Development of Novel Electrode Materials for Plasma Display Panel

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Abstract

In this paper, we mainly deal with metallic electrode materials and patterning processing of plasma display panels.
We focus on the recent development status, where low cost and high performance electrode materials such as Ag-based single-layered bus, low cost-in-use and anti-migration address electrodes are briefly introduced.
The technological trends and further works on novel electrode materials and processing are also discussed.

1. Introduction

Most and the foremost key issues on the current FPD (Flat Panel Display) markets are cost innovation and freedom in resolution embodiment with enhancement of luminous efficacy. While PDPs feature many superior visual properties, ever increasing customer expectations for quality and feature improvements are coupled with demands for lower costs and greater value. [1]

Electrode, which is composed of sustain (bus) and address, materials and processing in PDPs are very important roles in panel cost as well as PDP performance like any other electronic devices. [2]

Sustain electrodes in PDPs consist of indium-tin-oxide (ITO) transparent electrodes and metal bus electrodes at front side. The metal electrodes prevent a voltage drop along the ITO electrodes due to the non-negligible resistivity of the ITO film. These are related to the stable discharge and contrast. Therefore, bus electrodes have white-colored highly conductive Ag layers and black-colored insulated layers for enhancing contrast. [3]

Address electrodes are located at rear side in panel and are closely related to the resolution of display including freedom of design.

Besides aforesaid basic and indispensable function, electrodes are very important portion in panel cost because PDPs are using high precious silver (Ag) pastes. Lower material costs allow PDP manufacturers to compete more effectively with LCD technology.

In this paper, we describe trends in PDP electrodes including materials characteristics and fabrication process and current development status including introduction to newly-developed electrodes. Further works to enhance cost-competitiveness and PDP performance are presented.

2. Trends in PDP electrodes

Cost configuration of current 42inches PDP panels is illustrated in Fig. 1. Share rate of electrodes is 39%, which is first-ranked among panel materials. This result is mainly caused by skyrocket of Ag materials.

The cost of Ag was increased in about 60% since last two years whereas panel cost and electrodes (bus+address) cost were decreased 25% and 14%, respectively.

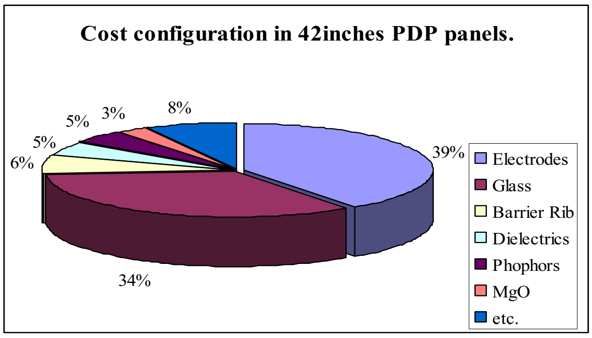


Fig. 1. Cost configuration in 42inches PDP panels.

This can be interpreted that in spite we endeavored to decrease Ag paste cost and the amount of usage and resultantly achieved many break-throughs, we must still incessantly develop new materials and process to meet market needs for lower cost and trends, as shown in Table 1.

Trends in PDP electrode materials and processing are illustrated in Table 1.

As shown in Table 1, it is thought that there are four things in choosing electrode materials and process; cost, high reliability, ultra-fine resolution and environmental friendliness. Because these key items are articulated with each other, development of optimum materials and processing concurrently enable PDP to realize aforesaid premises.

TABLE 1. Trends in PDP electrode patterning and materials.

Cost		
Subtractive	→	Additive
Noble metal	→	Base metal
High solid content	→	Low solid content
High reliability		
Unstable plasma discharge	→	Sufficient discharge margins
Ag migration	→	Anti-migration property
High edge-curl	→	Edge-curl-free
Ultra-fine resolution		
Normal resolution (HD)	→	FHD/4K2K/8K4K
Environmental Friendliness		
Lead-based	→	Lead and bismuth-free

Attempts to achieve cost innovation can be categorized as follows; changes in fabrication process, investigation on non-Ag materials and reduction of Ag paste usage, etc.

High reliability is related to lower resistance of bus electrodes for wider discharge margins and anti-migration of address electrodes of high-resolution models in severe environmental (High temperature and high humidity) conditions.

Ultra-fine resolution means freedom of design in dimension, angle and shape of electrode patterning. Narrower width of electrodes enables to make ultra-fine resolution and flexibility in degree of patterning enables PDP module to use multi-channeled driver IC, which is very helpful to decrease PDP module cost.

Lead-free of PDP electrodes, which are well-known as an environmental regulation such as RoHS and compulsory items in modern electronic devices, already completed. We are under investigating on electrode materials having lead and bismuth-free glass frit.

In this paper, we mainly describe the cost issue.

Almost PDP panel makers are using photo-lithography process as a main fabrication method of electrode patterning, as shown in Fig. 2. This thick-film metallization technology, which is representative subtractive method and selectively exposing the material to light, continues to set new global standards by enabling higher resolution and lower cost-in-use.

