

## 56.3: Development of One Drop Fill Technology for AM-LCDs

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### Abstract

A new cell process for TFT-LCDs which integrates the liquid crystal (LC) injection with the glass substrate assembly process has been developed and has similarities to that previously reported for passive LCDs.<sup>[1]</sup> In this process LC is applied in droplets directly onto the glass substrate, and results in reduced LC waste, reduction of fabrication time, and overall process simplification. With this technology, we fabricated 22 inch diagonal, high-resolution products and achieved better cell gap uniformity and fast (16.7 ms) time response for the in-plane switching (IPS) mode LCDs.

### 1. Introduction

In the recent decade, panel dimensions of LCDs have been increasing and now LCDs are expected to penetrate monitor market segments. Requirements for LCD monitors to replace CRTs include improvement to front of screen quality, increase in viewing angle, and fast response time for video. To realize fast response time, one of the easiest method is to make the cell gap narrower. To simultaneously achieve wider viewing angle, and faster response, adopting the vertical alignment (VA) optical mode with multi domain is one attractive solution.<sup>[2]</sup> These approaches, however, impose some manufacturing limitations, which come from the significantly longer LC injection time because of increase in the resistance of LC's flowing in the narrow gap space. For the conventional LC injection process, the LC material is filled into the cell by making use of liquid's capillary phenomenon and the pressure difference between the outside and inside of the cell. Therefore, the LC injection time depends on the alignment film wetting property and the cell gap. In spite of having such a disadvantage, this injection method has been used for large scale manufacturing. For the LCDs to continue to grow in the display market, LC injection must be simplified and improved with respect to the process time and its dependency. One drop fill (ODF) technology is one of the ways to actualize these requirements effectively. The objectives of our ODF development project were : (1) to reduce the lead time of the cell process regardless of the cell gap, panel size and the alignment film property, (2) to simplify the cell process by decreasing in the number of process steps, (3) to obtain high LC material usage efficiency, specifically for four-sided TAB products which high resolution like 200 pixels per inch requires.

### 2. ODF Technology for TFT-LCDs

ODF technology has been previously developed for passive matrix LCDs. However no one has expanded this efficient technology to TFT-LCDs so far on account of uv light shadow problem caused by the presence of the metal line shadowing the glue seal and the greater sensitivity to ion contamination which

comes from LC material's contact with uncured glue seal, inducing the degradation of voltage retention and LC alignment defect. From the view point of the tool development, there are other difficulties, such as how to hold the large size of the glass plate in the vacuum , precisely dispense a required LC amount and do fine alignment to the two glass plates with LC filled in between. To solve these problems, we applied newly developed uv curable glue seal materials and glass holding methods in the vacuum as well as the fine alignment of two glass plates filled with LC.

### 3. Merit of ODF and Process comparison

We have fabricated various sizes of LCDs from 5" to 22" with ODF process and it was found that there are many advantages from both the customers and the manufacturers' point of view. The most significant features of the ODF technology are the cell process simplification and the fabrication time reduction with no injection hole. By actualizing these points, ODF technology can give the high front of screen quality in terms of the fast response time realized by narrow cell gap and high resolution. This requires

