Individual role of manufacturing steps in PDP system contamination and their specific impact on ultimate operational parameters

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Abstract

In this paper we investigate, on the basis of experimental data, the correlations between contamination issues occurring during production process steps and final PDP operational parameters: these reciprocal relations are the result of dynamic equilibria established within the PDP system, amongst residual gases and sorbed species interacting with heat, ions and photons.

1. Introduction

PDP production is characterized by high temperature cycles in strong environmental conditions: under those circumstances, the internal surfaces of the panels undergo sorption and desorption processes, especially related to interactions with moisture and carbon oxides. In particular, carbonate formation on MgO protective layer has been addressed as a very detrimental phenomenon, leading to sizeable decrease in secondary electron emission capability. Together with magnesium oxide, also phosphors can be damaged by oxidative reactions [1] and residual H_2O and CO_2 molecules can also contaminate the internal gas mixture.

Our objective is to determine experimentally verified correlations between manufacturing process parameters and final PDP performances (firing/sustaining voltages, brightness, power, discharge current, efficiency), since they are linked by the system contamination features (internal surfaces, MgO, phosphors, buffer gas).

The knowledge of the most critical processes in display manufacturing is the starting point for providing specifically addressed solutions for better performing PDP's, towards higher image quality, lower power consumption and longer lifetime.

The rationale of this work is a comparative study, based on multiple variables, with the target of gaining as much information as possible on PDP sample/variable correlations.

The results of this work serve as a starting point for a goal-oriented production process optimization, by improvements specifically addressed to the minimization of contamination issues from moisture and carbonates.

2. Experimental

The upper and lower panels of each 6 inch plasma device have been manufactured according to the brief procedure description below.

Front panel. Photolithography is used to form the ITO sustaining electrodes on the glass. This step is followed by screen printing of sustaining bus, black stripe matrix and dielectric layer (5μm, 5μm and 30μm thicknesses, respectively). After firing, the dielectric film is characterized by ±2.5μm uniformity and 0.6μm average roughness, with 64% transmittance over the entire area.

Preliminary glass frit paste dispensing is performed and followed by 430°C baking (for one hour): this heat treatment is capable of removing all the organic binder, preventing contamination from organic molecules during the next MgO vacuum deposition step.

The protective layer is deposited by reactive e-beam: constant O_2 mass flow of 20 sccm is maintained during the entire process, in order to avoid stoichiometric oxygen deficiency (the substrate is heated up to 250°C by three UV lamps). During the evaporation, pressure stabilizes around $6 \cdot 10^{-4}$ mbar and the thickness rate at 5 Å/s: the process stops as soon as 7000Å MgO nominal thickness is achieved.

The deposition is immediately followed by a post-deposition annealing at 300°C for 90 minutes.

Rear panel. The screen printing process of the dielectric layer is the very same as for the front panel, with the only exception that TiO_2 based paste is here used, for enhancing reflectivity. The data electrodes screen printing is analogous to the sustaining electrodes process, with the use of the same Ag based paste.

Ribs material is screen printed on the dielectric layer in 15 steps of 12 μm each on the panel area, without pattern mesh. The waffle structure is formed by sand blasting after drying. The final overall 180 μm thickness is reduced to about 130 μm after subsequent firing. The lateral dimension of the barrier ribs thus obtained is in the range 80-100μm.

Phosphors are screen printed, entirely filling the empty volumes enclosed by the barrier ribs. After drying (evaporation of solvents) in clean air flow, the firing process takes place at 580°C.

Standard (reference) PDP's undergo the frit procedure at 500°C in air, for 2.5 hours in air. Once sealed, reference displays are pumped for 24 hours at 300°C (exhausting/baking step): the pressure read just above the turbo pump inlet is of the order of 10^{-6} mbar.

Keeping fixed the manufacturing flow of the two panel halves, further four groups of PDP's have been produced, by varying frit temperature, frit time, exhausting/baking temperature and exhausting/baking time, according to the following table 1.

One more set of panels have not been submitted to exhausting/baking: in this case, the devices have been evacuated at room temperature, for a very short time (less than half an hour).

TABLE 1. PDP Sample grouping according to modified process parameters.

