The Characteristics of Plasma Display with the Cylindrical Hollow Cathode

Kyung Cheol Choi and Heung-Sik Tae

***Abstract*—The newly designed plasma display with the cylindrical hollow cathode has been proposed and investigated to study the relationship between the photoluminous efficiency and the discharge characteristics. The photoluminous efficiency and the discharge characteristics are dependent on the geometry factors of cylindrical hollow cathode and gas pressure in the plasma display. When p (gas pressure)$\times d$ (the hole diameter of cylindrical hollow cathode) is below 2 torr • cm, the plasma display with the cylindrical hollow cathode has as much as five times higher luminous efficiency compared to that at above 2 torr • cm of $p \bullet d$ value and it also shows a positive current–voltage (I–V) slope as in an abnormal glow.**

I. Introduction

GAS DISCHARGES have been used in many engineering applications since their discovery. Up to now, the characterization of gas discharge has been investigated extensively due to these many applications. Among the gas discharges, the glow discharge has been used for a plasma display which is most promising for high-definition TV screens. Plasma display panels (PDP's), which utilize tiny glow discharges in display cells occupying about 0.03 mm^3 volume, have been investigated for this application by several companies [1]–[3]. Currently, the ac PDP, by using surface discharge, is a leading technology due to the higher photoluminous efficiency compared to that of the dc PDP [2]. However, both ac and dc PDP still require the improvement in photoluminous efficiency for commercial color display applications. Especially, in a dc PDP technology, high efficient discharges such as positive column glow, hollow cathode, and Townsend discharge can be a candidate to solve the poor efficiency problem for the TV screen application. There are some publications related to hollow cathode discharge [4], [5] which were employed by plasma display.

A hollow cathode is a structure to obtain the high efficient discharge by using the trapped electron [6]. There were some works on hollow cathode discharge as a light source in liquid crystal display (LCD) [7] and an application for the display device [8], [9]. Schoenbach suggested that the microhollow cathode discharge can be used for the flat panel display without using ballast at high gas pressure [8]. The plasma display is normally a high gas pressure operating device so that in what follows there is some research on the geometry to get the hollow cathode effect at such pressures.

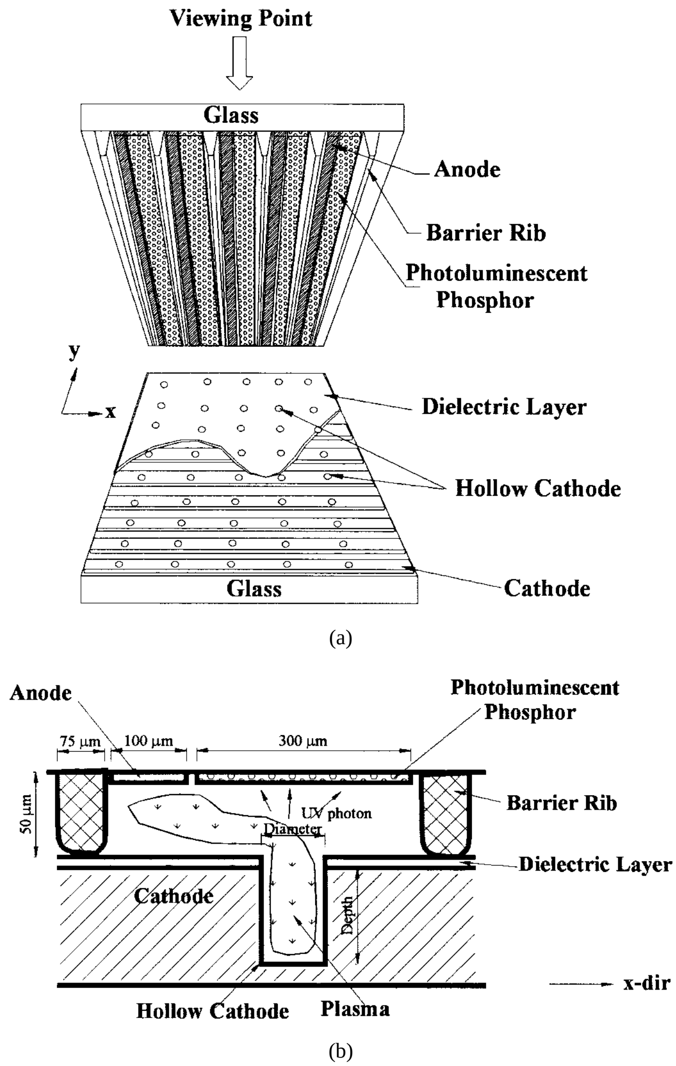

Fig. 1. (a) Schematic view of the PDP with the cylindrical hollow cathode. (b) Cross-sectional view of a cylindrical hollow cathode in the plasma display

