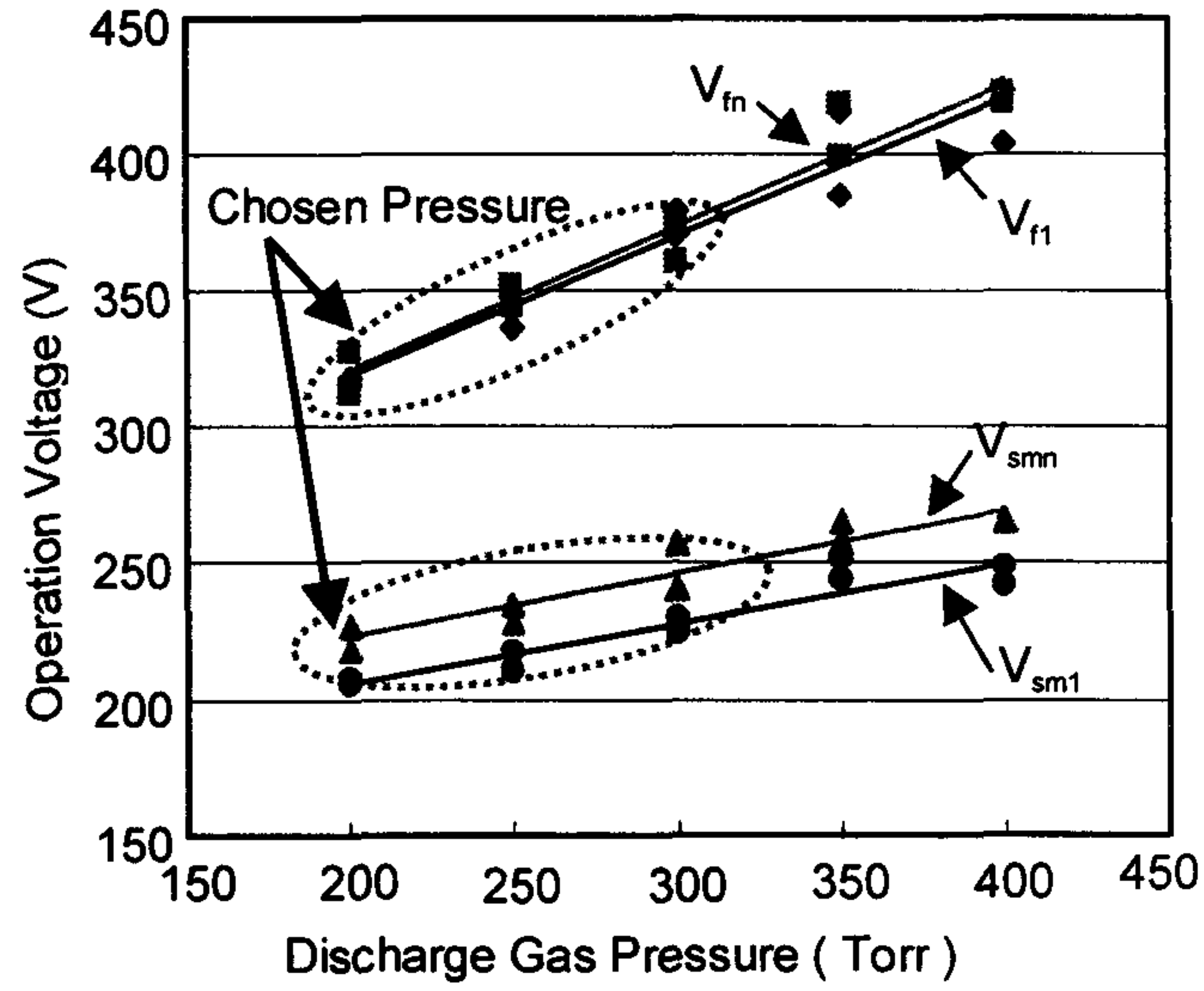


Figure 11 Operation Voltage of Ne-Xe 10% Discharge Gas

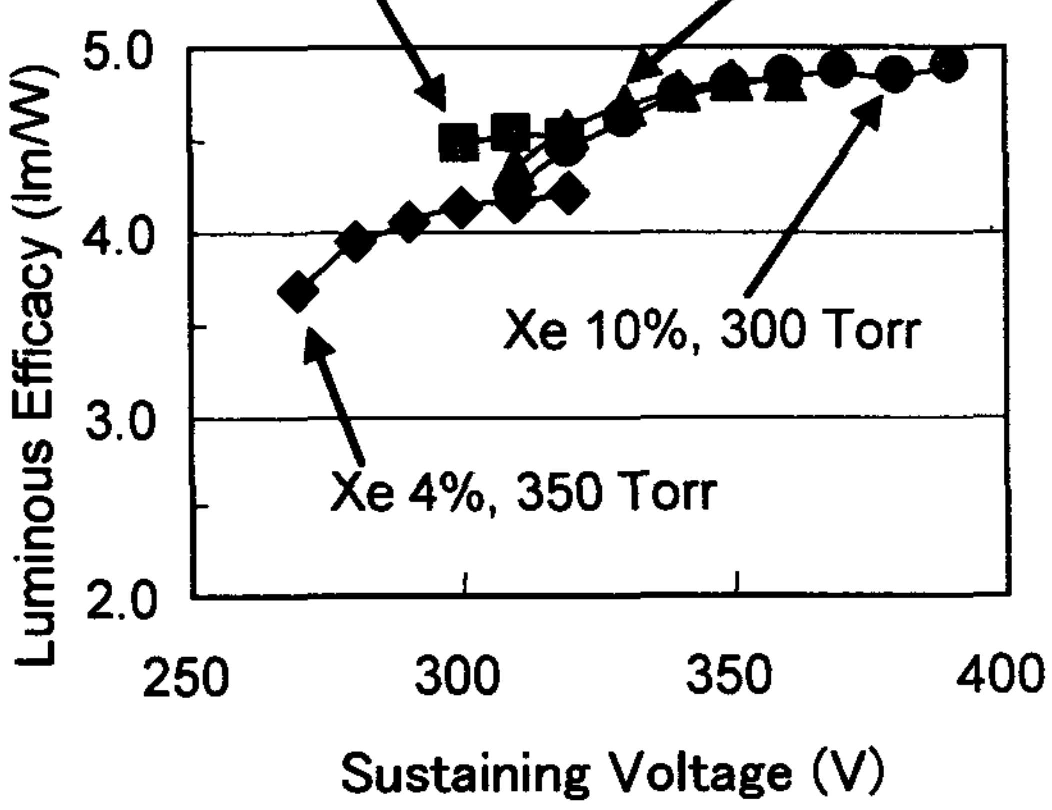


Figure 12 Luminous Efficacy of High Xe Gas Mixture Tube

4.4 Phosphor Materials

Recently phosphor materials are improved very rapidly. However we used to use conventional phosphor for test tubes. So, new generation phosphors are demonstrated for higher luminous efficacy. Figure 13 shows the results. In this case the discharge gas conditions were Ne-Xe 10% of 300 Torr total pressure. With these new phosphors very high luminous efficacy of 5.4 lm/W (@ 350 V) was achieved. In the same time they had good memory margin and were driven with enough low voltage by conventional circuit.

