Improvement in the Luminous Efficiency Using Ramped-Square Sustain Waveform in an AC Surface-Discharge Plasma Display Panel

Heung-Sik Tae, *Member, IEEE*, Ki-Duck Cho, Sang-Hun Jang, and Kyung Cheol Choi

***Abstract*—This paper proposes a new sustain waveform to improve the luminous efficiency of an alternate current plasma display panel (AC-PDP). The new sustain waveform is a superimposed waveform, which adds a ramp-waveform to a square-waveform, and has an increasing voltage slope between the rising and falling edge. This waveform can induce a longer-sustained discharge at the rising edge plus a self-erasing discharge at the falling edge, thereby improving the luminous efficiency. When compared with the conventional square sustain waveform, the proposed sustain waveform with a 9.3 V/μs voltage slope achieved a 65% higher luminous efficiency in a 4-in AC-PDP test panel even at a low frequency (62 KHz).**

***Index Terms*—Alternate current plasma display panels (AC-PDPs), luminous efficiency, ramped-square pulse.**

I. Introduction

THE recent focus on the development of flat panel display devices has resulted in an alternate current plasma display panel (AC-PDP) becoming a promising candidate for replacing the conventional cathode ray tube (CRT) display [1]. In addition, plasma display panels (PDPs) have exhibited great potential as flat panel devices for the large area (>40-in) full color wall hanging digital high definition televisions (HDTVs). For the successful realization of commercial full color digital HDTVs, further improvements to PDP devices are still needed, particularly in luminous efficiency [2]. Most previous research related to improving luminous efficiency has focused on optimizing the PDP cell structure [3], [4], including the emission of vacuum ultraviolet (VUV) [5]. Since luminous efficiency is determined based on the ratio of light emission intensity to input current amount, the development of a proper driving waveform for the sustain period, during which the red, green, and blue (R, G, B) visible light for displaying information is emitted, would contribute to the improvement of the luminous efficiency. In this sense, there has been some previous researches related to sustain pulse waveforms for improving the luminous efficiency [6], [7]; however, so far, luminous efficiencies have only been improved in a high-frequency region above 100 KHz (about 180 KHz). Based on the general concept of a PDP device, this frequency is too high to be usable in a current PDP device. Accordingly, a new sustain waveform, which can be operated at a frequency below 100 KHz, needs to be developed to improve the luminous efficiency.

This paper presents a new sustain waveform which adds a ramp-waveform to a square-waveform so as to improve the luminous efficiency. The effects of this new sustain waveform on the cell discharge and the improvement of luminous efficiency in an AC-PDP operated below 100 KHz are then examined.

Manuscript received September 13, 2000; revised January 30, 2001. This work was supported by the Brain Korea 21 Project in 2001. The review of this paper was arranged by Editor D. M. Goebel.

H.-S. Tae, K.-D. Cho, and S.-H. Jang are with School of Electronic and Electrical Engineering, Kyungpook National University, Taegu 702-701, Korea (e-mail: hstae@ee.knu.ac.kr).

K. C. Choi is with Department of Electronic Engineering, Sejong University, Kwangjin-Ku, Seoul, 143-747, Korea.

Publisher Item Identifier S 0018-9383(01)05343-6.

