

FLAT PANEL DISPLAY MANUFACTURING

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Flat Panel Display Manufacturing

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5

TFT-LCD Module and Package Process

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5.1 Introduction

In this chapter, the back-end manufacturing processes of TFT-LCD modules (LCMs) are described. As shown in [Figure 5.1](#), the back-end process includes polarizer attachment, chip on film (COF) or chip on glass (COG) bonding, which are called collectively the JI process, module assembly, aging, and packing for shipment. The acronym “JI” comes from Japanese pronunciation and means “bonding.” These processes are, in general, finished in a so-called module assembly (MA) factory. For some TFT-LCD module makers, the polarizer attachment may be done in a front-end cell fab and the MA factories do only the JI and remaining processes.

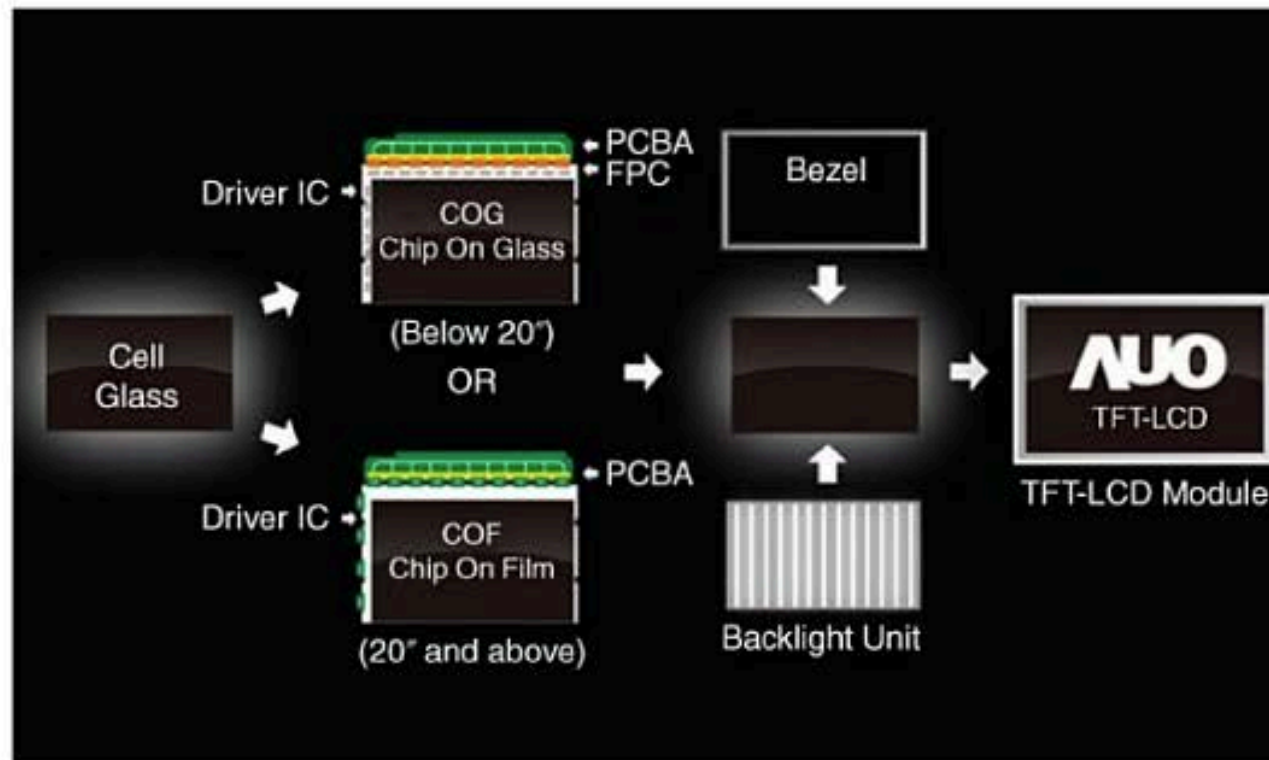


Figure 5.1 Typical LCM processes for a TFT-LCD panel maker [1].

