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Discharge Characteristics of a Plasma Display using Vertical Auxiliary Electrodes

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Abstract

In a conventional plasma display, the bus electrode was located on the ITO electrode at the outer part of each cell. We propose a new electrode configuration using vertical auxiliary electrodes which play a role of electrically connecting ITO and bus electrodes with the aim of enhancing discharge and luminous characteristics of the PDP (Plasma Display Panel). In this paper, luminance and luminous efficiency of the 3 in.-diagonal test panel are measured with various number of vertical auxiliary electrodes such as 2, 50 and 150. The change in the luminous characteristics is explained in connection with the discharge characteristics of the PDP cells such as current peak, IR emission peak and ICCD picture image.

Keywords : discharge characteristics, PDP, ITO electrode, bus electrode, auxiliary electrode

1. Introduction

Many researchers and manufacturers have been putting a lot of effort to improve the performance of plasma displays. One of the weak points of a conventional coplanar ac plasma display panel (PDP) is its low luminous efficiency. Today, the luminous efficiency of commercial plasma displays is about 1.0~1.5 lm/W. With the laboratory samples, the efforts of getting higher efficiency have been focused on structural optimizations, low temperature discharges, discharge gases and new electrode design. For example, the T-shaped electrode design combined with waffle-shaped rib structure led to the increase in 40% of luminance efficiency [1]. The application of low electric field discharges, such as positive column and RF (radio frequency) discharge [2] were also proposed. Increasing the Xe concentration to as high as 10% in the discharge cell or higher is the easiest way to improve the luminance and efficiency over 2 lm/W [3,4]. However, increasing the Xe concentration also increases the operation voltage and discharge ignition instability [5]. Experimental results relating to the change in the shape of ITO electrode [6,7], bus electrode [8] and address electrode [9] are also reported.

The luminous efficiency of the plasma display through the electrode design can also be improved by changing the position of the bus electrode on the ITO electrode. Kang [10,11] reported that the in-bus structure showed higher luminous efficiency and less delay time of discharge ignition compared to the conventional out-bus structure. Min *et. al.* [12] and Lee *et. al.* [13] also reported that luminous properties could be enhanced for in-bus structure due to the intensive electric field formation at the center of the cell. However, Lee *et. al.* [14] obtained contrary results where the out-bus structure is more efficient in the luminous characteristics. We have been interested in enhancing the luminous efficiency of plasma display by changing the electrode configuration and have proposed a new electrode configuration [15,16].

As shown in Fig. 1, most PDPs operate in a three-electrode configuration where each discharge cell is at the intersection of two parallel coplanar electrodes (sustaining electrodes) deposited on a glass plate (front plate), with a third orthogonal electrode (address or data electrode) located on a facing glass plate (back plate) [17]. In this configuration, bus electrodes placed on the ITO electrodes shut out emissive light generated from a discharge cell because they are opaque. Considering that the line resistance required for the bus electrode in 42 in PDP is less than 100 Ω, the width and thickness ranges of the bus electrode line are generally 50~100 and 5~10 μ ms, respectively. In our previous reports [15,16], therefore, we

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proposed moving the bus electrodes to the outside of the ITO electrodes. Figure 2 shows a basic concept of the new electrode structure proposed in our previous reports [15,16]. Horizontal bus electrode lines are separated from ITO electrode lines, which are electrically connected with ITO through vertical auxiliary electrodes. As the electrical conduction is performed through vertical auxiliary electrodes, the horizontal bus electrode lines need not be placed on ITO electrodes, and so most part of the ITO electrode area not covered with the bus electrode can play a role of a transparent layer. We may call it as an opening ratio of the ITO electrode, which is higher in the new electrode structure than in the conventional one. In Fig. 2, vertical auxiliary electrodes are placed on the same line along the horizontal bus line to maximize the opening ratio, because the vertical barrier ribs also block the emissive light generated from the discharge cell. In this paper, we changed the number of the vertical auxiliary electrode as 2, 50 and 150 to investigate how they influence the luminous and electrical characteristics of the PDP panel.

