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The Optimization of the Organic Passivation Process in the TFT-LCD Panel for LCD Televisions

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Abstract

The results of the optimization of the organic passivation process for fabricating thin-film transistors (TFTs) with a high aperture ratio on a seventh-generation glass (2200×1870 mm) substrate for LCD-TV panels are reported herein. The optimization of the organic passivation process has been verified by checking various factors, including the material properties (e.g., thickness, stain, etching, thermal reflow) and the effects on the TFT operation (e.g., gate/data line delay and display-driving properties). The two main factors influencing the organic passivation process are the optimization of the final thickness of the organic passivation layer, and the gate electrode. In conclusion, the minimum possible final thickness was found to be 2.42 μm via simulation and pilot testing, using the full-factorial design. The optimization of the organic passivation layer was accomplished by improving its brightness by over 10 cd/m^2 (ca. 2% luminance) compared to that of the conventional organic passivation process. The results of this research also help reduce the reddish stain on display panels.

Keywords: organic passivation, brightness, reddish stain, LCD TV, simulation

1. Introduction

From having small screens such as in cellular phones and notebooks, the thin-film transistor liquid crystal display (TFT-LCD) has been made to have large flat panel displays as in computer monitors and full-high-definition (FHD) televisions. The demand for large LCD TVs (liquid-crystal-display televisions) has been surging of late in the flat panel display (FPD) market, requiring new advanced technologies to achieve a high resolution, a fast response, low power consumption, and integrated driving circuits in the peripheral areas [1]. LCD TVs obtained a ca. 44% share of the TV market in 2008, and the LCD market is surprisingly increasing among other display devices [2].

The passivation layer of the vertical-alignment mode [3, 4], among the other types of LCD-fabricating methods, has a double-layered structure that consists of a lower silicon nitride (SiNx) layer for passivating the TFT channel and of an upper organic layer as an insulating layer. The organic and SiNx double-layered structure was introduced for the following reasons: to simultaneously increase the aperture and brightness of the LCD panels, and to increase the capacitor capability of the insulation between the gate/data electrode and the pixel electrode.

In general, SiNx films were used for the passivation layer, but the double-layered structure consisting of an SiNx film and an organic insulator film was based on process architecture (PA) so it would grow from a monitor to a large HD/Full HD television like “Bordeaux” and so that a high aperture and a high contrast could be realized [5-10].

The acrylic resin series is widely used as an organic insulator material. It can be patterned by exposing it so it would become a photoactive compound (PAC), such as a typical positive photoresist (PR), and can be classified into the positive and negative types. Of the two, it is positive organic PR that has attained greater progress in terms of research and development because of its mass productivity.

In TFT-LCD devices, the thickness of the film in each layer is decided by considering not only the optical properties, such as brightness and chromaticity, but also the electrical properties, such as RC delay and capacitance. The

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white light that comes out of a backlight unit (BLU) reduces the brightness by means of the absorption and interference effects in each layer of the PA of the TFT. This problem can be addressed, so that the optical transmittance could be maximized, by optimizing the organic passivation layer. If the thickness of the pixel and SiNx layers can be adjusted by considering the electrical properties, the optimized thickness of the organic passivation layer can likewise be adjusted to maximize the transmittance in the panel.

In this paper, a procedure for optimizing the organic passivation layer is presented via simulation, design of experiment (DOE), and pilot testing.

2. Experiments

2.1 Instrumentation

Photolithography of an organic photoresist was performed in this study with a mirror projection aligner, a slit coater, a puddle-type developer, and a proximity bake for the processing of a seventh-generation glass substrate. To cure the organic photoresist, it was thermally treated under a nitrogen atmosphere in a convection oven. Dry etching was performed with a plasma etcher. The UV-visible spectra were measured on a glass substrate using a UV-visible spectrometer. The thickness was measured using 6500F-NANO from NANO Metrics. The thickness difference was measured using the surface profiler SPR2300. SEM (scanning electron microscope) and FIB (focused ion beam) are basically the same machines, and SEM images were captured by Strata 400S (Quanta 3D). The electrical data, the I_d vs. V_g (output characteristic) transfer curves, were obtained from HP4156 (Agilent Co). The optical properties (e.g., brightness and color coordinates) were measured using Minolta CA-210 (Minolta Co.). Optical simulation was performed using WVASE32 (J.A. Woollam), an ellipsometer operating and fitting software. The optical properties along the thickness of the organic film were measured and simulated using the ellipsometer and a fitting program. Micrographs were obtained using an inspection microscope attached to a digital camera. All the instruments were located and used in a clean room, except for Minolta CA-210.