II. Single Pixel of Surface-Type AC-PDP Cell and its Driving Waveforms

Fig. 1(a) shows a schematic configuration of a single pixel in the 4-in AC-PDP test panel employed in this research. A single pixel is the minimum unit for displaying a full-color image, and consists of three cells that emit red, green, and blue light based on the stimulation of R, G, and B phosphor layers by the VUV (147 nm) produced from a He-Ne-Xe plasma discharge, respectively. Fig. 1(b) shows the voltage waveforms applied to the three electrodes to drive the PDP test panel illustrated in Fig. 1(a). The X and Y electrodes on the front glass plate in Fig. 1(a) are the sustain electrodes, and the first and second waveforms in Fig. 1(b) are the voltage waveforms applied to the sustain electrodes. The Z electrode on the rear glass plate in Fig. 1(a) is the address electrode, and the third waveform in Fig. 1(b) is the voltage waveform applied to the address electrode. The driving regions are divided into three periods, the reset, address, and sustain periods. In the reset period, the wall charges generated in the previous sustain period are erased, so that all the cells in the PDP have the same initial conditions. In the address period, wall charges are accumulated from the space charge of the plasma discharge produced in the address region. Thereafter, only those cells with wall charges accumulated in the address period can display information using the voltage waveform in the sustain period. In the sustain period, alternate voltage pulses are applied to the sustain electrodes (X and Y electrodes) of all the cells, and a plasma discharge is only produced in those cells with wall charges. This new sustain waveform in the sustain period is then used to improve the luminous efficiency.

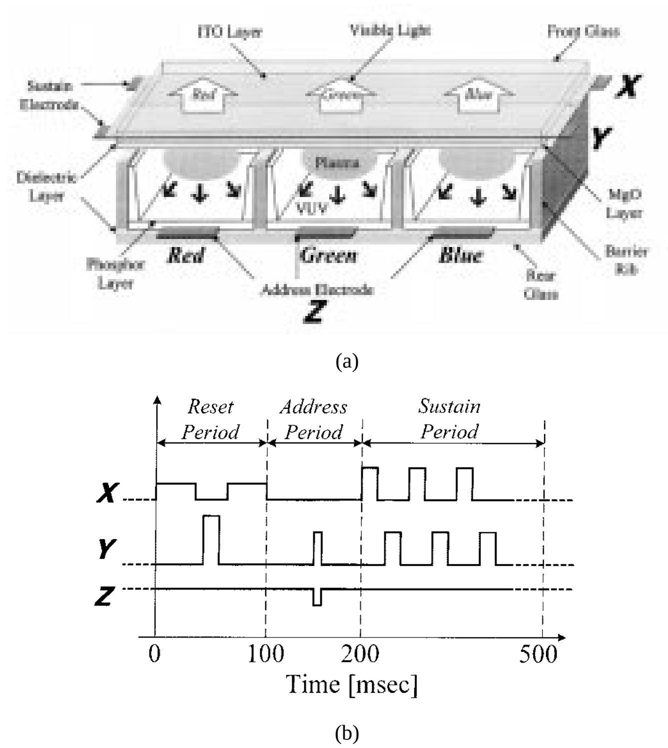


Fig. 1. Schematic diagram of 4-in AC-PDP test cell and its driving waveforms. (a) Single pixel structure. (b) Voltage waveforms applied to the three electrodes.