In the previous work, a possibility of plasma display with holes in the cathode was suggested for the display device without using a current limiting resistor and operating in the current range of 100–1000 μA [10]. In this work, the hole diameter is reduced to obtain a hollow cathode discharge with the plasma display pixels operating at below 50 μA without a current limiting resistor, i.e., with positive resistance

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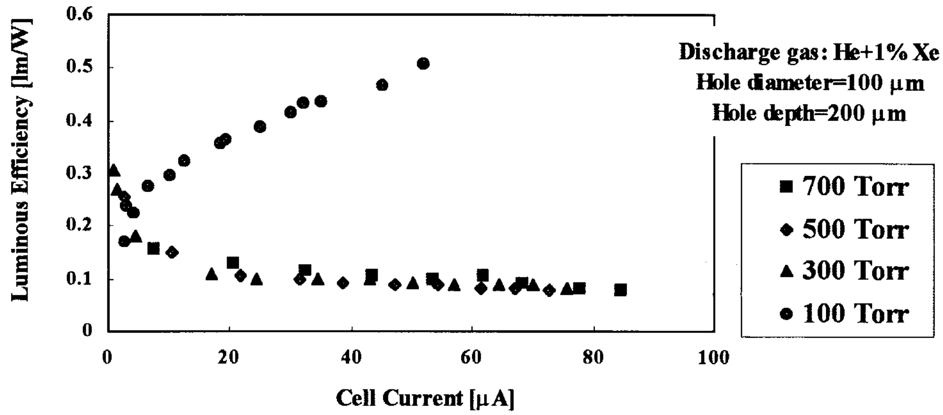

Fig. 2. Photoluminous efficiency of He + 1% Xe discharge in the plasma display cell with 100-μm hole diameter and 200-μm hole depth of cylindrical hollow cathode as a function of the cell current and gas pressure.

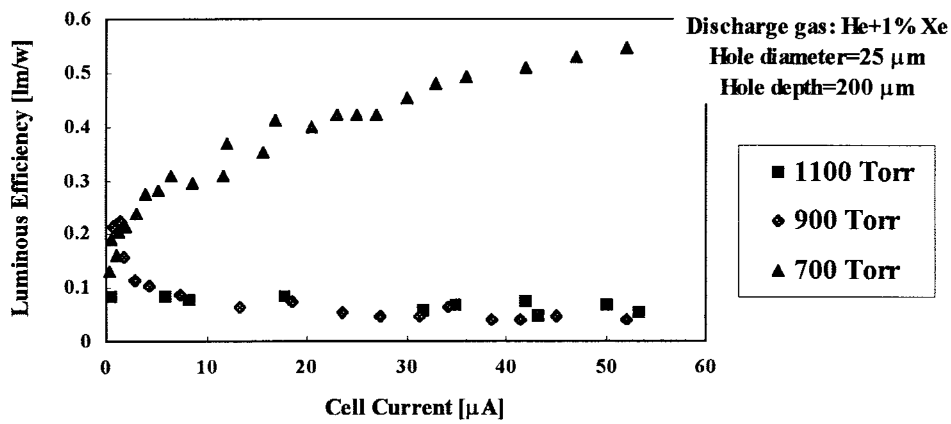

Fig. 3. Photoluminous efficiency of He + 1% Xe discharge in the plasma display cell with 25-μm hole diameter and 200-μm hole depth of cylindrical hollow cathode as a function of the cell current and gas pressure.

in the current–voltage (I–V) characteristic. The relationship between the photoluminous efficiency and I–V characteristics of helium and xenon gas mixture discharge has been investigated as a function of the dimension of the cylindrical hollow cathode and the gas pressure in a plasma display cell. In this work, the planar anode on the phosphor plate has been used instead of the bridge anode of the previous work [10].

II. Experiment Results and Discussion

Fig. 1 shows the schematic and the cross-sectional view of the cylindrical hollow cathode used for the experiment in this work. The array of cylindrical hollow cathodes has been fabricated for plasma display cells. Here, 25- and 100-μm hole diameters have been used, and the depth of hollow cathode is 200 μm. The cathode has been formed by using a screen printing technique. The cathode material is aluminum thick film paste. The dielectric paste film has been covered on the cathode. The thickness of dielectric layer is about 10 μm. The height of the barrier rib is 50 μm. The width of anode is 100 μm. The cylindrical hole in the cathode has been made by Nd–Yag laser. The photoluminescent phosphor has been coated by screen printing technique beside the anode. The volume of one cell used in this paper is 0.034 mm^3 (0.475 mm $\times$ 1.425 mm $\times$ 0.05 mm). In this experiment, multiple discharges have been measured and the averaged values have been obtained. The visible light transmitted through the phosphor has been measured.