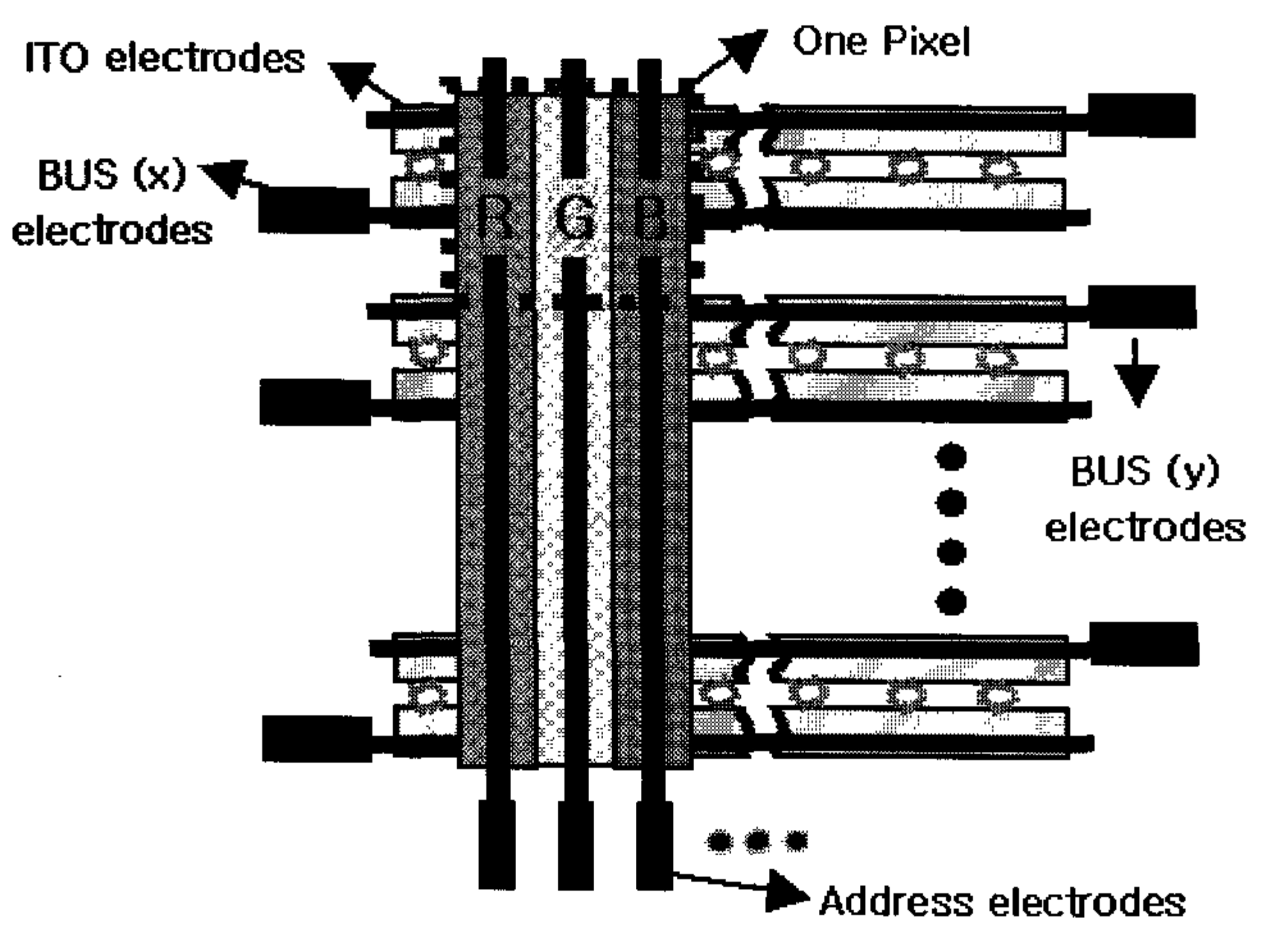

Fig. 1. Structure of bus, ITO and address electrodes in a plasma display panel.

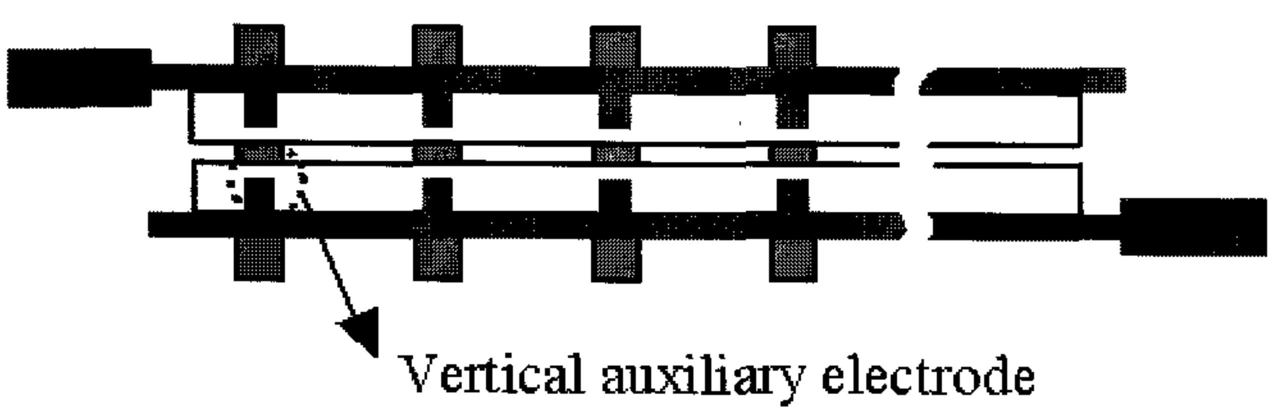

Fig. 2. Schematic drawing of the new electrode pattern.

2. Experimental

Experiments were performed using a 3-in. test panel with a cell area of 360 × 1,080 μ ms^2 following the typical dimension of a discharge cell of 42-in. PDPs. The number of the pixels was 50 lines for the horizontal direction (the number of the cells is 3 times, that is, 150 lines) and 40 lines for the vertical direction. Table 1 shows the specification of the test panel which is manufactured in this experiment. ITO-coated 2.8-mm-thick PD200 (Asahi Glass) glass substrates were used as the front substrates. The ITO and bus electrode patterns were manufactured by photolithography using a photosensitive dry film and a photosensitive Ag paste. Figure 3 shows the schematic drawings of three different types of the electrode designs used for this experiment. The number of the vertical auxiliary electrodes was varied as 2, 50, 150 as shown in Figs. 3 (a), (b), and (c), respectively. When the number of the cell in the horizontal direction is 150, every cell has its own auxiliary electrode as shown in Fig. 3 (c), and every three cells has one auxiliary electrode in Fig. 3 (b) and only most left and most right cells have auxiliary electrodes in Fig. 3 (a). A 30-μ m-thick transparent dielectric layer formed on the ITO and bus electrodes and a 7,000 Å-thick MgO layer was formed on the dielectric layer as a result of the electron beam evaporation method to get a uniform surface morphology. [18] 2.8 mm-thick PD200 glass substrates were also used for the rear substrates. An address electrode pattern was manufactured by the same method that was used for bus electrode patterning. Barrier ribs are manufactured by chemical etching, and green phosphors are printed into the cell volumes. The front and rear substrates were assembled and pumped at 350℃ during several hours, and filled with a gas mixture of Ne-5% Xe in 400 Torr.

The discharge and luminous characteristics of the panel are measured with the application of 25 kHz continuous

Table 1. Specification of the test panel.

bus width	Horizonal :100 μ m Vertical :70 μ m
ITO width	320 μ m
ITO gap	80 μ m
Dielectric thickness	30 μ m
MgO thickness	7000 Å
Barrier rib height	130 μ m
Gas pressure	400 Torr