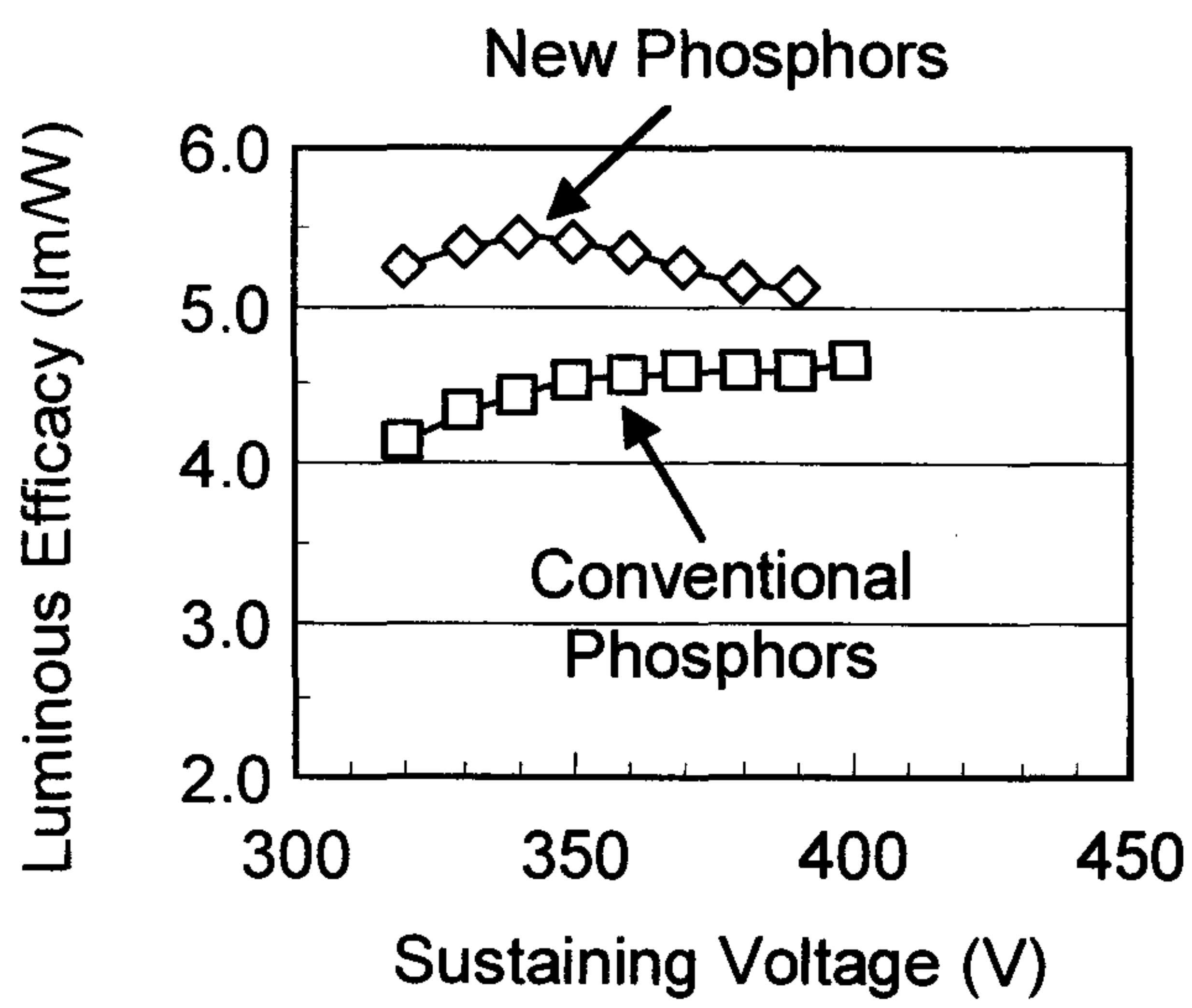


Figure 13 Luminous Efficacy with New Phosphors

5. Discussion

We have shown the ability of plasma tube structure for very high luminous efficacy. Here, the mechanism of the high luminous efficacy is discussed in comparison with conventional PDPs.

In the case of PDPs, the luminous efficacy is not proportional to the discharge gap as we have reported [3]. Figure 14 shows the schismatic picture of the test cell and figure 15 shows the luminous efficacy with various discharge gap.

The luminous efficacy was saturated when the discharge gap was wider than 0.1 mm. In contrast it is proportional to the gap in the case of plasma tube as shown in figure 6. From these results it can be understood that the structural difference between the tube and the PDP affects the luminous efficacy characteristics. So it would be useful to understand this difference to know the mechanism of high efficacy of the plasma tube.

