Laterally Encapsulated Cathode Structure for DC Plasma Display Panels

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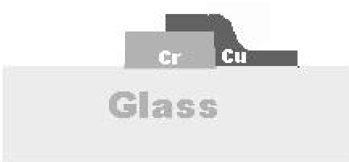
Abstract
We report a novel approach for encapsulating of cathode electrodes in DC plasma pixels. Anode and cathode electrodes are laterally placed on a single substrate. The encapsulated electrode minimizes the sputtering of the cathode without significantly altering the turn-on voltage-pressure characteristics. An abnormal glow in current-voltage characteristics is also observed.

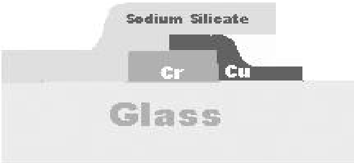
1. Introduction
Plasma display panels are of great importance for the realization of large area flat panel displays[1-3]. The creation of a local plasma between a passive addressable X-Y matrix results in the generation of images with high quality. The conversion of ultra-violet illumination into visible light is accomplished using proper phosphorescence coatings on each individual cell. PDPs are usually realized using two substrates holding the anode and cathode electrodes and by applying an appropriate AC or DC voltage between such electrodes, the plasma is ignited and the pixel turns on. We have recently reported a pixel structure in which the anode and cathode electrodes are placed on a single substrate suitable for DC PDP's[4]. First images have also been obtained using this configuration. There are two obstacles in extending the area of the panels using this method. The first problem is the sputtering of the cathode electrode by the energetic ions inside the plasma and the second one is the need for a series resistance in every cell. In this paper, for the first time, a laterally encapsulated cathode for the fabrication of DC plasma display panels is reported. The DC PDP pixel structure consists of laterally placed cathode and anode electrodes on a single substrate where the isolation of the electrodes is possible by an insulating layer such as water-glass. The cathode in this paper is encapsulated in a tunnel-like structure where one side of the tunnel is opened and the cathode electrode is placed on the other end (closed side) of the structure. This structure is similar to a hollow cathode structure where the small tunnel on cathode acts as the hollow cathode[5]. The anode is placed perpendicular to the cathode on the very same substrate. A second substrate is needed to carry the phosphor coating. This encapsulation protects the metallic electrode from being bombarded by plasma ions, hence minimizing the sputtering of the electrodes and extending the life time of the pixel.

2. Fabrication Flow
As seen in Figure 1, fabrication starts with depositing of a 0.3μm thick chromium layer on a glass substrate. After patterning this layer to form X-addressing lines, a sacrificial layer of cupper is deposited with a thickness of 2μm to act as a "mold" for the future tunnel (a) fabrication. After patterning the Cu layer, the whole substrate is coated by an insulating layer and the sample is thermally cured. In this stage, we use liquid glass which is typically cured at a temperature of 150°C under strong ultra-violet illumination. The duration of the curing varies between 5 to 20 hours and during this time the temperature of the substrate can rise from 150 to 300°C to assure that a solid glass is formed. The insulating layer is then patterned to open windows just on one side of the cupper sacrificial layer (b). Once the windows in glass are opened, the sample is immersed in the cupper solvent to remove the cupper from underneath of the insulating oxide layer (c). This is essentially a surface micro-machining process which yields a smooth removal of the underneath cupper through the channel.

Since the top insulating layer (glass) is only 1-2μm thick, the cupper sacrificial layer must be narrow to avoid collapsing the glass. In this way, there will be an offset between the cathode (Cr) and the opening of the tunnel. The fabrication of the main substrate is finalized by depositing and patterning the second electrode (silver) to form the anode electrode. Part (d) in Figure 1 shows the schematic diagram corresponding to the final pixel structure.



(a)



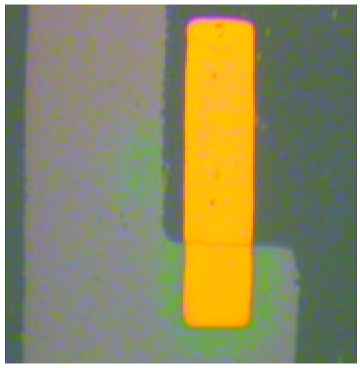
(b)

(c)

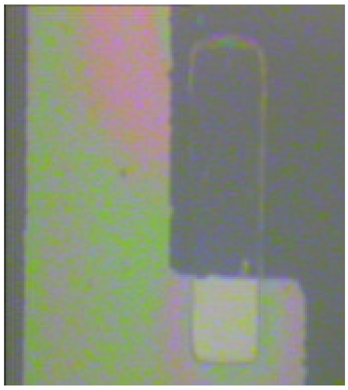
(d)

Figure 1: Fabrication flow of the encapsulated cathode DC pixels. Chromium and silver are acting as cathode and anode electrodes, respectively.

Figure 2 shows the optical images of the PDP pixels before (a) and after (b) immersing in the cupper solvents to prepare the tunnel (lateral hollow cathode). Such patterns are placed perpendicular to the anode lines to realize an X-Y matrix. Since the front end of the covering glass has been used to remove the buried cupper, it acts as the opening of the tunnel structure for the generation of the plasma between the covered negative electrode and the positive exposed electrode. The presence of the insulating coverage protects the cathode electrode from being bombarded by the energetic ions as well as it may act as the hollow cathode structure where the need for a series resistance is relieved.