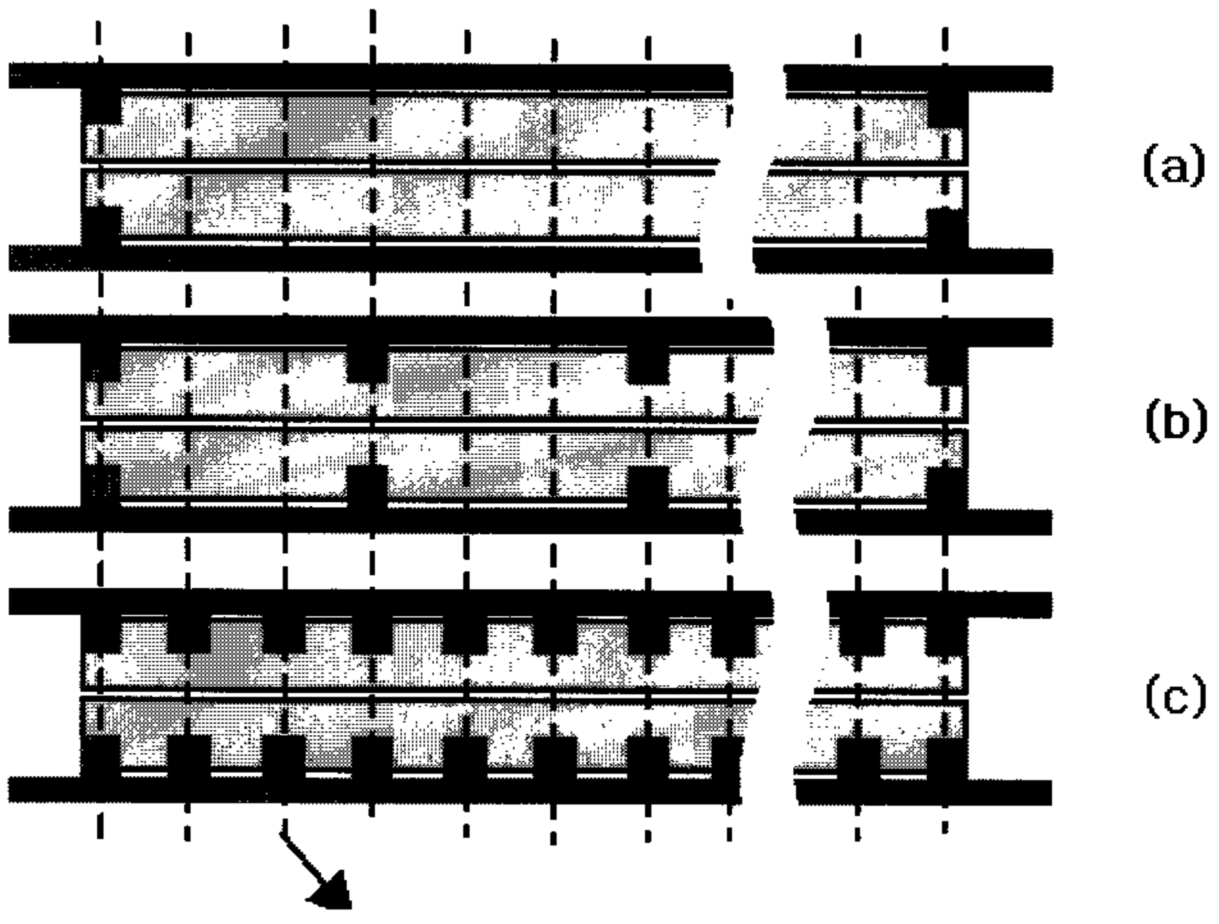

Fig. 3. Schematic drawings of patterns which have different number of vertical auxiliary electrodes. (a) n=2, (b) n=50, (c) n=150.

sustaining pulses with 25% of duty ratio. All the characteristics of the panel are observed at the median of the voltage margin measured. The luminance (cd/m²) is measured by luminance colorimeter (BM-7, TOPCON) and electrical power consumption (W) is calculated using

$$P = P_{on} - P_{off} \quad (1)$$

where P_{on} and P_{off} are the power consumptions when all the cell is on and off, respectively. Luminous efficiency is estimated as

$$\eta = \frac{\pi LS}{P} \quad (2)$$

where L is the luminance, S is the total area of the discharge cells and P is the power consumption. Current peaks for the overall discharge area are measured using an oscilloscope, and IR emission peaks for one cell are measured using a photometer with 823nm filter. Evolution of the emission lights within a discharge cell is observed using ICCD (C8484-05G, Hamamatsu) while 200V of sustaining pulses are applied with 35 kHz of frequency, and 25% of duty ratio.

3. Results and discussion

Figure 4 shows the power consumption which is calculated using eq. (1) with a variation of n, the number of the vertical auxiliary electrodes, in the test panel. As shown in Fig. 4, the power consumption shows the highest value in n=150 than in n=2 and 50. This is explained by the fact that the power consumption is increased with the increase in the total area of the vertical electrode in n=150. Figure 5 shows the luminance data which was estimated for the test panels. As shown in Fig. 5, the structure in Fig. 3 (c) (n=150) shows the highest luminance than in the cases of n=2 and 50. It is expected that the luminance is increased with the power consumption, and the ratio of the increment in luminance and power consumption is a matter of great interest in the characteristics of PDP. Figure 6 shows the luminous efficiency data which is calculated using eq. (2) for the test panels. The luminous efficiency of the structure in Fig. 3 (c) (n=150) shows the highest value as in the result of luminance.