Ag-based photosensitive thick-film paste is well established as a leading technology for the metallization of bus/address electrodes to provide high resolution and improved image quality for large format, full high definition.

Recently, off-set process, which is representative additive (selectively patterned) methods are attempted to save 50%~70% paste usage at a maximum extent as illustrated in Fig. 3. In selection of patterning process, it is very important that we must deliberate not only total cost including cost of consumption goods and degree of recycle but also process flexibility such as easy job-change and ultra-fine resolution availability.

Concepts of lower usage stand for printability, better resistivity and wider processing margin and latitude.

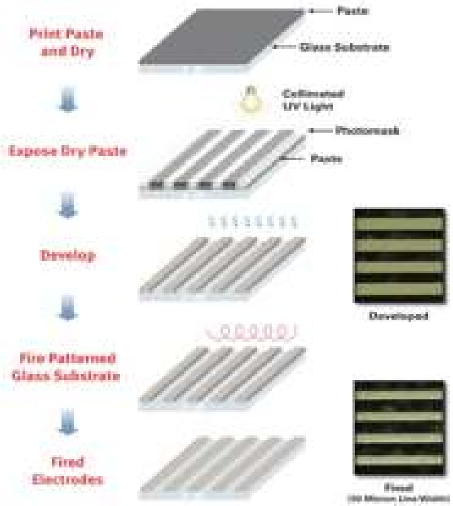


Fig. 2. Process flow of conventional photo-sensitive processes. (Courtesy by DuPont)

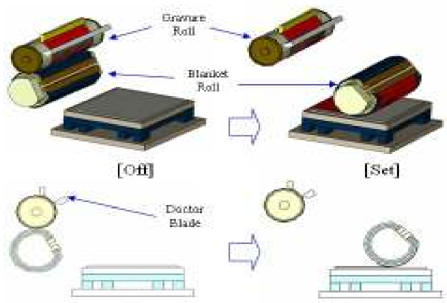


Fig. 3. Schematics of off-set process.

Our recent research results tell that thin-film like photolithography process and Al-based photosensitive thick-film pastes are most feasible method to materialize aforesaid premises simultaneously. Current study status on Al-based materials will be briefly discussed at Part 4.

3. Development of bus electrode materials

The PDP front-side glass's electrode bus systems are generally consisted of white-colored silver electrode paste and black paste co-fired together in a double-layered structure. Main reasons of double-layered are the offer of conduction path and high bright room contrast ratio (to minimize reflections that degrade contrast ratio), respectively. Therefore, if single-layered structure with same conductivity and reflectance of panels concurrently comparing with conventional double-layered system can be applied in PDPs, it can be considerably helped in view of cost-in-use and process efficacy.

We developed the lead-free single-layered bus electrode materials based on preliminary studies about relationships between line resistance of bus electrode and the luminous efficacy, which have almost similar optical and electrical properties of conventional double-layered system. Degree of edge-curl phenomenon is considerably declined by no existence of thermal and chemical mismatching between bus black and white layers. Moreover, uniform thickness of front dielectrics by lower thickness of bus electrodes can be helped to maintain stable discharges.

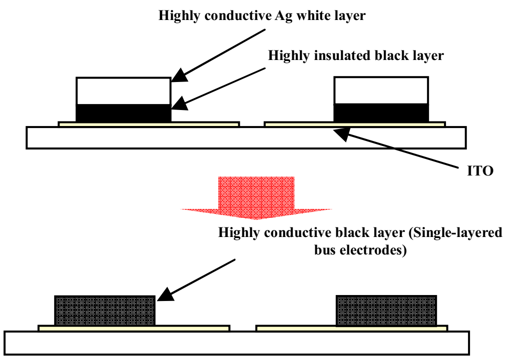


Fig. 4. Basic concept of Single layered bus electrodes.

Through this development, we could find accurate resistance margin in various kinds of models. We are using this output to design and decide electrode dimension and line resistance in newly developed PDP model.

4. Development of address electrode materials

Key issues of address electrodes can be divided into cost and freedom of design including ultra-fine resolution.

To comply with these needs, we developed address electrodes having low defect, cost-in-use and anti-migration properties, and are now under developing photosensitive Non-Ag electrode materials without any changes in existing processes. As previously mentioned, it is valued that development of Non-Ag materials can simultaneously achieved cost innovation and real freedom of design by migration-free properties.

Because PDPs are based on thick-film technology and used highly reactive Ag as an electrode paste, there are many limitations to realize fine resolution. That is, precious Ag materials are very useful to high conductivity but its peculiar migration property, as shown in Fig. 5, is one of the major factors to inhibit embodying ultra-fine resolution such as QFHD (Quad Full-High Definition) and 8K4K resolution in PDPs, which must make much more address lines in restricted space than HD and therefore both of line width and space must be considerably minimized.

We developed newly formulated lead-Free Ag/Frit modified address systems having the usage reduction and anti-migration properties. It is thought that their high performance such as anti-migration and the cost-competitiveness without any loss of performance in paste, process and luminous efficacy are originated from the optimum controlling of Ag/Frit weight ratio and low specific gravity by low Ag contents, respectively. [4]

Generally, glass frits in electrodes are mainly used as a sintering promoter and necking former of silver particles as well as adhesion media between glass substrate and electrodes.