In this structure, the plasma distributes from the anode to the hollow cathode and is contained primarily inside the hollow cathode. However, the hollow cathode discharge is high-density plasma and produces more ultraviolet (UV) photons compared to the ordinary glow discharges. The hollow cathode is located under the phosphor layer to get the larger solid angle available to reach the phosphor. In this work, helium plus xenon gas mixture is used as the discharge gas in plasma display. The 147 nm line UV emitted from xenon excited state stimulates a photoluminescent phosphor in a display cell.

This pixel operates by using time limited sustain pulses. Here, the width of the sustain pulse is 2 μs and the pulse period is 10 μs.

Fig. 2 shows the photoluminous efficiency of He + 1% Xe mixing gas discharge in the plasma display cells with the 100-μm hole diameter and 200-μm hole depth of cylindrical hollow cathode. The photoluminous efficiency is the luminance of visible light emitted from the phosphor layer divided by the power density consumed in display cell. As shown in Fig. 2, the luminous efficiency has been measured as a function of gas pressure and cell current. At above 300 torr, the luminous

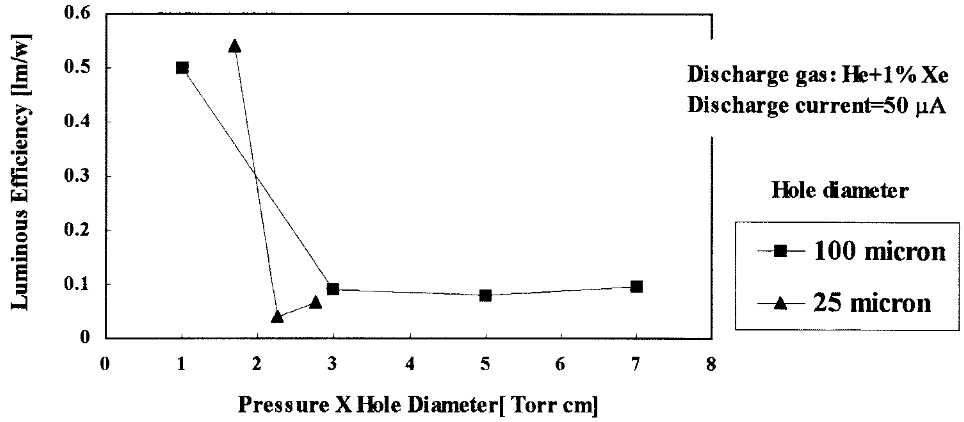

Fig. 4. The luminous efficiency of He + 1% Xe discharge in the plasma display as a function of the $p \bullet d$ value.

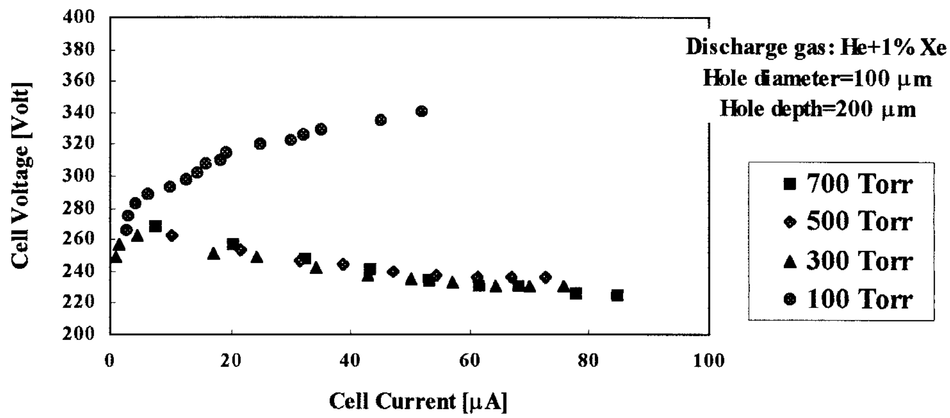

Fig. 5. Cell voltage of He + 1% Xe discharge in the plasma display cell with 100-μm hole diameter and 200-μm hole depth of cylindrical hollow cathode as a function of the cell current and gas pressure.