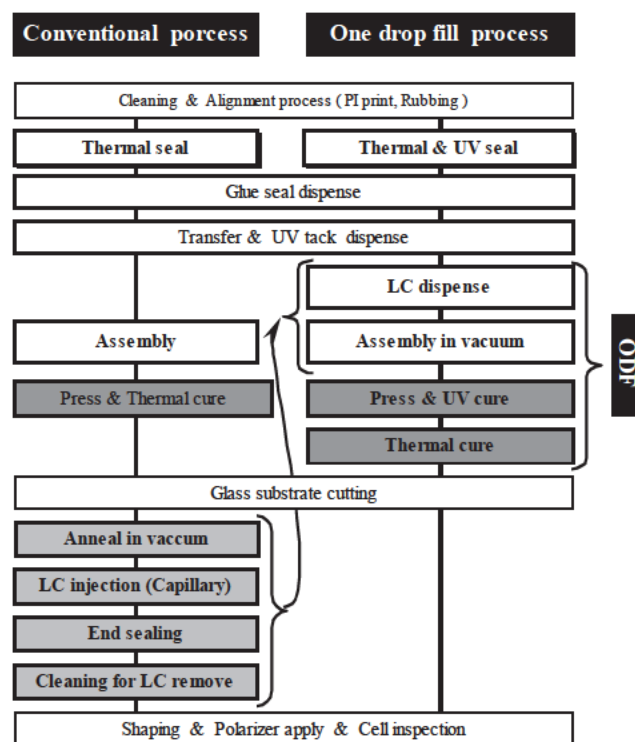


Figure 1 ODF process flow with conventional cell process

four-sided TAB bonding due to the high density of signal and gate bus lines, which could not easily be accomplished using traditional fill hole injection. Better cell gap uniformity is also obtained by dispensing a precisely controlled amount of LC materials.

### (1) Cell process simplification

Figure 1 shows the process comparison between the conventional cell process and ODF. The ODF process is very simple and the number of process step is less than that for the conventional process. What is most different is the dispensing by droplets the exact required amount of LC on the glass substrate and then bringing the two glass plates together in the vacuum. This LC filling method eliminates time consuming processes such as LC injection and end sealing process. Moreover cleaning LC residues can be eliminated because no LC is leaked outside of the cell.

### (2) Cell process lead time reduction

The ODF process lead time was compared to the conventional cell process with 22" four-sided TAB products as shown in table 1. According to experimental data of 22" products with a 4.5  $\mu\text{m}$  cell gap, there was a quite large difference, showing that the total lead time of significant process steps (circled in dotted line) was about 30.5 hours for the conventional cell process, and 1.5 hours for ODF respectively. Furthermore, in the case of narrow cell gap like 2.7  $\mu\text{m}$ , conventional process time increases by 9 hours while ODF process time shows almost no increase. Comparing the process time between 15" and 22" products, they were almost same for ODF. Such a quite low dependency of process time on cell gap and panel size enables flexible design of LCDs.

Table 1. 22" 200 dpi 4-sided TAB product lead time estimation

Current Process	Process time		ODF Process
	4.5 $\mu\text{m}$	2.7 $\mu\text{m}$	
Seal, Transfer and Tack Dispense	0.5 h	0.5 h	Seal, Transfer and Tack Dispense
<b>Assembly</b>	0.5 h	0.5 h	<b>ODF (Assembly)</b>
Press & Thermal cure	4.5 h	1.0 h	UV & Thermal cure
Glass Cut	0.5 h	0.5 h	Glass cut
Anneal in Vacuum	3.0 h		N/A
Capillary LC injection	18.0 h (4.5 $\mu\text{m}$ )		N/A
	27.0 h (2.7 $\mu\text{m}$ )		
End seal	3.0 h (4.5 $\mu\text{m}$ )		N/A
	3.0 h (2.7 $\mu\text{m}$ )		
Cleaning for LC residues	1.5 h		N/A
	(4.5 $\mu\text{m}$ ) 30.5 h	(4.5 $\mu\text{m}$ ) 1.5 h	
	(2.7 $\mu\text{m}$ ) 39.5 h	(2.7 $\mu\text{m}$ ) 1.5 h	

### (3) High LC usage efficiency for 4-sided TAB applications

LC material usage efficiency of ODF process is very high, about 95% or more, regardless of the panel size, cell gap and TAB structure because precisely required LC amount is dropped on the glass substrate before assembly process. ODF process has an especially big advantage for four-sided TAB products which are needed to supply electrical voltage from up and down side of the TFT for the driving signal line, and the right and left side for the bus line. In the case of conventional LC injection process, LC material usage efficiency is quite low (high waste) because injection holes don't exist at the edge of the cell, which requires lots of LC material to dip injection holes completely as shown in

figure 2. In this respect, LC material cost can be dramatically lowered with ODF technology for high resolution products which need four-sided TAB bonding while there is only a small advantage for three-sided TAB products.