2.2 Materials

The organic insulator material, a solution of acrylic resin and PAC (a photoactive compound) with the positive tone DNQ (diazonaphtoquinone) in the solvents, made use of a photo-definable organic positive resist for mass production. The developer used a TMAH (tetramethylammonium hydroxide) solution in deionized water. The thinner that was used was a solution consisting of propylene glycol methyl ether (PGME), n-butyl acetate, and propylene glycol monomethyl ether acetate (PGMEA).

2.3 Fabrication of the TFT-LCD Devices

Thin-film transistors were fabricated through the five-mask process. Each of the other processes, such as that involving the use of a color filter substrate, the injection of liquid crystal, and the use of a backlight unit (BLU) module assembly, for fabricating TFT-LCD panels was followed by a standard recipe. In this paper, only the process of organic passivation was discussed in detail. The thin-film transistors were fabricated with bottom contact geometry with a patterned Al/Mo gate and an insulating layer made of silicon nitride. The data electrode was connected to the pixel electrode, and the organic insulator was located between the SiNx passivation layer and the pixel electrode. The schematic array structure of a thin-film transistor through the five-mask process is shown in Fig. 1.

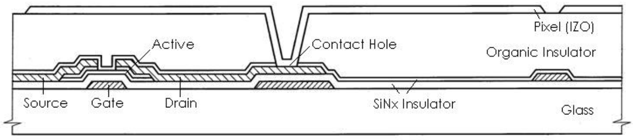


Fig. 1. Cross-sectional array structure of conventional TFT substrate with an organic passivation

2.4 Organic Passivation Process

After completing the source/drain process, TFT substrates were prepared from silicon nitride deposited via chemical vapor deposition (CVD). The substrates were coated with an organic photoresist (photodefinable acrylic resin) in each thickness, using a slit linear coater, and were dried in a vacuum dry chamber. The slit-coated organic photoresist was dried again by heating it in a proximity oven, after which a suitable dose of it was exposed in an aligner. The exposed organic photoresist was developed using the TMAH solution, after which its entire surface was exposed via UV irradiation. The organic photoresist was cured by thermally treating it under a nitrogen atmosphere, in a convection oven. The cured substrates were treated with sulfur hexafluoride (SF_6) gas plasma (for the silicon nitride passivation layer) for etching, and then the pixel process was performed.

All the electrical characteristics of the TFT-LCD devices were measured in air. There was no difference between the performance of the devices prepared in air and that of the devices prepared in a clean room.

3. Results and Discussion

Fig. 1 shows the cross-sectional array structure of thin-film transistors with an organic passivation layer through the general five-mask process consisting of the gate-active-source/drain-passivation-pixel steps. The array substrate with a pixel region defined by gate and source lines and by transmitting light to each pixel region includes a switching device, a pixel electrode, an organic insulating layer made of acrylic resin, and a lower insulating layer made of silicon nitride. The switching device is connected to a gate and a source line and is disposed at the pixel region. A pixel electrode is electrically connected to the switching device. An organic insulating layer is disposed on the switching device, and a lower insulating layer is disposed under the organic insulating layer.

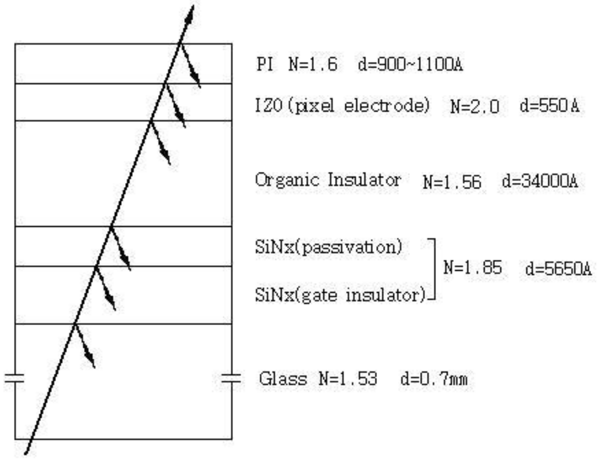
3.1 Optical Simulation

Optical transmittance simulation was performed using the WVSE32 software (J.A. Woollam Co.) [11]. The Cauchy model was applied to confirm the change in the reflection and transmission on each layer of the thin-film transistor substrate. The experiment data were fitted using the Cauchy model, as follows:

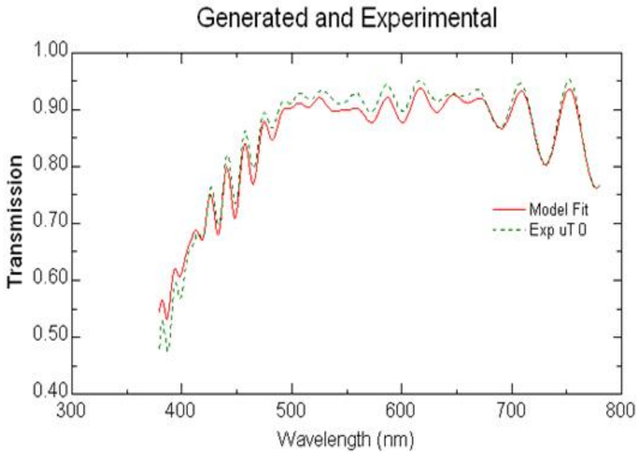
$$n(\lambda) = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4}. \qquad (1)$$

The Cauchy model is useful for many common dielectric materials and is given by the expression where A, B, and C are constants to be determined.

Fig. 2(a) shows the initial structure, particularly its array substrate with a refractive index, and the thickness of each layer. This initial structure was made more efficient by applying the proper thickness thereto. Fig. 2(b) shows that the simulative spectrum coincided with the experimental spectrum as per the results of each test.



(a)



(b)

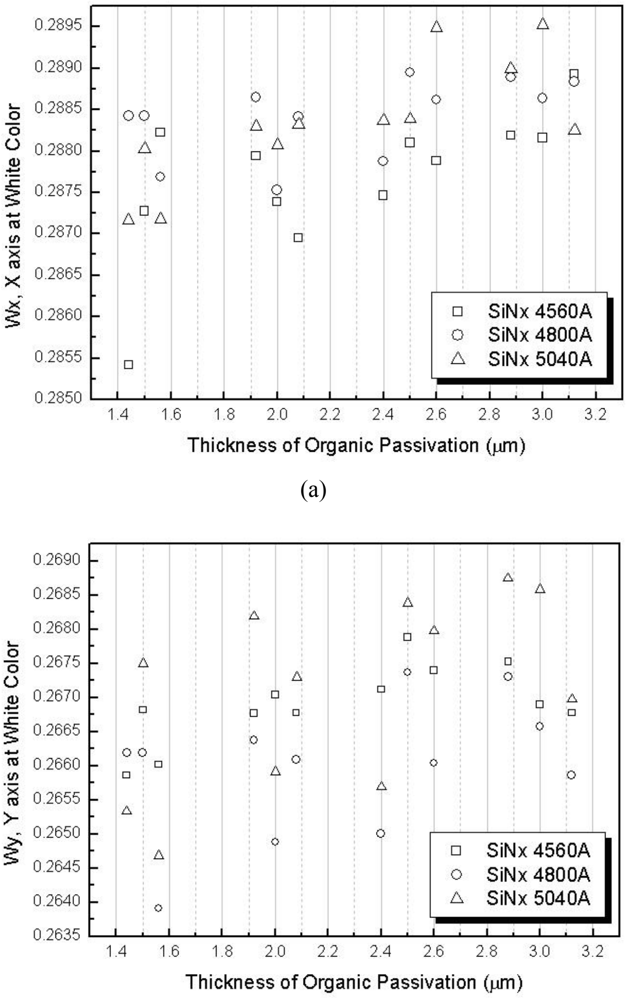
Fig. 2. (a) Initial array structure for optical simulation, (b) The initial example of approximately good agreement between calculated and experimental spectrum (screen-captured image)

A simulation was performed for four cases, from 3.0 μm to 1.5 μm, by 0.5 μm, on the assumption that the thicknesses of the silicon nitride and the organic insulator were distributed ±5.0% and ±4.0% in the process, respectively. The simulation results are shown by the dots plotted in Fig. 3(a) and 3(b). The change in the transmission by thickness showed nonlinear features in the simulation. The increase in the Wx value resulted from the increase in the thickness of the organic passivation layer, but the distribution shows a decreasing tendency in Fig. 3(a). This can be explained in the same way, that is, that the organic insulator made of acrylic resin becomes reddish when the absorption increases in a visible wavelength from 380 to 500 nm by increasing the final thickness of the organic photoresist on the glass substrate (refer to Fig. 6). The increase in the Wy value in Fig. 3(b) also resulted from the increase in the thickness of the organic passivation layer, but the increase in the Wy value is insignificant for the reddish stain on the panel.