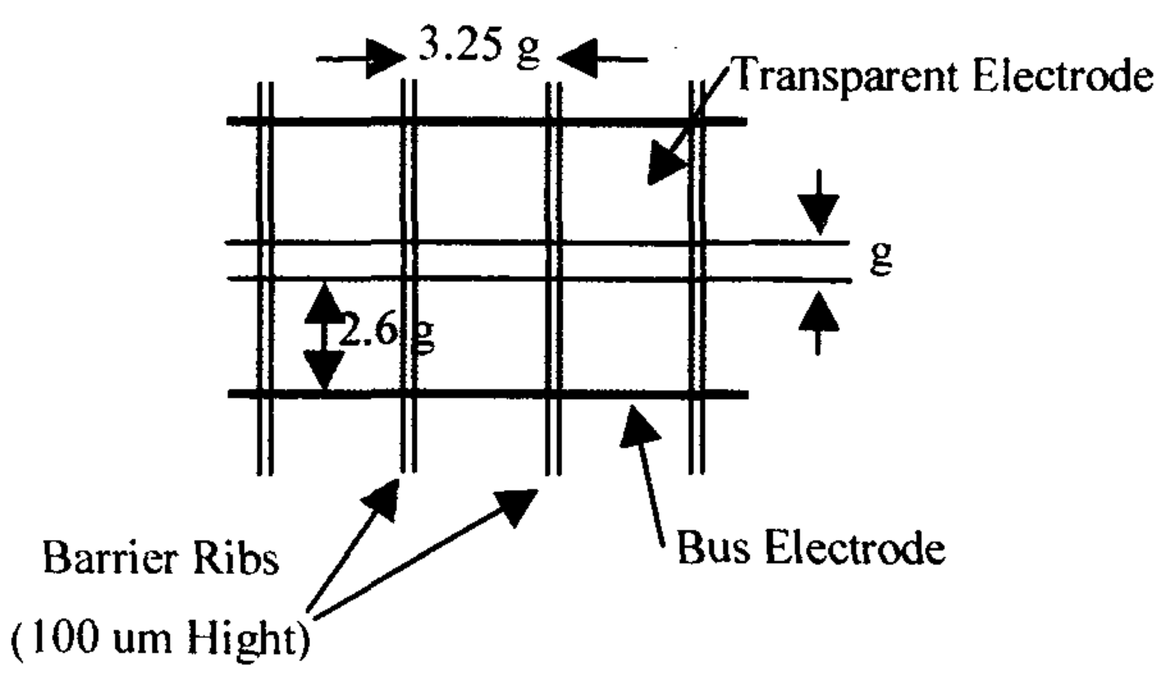


Figure 14 Dimension of the Test Cell

