Numerical Analysis of One Drop Filling Process with Photo-definable Spacer

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Abstract

In this paper, we demonstrate the deformation of TFT-LCD panel using numerical analysis based on the finite element method. To make better uniform cell gap and less stress at a photo-definable spacer (spacer), we have investigated process and design factors such as amount of liquid crystal (LC), spacer density, area, height, and material property. Furthermore we optimized design factors and achieved the robust design through the simulation.

1. Introduction

Currently the market of liquid crystal displays (LCDs) is expanding. Especially monitor and TV market are more rapidly growing than that of other LCD applications. In these markets, it is required to make large size panel without the increase of production time and to make panel more uniform cell gap. The uniform cell gap is one of the key parameters to achieve a large size panel with high quality. Therefore one drop filling process and photo-definable spacer had been combined and recently introduced to the manufacturing line [1].

One drop filling process consists of two major steps. One step is LC-dropping onto the lower substrate and the other is assembling upper and lower substrates in vacuum [2]. Spacer is made from the organic material by photolithographic process and its material properties are as almost same as color resist's.

As these two processes combined, the deformation of panel is the result of the competition between the atmospheric pressure and the repulsive force of panel. The repulsive force of panel depends on the amount of LC and the spacer design factors such as density, area, height, and material property. And it can be varied by the change of LC amount and spacer design. Furthermore these factors including LC amount affect on the stress of spacer imposed by the upper substrate and atmospheric pressure.

In this work, we have investigated the deformation of panel and the stress of spacer through the numerical analysis by changing the LC amount and spacer design factors.

2. Numerical Model

To calculate the deformation of panel and the stress at each spacer we have used the ABAQUS installed on the supercomputer. The ABAQUS is based on a finite element method (FEM) and it is effective to convert panel components into the ideal models [3].

Figure 1 shows the schematic diagram of geometric mesh. In this diagram, we have described the 730 x 920 mm^2 glass substrate with 6 panels of 17 inch diagonal size by using the 1/4 sub-modeling method. Main components in the diagram are glass substrates (below green), sealant (red), panel (gray), and spacers inside of substrates. We have modeled the panel as fluid-filled cavity and LC as an incompressible liquid.