3.2 Electrical Simulation

Electrical simulation was performed using the SPICE software (EECS Department, UC Berkeley) on UNIX O/S. SPICE is a general-purpose circuit simulation program for nonlinear DC, nonlinear transient, and linear AC analyses. The electrical simulation was performed in terms of the charging rate, kickback voltage (V_{kb}), and gate and data line capacitance for the 32- and 40-inch devices. The model that was fabricated to fit the devices used herein was applied.

The electrical simulation was performed for five cases, from 3.0 μm to 1.0 μm, by 0.5 μm, the final thickness of the organic passivation layer. Although the charging rate was slightly decreased when the thickness of the organic passivation layer was reduced, it was considerably under 1.5 μm of the final thickness of the organic passivation layer in both devices. The kickback voltage is increased by reducing the thickness of the organic passivation layer. If the kickback voltage is increased in a large LCD panel, it is difficult to control the flickering through the whole screen because it is not able to make up for V_{offset} (offset voltage) by one V_{com} (common-mode voltage) on the entire LCD panel. Particularly, both the gate and the data line capacitance are significantly increased by reducing the thickness of the organic passivation layer. The increase in the RC delay can be foreseen in the results of the simulation. The increase in the line capacitance and kickback voltage raised the problem of the weakening of the operation margin on the LCD panel with the lower thickness of the organic passivation layer. The 2×2 full-factorial design of the experiment must be introduced for the thickness factors of the Al gate electrode and the organic passivation layer, to solve the problem with the operation margin.



(a)

(b)

Fig. 3. The shift of (a) Wx and (b) Wy on white color in different thickness of organic passivation (from simulated data)

3.3 The Optimization of the Organic Passivation Process

The final thickness of the organic passivation layer was controlled by the following two methods, which apply the thickness in the process based on optical and electrical simulation: (1) controlling the dispensing amount of the organic photoresist on a substrate; or (2) controlling the etching amount of the organic insulator in the plasma etch process. In this research, the final thickness was decided by controlling the dispensing amount of the organic photoresist on a substrate without changing the plasma etching condition. Table 1 summarizes the results obtained from the plasma etching. The equal processability in the conventional organic passivation process was confirmed. It is important to control the angle of the organic photoresist to establish contact between the gate/data electrode and the pixel electrode in each thickness of the organic passivation layer. The profile angle of the organic photoresist was decreased in proportion to the decrease in the final thickness of the organic passivation layer. Fig. 5 shows the profile angle of under 20° of the organic passivation layer on the contact hole in the focused ion beam (FIB) image.

Fig. 6 shows the change in the transmission spectra when the final thickness of the organic passivation layer

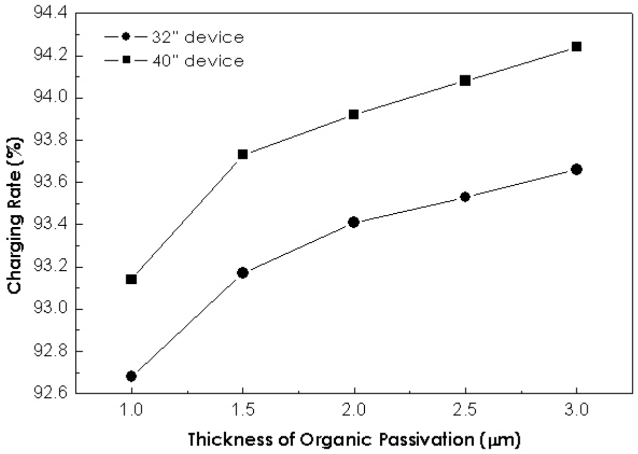


Fig. 4a. The change of charging rate in different thickness of organic passivation (from simulated data)