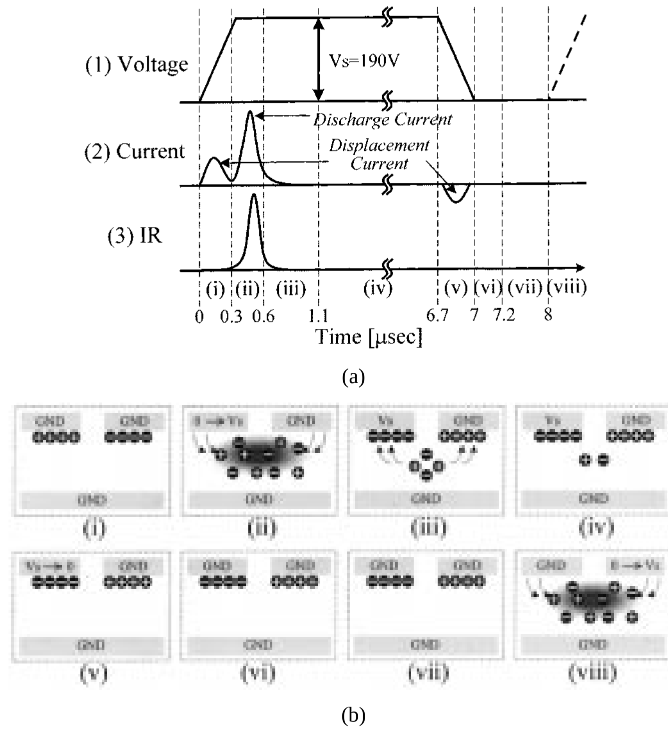


Fig. 2. Current and IR (828 nm) waveforms and schematic model for temporal behavior of wall charges in 4-in AC-PDP with conventional square sustain waveform. (a) Conventional square sustain waveform. (b) Temporal behavior of wall charges within cell.

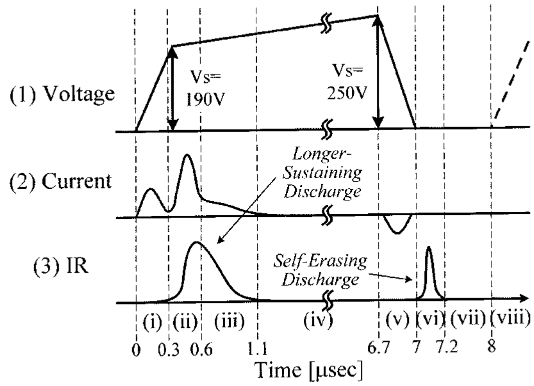
III. Effects of New Sustain Waveform on Cell Discharge

A. Cell Discharge Physics in Conventional Square Sustain Waveform

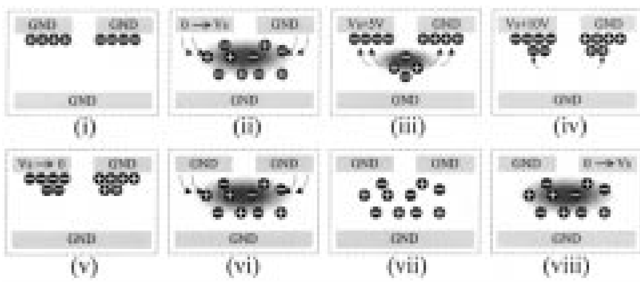
Fig. 2(a) shows the schematic waveforms of the (1) voltage, (2) current, and (3) infrared (IR: 828 nm) based on the actual waveforms measured from the 4-in AC-PDP test panel in the case of a conventional square sustain waveform. The other driving conditions of Fig. 2(a) were a frequency of 62 KHz, duty ratio of 40%, and sustain voltage of 190 V. The voltage and current waveforms were measured by the voltage and current probes, respectively. The power dissipated in the 4-in PDP was measured in the power line between the driving circuit and the test panel using the PM3000A power analyzer. The IR (828 nm) signals were measured by the digital oscilloscope after being converted as electrical signals by the PMT tube. The PR-704 spectrometer was used to measure the luminance of the 4-in PDP test panel. Fig. 2(b) shows a schematic model of the temporal behavior of the wall charge produced within the cell with a conventional square sustain waveform. In Fig. 2(b), the upper two electrodes are the sustain electrodes, whereas the lower one is the address electrode. The wall charges are accumulated on the dielectric layer below the two sustain electrodes during the address period prior to applying the sustain pulse, as shown in (i) of Fig. 2(b). As the sustain pulse in (1) of Fig. 2(a) is initially applied to each sustain electrode, the displacement current, as shown by (i) in Fig. 2(a), starts to flow. Then, when the electric field intensity generated within the cell by the sustain voltage plus the accumulating wall charges satisfies the discharge condition, the discharge current also begins to flow, thereby indicating the production of plasma within the cell, as shown in (ii) of Fig. 2(b), and the simultaneous emission of IR light emitted, as shown in (i) of (3) inFig. 2(a). At this point, the space charges produced during the plasma discharge are accumulated on the sustain electrodes with an opposite to the polarity to the space charges due to the electric field caused by the sustain voltage, as shown in (iii) of Fig. 2(b) [8]. As illustrated in (2) and (3) of Fig. 2(a), as soon as the discharge current flows, light is emitted and then abruptly disappears because the accumulation of wall charges from the space charges during the plasma discharge causes a reduction in the electric field intensity. However, as shown in (iii) of Fig. 2(b), energetic space charges and metastable atoms still remain after the abrupt extinction of the discharge, although only for a very short time, and disappear as illustrated in (iv) of Fig. 2(b) [9]. Accordingly, these energetic space charges and metastable atoms must be utilized to improve the luminous efficiency. The displacement current starts to flow again at the falling edge of the sustain pulse, as shown in (v) in Fig. 2(a), and the cells shown in (vi) of Fig. 2(b) exhibit the same condition as the previous state. When another sustain pulse is applied, the plasma is again produced within the cell, as shown in (viii) of Fig. 2(b). This process for creating discharges and emitting light is repeated for the duration of the sustain period.