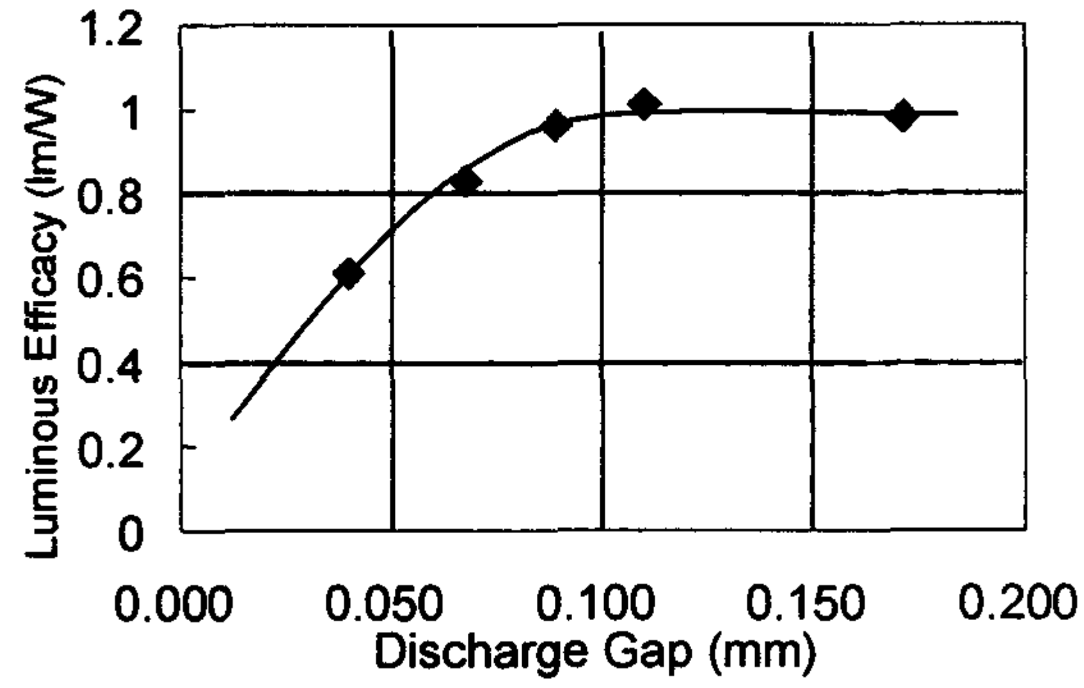
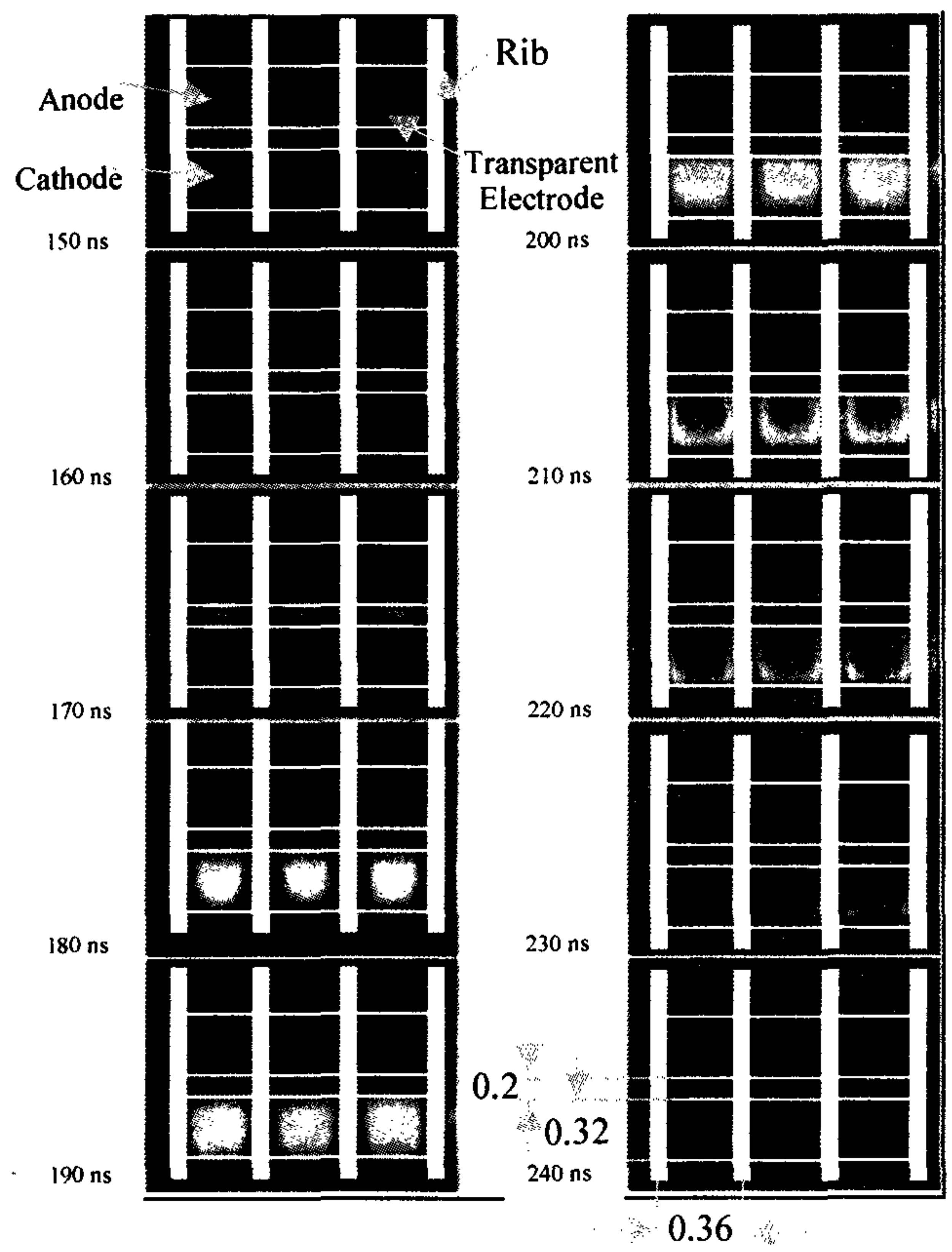