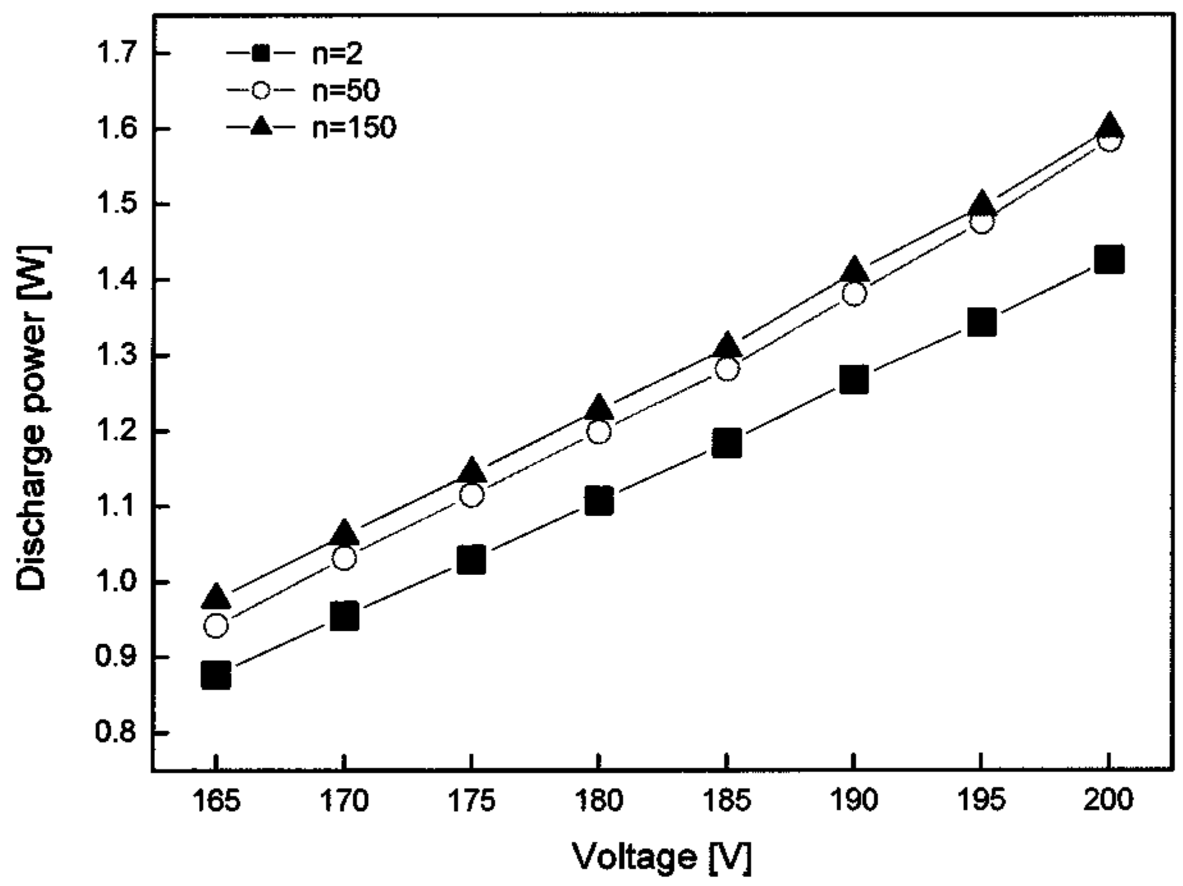

Fig. 4. Comparison of the discharge power consumptions measured for n = 2, 50 and 150 for the structure in Fig. 3 (a), (b), and (c).

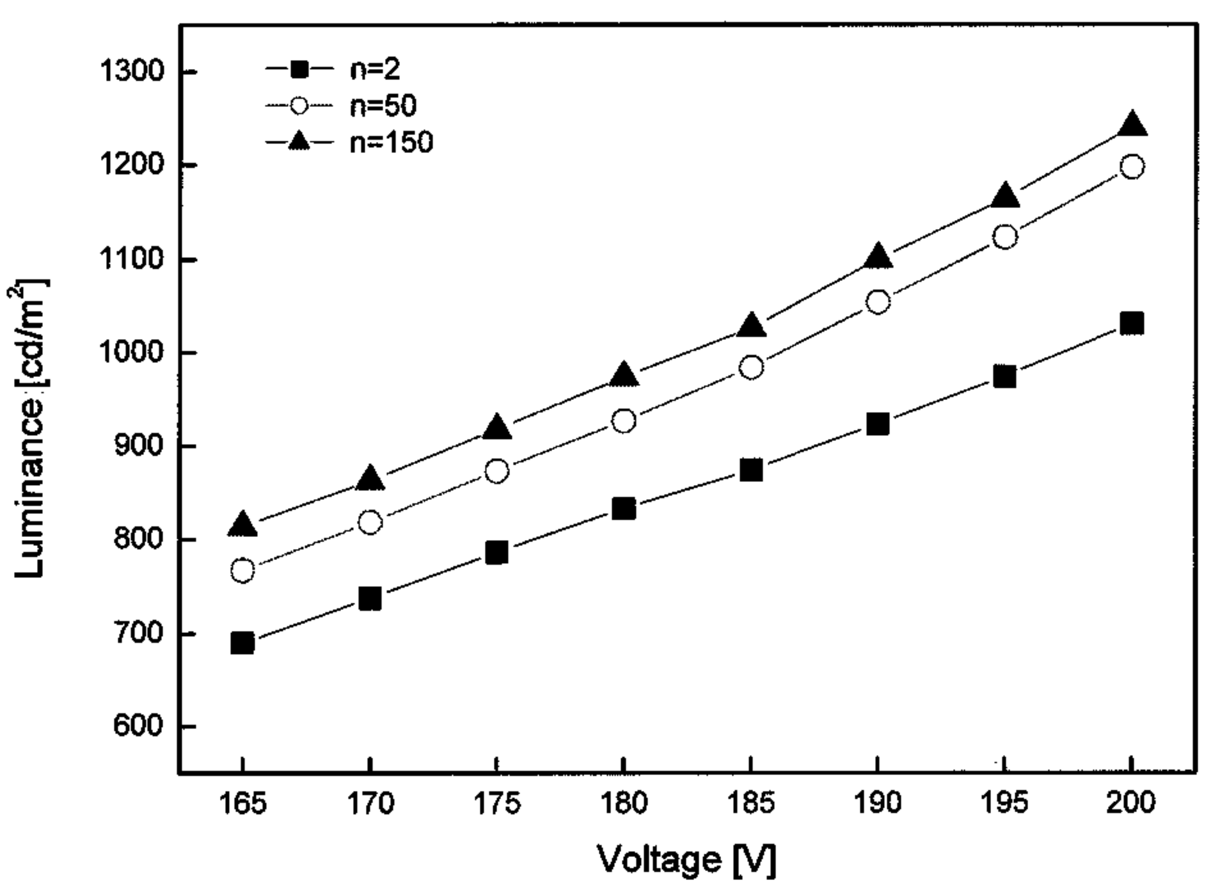

Fig. 5. Comparison of the luminance measured for n = 2, 50 and 150 for the structure in Fig. 3 (a), (b), and (c).