B. Effects Due to Longer-Sustained Discharge

Fig. 3(a) shows the schematic waveforms of the (1) voltage, (2) current, and (3) IR based on the actual waveforms measured from the 4-in AC-PDP test panel in the case of the proposed new sustain waveform. Fig. 3(b) shows a schematic model of the temporal behavior of the wall charges produced within a cell with



(a)



(b)

Fig. 3. Current and IR (828 nm) waveforms and schematic model for temporal behavior of wall charges in 4-in AC-PDP with new ramped-square sustain waveform. (a) New ramped-square sustain waveform. (b) Temporal behavior of wall charges within cell.

a ramped-square sustain waveform. The voltage magnitudes at the rising and falling edge were 190 V and 250 V (constant slope: 9.3 V/μs), respectively. The other driving conditions were the same as those in Fig. 2(a). As shown in (i) of Fig. 3(b), the wall charges are accumulated below the two sustain electrodes due to the write pulse during the address period. As the ramped-square sustain pulse is applied to the sustain electrode, the displacement current begins to flow, as shown by (i) in Fig. 3(a). Thereafter, the discharge current begins to flow and IR and visible light are simultaneously emitted, indicating the production of plasma within the cell, as shown by (ii) in Fig. 3(a) and (b). As shown in (iii) of Fig. 3(b), the space charges produced during the plasma discharge are accumulated on those the sustain electrodes with an opposite the polarity due to the electric field, resulting in a reduced electric field strength and weak discharge. At this point, the ramped-sustain waveform with an increased voltage slope is able to prevent the abrupt extinction of the electric field caused by the accumulation of the wall charges, resulting in a longer-sustained discharge due to the remaining space charges or metastable atoms, as shown in (iii) of Fig. 3(a) and (b). Since this additional discharge after the first main discharge is due to the metastable atoms, it only requires a very small current, thereby enabling the proposed ramped-square sustain waveform to improve the luminous efficiency.

C. Effects Due to Self-Erasing Discharge

At the falling edge in (1) of Fig. 3(a), another discharge is produced without any additional discharge current consumption and the corresponding light is emitted, whereas, at the falling edge in (1) of Fig. 2(a), there is only a displacement current flows with no light emission. Owing to the increased voltage slope in the ramped-square sustain waveform, as shown in (iv) of Fig. 3(a), the electric field intensity in the discharge cell after the discharge-off at the rising edge remains almost constant such that additional wall charges are accumulated from the space charges, as shown in (iv) of Fig. 3(b). This then causes a self-erasing discharge due to the excessively accumulated wall charges at the falling edge of the ramped-square sustain pulse, with the two sustain electrodes grounded, as shown in (vi) of Fig. 3(b). Since this self-erasing discharge is produced only by those wall charges accumulated within the cell, the light emission is generated without any additional discharge current consumption, as shown in (vi) of (2) and (3) in Fig. 3(a). Therefore, this self-erasing discharge can also improve the luminous efficiency. Furthermore, in addition to removing wall charges, this self-erasing discharge also produces the space charges, as shown in (vii) of Fig. 3(b), which are necessary for the next sustain discharge. Accordingly, since the next sustain pulse is applied within the 0.8 μs after the self-erasing discharge, as shown in Fig. 1(a), the next sustain discharge is produced using only the space charges, as shown in (viii) of Fig. 3(b) [9]. However, this result does not guarantee whether the wall charges during the self-erasing discharge is completely removed [10]. Through the further study, we will try to make it sure whether a nonnegligible amount of wall charges still remains after the self-erasing discharge.

