Full Color Large Area Flexible Plasma Displays

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Abstract

Imaging Systems Technology is conducting research and development in large area flexible plasma displays. These displays will be used for low cost dynamic signage and billboards. In this paper, IST will report its current progress in achieving very bright full color displays.

1. Introduction

There is increasing interest in flexible displays and electronics. Industry is motivated to develop flexible display and electronics for two basic reasons. First, flexible displays and electronics will lead to new and emerging applications. And second, they promise low cost production methods. New and emerging applications include small hand held devices such as cell phones, ipods, RFID tags, and smart cards. Slightly larger emerging applications include ebooks, electronic paper, and wearable electronics. Finally, large applications include dynamic signage, conformable immersive displays for games and entertainment, and simulation and training.

Flexible displays and electronics provide opportunity for low cost production. First, traditional semiconductor processes are eliminated. Many of the fabrication techniques now being developed for flexible displays make use of simple printing processes at room temperatures instead of various photolithographic techniques. Materials can be applied as an additive process instead of a subtractive process thereby lowering waste. Second, as the production of flexible displays and electronics matures, batch processes used in the display and electronics industry will move to roll-to-roll processes. This is a complete paradigm shift from processes associated with the traditional semi conductor industry to processes traditionally associated with the printing industry and plastic production.

There are a number of flexible display technologies now under development including organic light emitting diode (OLED), electrophoretic paper (E-paper), flexible LCD, and flexible PDP.

Flexible plasma displays are being developed for large area multi-view applications [1]. As with all flexible display technologies, the primary challenge is to obtain flexibility while maintaining the performance of the conventional rigid display.

To address the challenges of making a flexible display, three unique approaches have been successfully demonstrated. The University of Illinois, Urbana, Illinois, USA has demonstrated a flexible plasma display with hollow wells drilled into a flexible foil (microdischarge display). Shinoda Plasma Corp., Kobe, Japan has demonstrated a plasma tube display. The Shinoda display consists of meter length tubes of one-millimeter diameter arranged in parallel to form red, blue, and green columns. Imaging Systems Technology, Toledo, Ohio, USA has demonstrated a flexible plasma display using hollow spheres (Plasma-sphere™ display).

The Plasma-sphere PDP shown in Figure 1 is comprised of multiple microspheres (3c) that encapsulate the ionizable gas (6).

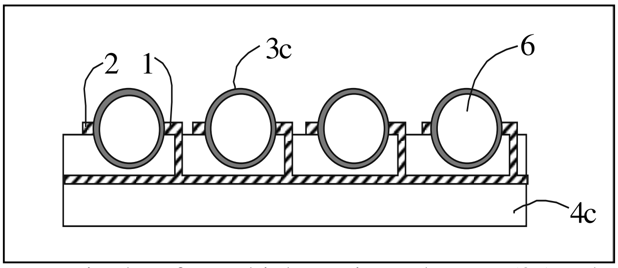

Fig 1. Plasma-sphere Display

Each microsphere comprises a dielectric shell material with highly uniform diameter and thickness formed with IST's proprietary processes. Because the pressurized gas is contained in a microsphere, the Plasma-sphere substrate (4c) does not need to be rigid or impermeable. Nor does it require a top substrate. Additionally, because each Plasma-sphere defines the crucial parameters of gap and dielectric thickness, critical tolerances are not required for the substrate. Essentially, the critical parameters in a conventional PDP have been moved from the substrate to the less complex Plasma-sphere, resulting in greater flexibility. Plasma-spheres can be configured with gas pressures above one atmosphere, and with two, three, or more electrode configurations.

IST has developed proprietary manufacturing processes, which produce optically transmissive, uniform hollow spheres that are free of contaminants. With these processes, IST controls shell thickness to within a few microns and gas pressure to within one Torr. Microspheres are produced in a chamber that is devoid of human contact or intervention and thus clean room environment is not required. The microsphere yields are over 98%. The Plasma-sphere pixel elements are formed separately from the substrate. Because of the separation of processes, the substrate is not exposed to heat or reactive chemicals. The manufacture of the flexible substrate includes a roll-to-roll process instead of a batch process. Flexible substrates can be produced on wide web equipment using techniques and equipment such as those used in the paper industry. Mass assembly and inspection of Plasma-spheres on the substrate may be accomplished as part of a roll-to-roll manufacturing process. The technologies of these proprietary production techniques are simple when compared to those of conventional displays that require handling and cutting large pieces of glass to form a pair of rigid substrates. Additionally, the Plasma-sphere arrays eliminate many of the other process steps used in the manufacture of traditional rigid two substrate plasma displays such as sand blasting, vacuum deposition, and gas processing. The elimination of these conventional process steps coupled with a roll-to-roll process offers automation and the advantages of high yield and low cost.

The Plasma-sphere is an enclosed pixel structure. Each Plasma-sphere is physically and electrically isolated from its neighbors. The ionizable gas that is encapsulated inside the Plasma-sphere is isolated from the gas inside the neighbor pixels. This enclosed pixel structure is an important factor in the operating window of the Plasma-sphere array.