Samples grouping	**Frit Temp.** (°C)	**Frit Time** (hrs)	**Ex/Bake Temp.** (°C)	**Ex/Bake Time** (hrs)
Reference	500	2.5	300	24
Frit @470°C	**470**	2.5	300	24
Frit for 3.5 hrs	500	**3.5**	300	24
Exhaust @350°C *	500	2.5	**350**	24
Exhaust for 12 hrs	500	2.5	300	**12**
No exhaust	500	2.5	ND	**0**

* This panel accidentally broke after 12 hours aging.

The operational parameters (experimental data), comprising breakdown/sustaining voltages, brightness at static margin (with spatial resolution), firing and discharge currents, dissipated power and efficiency at static margin have been measured on freshly manufactured PDP's and after 8, 12 and 24 hours aging: Pulse Driving System (PDS) has been used, with AC pulses fixed at 35kHz (0.25 duty ratio).

3. Results and discussion

The static margin voltage (V_{SM}) is considered the operational parameter more directly related to the MgO surface conditions [2], since it is greatly affected by the secondary electron emission yield [3]. V_{SM} is defined as the mean between the maximum sustaining voltage (all pixels ON) and the minimum firing voltage (first pixel lit):

$$V_{SM} = \frac{1}{2}\left(V_{S,Max} - V_{F,Min}\right). \quad (1)$$

The following figure 1 shows the trend of V_{SM} for all the samples. V_{SM} values typically decreases during aging, in virtue of the sputtering/heating effect [4] of plasma, which tends to clean the internal cell surfaces from adsorbed contaminants. It is expected that most H_2O and CO_2 molecules (and eventually $Mg(OH)_2$), initially covering the MgO surface [5], can be sputtered away during this phase, redistributing over the entire internal surface of the device; this cleaning effect is most unlikely to happen for $MgCO_3$, which irreversibly makes the protective layer surface more brittle and does not decompose up to 360°C.

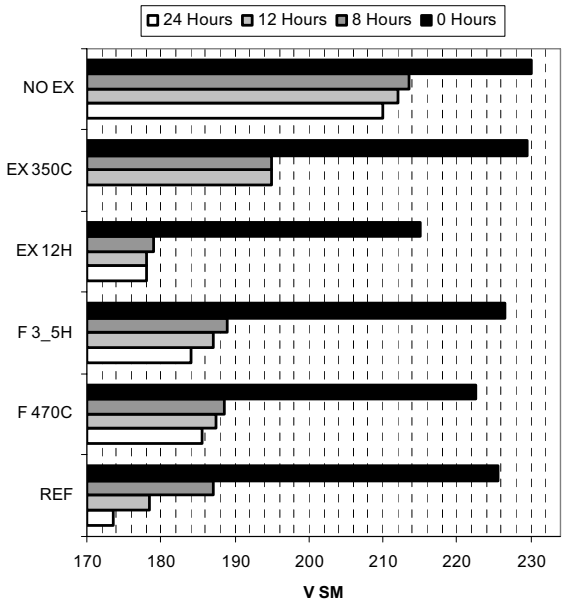


Fig. 1. Decreasing trends of V SM during aging.

The big variation of reference panels, from 226V to 174V at the end of aging, with respect to the smaller decrease of not exhausted ones (from 230V down to 210V) can be explained hypothesizing much higher degree of contamination (and especially carbonate formation) caused by the absence of long evacuation of the system. The other panels are characterized by intermediate trends, giving final V_{SM} values always higher than the reference one.

The aging has a stabilizing effect for brightness, increasing spatial uniformity, but also lowering the intensity mean value. The change in standard deviation of the measured brightness data points on the display area (table 2) is an indication of the effectiveness of aging cleaning, due to reversible and/or low contaminations.

TABLE 2. Brightness at static margin (B_{SM}) before and after aging.