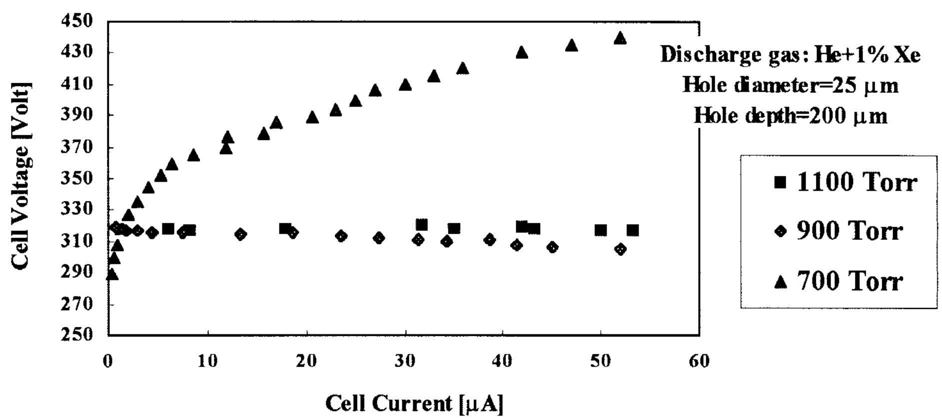

Fig. 6. Cell voltage of He + 1% Xe discharge in the plasma display cell with 25-μm hole diameter and 200-μm hole depth of cylindrical hollow cathode as a function of the cell current and gas pressure.

efficiency decreases with current and saturates with an increase of gas pressure. However, the luminous efficiency increases with increase of the cell current at 100 torr.

In Fig. 3, the photoluminous efficiency of He + 1% Xe gas discharge with 25-μm hole diameter and 200-μm hole depth has been investigated as a function of gas pressure and cell current. The photoluminous efficiency increases with increase of cell current at 700 torr and decreases with increase of the cell current at 900 and 1100 torr.

The p (Gas Pressure) $\times$ d (hole diameter of cylindrical hollow cathode) can be defined as a parameter to determine the criterion of getting a hollow cathode effect [8]. Fig. 4 shows the luminous efficiency as a function of the $p \bullet d$ value. The critical point of $p \bullet d$ value is between 1 and 2 torr $\bullet$ cm in Fig. 4. From the results, it is found that $p \bullet d$ value should be kept below 2 torr $\bullet$ cm to get the high efficient discharge in the plasma display with the cylindrical hollow cathode. Fig. 4 makes it clear where the discharge mode shifts.

Compared to the result from the luminous efficiency measurement, the value of $p \bullet d$ is consistent with that of the cell voltage measurement. Fig. 5 shows the relationship between the discharge current and cell voltage in the plasma display cell with 100-μm diameter and 200-μm depth cylindrical hollow cathode. The normal glow characteristic was observed at above 300 torr as shown in Fig. 5. The discharge mode transited to an abnormal type of glow at around 100 torr. Fig. 6 shows the $I-V$ curve of He + 1% Xe discharge in the display cell with 25 μm diameter and 200 μm depth. The slope of the $I-V$ curve has decreased with increasing of the gas pressure and become a flat line that is a typical normal glow I–V curve above 2 torr • cm. From the results, it is found that there is some relationship between higher luminous efficiency and abnormal glow discharges compared to that of normal glow discharges. In addition to the previous result [10], it is found that the positive slope of I–V curve of helium and xenon mixture gas discharges in the abnormal mode is associated with a higher luminous efficiency for the plasma display compared to that of the gas discharges in the normal glow mode.

III. Conclusion

A plasma display device with the cylindrical hollow cathode has been proposed. This newly designed structure is based on the previous work. In this work, the relationship between the hole diameter of the cylindrical hollow cathode and the gas pressure in the plasma display for getting high efficient hollow cathode discharge has been investigated by measuring the photoluminous efficiency and the cell voltage as a function of the cell current. At below 2 torr • cm of $p \bullet d$ value, the luminous efficiency increases with increase of the discharge current in a cell of plasma display. Also, the slope of I–V curve turns out to be positive at around 2 of $p \bullet d$ value. When the discharge current in the cell is 50 μA, the luminous efficiency at below 2 torr • cm is five times greater than that at above 2 torr • cm. In the conventional dc PDP, which is optimized by the cell arrangement, phosphor layer and so on, the luminous efficiency is about 0.4 lm/W [11]. Further improvements are hoped for in optimizing the application of hollow cathodes with other geometry.

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