As a display device, a TFT-LCD panel doesn't emit light by itself. A bright and uniform illumination source is needed to produce an image, with the TFT-LCD panel acting as a spatial modulator. As shown in Figure 5.2, in addition to the light source, the TFT-LCD module includes several optical elements. In order to simplify the assembly of the TFT-LCD module, these optical components can be preassembled as a backlight module, which is subsequently used for final LCM assembly in another factory. Often, this makes the MA process as simple as just stacking together the display panel and the backlight module.

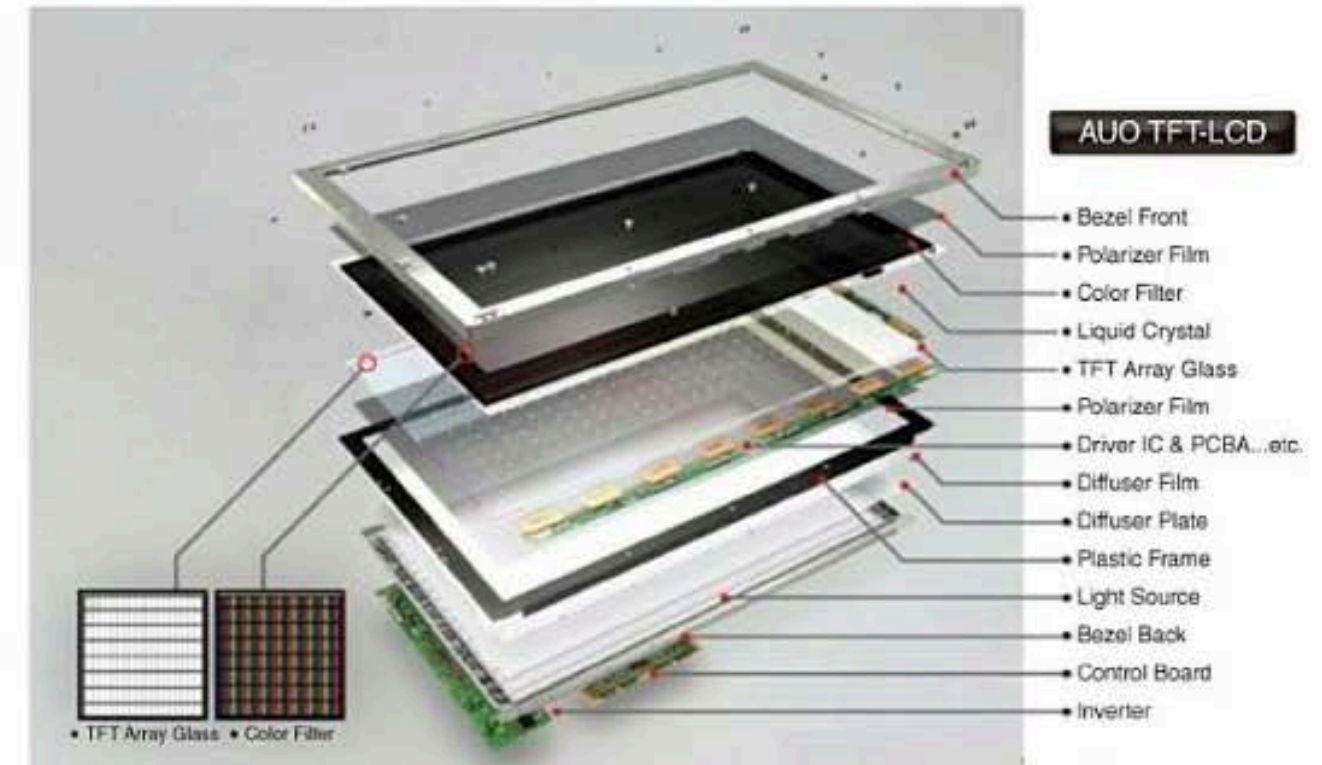


Figure 5.2 Components of a typical TFT-LCD module [1].