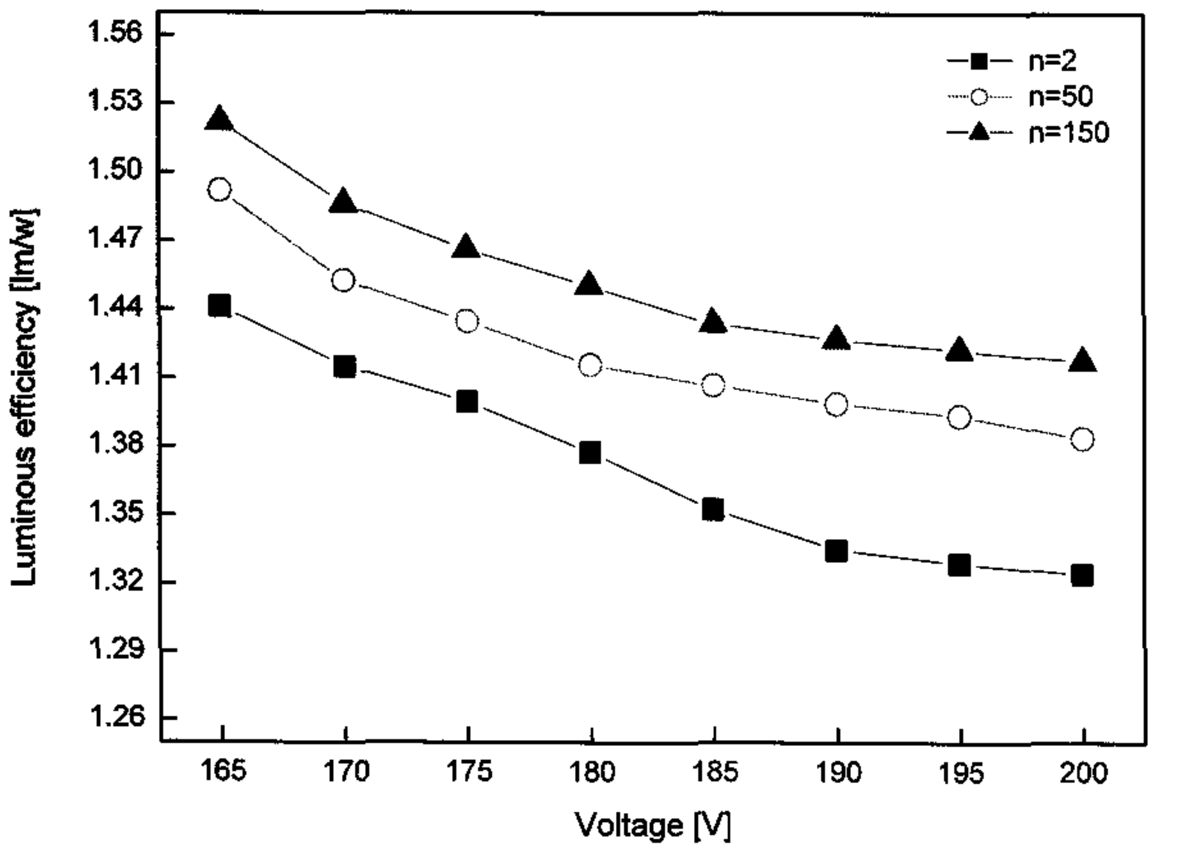

Fig. 6. Comparison of the luminous efficiency measured for n = 2, 50 and 150 for the structure in Fig. 3 (a), (b), and (c).

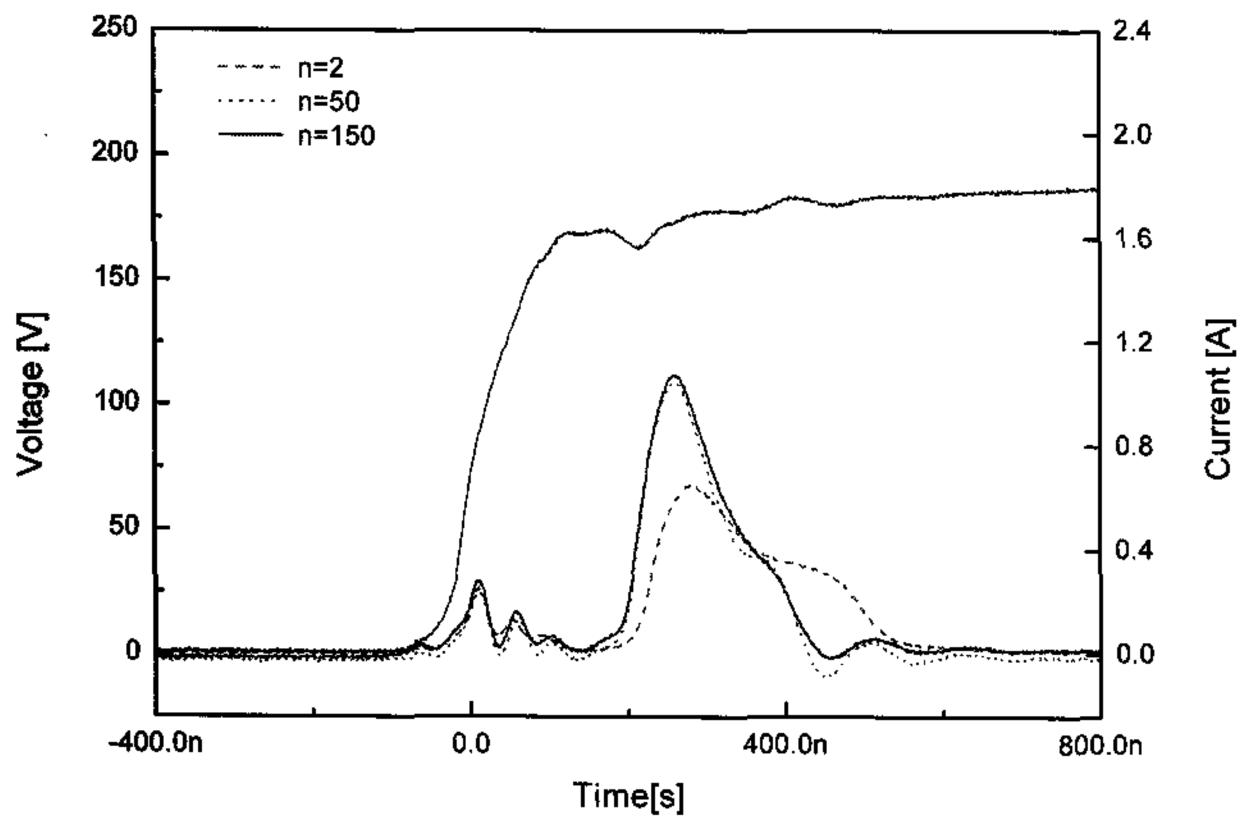

Fig. 7. Comparison of the discharge currents for n = 2, 50 and 150 for the structure in Fig. 3 (a), (b), and (c).