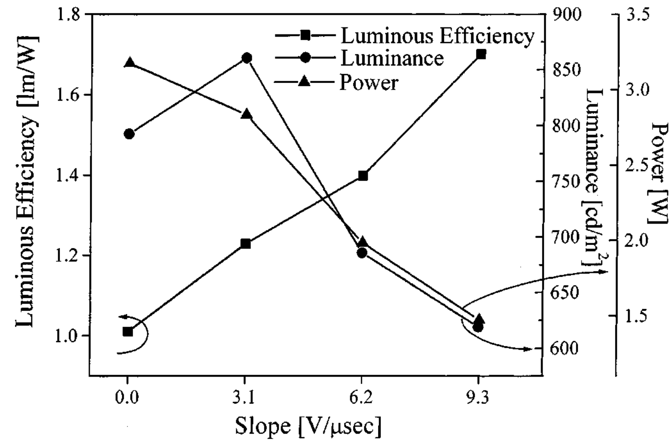


Fig. 4. Change in luminance, consumption power, and luminous efficiency with increased voltage slope in new ramped-square sustain waveform.

IV. Improvement of Luminous Efficiency with Various Voltage Increase Rates

Fig. 4 illustrates the changes in the luminance, discharge current consumption, and luminous efficiency measured from the 4-in AC-PDP test panel employing the new ramped-square sustain pulses with increased voltage slopes from 0 V/μs to 9.3 V/μs. The other driving conditions are similar to those in Figs. 2 and 3. As the voltage increase rates increased from 0 V/μs to 9.3 V/μs, the consumption power decreased from 3.17 W to 1.47 W, and the luminance decreased from 792 cd/m^2 to 619 cd/m^2, except for the condition of 3.1 V/μs. In contrast, the luminous efficiency improved 1.03 lm/W to 1.7 lm/W (65% improvement), as the voltage increase rates increased from 0 V/μs to 9.3 V/μs.

V. Conclusion

A new ramped-square sustain waveform is proposed to improve the luminous efficiency of an AC-PDP. This sustain waveform has a increasing voltage slope between the rising and falling edge, so that it can induce a longer-sustained discharge at the rising edge and a self-erasing discharge at the falling edge. When compared with the conventional square sustain waveform, the proposed sustain waveform with a 9.3 V/μs voltage slope achieved a 65% higher luminous efficiency in a 4-in AC-PDP test panel even at a low frequency (62 KHz).