This chapter introduces in sequence the TFT-LCD back-end processes, starting from polarizer attachment to packing for shipment. For small and large panels the processes are similar but not identical. Process introductions are in separated sections. Furthermore, since the backlight module plays an important role in an LCM (TFT-LCD module), optical components and assembly process are described in a separate chapter. The status of art and trends of automation in the assembly process are included too. At the end, representative business models and material flow in LCM manufacturing are introduced.

5.2 Driver IC Bonding: TAB and COG

TAB (tape automatic bonding) and COG (chip on glass) are two different processes for bonding driver ICs with the TFT-LCD cell. The process used depends on the configuration of the LCD panel. For TAB process, driver ICs are bonded onto flexible printed circuit boards (FPC), called COF (chip on film), and then COFs are bonded to the TFT-LCD cell glass. For COG process, driver ICs are bonded directly

onto the TFT-LCD cell glass. In general, TAB process is better for production yield but is more expensive because of the FPC. Furthermore, without IC on glass, cell thickness can be thinner. On the other hand, the COG process will be more cost effective without using FPC. Since the ICs are bonded on glass, they are protected from deformation and damage. Furthermore, because of thinness in configuration, the TFT-LCD module can be designed to be smaller.

5.3 Introduction to Large-Panel JI Process

Most of the large panels utilize COF for panel driving. Driver ICs are mounted on FPC instead of the cell glass. COFs are used as packed components. The JI process doesn't include IC bonding. As shown in Figure 5.3, JI process includes three major sub-processes. They are COF bonding, PCB bonding, and PCB test. They are described as follows:

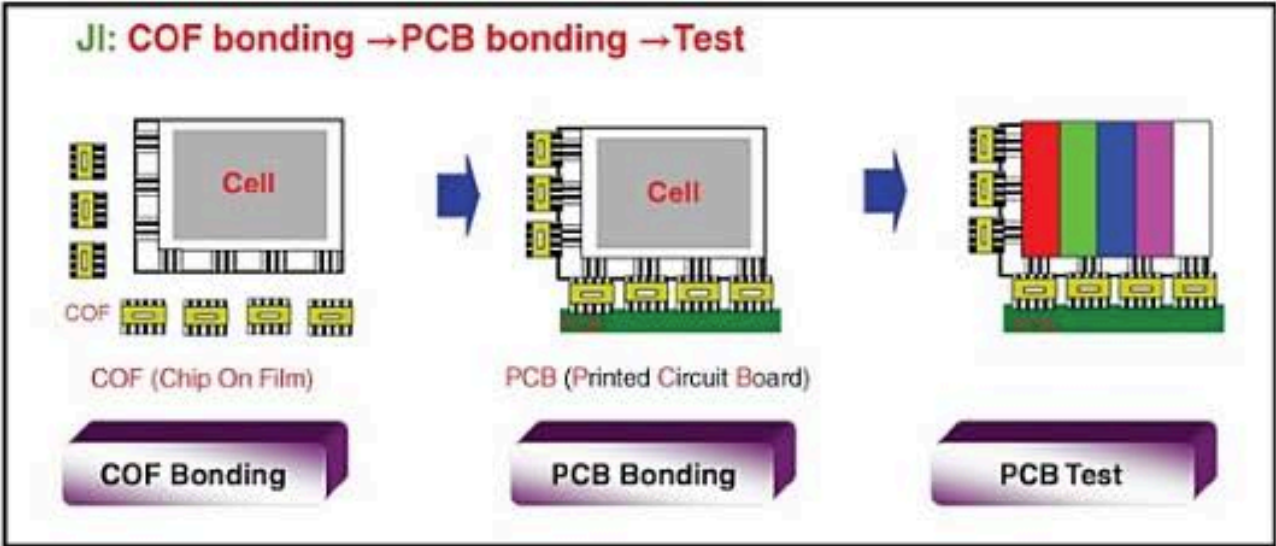


Figure 5.3 Illustration of large-panel JI process [1].