We have used the parametric design to cover all the substrate size and panels in it. Then we have sampled the deformation data from the massive output data file and it corresponds to the dark gray colored region.
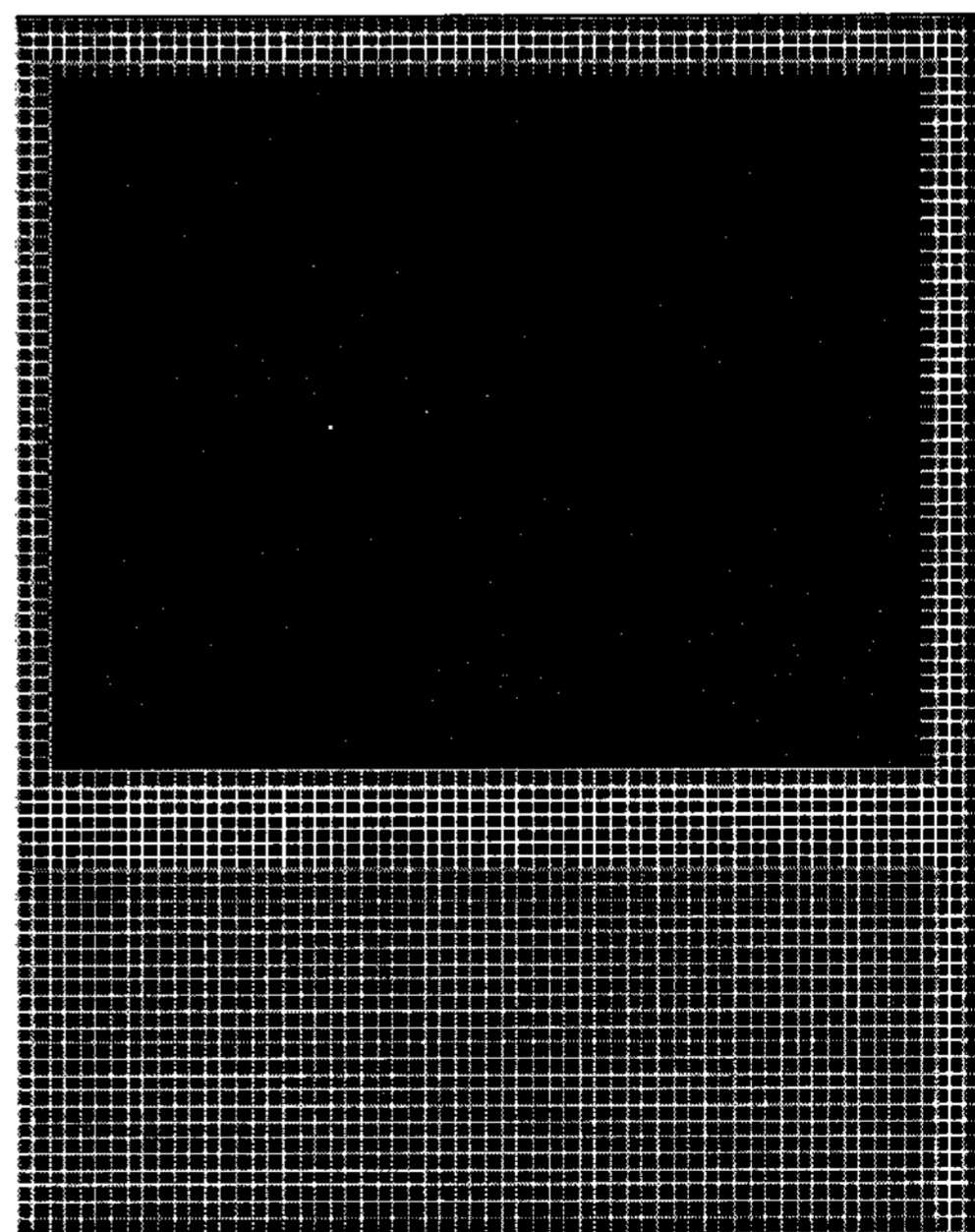

Fig. 1. Schematic Diagram illustrates the quarter section of the 730 x 920 mm^2 substrate.

3. Simulation results and discussion

Deformation of panel is the same quantity as the cell gap between upper and lower substrate, then we have defined this as deformed cell gap. But optical cell gap can be defined as uniformly spread LC layer thickness and it only depends on LC amount.

First, we have simulated the effect of LC amount on the optical cell gap and the maximum stress of spacer. We have used the parameters, which is summarized at the Table 1. Figure 2 shows that the optical cell gap increases linearly as a function of LC amount. Because of the incompressibility of LC, the averaged optical cell gap always linearly increases according to the LC amount.

As shown in Figure 2, maximum stress of spacer is constant to 445 mg. Main repulsive force to atmospheric pressure is due to spacer under 445 mg, so it is constant. But it sharply decreased after 445 mg. This can be explained that LC layer supports the upper substrate and repulses to atmospheric pressure, so the stress of spacer is reduced according to the increase of LC amount. Threshold of LC amount like 445 mg depends on the spacer design and the stress can be relieved if LC dropped more than threshold of LC amount.

Parameter	Unit	Value
Panel Dimension	mm	337.92 x 270.336
Pixel Dimension	um	88 x 264
Spacer Height*	um	4
Spacer Area	um^2	700
Spacer Density	ea/pixel	~0.1
Spacer Taper Angle	deg.	45
Young's Modulus**	N/mm^2	~487
Poisson's Ratio	-	0.3
Target cell gap	um	4.6

* Spacer height depends on the panel architecture such as sub layer thickness.

** Young's modulus of spacer is so critical to the simulation that we have used the averaged experimental results.

Table 1. List of parameters used in the simulation

Second, we have simulated the effect of spacer design on the cell gap by using the stiffness factor (SF), which is defined as the multiplication of spacer area and density. SF value can be characterized as the compression of spacer under the atmospheric pressure. The bigger of SF value, the more difficult to compress

the spacer. From a macroscopic point of view, increase of spacer density and area has the same effect.