In case of these newly-developed materials, there are excessive amount of frit except aforesaid usages. After necking between solid-state Ag to make conduction path and adhering between electrodes and glass substrate, extra frit materials rapidly slip out of inner side to each sides and surface. Therefore, two-layered (highly insulated blocking layer and conducting layer, respectively) structure is formed as shown in Fig. 6.

Results of damp-proof cycle (high temperature and humidity) test reveal that there is no migration whereas vertical-line short phenomenon between adjacent address electrodes was happened at over 40% of conventional PDP panels within 3 cycles, which attribute to entirely wrapped Ag electrode by highly insulated blocking-layer and coincided with that of test panel.

Recently, we developed address electrode materials with higher layer density and ultra-low paste usage without any loss of resistivity. This new materials enable address electrodes to embody under 2μm thickness as shown in Fig. 7. Higher densification of electrodes, which is originated from fine Ag and optimum composition control of Ag/Frit, can considerably alleviated defect and repair rate in pattern fabrication processes.

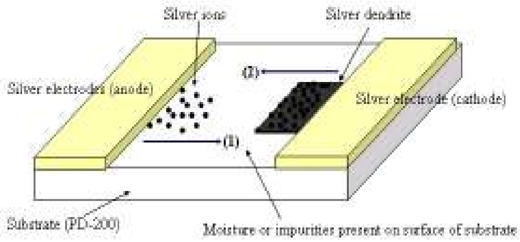
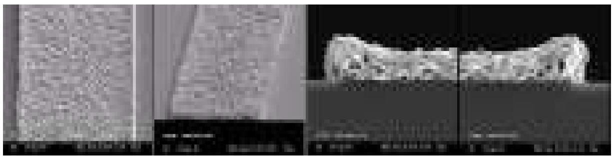


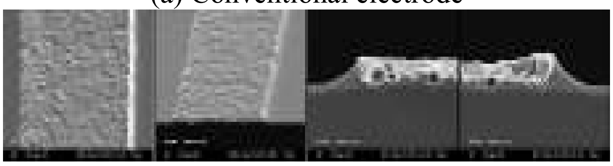
Fig. 5. Schematic diagram of silver migration.

1) At the anode, silver corrodes and positive metal ions, Ag^+ are formed. Through ionic transport, the ions cross the surface of the substrate to the cathodes.

2) At the cathode, the Ag^+ ions are reduced metal Ag ($Ag^+ + e^- \rightarrow Ag$) which from dendrites. Eventually, if enough silver is available, the dendrite growth reaches the anode and a short circuit occurs. [5]



(a) Conventional electrode



(b) VE electrode

Fig. 6. FE-SEM photographs of fired (a) conventional and (b) VE address electrodes.

Current studies on photosensitive non-Ag electrode materials reveal that aluminum (Al) is most feasible materials to substitute Ag materials in view of mass productivity and cost-effectiveness. General characteristics of Al electrodes was totally different to that of conventional Ag electrode materials; resistivity of electrodes was decreased with the increasing of metal particle sizes and the amount of frit content and there is no width variation between developed and fired electrodes layers.

Fig. 8 represents FE-SEM images of photosensitive Ag and Al electrodes. Microstructures of fired electrodes implied that Al electrodes had different mechanism on necking between metal particles and making electrical conducting path.

Nevertheless these discrepancies, we are under developing and optimizing Al materials as address electrodes in PDPs.

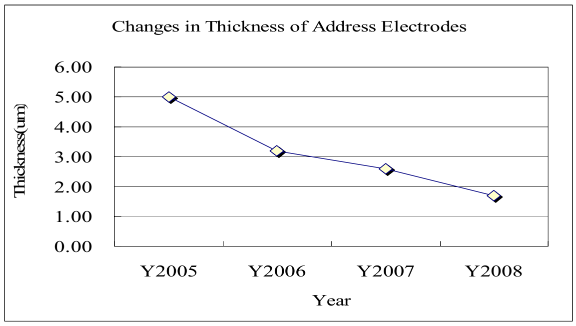


Fig. 7. Changes in fired thickness of address electrodes.

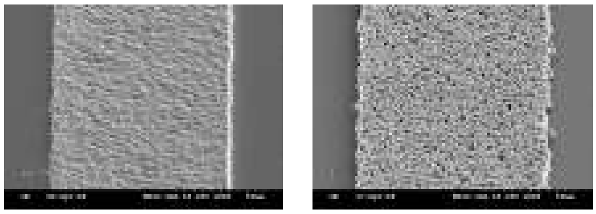


Fig. 8. Comparisons in microstructure of photosensitive Ag (left) and Al (right) electrodes.

5. Summary

Although there are many improvements such as single-layered bus and anti-migration and ultra-low Ag content address electrodes, electrode materials are still occupying big portions in panel cost.

Therefore, further study and investigation on cutting-edge development in cost innovation such as Non-Ag materials as well as enhancement in productivity including higher printability, defect-free and co-firing are strongly required.

Acknolwdgement

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6. References

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