It is notable that the structure in Fig. 3 (c) is more effective than the structures in Figs. 3 (a) and (b) in terms of luminous efficiency, which means that we can get higher luminance under the same power consumption. This result implies that the increment of the luminance is greater than that of the power consumption with increase in the number of the vertical auxiliary electrodes. The amount of the difference in the luminous efficiency of the structure in Figs. 3 (a), (b), and (c) is not so big (just 5~7% difference), however, the difference can be greater in 42-in. panel considering that the length of the bus electrode line of 42-in. panel is about 20 times of that of the test panel which is used in this experiment. Therefore, it is important to elucidate the difference of the luminous efficiency in connection with the electrode structure in Figs. 3 (a), (b), and (c).

To explain this luminous characteristic, we investigated the differences in discharge current and IR emission waveforms for the structure in Figs. 3 (a), (b), and (c). It is shown that, under the same voltage, discharge current peak and IR emission peak are the largest when n=150 compared to when n=2 and 50. For more information on the luminous characteristics, we compared IR emission peaks for three cells at different positions in the same horizontal electrode line, one is middle and the other two are the edges (most left and right) as shown in Fig. 8.

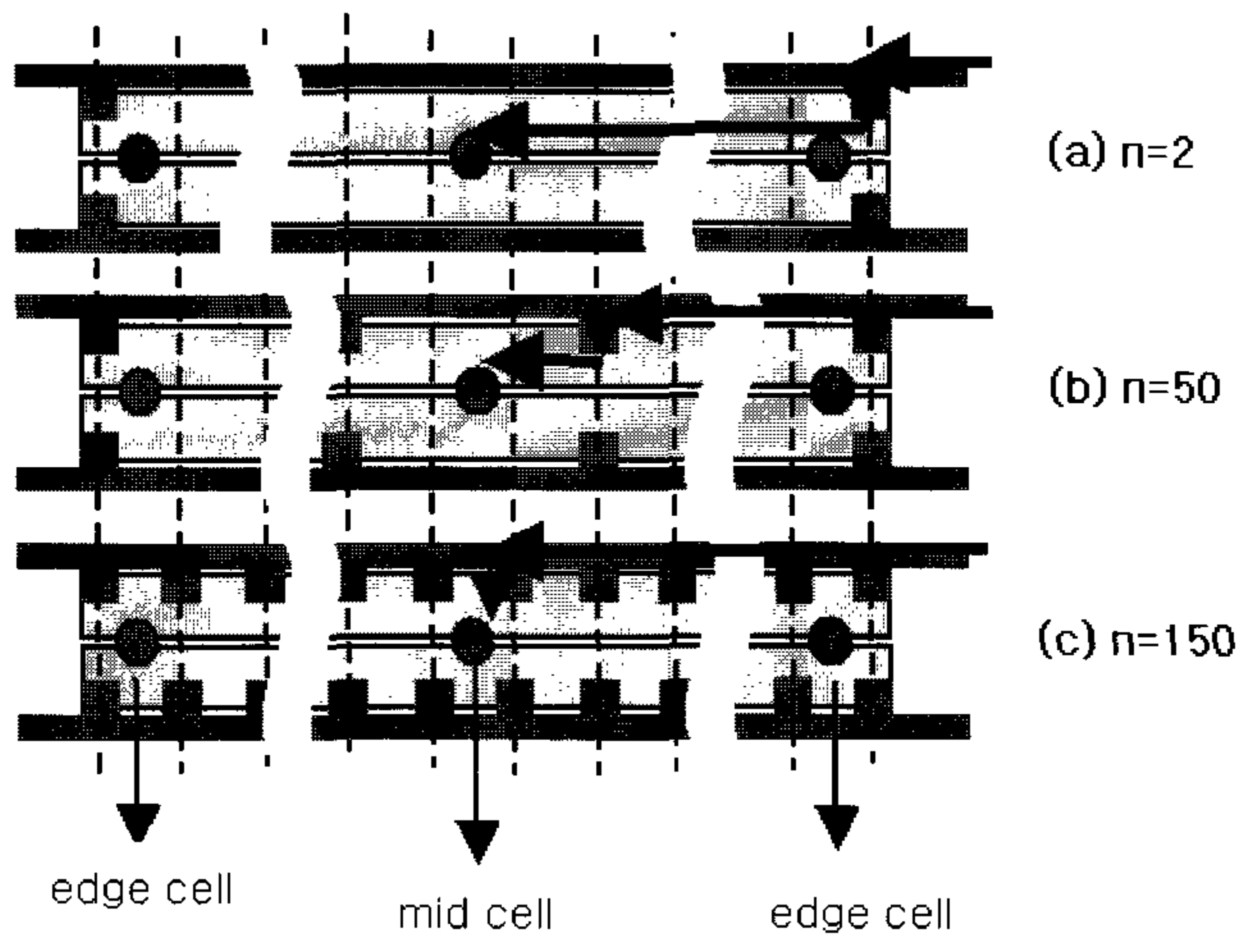

Fig. 8. Schematic drawings of electrical transmission in the cells at different position in a same bus line. (a) n=2, (b) n=50, (c) n=150.

Figure 9 shows the measured IR emission peaks for the cells at three different positions. When n=2, the edge cell shows larger peak height and rapid ramp-up than in the mid cell, however, the peaks are almost the same regardless of the different cell position when n=50 and 150. This is explained in terms of the electrical resistance between ITO and bus electrode lines as shown in Fig. 8. When n=2, the cell in the center doesn't have its own auxiliary electrode inside, and ITO electrode is connected to the bus line through most outer cells. Therefore, current supply from the bus line to the cell in the center is conducted after transmitting through the ITO electrode line. In the structure of Fig. 3 (a), the electrical resistance from the current supplier to the discharge cell in the center is 20 kΩ while 3Ω to the discharge cell in the edge. It can be said, therefore, that the IR emission peak for the cell in the center as in Fig. 9(a) is smaller than that for the edge cell due to the higher electrical resistance from the current supplier. This explains why smaller current peaks were observed when n=2 than when n=150 in Fig. 7. The current peaks for overall discharge area are the sum of the IR emission peaks of all discharge cells.