The Plasma-sphere is immune to charge spreading. Charge spreading occurs in open cell plasma displays when a pixel is overly energized and the ionized plasma from that pixel causes neighbor pixels to light. The enclosed pixel structure also leads to higher ON voltages. This leads to wider memory margins and the ability to use a higher voltage sustain pulse that increases the light output of the Plasma-sphere. The Plasma-sphere array also has increased brightness and efficacy. Like the plasma tube display, the Plasma-sphere display allows for large area low cost and flexible displays. These displays may be used in stadiums, dynamic signage, simulation, and games and entertainment. The Plasma-sphere display has additional application in ultra bright outdoor signage.

2. Experimental

Because the Plasma-spheres are encapsulated and separate from one another, they are not susceptible to charge spreading. This makes it possible to go to very high sustain frequencies without loss of operating margin. Previous work conducted by the IST team demonstrates this principle [2]. It is summarized in Table 1.

Table 1 Comparison of Plasma-sphere characteristics at 50kHz and 1.2MHz for monochrome display

	50	1.2 MHz
Brightness	600 cd/m2	9,500 cd/m2
Memory Margin	140 V	195 V
Efficacy	0.346 lm/W	0.535 lm/W

Table 1 shows a comparison of the two frequencies. At 50kHz, the brightness of the Plasma-sphere display is 600cd/m^2. This is 6 times brighter then a conventional monochrome orange plasma display, which has a typical brightness of 100cd/m^2. When the 1.2MHz sustain is applied to the Plasma-sphere display, the brightness increases another 16 times to 9,500cd/m^2. The memory margins for both the 50kHz and 1.2MHz are over 100V. The efficacy at 50kHz is 0.346 lm/W. A conventional neon orange monochrome plasma display's efficacy is 0.2 lm/W. The Plasma-sphere's efficacy at 50kHz is 73% greater then the standard plasma display. At 1.2MHz the efficacy is 55% over the 50kHz.

This results in increased memory margins and the ability to use a higher voltage sustain pulse, which increases the light output of the Plasma-sphere. The

Plasma-sphere array shows increased brightness and increased efficacy.

IST is developing bright full color flexible displays. Work has centered on selecting bright phosphors compatible with the manufacturing process.

IST has investigated the efficacy of red and green Plasma-spheres under various sustain frequencies to determine if they are as efficient as monochrome neon at high frequencies. Standard plasma phosphors were used.

For the past several years IST has been producing color Plasma-spheres using its proprietary process. Long-term aging tests have begun on red and green spheres. To date, red spheres have been aged for over 5,000 hours and show no degradation in brightness, color, or operating window. They have a dominant wavelength of 628nm and a peak wavelength at 640nm. Color coordinates are 0.7x and 0.29y. To date green plasma-spheres have been aged for about 3,000 hours. They show no degradation in brightness, color, or operating window. The dominant wavelength is 548nm and the peak wavelength is 529nm. The color coordinates are 0.29x and 0.66y.

3. Results and discussion

Early results with red and green spheres indicate it will be possible to achieve large area flexible color Plasma-sphere displays with brightness over 500cd/m^2, long life, wide operating window, and improved efficacy.

Red and green Plasma-spheres were driven with sustain frequencies ranging from 100Hz to 1.12MHz. As shown in Figure 2, red Plasma-spheres brightness increase linearly as frequency increases. Green Plasma-spheres do not increase linearly and level off in brightness after about 200kHz. We believe that the green phosphor becomes saturated at higher frequencies past about 200kHz. Currently, the green phosphor shows a peak efficacy of around 2 lumens per watt at sustain frequencies between 20 and 288kHz. The red phosphor's efficacy appears to be linear.

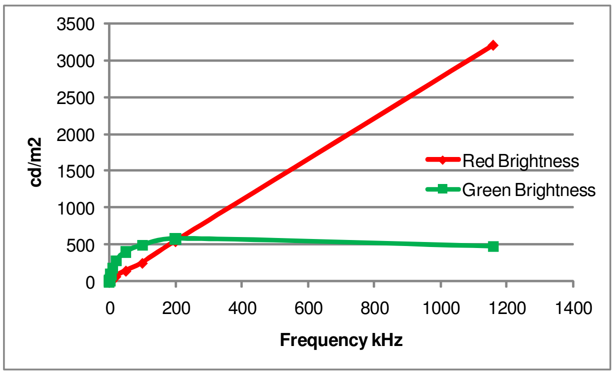

Figure 2 Brightness vs. Sustain Frequencies

4. Summary

Early results indicate efficacy of color Plasma-spheres is not enhanced with higher frequency. This appears to be due to the phosphor saturating. The red Plasma-spheres maintain essentially the same efficacy over the frequency range. Green Plasma-spheres show maximum efficacy at sustain frequencies between 200kHz and 288kHz.

To date, most research has focused on material selection. It is anticipated the efficacy will be greatly increased in the future with a number of changes to the Plasma-sphere structure including shell architecture, electrode area, gas mixture, and gas pressure.

5. References

1. Shinohe, K. et al "Light and Flexible Plasma Tube Array with Film Substrate" IDW 2004

2. Wedding, C "Ultra-Bright High- Frequency Flexible Plasma Displays" The International Display Research Conference (IDRC) September 18-21 2006

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