5.3.1 COF Bonding

This process bonds COF onto the cell glass, as shown in Figure 5.4. The adhesive used is ACF (anisotropic conductive film). Figure 5.5 shows details of the bonding process.

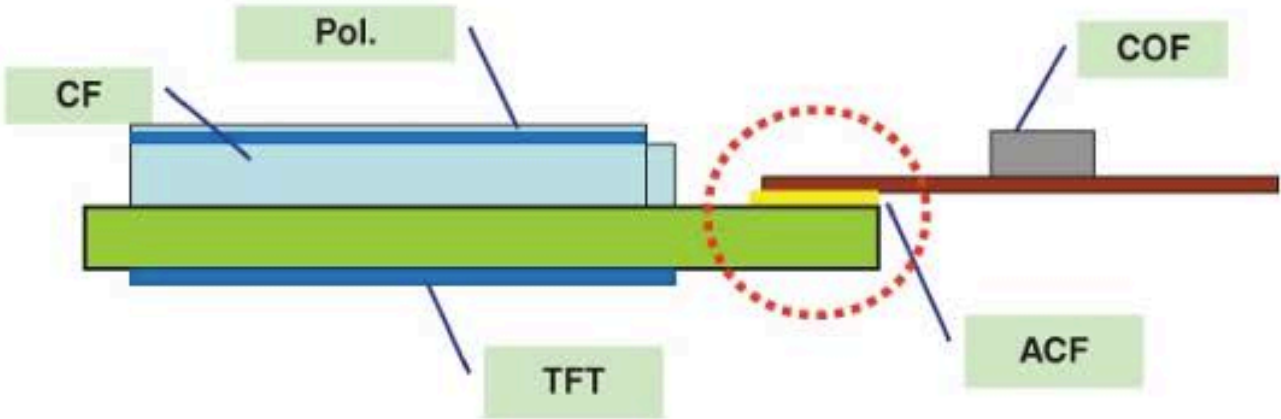


Figure 5.4 COF bonding structure.

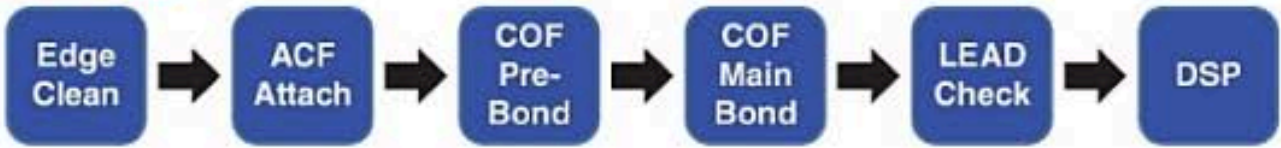


Figure 5.5 COF bonding procedure.

5.3.1.1 Edge Clean

To ensure good bonding quality, the area for cell-COF bonding has to be well cleaned to avoid the presence of any particles and residues on the bonding pad surfaces. Four processes are included:

- Dry clean:** to remove large foreign particles from the cell surface.
- Wet clean:** supersonic waves are to remove particles stuck on cell surface.
- Wiper with solvent:** to wipe out particles on cell surface
- Plasma:** to remove organic contamination from the cell surface.

Cleaning results of this process should be carefully monitored. Any particle left on the surface may induce panel fracture during the subsequent bonding process. Figure 5.6 shows an example of the edge cleaning equipment stages.