We have calculated cell gap for various SF values and it is shown in Figure 3. As SF increases in LC amount of 430 mg, the deformed cell gap is constant to 40 and then sharply increases. The constant region considered that the panel has been deformed until LC layer thickness, so deformed and optical cell gap have the same value. It is difficult to compress the spacer according to the increase of SF, and then deformed cell gap increases. While the optical cell gap is not varied due to constant LC amount.

The difference between deformed and optical cell gap indicates that there are unfilled area in the panel. At the LC amount of 430 mg and Young's modulus of 487 N/mm^2, unfilled area occurred around SF of 40. If we designed SF value above 40, we may fail to manufacture good panels due to the unfilled problem.
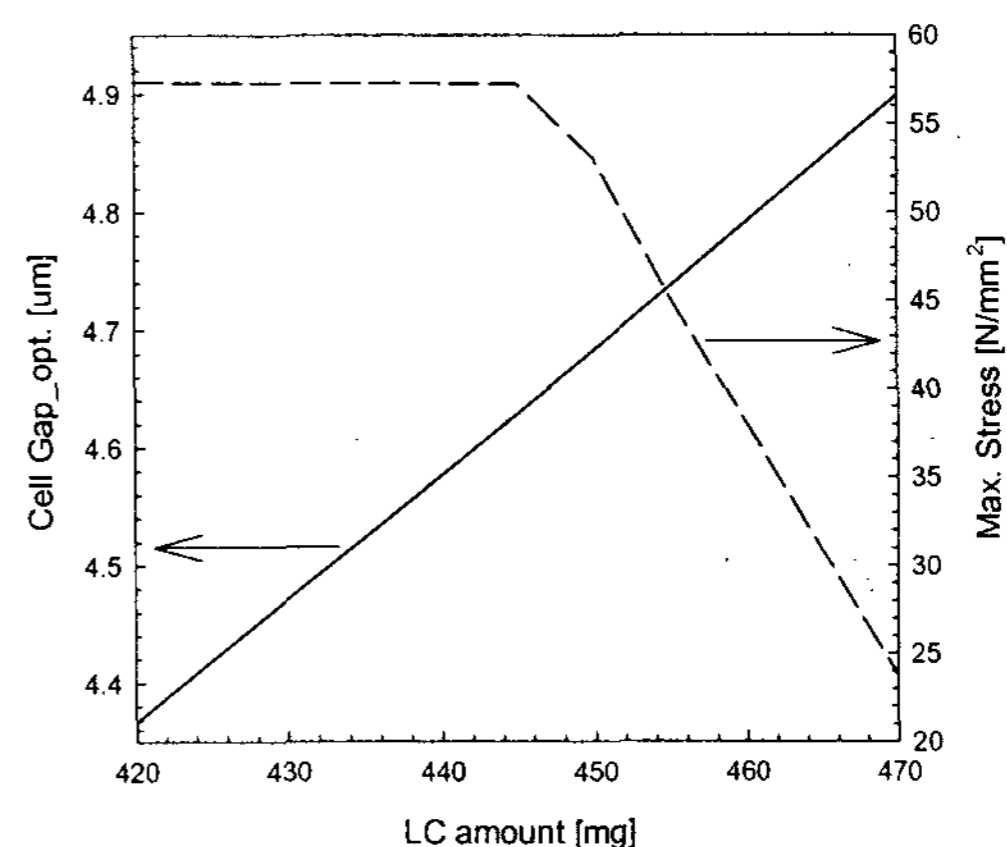