Samples grouping	Aging (hours)	B_{SM} Mean (cd/m^2)	StDev/ Mean	B_{SM} Mean Decrease
Reference	0	644	0.061	-
Reference	24	426	0.026	33.90%
Frit @470°C	0	483	0.057	-
Frit @470°C	24	430	0.036	10.91%
Frit for 3.5 hrs	0	498	0.040	-
Frit for 3.5 hrs	24	395	0.040	20.63%
Exhaust for 12 hrs	0	555	0.029	-
Exhaust for 12 hrs	24	459	0.053	17.37%
Exhaust @350°C	0	431	0.022	-
Exhaust @350°C	12*	417	0.023	3.28%
No exhaust	0	449	0.034	-
No exhaust	24	437	0.021	2.72%

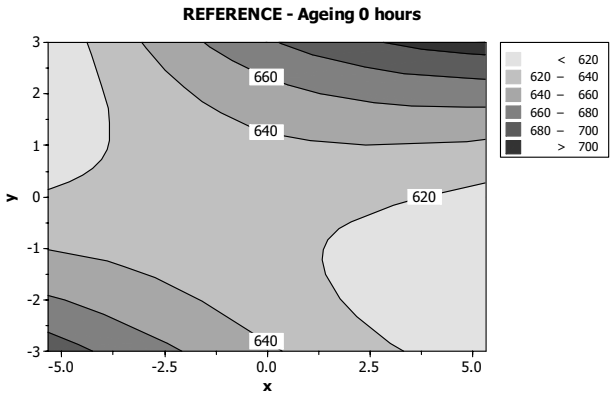


Fig. 2. Contour plot of brightness at static margin for reference panel, before aging (values expressed in cd/m^2).

Contour plots of luminance (e.g. figure 2) for different aging times reveal that the intensity gradient seems not to be directly related to the position of the exhausting tube, as expected [6]: the apparent randomness of brightness maxima and minima is likely to be related to the very high and irregular impedance values of the channels edged by barrier ribs, whose heights and lateral dimensions present evident fluctuations.

The following are the score and loading plots, relative to the first two principal components (more than 70 % of total variance explained) coming from Principal Component Analysis (PCA).

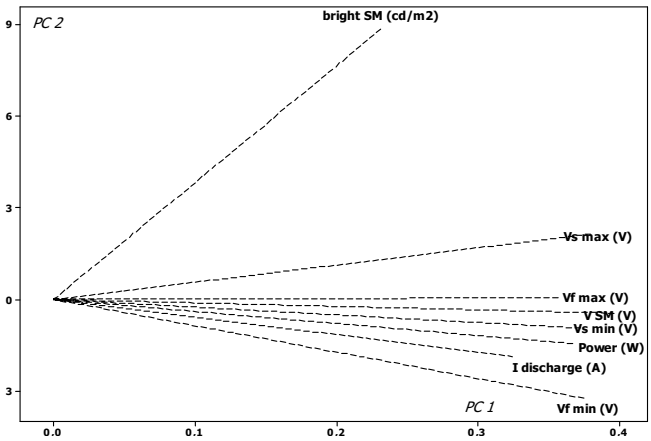


Fig. 3. PCA LOADING PLOT: first two principal components (PC 1, PC 2).

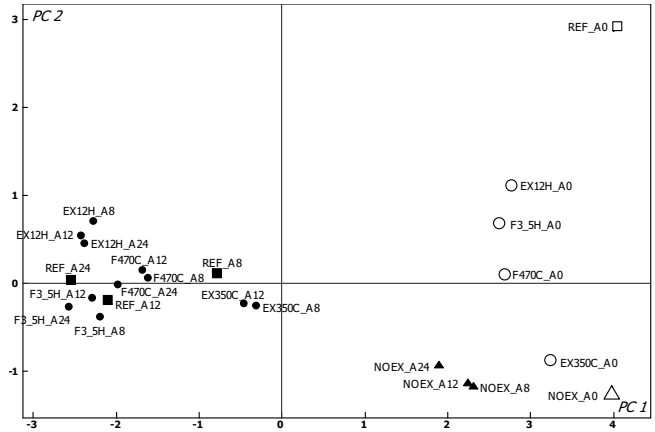


Fig. 4. PCA SCORE PLOT: first two principal components (PC 1, PC 2).

As expected, power (W) and discharge current (I) result pointedly covariant, holding $W=V_{SM}\bullet I$. All the driving voltages are also covariant, i.e. their response is in the same direction (increasing or decreasing) after variations of each process parameter.