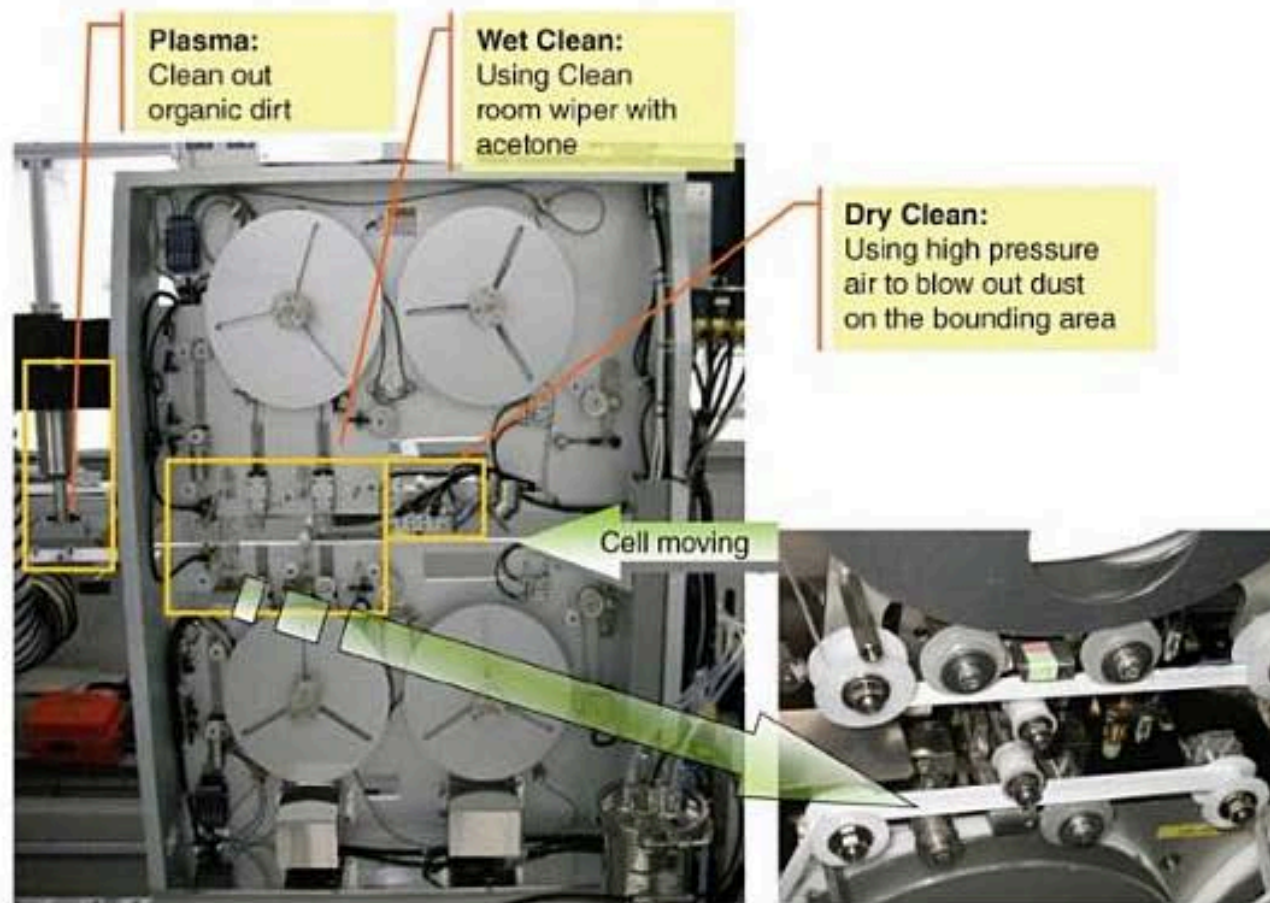


Figure 5.6 Edge clean [1].

5.3.1.2 ACF Attachment

ACF is a double-sided adhesive tape coated with a mixture of adhesive binder and electrically conducting particles, as shown in **Figure 5.7**. The conducting particles in ACF are discrete and dispersed uniformly. These particles can form an electrical connection between two adhered metal parts pressed together. ACF is typically used in cases where high temperature soldering cannot be applied.