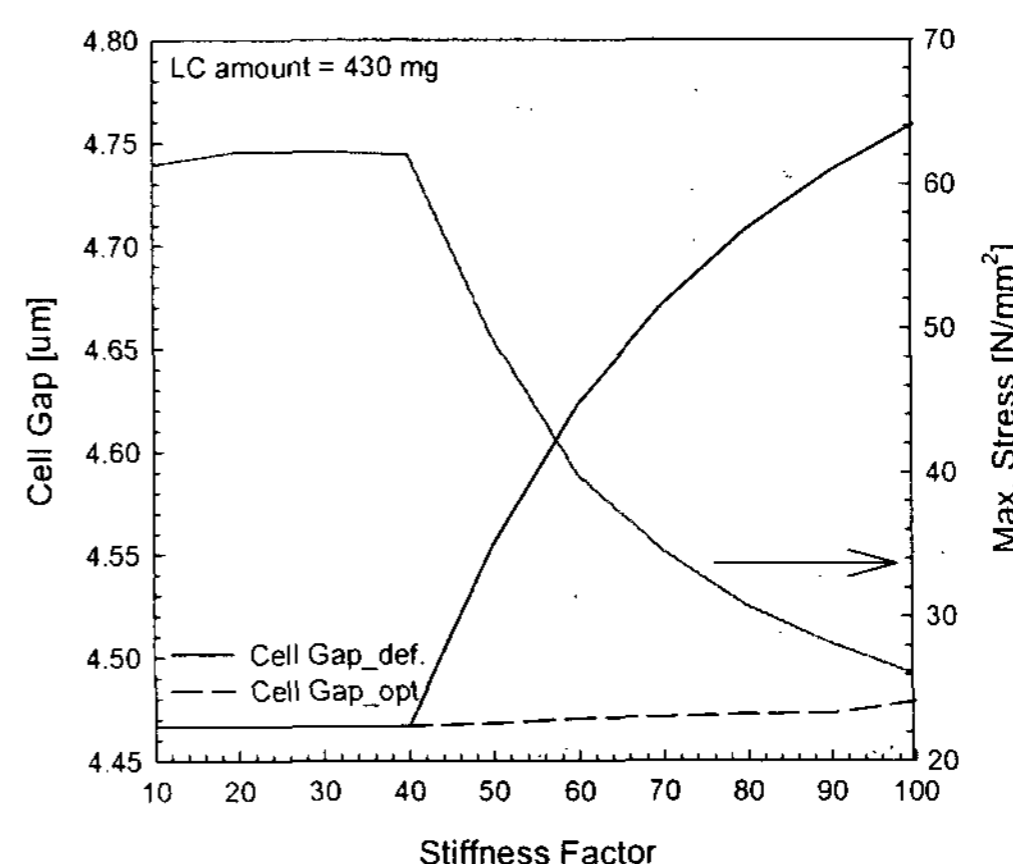Fig. 2. Optical cell gap and maximum stress of spacer

Fig. 3. Variation of cell gap for various SF

To reduce the unfilled cell gap, we must drop more LC amount or design spacer with lower SF value. But the increase of LC amount makes the optical cell gap higher than target and leads to poor optical quality. On the contrary, if the SF value is too low, the external pressure may change the cell gap easily and damage the spacer including its sub-layer. The increase of SF can reduce the stress imposed to the spacer as well as the increase of LC amount.

Finally, we have studied the variation of Young's modulus (YM) and its effects on the cell gap. To know an accurate YM, we have measured the load-displacement curve for various height and area condition of spacer [4].

The spacer had been prepared on the real panel and the experiments were performed using a Shimadzu DUH-201. We have converted the load-displacement curve into stress-strain curve to obtain the YM. The YM has a wide range from 300 to 700 N/mm^2 according to the spacer design. Spacer is patterned by photolithographic process and its shape is not a regular structure. Generally speaking, taper angle of the bottom part in spacer is higher than that of top part. So the irregular shape of spacer makes the variation of YM.