In contrast to the structure when n=2, the IR emission

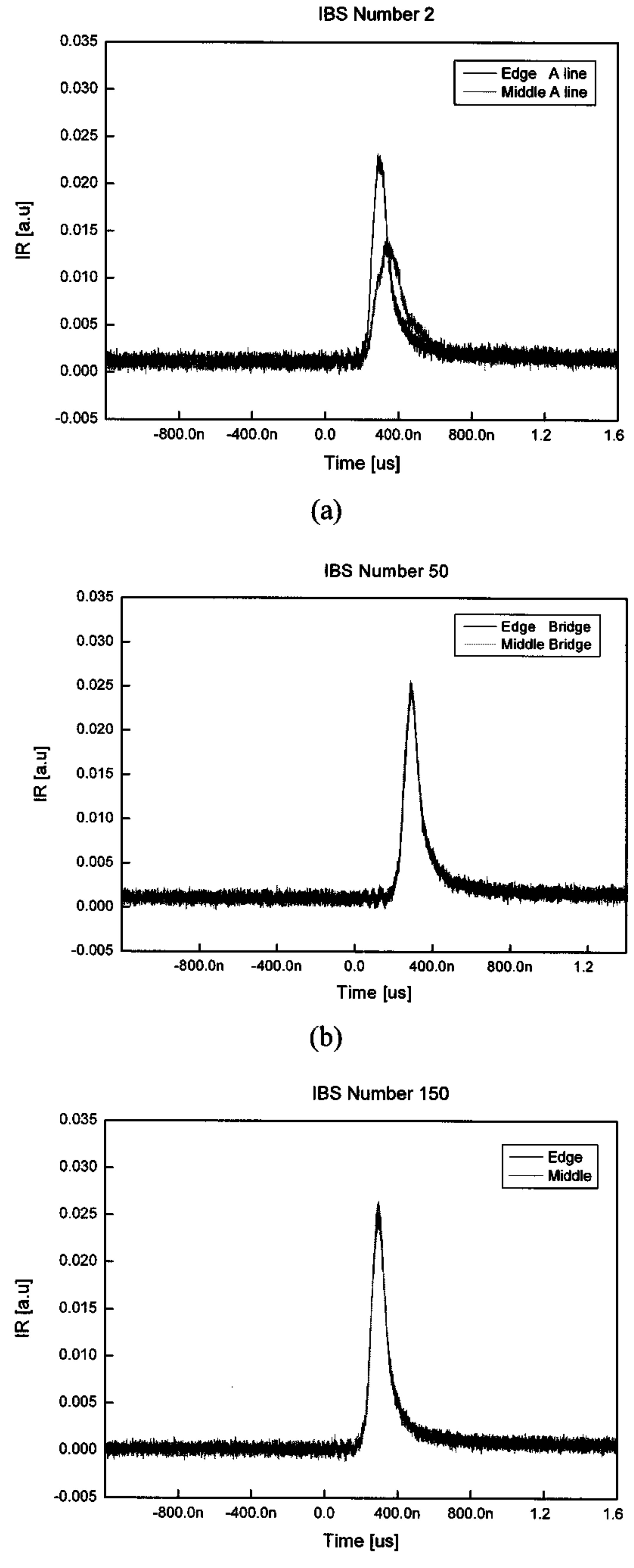

Fig. 9. Comparison of IR emission peaks for mid cell and edge cell. (a) n=2, (b) n=50, (c) n=150.

peaks from the discharge cells of the center and the edge shows no differences when n=50 and 150 as shown in Fig. 9(b) and Fig. 9(c). This can be explained when n=150 by the fact that every cell has its own auxiliary electrode, where the electrical transmission from the current supplier to the cell in the center is conducted directly through the bus line as shown in Fig. 8, so there is no big difference in IR emission peaks regardless of the position where the discharge cell is located. When n=50, the cell in the center doesn't have its own auxiliary electrode, however, the electrical path through the ITO line is very short (1.5 times of a cell size at maximum) as shown in Fig. 8. So, the IR emission peak of the cell in the center is almost the same as in the edge cell. Figure 10 shows the ICCD picture images of the cell in the center with the time evolution starting t=0 when the emission begins. Stronger emission lights are investigated when n=50 and 150 than when n=2. This result is expected considering that higher luminance (Fig. 5), higher luminous efficiency (Fig. 6) and bigger current peak (Fig. 7) were investigated when n=50 and 150 than when n=2. It is notable that the discharge characteristics when n=2 of the structure of Fig. 3 (a) is obviously different from that of the structure of Fig. 3 (b) (n=50) and Fig. 3 (c) (n=150), which shows more definite differences than in terms of the luminous efficiency in Fig. 6. This result shall be used for developing the electrode structure proposed in the previous reports [15, 16] in the direction of getting higher contrast and higher luminous efficiency.