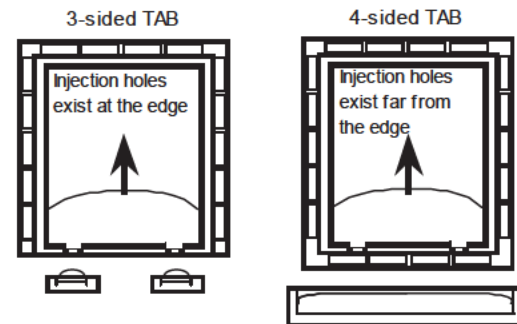


Figure 2 Four-sided TAB future cell LC injection process

### (4) Other merits

From the manufacturers' point of view, being able to establish in-line process by shortening the process time and reducing the number of cassettes needed for each products are other merits. Moreover, shorter fabrication time makes it faster to find a problem causing a sharp yield decrease which is only detected in the cell final inspection. In the case of small size panel such as personal digital assistant (PDA) and mobile phone applications, ODF also shows big advantage because there is no need for injecting the LC material individually. Judging from our experience and investigations, ODF technology can be an LCD dream process come true which until now has not been implemented in the TFT-LCD world.

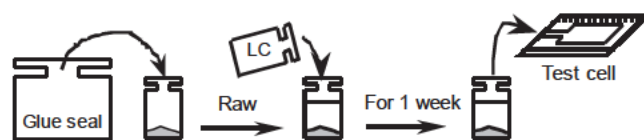
## 4. UV glue seal development

One of the biggest technical hurdles of ODF is that an uncured glue seal is in contact with the LC material, which can cause fatal contamination of the LC material. In addition, the glue seal should be cured quickly with no damage to the LC material. For this reason, high viscosity glue seal and curing by uv light are inevitable and two different types of uv setting glue seal have been investigated for ODF process. One is a pure uv setting glue seal cured by only uv light. And the other one is a uv and thermally setting hybrid glue seal cured by both uv light and heating. Another difficulty is to cure the sealant underneath the metal bus lines which prevent the glue seal from being exposed to the uv light. The technical key requirements are : (1) dispensability, the need to dispense a seamless pattern with no injection holes, (2) adhesion, (3) wide process margin against seal collapse defect where no seal breakage or damage occurs upon physical attack from the LC and the atmospheric pressure, (4) easy to squeeze for excellent uniform cell gap, and (5) reliability. In order to achieve these requirements, a taking good balance among the characteristics of the glue seal, ODF process design and equipment function is needed. In this respect, developing the ODF technology is rather complicated compared with the conventional cell process which enjoys the luxury of independence of these functions and requirements.

Our estimation procedure for an ODF glue seal is : (1) glue seal solubility test under several curing conditions with a vial

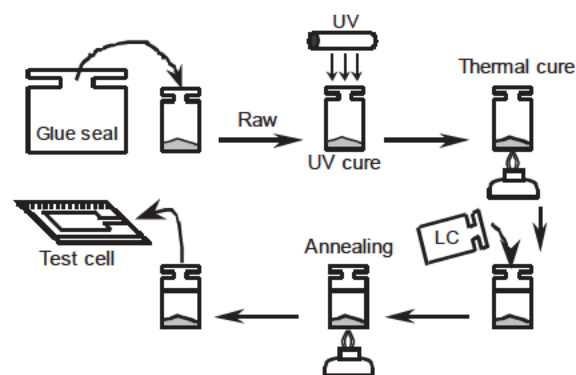
container, (2) adhesion test with crosswise glass cell, before and after giving the stress by a pressure cooker, (3) comprehensive test with 5" ODF fabricated cell. And then some which passed above tests are applied to actual products to estimate process margins and do our series of associated reliability tests.

Glue seal's solubility test is the first to do for finding out how to match with our LC materials and the way of preparing samples are shown in figure 3 and 4. Test cells are fabricated with conventional process with a thermally setting epoxy. The vial container which doesn't contaminate the liquid crystal even when it is heated is carefully selected. With these test cells filled with contaminated liquid crystal, several electrical measurements like voltage holding ratio (VHR) and ion density were performed. Some experimental results are shown in figure 5 where x-axis is the solubility of uncured glue seal keeping in contact with the



1. Put uncured glue seal into a vial. Then it is blended with LC material to be contaminated.
2. Keep it dark and at room temperature for 1 week.
3. Contaminated LC material is injected into prepared cell by capillary method.

Figure 3 Solubility test for glue seal material



1. Put uncured glue seal into a vial. Then it is UV and thermal cured.
2. Add the LC material to the vial. And heat up for annealing.
3. Contaminated LC material is injected into prepared cell by capillary method.