References

[1] L. F. Weber, "Status and Trends of Plasma Display Device Research," in *Euro Display Dig.*, 1999, pp. 1–6.
[2] ——, "Plasma Display Devices Challenges," in *Asia Display Dig.*, 1998, pp. 15–27.
[3] O. Toyoda, T. Kosaka, F. Namiki, A. Tokai, H. Inoue, and K. Betsui, "A High Performance Delta Arrangement Cell PDP with Meander Barrier Ribs," in *IDW Dig.*, 1999, pp. 599–602.
[4] T. Komaki, H. Taniguchi, and K. Amemiya, "High luminance AC-PDPs with Waffle-structured Barrier Ribs," in *IDW Dig.*, 1999, pp. 587–590.
[5] J. Kang, W. G. Jeon, O. D. Kim, and J. W. Song, "Improvement of Luminance and Luminous Efficiency in PDPs Driven by Radio Frequency Pulses," in *IDW Dig.*, 1999, pp. 691–694.
[6] T. Hashimoto and A. Iwata, "Improvement of Luminous Efficiency in an AC PDP by Self-Erase Discharge Waveform," in *SID Dig.*, 1999, pp. 540–543.
[7] S. T. Lo, C. L. Chen, K. M. Lee, and J. F. Huang, "Improvement of Luminous Efficiency by a Novel Sustaining Waveform for Plasma Display Panels," in *SID Dig.*, 2000, pp. 702–705.
[8] C. Punset, J.-P. Boeuf, and L. C. Pitchford, "Two-dimensional simulation of an alternating current matrix plasma display cell: Cross-talk and other geometric effects," *J. Appl. Phys.*, vol. 83, no. 4, pp. 1884–1897, 1998.
[9] Y. Ikeda, J. P. Verboncoeur, P. J. Christenson, and C. K. Birdsall, "Global modeling of a dielectric barrier discharge in Ne-Xe mixtures for an alternating current plasma display panel," *J. Appl. Phys.*, vol. 86, no. 5, pp. 2431–2441, 1999.
[10] C. Punset, S. Cany, and J.-P. Boeuf, "Addressing and sustaining in alternating current coplanar plasma display panel," *J. Appl. Phys.*, vol. 86, no. 1, pp. 124–133, 1999.

Heung-Sik Tae (M'00) received the B.S. degree from the Department of Electrical Engineering, Seoul National University (SNU), Seoul, Korea, in 1986, and the M.S. and Ph.D. degrees in plasma engineering from SNU in 1988 and 1994, respectively.

In 1995, he joined Kyungpook National University, Taegu, Korea, where he has been an Associate Professor in the School of Electronic and Electrical Engineering. His research interests include the optical characterization and driving circuit of plasma display panel, the design of millimeter-wave guiding structure, and MEMS or thick-film processing for millimeter-wave device.

Dr. Tae is a member ofthe Korean Information Display Society.

Ki-Duck Cho received the B.S. and M.S. degrees in electronic engineering from Kyungpook National University, Taegu, Korea, in 1999 and 2001, respectively. He is currently pursuing the Ph.D. degree in electronic engineering at the same university.

His current research interests include the driving circuit design of PDPs.

Sang-Hun Jang received the B.S. and M.S. degrees in electrical engineering from Kyungpook National University, Taegu, Korea, in 1996 and 1998, respectively. He is currently pursuing the Ph.D. degree in electronic engineering at the same university.

His current research interests include the design and fabrication technique of new cell structure in an AC-PDP.

Kyung Cheol Choi received the B.S. degree from the Department of Electrical Engineering, Seoul National University (SNU), Seoul, Korea, in 1986, and the M.S. and Ph.D. degrees in plasma engineering from SNU in 1988 and 1993, respectively.

From 1993 to 1995, he was with the Institute for Advanced Engineering, Seoul, where his work focused on the design of field emission display devices. He was a Research Scientist in the Microbridge Plasma Display Panel of Spectron Corporation of America, Summit, NJ, from 1995 to 1996. He was a Senior Research Scientist at Hyundai Plasma Display, Hawthorne, NY, from 1996 to 1998, where his work was to continue developing plasma display technology. From 1998 to 1999, he was involved in the development of an AC 40-in PDP at Advanced Display R&D Center of Hyundai Electronics Industries, Kyoungki-do, Korea, as a Senior Research Scientist. Since March 1, 2000, he has been an Assistant Professor in the Department of Electronics, Sejong University, Seoul. His research interests include plasma display panel, field emission display, plasma engineering, and plasma modeling.

Dr. Choi is a Member of the Korean Information Display Society.