Figure 15 Luminous Efficacy of Conventional PDPs in Operation of Static Center Voltage with Various Discharge Gap

The light emission by discharge of plasma tube and the conventional PDP structure was observed with the high speed gate camera to see the difference of the discharge. The visible emission of Ne (640 nm) was observed in both case. Figure 16 shows the observation results of conventional plasma display as time-delayed sequence.



Ne-Xe 4% 500 Torr, Discharge Gap = 0.2 mm, Applied Voltage =200 V

Figure 16 Neon Light Emission from the Conventional Plasma Display

The light emission starts from the discharge gap and is spread widely along the cathode electrode. Finally, it reaches to the rib wall and disappears. For example, 220 ns after the trigger (Figure 17), the bright light emission can be observed around the rib wall. This means that the energetic ions are spreading but the rib wall prevents that. Therefore some ions or excited gas atoms just loose the energy by the collision with the rib wall. Also since the discharge distributes wider and more quickly when the discharge gap is wider, the collision may be more frequent. That is the reason why the luminous efficacy saturates with the discharge gap.

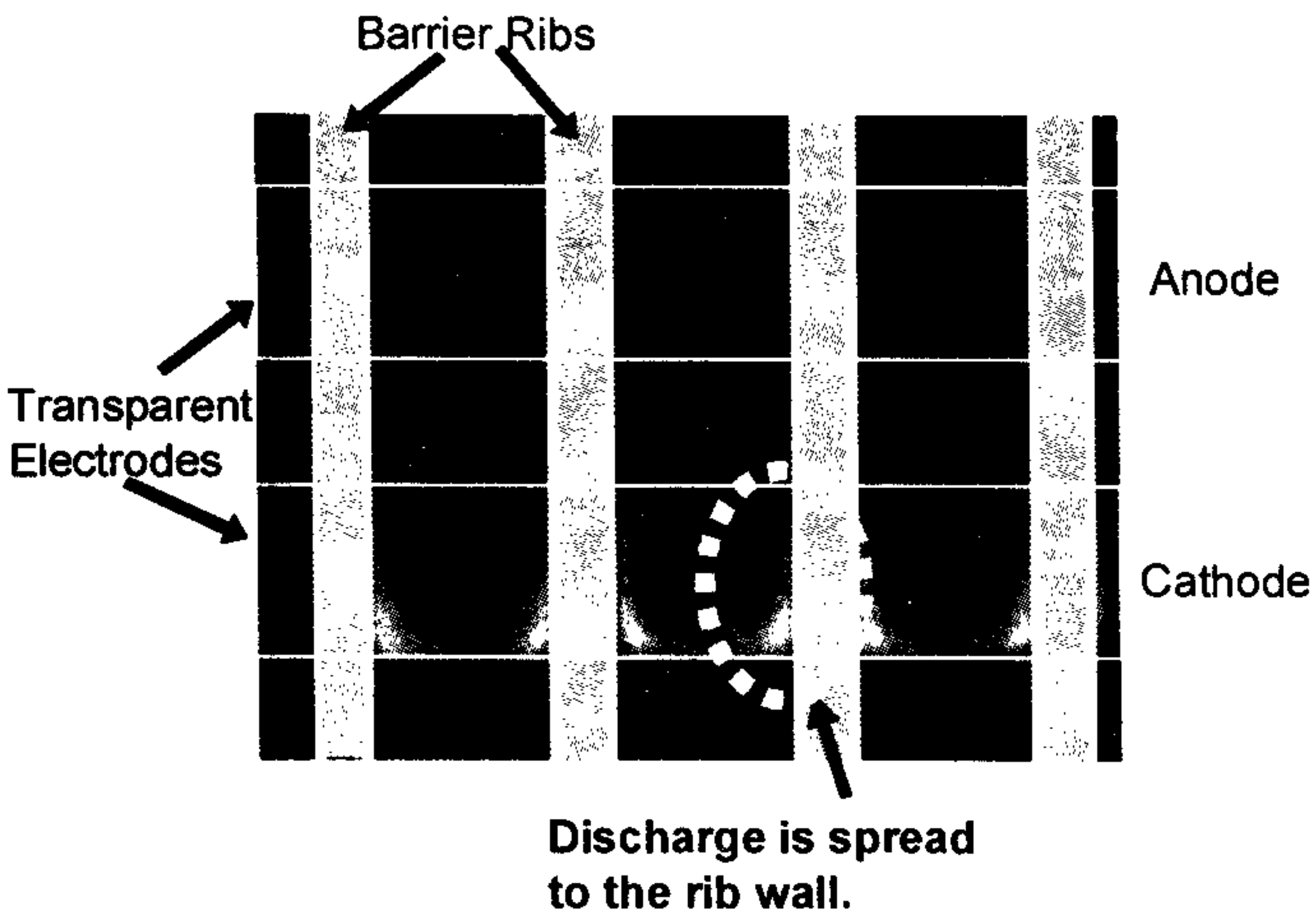


Figure 17 Enlarged Discharge Image of 220 ns after the Trigger

Figure 18 shows the discharge observation of the plasma tube. The emission starts from the center of the gap and it grows along the tube. However it did not seem to be spread to full width of the tube.