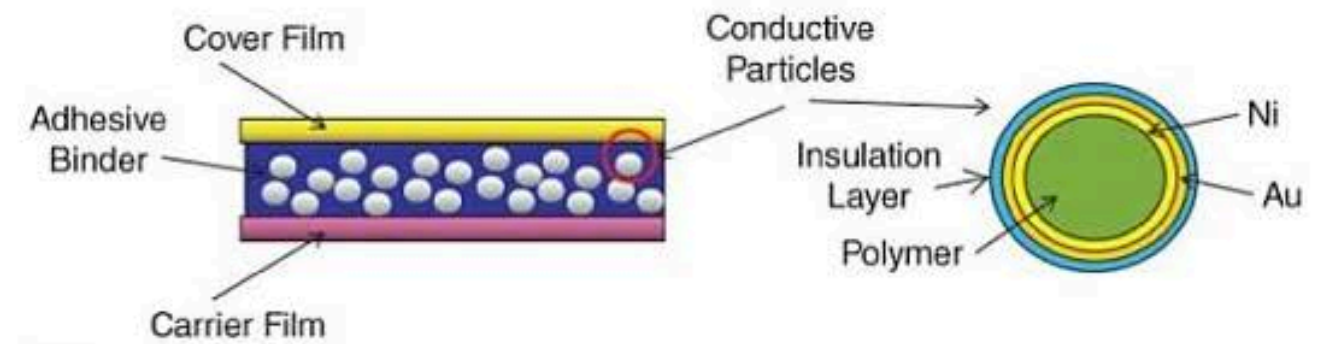


Figure 5.7 Anisotropic conductive film structure [1].

Figure 5.8 shows a basic diagram of ACF bond structure. When COF is attached to the glass and pressed together, the conducting particles between two electrodes are squeezed and they break through the insulating polymeric matrix to contact the electrode pads. As shown in the figure, the conduction is unidirectional in the vertical direction. Those nonsqueezed particles remain insulated and therefore no conduction occurs in the horizontal direction.

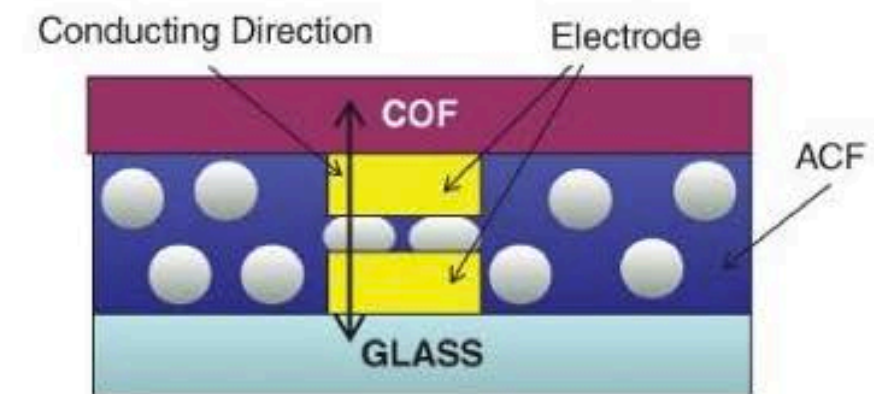


Figure 5.8 ACF bonding structure with electrical contact only in vertical direction [1].

Prior to bonding, the ACF tape needs to first be laminated as shown in **Figure 5.9**. First, the carrier film is removed and then the ACF film is laminated onto the cleaned cell glass surface with controlled pressure, temperature, and duration. After the lamination is completed, the ACF protection is removed for the next process step.