We have used the regression equation from the experimental results to reflect real panel condition and to make analysis results more accurate. Figure 4 shows the regression curve and YM is varied by the spacer height and area.
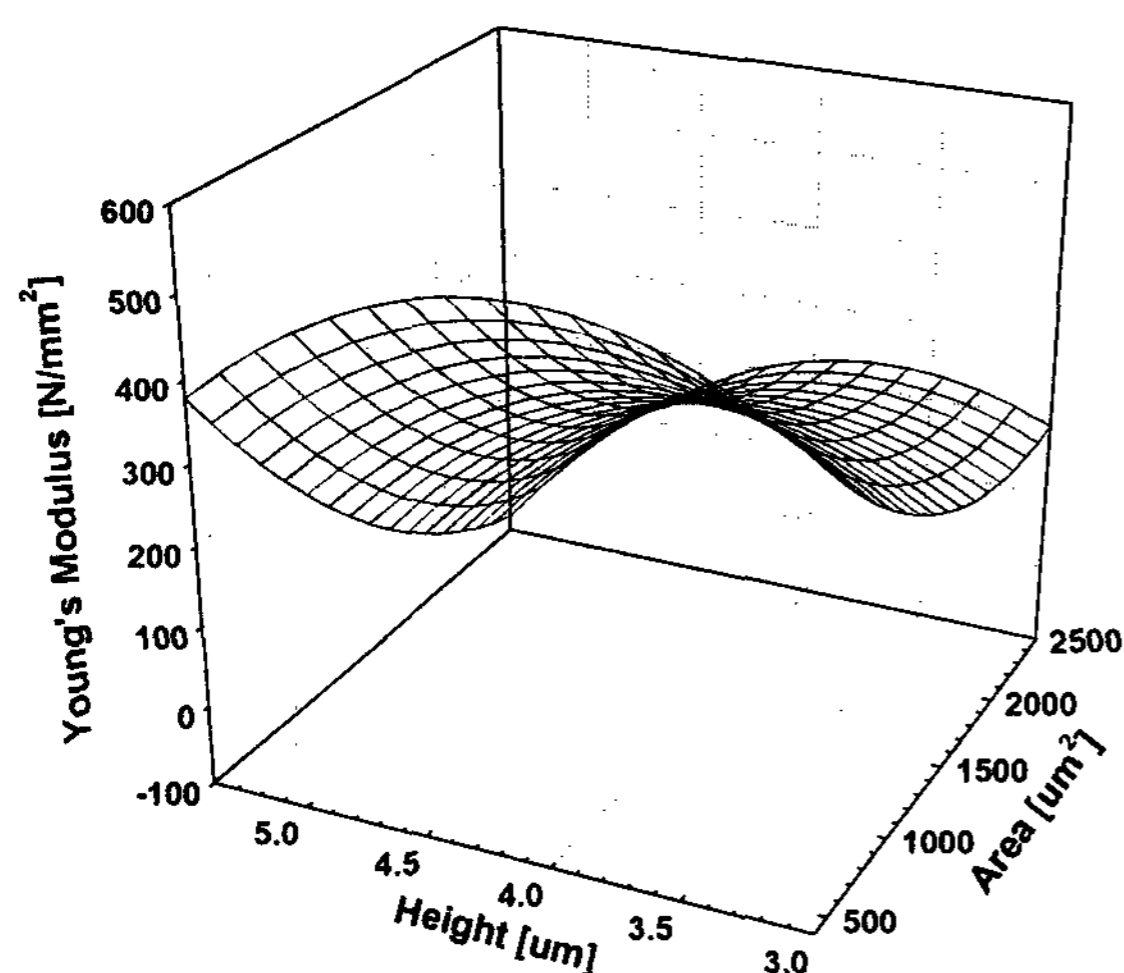

Fig. 4. Regression curve of YM

Figure 5 is the simulation results according to the variation of SF and YM simultaneously. Deformed

cell gap behavior is same as Figure 3 and the threshold of SF occurred at 20. This is lower than threshold of SF in case of fixed YM as shown in Figure 3. The shift of threshold means narrower process margin of LC amount in the real panel. YM at the region form 20 to 40 is higher than fixed YM of 487 N/mm^2, so resulted in less deformation of panel. The possibility of occurrence of an unfilled area increases in the real panel by the increase of YM.

The compression ratio of spacer is inversely proportional to the SF in the unfilled reign and it is constant when the panel is perfectly filled with LC.