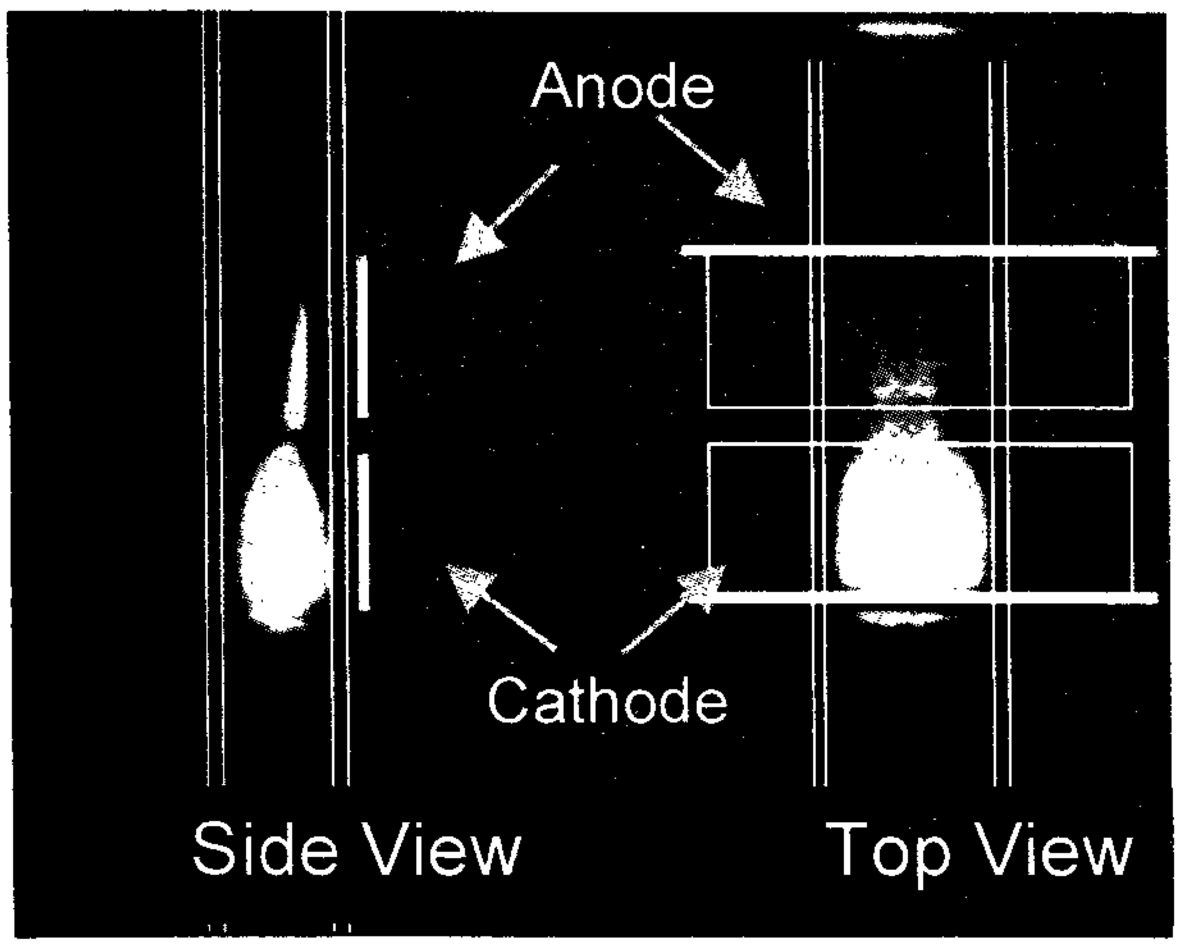


Figure 18 Discharge Observation of Plasma Tube

Figure 19 and 20 show the discharge distribution model. The pictures show the cross section of a cell.

In the case of the conventional PDPs, the horizontal and vertical ratio is about 3:1. Once the discharge starts, it grows along the electrode horizontally as shown in figure 16 and also it grows vertically at the same time. However the horizontal growth is stopped by the rib wall and also vertical growth easily reach to the phosphor layer. Therefore, the energetic gas atoms will loose their energy by the collision without emitting the photons.

In contrast, in the case of the plasma tubes, since the effective electrode width as shown in figure 20 is narrower than the inner tube width, the discharge that grows along the electrode does not reach to the tube wall. Also the vertical growth of the discharge hardly reaches to the phosphor layer because of much smaller horizontal and vertical ratio than conventional PDPs.

Therefore the chance of the collision between energetic gas atoms and tube (or rib) wall is much smaller than that of conventional PDPs. This is one of the reasons why the tube structure has such high luminous efficacy.