The weak correlation of brightness at static margin with the other operational parameters (especially the driving voltages) could be explained by the dependence of luminance on phosphor and gas

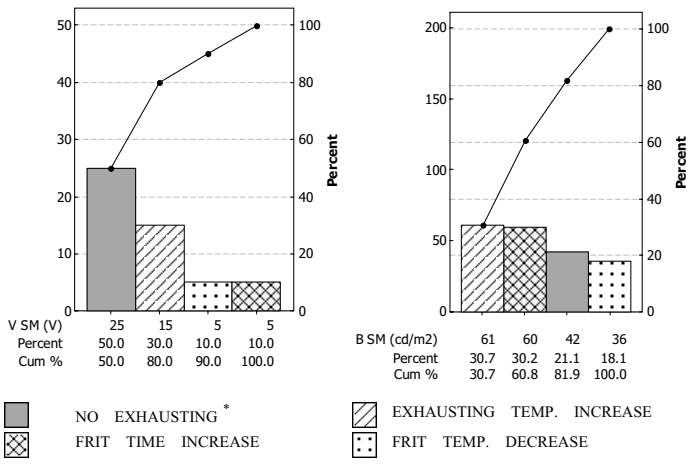
mixture contamination, other than MgO surface conditions (which is by far the main source of voltage fluctuations). From PCA score plot it is evident the correspondence between aging time and the PC1 direction: non aged samples (empty symbols) all lie in the far right side of the plot, which corresponds to high driving voltages and currents.

Going left along PC1, mean brightness tends to diminish and stabilize, together with V_{SM}, whose minimum value is reached at the end of aging: reference devices (square dots) show a remarkable trend of optimization during aging, covering the maximum variance of PC1. On the contrary, samples which have not been exhausted/baked cluster in the lower right side, corresponding to very high and stable contamination (very short variance along PC1), together with overall low luminance (negative values of PC2). All the other samples lie at intermediate clusters, thus indicating rather acceptable but not optimized manufacturing process steps.

Under the hypothesis of a (roughly) linear superposition of detrimental manufacturing effects on the final properties of PDP's, we have compiled Pareto charts (figure 4) on the basis of our experimental data. We have considered the main values, during the entire aging period, of the (negative) variations of V_{SM} and B_{SM}, for each fabrication faulty parameter (Π), with respect to reference:

$$\Delta V_{SM} = \frac{1}{4}\sum_{i=1}^{4}\left(V(\Pi)_{SM,i} - V(REF)_{SM,i}\right) \qquad (2)$$

$$\Delta B_{SM} = \frac{1}{4}\sum_{i=1}^{4}\left(B(REF)_{SM,i} - B(\Pi)_{SM,i}\right) \qquad (3)$$



* We have verified that, down to 12 hours exhausting, the final performances are not affected, while *no exhausting* is very critical.

Fig. 4. Pareto charts for V_{SM} and B_{SM}.

4. Summary

In order to obtain valuable experimental results, several six-inch PDP's have been produced under different process conditions: the analyses of the resulting performances thus obtained can be compared to theoretical findings and previous works on single specific issues, trying to set a bridge starting from the real manufacturing steps. The rationale of this work has been a comparative study, based on multiple variables, with the target of gaining as much information as possible on PDP sample/variable correlations.

Table 3 summarizes the expected effects on V_{SM} and B_{SM} of the increase of fundamental process parameters, on the basis of the multivariate analysis (comprising Partial Least Squares, PLS) on our experimental data.

TABLE 3. Outline of causal relations between process and operational parameters.

Parameters increased	Effects on V SM		Effects on B SM	
	INCREASE/ DECREASE	HIGH/LOW IMPACT	INCREASE/ DECREASE	HIGH/LOW IMPACT
Presence of Exh.	↓ DECR.	HIGH	~	~
Exh. Temperature	↑ INCR. °	MID	↓ DECR.°	HIGH
Frit Time	~	~	↓ DECR.	HIGH
Frit Temperature	~	~	↑ INCR.	*LOW*
Aging	↓ DECR.	HIGH	↓ DECR.*	HIGH

° This has been observed in the analyzed range of 300°C-350°C.
* Aging greatly increases brightness spatial uniformity.

Since improving PDP performances by changing each process parameter in the directions suggested by the analysis could not be optimal, or even possible, and the pumping process has resulted very critical, our study will be now addressed on suitable getter configurations, capable of coping with contamination sources, during the most detrimental process step(s).

5. References

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