(a)



(b)

Figure 2: Formation of lateral tunnel by removing the sacrificial cupper layer (a). The image in (b) shows the transparent glass layer remaining after removal of Cu.

3. Results and Discussions

In this section, some of the preliminary results obtained from such a structure are reported. By applying proper voltage between cathode and anode electrodes, plasma is generated and the pixel is turned on. Figure 3 shows the turn-on voltage versus pressure curve for the encapsulated pixels evidencing an abnormal behavior. At a pressure of 60torr, the graph passes through its minimum value of 370 V. At higher pressures, the turn-on voltage shows a monotonic rise until a saturation is reached. At pressures higher than 100torr no considerable rise is observed in the turn-on voltage. For standard parallel plate structures, a monotonic rise is expected after passing the minimum point of the curve. In our structure, however, the presence of a long tunnel has caused a sharp initial rise followed by a soft increase at pressures higher than 80 torrs.

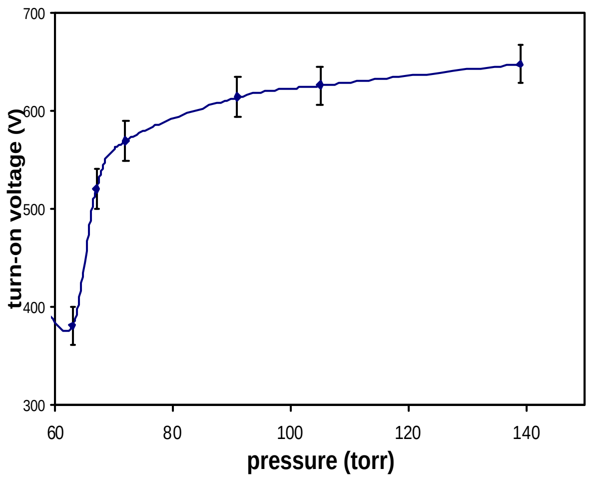


Figure 3: Turn-on voltage vs. Pressure curve, evidencing a saturation regime.

In Figure 4 we have collected the data corresponding to the measured pixel current versus the applied voltage between electrodes. For a normal glow, a negative resistance effect is observed, whereas for the encapsulated cathode, an abnormal glow is seen which is due to the fact that the flow of ions through the lateral tunnel is limited by an inherent resistor. Although it is too early to exclude the need for a series resistance, the evolution of abnormal glow seems promising in this respect.

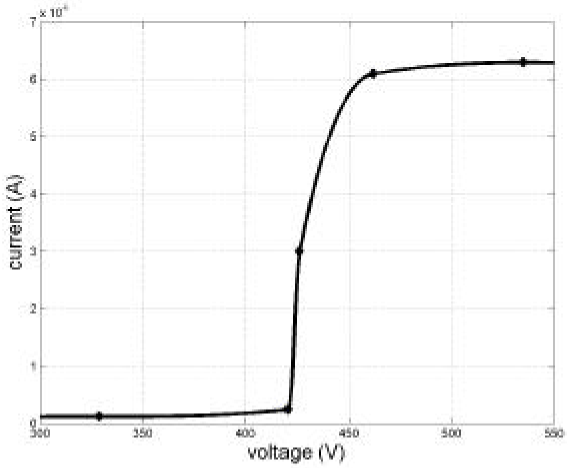


Figure 4: Current-voltage characteristics of the encapsulated pixel evidencing an abnormal glow.

For comparison we are presenting the results of similar pixel structures without the encapsulating layer indicating a normal characteristics (see Figure 5).

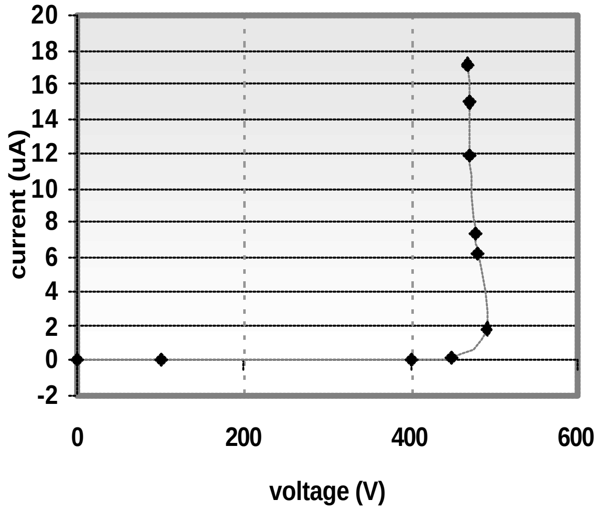


Figure 5: Current-voltage characteristics of the lateral pixels without the use of encapsulation.

We have also fabricated display panels using lateral structures on both glass and plastic (PET) substrates and various images have been obtained. A preliminary image is given in Figure 6. For this image, *non-encapsulated* pixel structures have been used and the addressing of pixels has been achieved using external series resistance at each line.

Figure 6: The preliminary image of a cartoon character on the PET flexible substrates under an intentional bent.

Also the green phosphor-containing substrate is placed opposite to the main substrate. We are planning to fabricate long-lasting display panels on both glass and plastic substrates. Fabrication of a medium size panel is underway. Also results on flexible bases are reported.

4. Acknowledgements

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5. References

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