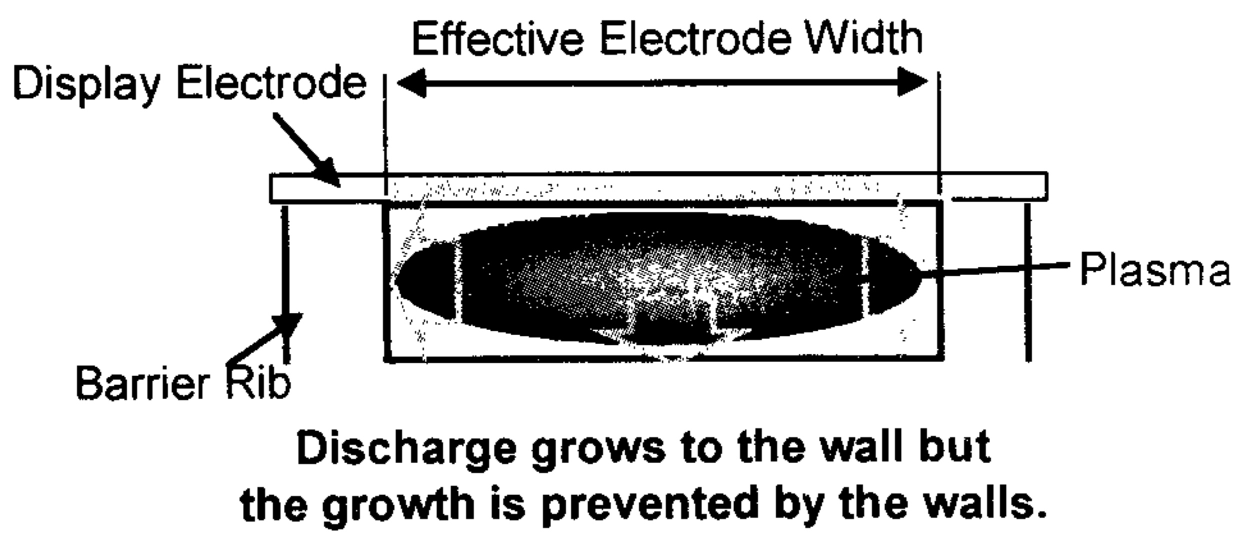


Figure 19 Discharge Distribution Model of Conventional PDPs

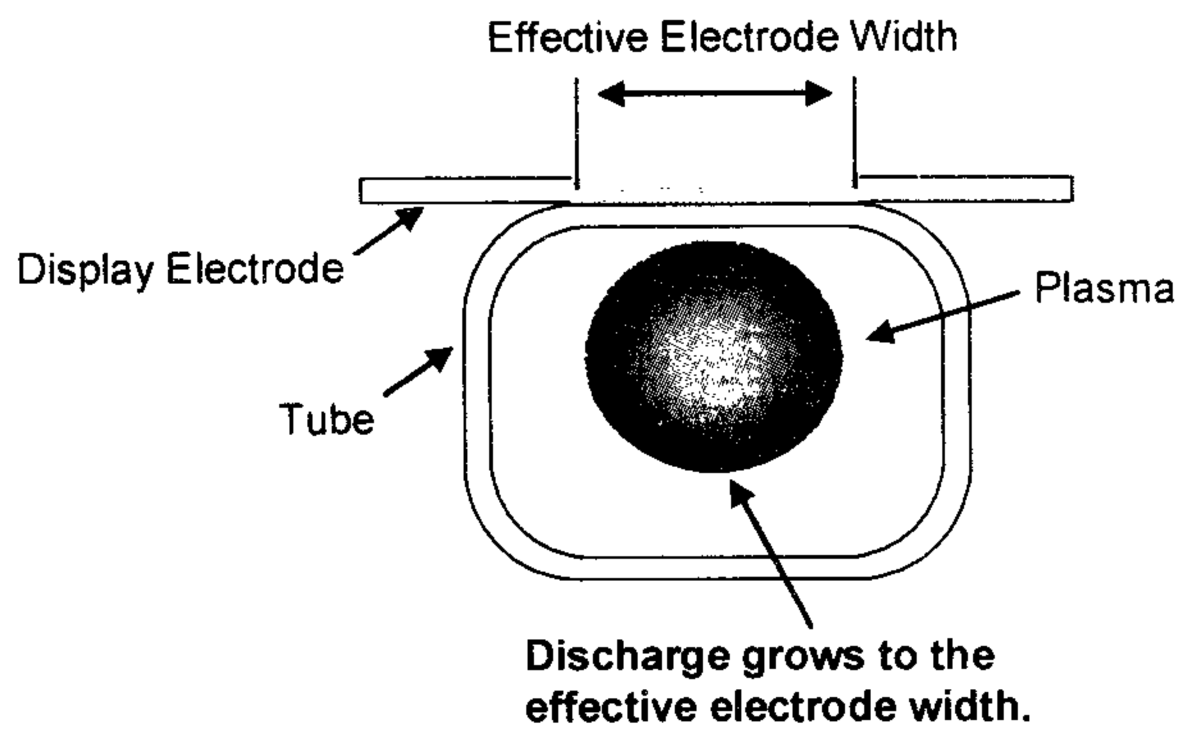


Figure 20 Discharge Distribution Model of Plasma Tubes

6. Conclusion

The tube design for high luminous efficacy was described. The luminous efficacy was proportional to the discharge gap. Also the efficacy increased by large volume angle from the discharge to the phosphor layer. High Xe content discharge gas improved the efficacy as same as the conventional PDPs. With the results of the investigation of tube design, very high luminous efficacy as 5.4 lm/W (@350 V) was achieved.

In the case of conventional PDPs, the operation voltage becomes higher as the efficacy is higher generally. For example high luminous efficacy as 5 lm /W was achieved by Philips group but the operation voltage rose about 1.6 times higher (175 V to 275 V) compared to the conventional structure [4]. In contrast in our case of plasma tubes the operation voltage was controlled and it rose just 6 % (330 V; Fig.6 to 350 V; Fig.13) even when the efficacy rose 2.5 times higher. This means that the tube structure has an ability of higher luminous efficacy basically.

Also the difference between the plasma tubes and conventional PDPs was discussed by the discharge observation. The discharge model was proposed from the observation and the dimension of the cell structure. According to the model, the collision between the energized gas atoms and tube (rib) wall hardly happen in the case of the plasma tube structure. Therefore the energized gas atoms have less chance to loose their energy by the collision. This would be one of the reason why the tube structure has high luminous efficacy.

The plasma tube structure has much wider design flexibility than conventional PDP's structure in tube (rib) height, gas pressure, and so on. That is big advantage of this structure. This time only luminous efficacy was discussed. However other parameters such as the strength and reliability are also important for the production [5]. Therefore the tube design for other parameter should also be investigated with this design flexibility for the real production.

7. References

[1] T. Shinoda et al. Proceeding of SID 2002, p1072 (2002)

[2] M. Ishimoto et al. Proceeding of IDW 2002, p665 (2002)

[3] M. Ishimoto et al. Proceeding of SID 2003, p36 (2003)

[4] G. Oversluizen et al. Proceeding of SID 2003, p28 (2003)

[5] M. Ishimoto et al. Journal of SID, in press (2004)