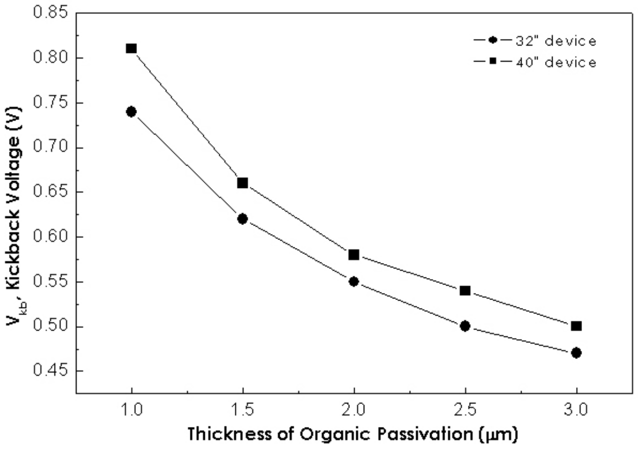


Fig. 4b. The change of kick-back voltage in different thickness of organic passivation (from simulated data)

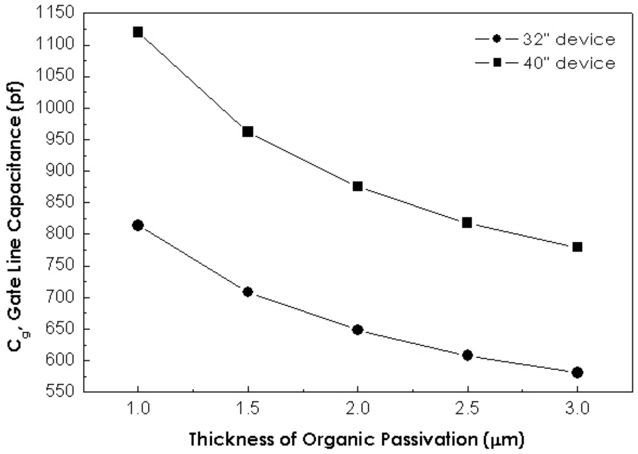


Fig. 4c. The change of gate line capacitance in different thickness of organic passivation (from simulated data)

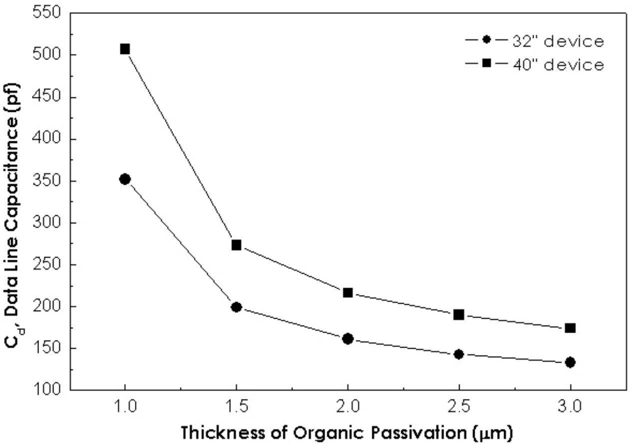
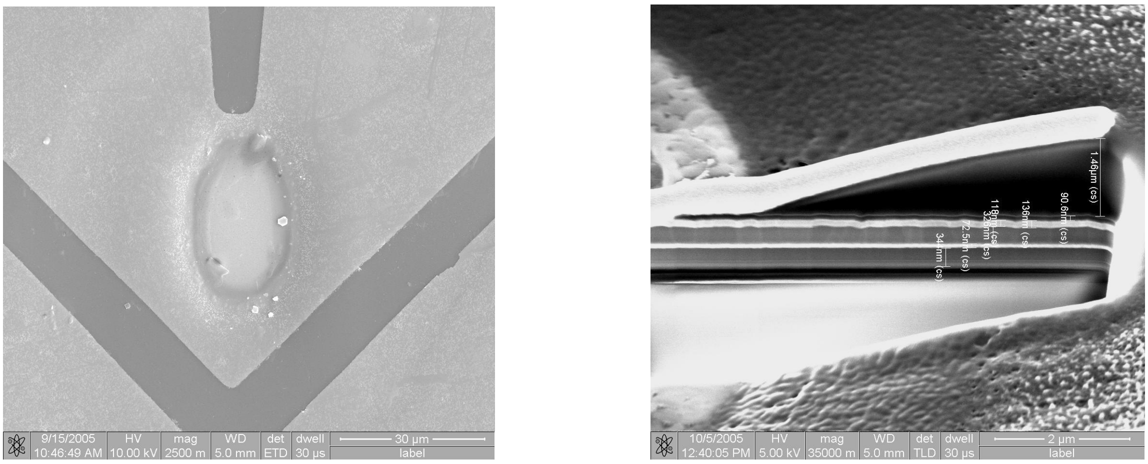