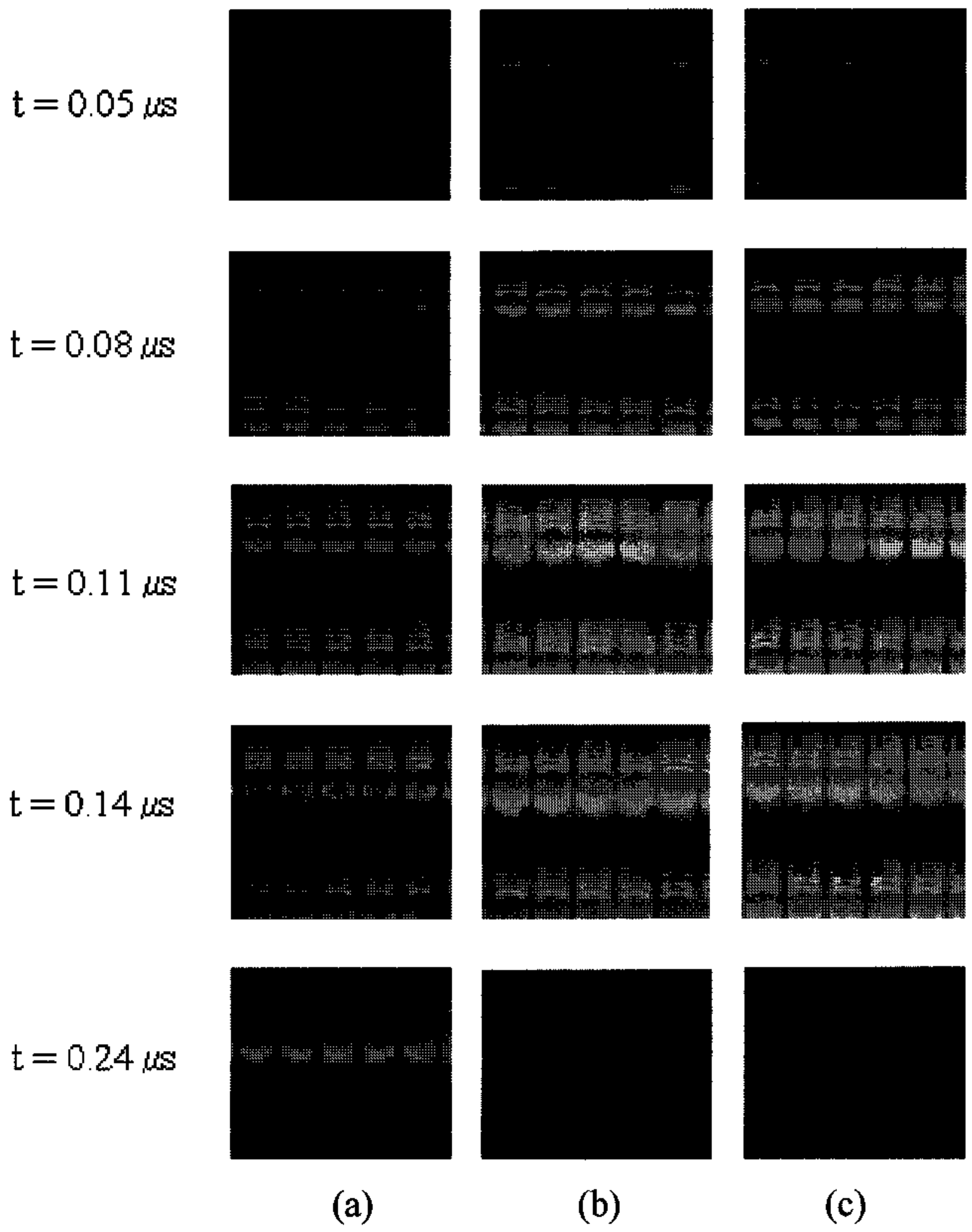

Fig. 10. ICCD pictures of the mid cell with the time evolution starting t=0 when the emission begins. (a) n=2, (b) n=50, (c) n=150.

4. Conclusion

The number of the vertical auxiliary electrodes that connect electrically isolated ITO and bus electrode lines was varied as n= 2, 50 and 150. The highest luminance and luminous efficiency were obtained when n=150, which is attributed to the large IR emission peak and rapid current ramp-up characteristic. Almost the same luminous characteristics were obtained when n=50 as when n=150, but the structure with n=2 showed poor luminous characteristics. This is explained by the fact that the poor electrical conduction to ITO electrode with increased line resistance deteriorates luminous characteristics, so the emission starts later and the intensity is weaker.

References

[1] Y. Sato, K. Amemiya, N. Saegusa, and M. Uchidoi, in *IEDM Tech. Dig.* (2002) , P. 1060.

[2] J. W. Kang, *J. Vac. Sci. Technol. B.* **21**, 1108 (2003).

[3] G. Oversluizen, M. Klein, S. de Zwart, S. van Heusden, and T. Dekker, *J. Appl. Phys.* **91**, 2403 (2002).

[4] M.F.Gillies and G. Oversluizen, *J. Appl. Phys.* **91**, 6315 (2002).

[5] T. Yoshioka, A. Miyakoshi, A. Okigawa, E. Mizobata, and K. Toki, in *Proc. 7th Int. Workshop* (2000) , p. 611.

[6] B. J. Shin, *Trans. KIEE.* **52C**, 529 (2003).

[7] C. H. Park, S. H. Lee, D. H. Kim, Y. K. Kim, and J. H. Shin, *IEEE Trans. Electron.* **48**, 2255 (2001).

[8] N. Nagao, N. Kosugi, Y. Takata, N. Nishimura, K. Sumida, and S. Fujiwara, in *IDW' 02 Dig.* (2002) , p. 765.

[9] J. Y. Kim, S. K. Jang, H. S. Tae, and E. Y. Jeong, in *SID' 06 Dig.* (2006) , p. 571.

[10] J. W. Kang, *IEEE Trans. Electron Devices.* **52**, 922 (2005).

[11] J. W. Kang, *IEEE Trans. Plasma Sci.* **34**, 371 (2006).

[12] W. K. Min, J. Kang, S. C. Choi, J. W. Song, J. B. Park, and J. R. Lim, in *SID' 03 Dig*, (2003) , p. 422.

[13] I. S. Lee, S. J. Yoon, O. D. Kim, and K. Y. Choi, *in IDW' 04 Dig*, (2004) , p. 1055.

[14] S. B. Lee, B. H. Hong, and E. H. Choi, in *IDW' 06 Dig.* (2006) , p. 1117.

[15] K. N. Kim, S. H. Yang, and C. H. Moon, in *IDMC' 07 Dig.* (2007) , p. 604.

[16] S. H. Yang, J. S. Moon, K. N. Kim, and C. H. Moon, in *IMID' 07 Dig.* (2007) , p. 589.

[17] J. Ouyang, Th. Callegari, B. Caillier, and J. P. Boeuf, *IEEE Trans. Plasma Sci.* **31**, 422 (2003).

[18] K. H. Park and Y. S. Kim, *JID.* **vol.7, no.2**, 1 (2006).