Figure 4 Annealing effect test for cured glue seal material

liquid crystal for a week and y-axis is the extent of contamination of cured glue seal extracted by annealing respectively. In this figure, the data of reference, white square, was obtained from the LC material in a vial with no contamination source like a glue seal. Some adhesives showed good results similar to the reference though, most of them are not available due to another reason such as short of the seal collapse margin, insufficient dispensability and adhesion.

2nd is the adhesion test by pulling the crosswise glass cell composed of glass plates on which several possible films are formed to simulate the real surface conditions. Degradation of adhesion after pressure cooker stress and how to break, especially

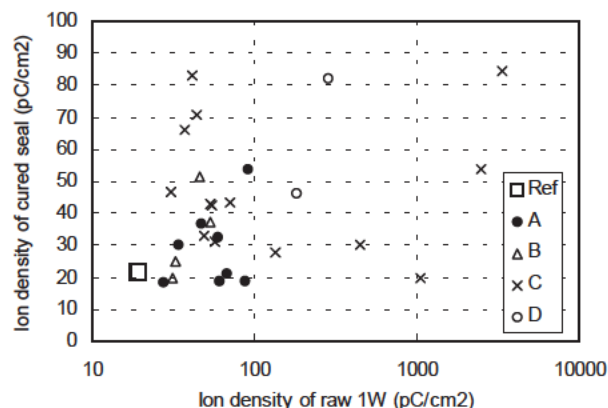


Figure 5 Ion density evaluation for the LC contaminated by glue seal

which part of the glue seal, for example surface, balk or both, is peeled are very important. According to these fundamental estimation, feasible adhesives were carefully selected.

3rd is the comprehensive test using 5" ITO patterned cell fabricated by ODF process. In this phase, Seal collapses margin and Squeezability have to be focused because both are quite related to ODF process itself. Tool design and process parameters should be determined in such a way as to maximize these process margins. In addition, more real panel defect such as image sticking, degradation of the voltage holding ratio and LC alignment defect are investigated.

By taking these systematic approaches, well balanced glue seal suitable for our ODF process has been developed.

## 5. Tool and process development

Among each ODF process step already shown in figure 1, LC dispenser and aligner in vacuum are newly developed tools and processes. Although seal dispenser is similar to that for conventional tool basically, some improvements are required because of high viscosity glue seal and ODF unique seal pattern.

### (1) Seal dispenser

In general, glue seals for ODF process tend to have high viscosity so as to yield wide process margin of seal collapse defect and prevent a seal component from being dissolved into the liquid crystal. High viscosity glue seals, however, are difficult to dispense with allowable width dispersion and no disconnected defect. In addition, what we were concerned about was how to actualize the injection hole-less seal pattern. As a result, seamless rectangular pattern which requires sophisticated start and stop control was adopted. To obtain reliable seal dispense for high viscosity, great attention, especially regarding air pressure circuit, was paid to selecting the tool vendor. Eventually dispensing higher viscosity glue seal than a thermally setting epoxy currently used in a manufacturing facility with excellent start and stop control was obtained.

### (2) LC dispenser

Dispensing the liquid crystal by droplets is completely new process whose major requirements are precise control of LC amount with small variance, no contamination to the liquid crystal and long run stability. Basically, dropped LC amount and one drop precision determine the cell gap and its uniformity



respectively. In a certain cell gap range which is decided by the post spacer's height, elasticity and plasticity property, LC amount is proportional to the cell gap. With an LC dispenser, it was confirmed that the LC amount can be maintained within a variance of  $\pm 1.0\%$  in 4 sigma, corresponding to  $\pm 0.045\text{ }\mu\text{m}$  for  $4.5\text{ }\mu\text{m}$  in the cell gap. In terms of the long run stability, no degradation of LC dispense accuracy and no increase in contamination to the liquid crystal was found after 1,500,000 shots.

### (3) Assembly and aligner

To fabricate an LCD panel with no air bubble, assembly process of ODF is performed in vacuum because it's quite difficult to eliminate the molecule of air from inside the cell when two glass plates are joined in the atmospheric pressure. Therefore, handling glass substrates in vacuum is mandatory. Several methods of holding in vacuum were investigated as shown in table 2.