Fig. 4d. The change of data line capacitance in different thickness of organic passivation (from simulated data)



(a) Top view image

(b) Vertical image

Fig. 5. (a) SEM (top view) and (b) FIB (vertical) images on contact hole

Table 1. Summary of the process characteristics of organic passivation in each final thickness

Target thickness (㎛)	Final thickness (㎛)[a]	Uniformity (%)[a,b]	Profile angle[c]	Transmission (%) at 400 nm[d]
3.00	2.98	7.3	23°	91.0
2.50	2.52	7.3	15°	93.5
2.30	2.31	5.1	22°	(94.4)[e]

[a] average of over 3 samples
[b] average of 18 points a sample
[c] average of two FIB images on contact hole
[d] UV-visible spectra on transmission mode
[e] an estimated value by means of the regression equation

Table 2. Summary of operating margin and optical properties in different thickness of organic passivation (p-org) and gate electrode (g-Al)

Thickness (㎛)		Gate RC delay (μsec)[a]	Operating frequency (Hz)[a]	White brightness (cd/m^2)[a]		Chromaticity	
g-Al	p-org			Center	Average[b]	Wx[c]	Wy[d]
0.25	3.00	4.72	81	490	465	0.2827	0.2893
0.25	2.50	5.12	77	496	471	0.2815	0.2880
0.30	2.50	3.92	84	506	479	0.2815	0.2870
0.25	2.30	5.52	72	498	478	0.2850	0.2890
0.30	2.30	2.64	75	508	478	0.2860	0.2920

[a] average of over 2 samples
[b] average of 9 points a sample
[c] The Wx is the x axis value on the CIE (International Commission on Illumination) xy chromaticity diagram of the operating white light of test panels.
[d] The Wy is the y axis value on the CIE xy chromaticity diagram of the operating white light of test panels.

was reduced. The increment of the transmission in the blue region was verified to be from 380 to 500 nm in wavelength, and it is expected to positively increase the brightness of LCD panels.

3.4 I-V Characteristics

The electrical data, which are the Id vs. Vg (output characteristic) transfer curves, were obtained from HP4156 (Agilent Co). The transfer curves in the different thicknesses of the organic passivation layer (2.3, 2.5, and 3.0 ㎛) and the gate electrode (only 3000 Å in Org. 2.5a and 2500 Å in the others) are shown in Fig. 7. All the transfer curves were found to exhibit the conventional TFT characteristics. It can be known that a change in the final thickness of the organic passivation layer will not significantly affect the TFT characteristics.

3.5 The Optimization through the 2×2 Design of Experiment (DOE)

Statistical analysis of the experiment data was performed using the Minitab software (Minitab Inc.). 2×2 DOE was used to optimize the organic passivation layer. Most of the experiment data were verified by statistical decision below the 0.05 significance level. The factors were the thickness of the organic passivation layer and the gate electrode, and the levels of the factors were -1 (2.3㎛), +1 (2.5㎛) for the organic passivation layer, and -1 (2500 Å), +1 (3000 Å) for the gate electrode, based on both the simulation and the experiment data, respectively. The result of the 2×2 DOE was optimized, using the response optimizer, at the 80 Hz operating frequency.

The following equation (2) is a correlation equation in coded units from the 2×2 DOE:

$$\gamma = 2.762\times\alpha + 2.738\times\beta + 1.488\times(\alpha\times\beta) + 76.513. \quad (2)$$

Here, α is the thickness of the organic passivation layer, β the thickness of the gate electrode, and γ the operating frequency.

Fig. 8 shows the result of the over-2.42-㎛-thick organic passivation layer and of the over-3000-Å-thick gate electrode to be over the 80 Hz operating frequency. Moreover, it was found that the reddish stain on the display panel can be considerably reduced with the use of a 2.4- to 2.5-㎛-thick organic passivation layer. Fig. 9 shows the display images (a) before and (b) after the optimization of the organic passivation process.