As described above, the cell gap is affected by the LC amount, SF, and YM. And YM can be described by the function of area and height. We have optimized these factors by using the statistical method. When a panel has been manufactured with an optimized design of spacer, the one-drop filling process is robust to LC amount.
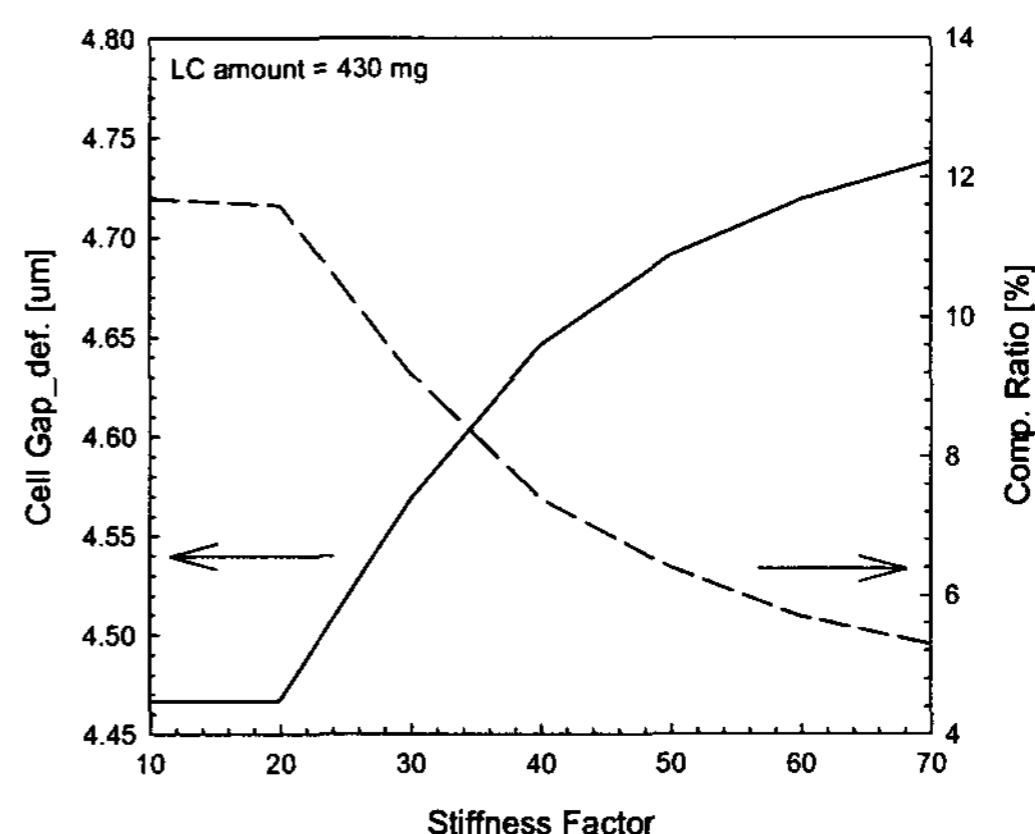

Fig. 5. Variation of cell gap and compression ratio

4. Conclusion

In this work, we have investigated the effect of the design factors on the cell gap. The optical cell gap is mainly affected by LC amount and it is linearly proportional to LC layer thickness. On the contrary the deformed cell gap is influenced by all the factors. The difference between optical and deformed cell gap causes the unfilled area on the panel and this is a critical problem to manufacturing line. The stress imposed to spacer can be relieved by the LC amount and its SF value. If the stress is too high, spacer can be damaged by the external pressure as well as its sub-layer.

The cell gap is the results of the competition between atmospheric pressure and the repulsive force of spacer and LC. Therefore it is necessary to optimize the design factors to make uniform cell gap and to meet the cell gap target.

5. References

[1]. S. Odahara, *et.al* : SID 01 Digest, 1358(2001)

[2]. H. Kamiya *et al* : SID 01 Digest, 1354(2001)

[3]. Refer "www.abaqus.com"

[4]. Y. Pae, *et al* : IDMC 2002 Proc., 119(2002)