Vacuum chucking method widely used in the conventional facility is also one of the candidates. Since its chucking force is basically proportional to the pressure difference, the volume of the air bubble inside the cell increased as the operating pressure was increased. With ordinary ODF process, small air bubble happens just after glue seal's thermal curing. To obtain sufficient suction

**Table 2. Substrate holding method in vacuum**

	Vacuum chucking	Mechanical holding	Electro-static chucking
Cost	Inexpensive	Inexpensive	Expensive
Feasibility	Widely used method	Ordinarily used method	New method
Large glass size capability	No problem	Difficulty in glass bend effect	Difficult to make and maintain
Operating pressure	High operating pressure inevitable (About 10 torr or more)	No dependency	No dependency
Concerns	Air bubble defect comes from high operating pressure	Dust and crack from contacting part Weak holding force	TFT damage Conductive layer needed

force, higher operating pressure is needed, inducing air bubble defect in the cell. In order to adopt the vacuum chucking method, eliminating the air bubble or smaller operating pressure should be considered.

Mechanical chucking methods such as framing, clipping and clamping, are the most primitive though, it has big advantage in terms of the cost and no dependency of the operating pressure. Particularly in the case of different size of glass substrates which is forming the cell, it is easy to design with low cost because there is some peripheral space on the film side which is allowed to get in contact with mechanical parts. Concerning the demerit, mechanical contact and friction necessarily generates dust, which might lead to yield loss. In addition, it is not flexible to the change of mother glass size because the glass plate evidently bends and its extent depends on the glass size when it is only held at the peripheral area of the substrate. Therefore some break through for compensating the size dependency of the bend is necessary.

Electrostatic chucking method has never used in the cell process though, there is also a big advantage that the holding force doesn't

depend on the operating pressure. Meanwhile, it is difficult to confirm that there is no risk of electrostatic damage to the thin film transistor (TFT) even if its structure and materials are changed in the future. Since this concern is very significant, some effective estimation method should be required. Besides the limitation of glass substrate film configuration is unavoidable to establish sufficient suction force since it is related to the presence of conductive layer. In the case of IPS mode, the color filter (CF) substrate has no ITO film, therefore the suction force considerably decreases. In order to use a electrostatic chucking method, some improvement is required to hold the substrate with no conductive layer.

A more flexible chucking method which has less limitation is under investigation though, we've developed a novel aligner which is equipped with a certain glass holding function in vacuum suitable for our ODF process and confirmed the extent of alignment error is the same as the conventional one with no air bubble inside the cell and with better cell gap uniformity as shown in table 3.

When a cell process facility is designed, the most appropriate glass chucking method can be adopted according to the line concept and the product variation, considering above each merit and demerit.

**Table 3. Cell gap uniformity**

Cell gap capability	Current (*1)	Current (*2)	ODF (*3)	ODF (*4)
Gap uniformity - Lot (f $\Phi$ )	0.088f $\Phi$	0.073f $\Phi$	0.049f $\Phi$	0.014f $\Phi$
Gap uniformity - Cell (f $\Phi$ )	0.062f $\Phi$	0.072f $\Phi$	0.037f $\Phi$	0.043f $\Phi$
Average	4.539f $\Phi$	4.530f $\Phi$	4.569f $\Phi$	4.550f $\Phi$
Number of samples	128pcs	120pcs	40pcs	32pcs
Number of all measurement points	1152points	1080points	360points	288points

(\*1,\*2,\*3,\*4) Date is different

## 6. Conclusion

We have developed an ODF technology for TFT-LCDs and 22" IPS-mode LCD panel with 4-sided TAB bonding. It has been successfully fabricated in a manufacturing environment. Simplifying the cell process and reducing the fabrication time has been demonstrated with high usage efficiency of the LC material. With the ODF process, quite small dependency of fabrication time on the cell gap and panel size can be expected, which is suitable for monitor applications, and which is a major advantage over capillary fill techniques. From the environmental point of view, this technology can make a big contribution by eliminating several thermal and vacuum processes which are energy intensive. Elimination of LC waste is an additional environmental benefit.

## 7. References

- [1] N. Ohshima et al, Matsushita Corp. 8-20627 PATENT.
- [2] A. Takeda et al., A super-High-Image-Quality Multi Domain Vertical Alignment LCD by New Rubbing Less Technology, SID98 Digest, pp.1077.