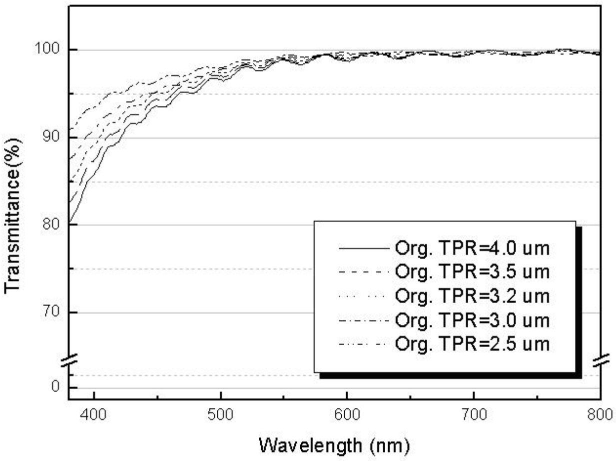


Fig. 6. UV-visible spectra in different thickness of single organic layer on glass substrate after curing (from measured data)

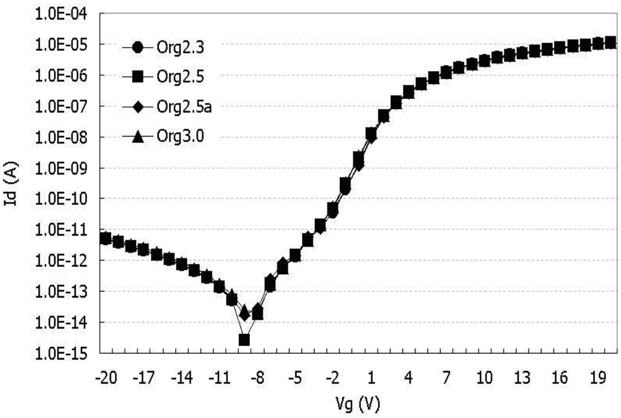
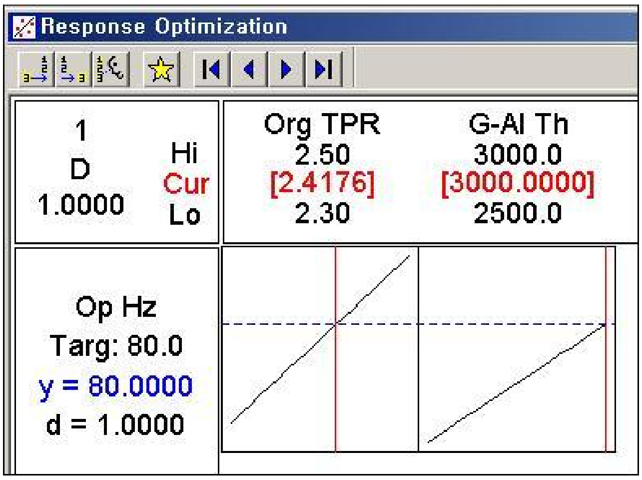


Fig. 7. Transfer curve (I_d-V_g) in different thickness of organic passivation and gate electrode.



1
D
1.0000

Hi
Cur
Lo

Org TPR
2.50
[2.4176]
2.30

G-Al Th
3000.0
[3000.0000]
2500.0

Op Hz
Targ: 80.0
y = 80.0000
d = 1.0000

Fig. 8. The result of response optimization on the DOE (screen-captured image)

(a) before

(b) after

Fig. 9. Display images (a) before and (b) after the optimization of organic passivation process.

4. Conclusions

The optimization of the organic passivation process was verified by checking the various factors influencing it, which are its material properties (e.g., thickness, stain, etching, thermal reflow) and its effects on the TFT operation (e.g., gate/data line delay and display-driving properties). The two main factors influencing the organic passivation process are the optimization of the final thickness of the organic passivation layer, and the gate electrode. The minimum possible final thickness was found to be 2.42㎛ via optical and electrical simulation and pilot testing, using the full-factorial design. In conclusion, the optimization of the organic passivation layer was accomplished by improving its brightness by over 10 units (cd/m^2) compared to that of the conventional organic passivation process. The results of this research can also help improve the reddish stain on display panels.

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