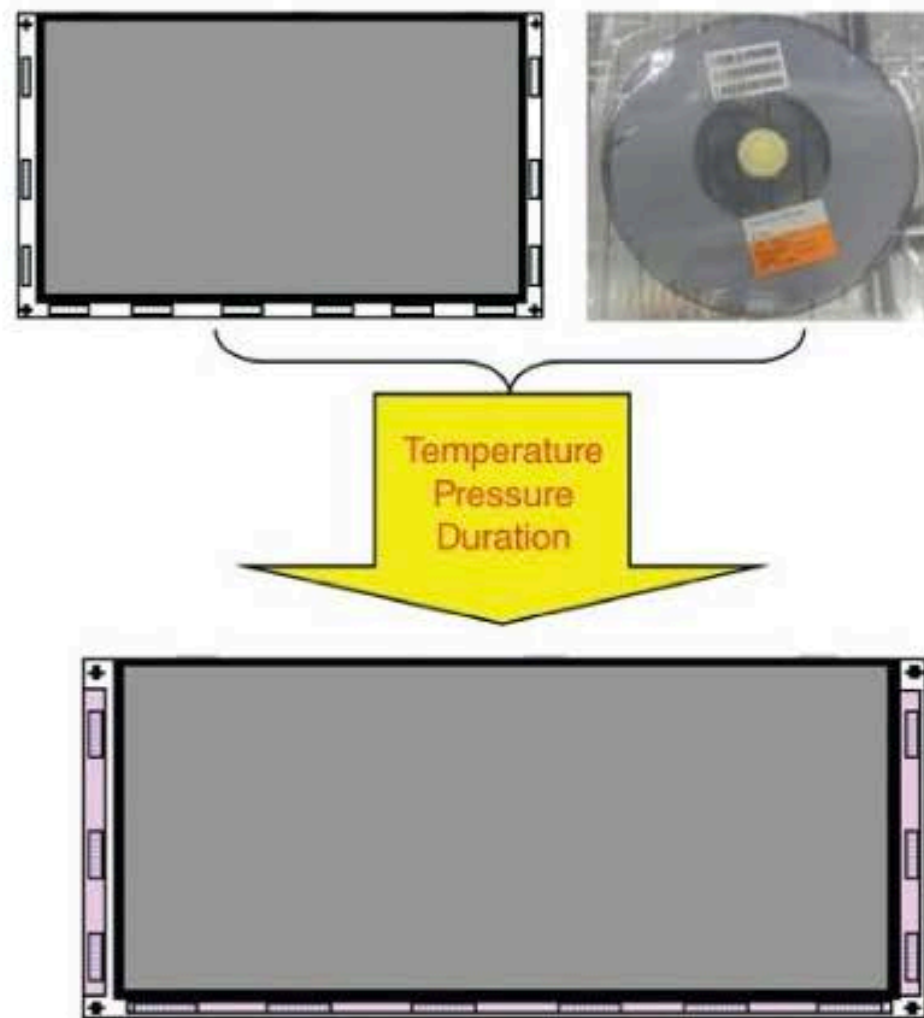


Figure 5.9 ACF attachment.

5.3.1.3 COF Pre-Bonding

In this process, COFs are first taken out from COF tape by a punch die and then placed on the cell glass at the designated location by imaging positioning. After alignment, a small pressure is applied on the COF to fix in place. All the COFs are attached to the cell glass and pressed one by one (**Figure 5.10**).

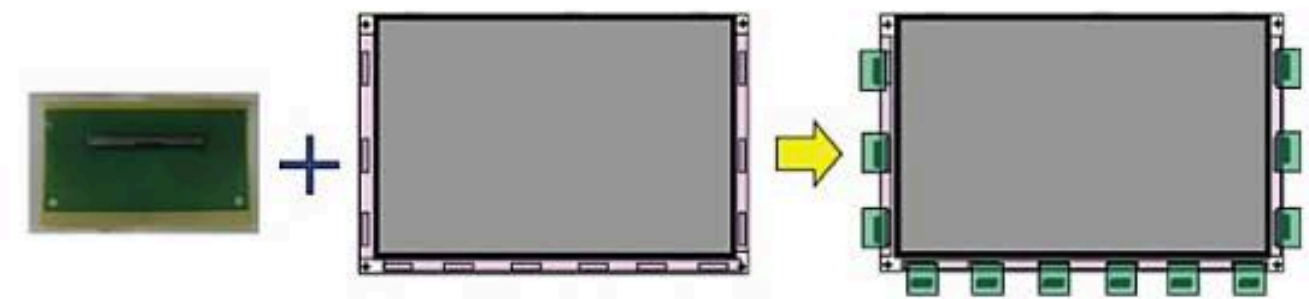


Figure 5.10 ACF pre-bonding.

5.3.1.4 COF Main Bonding

After pre-bonding, the cell is transferred to the next stage. At first, the position of the cell will be adjusted during an optical inspection process. Then, a heated bonding head will fall down and apply localized pressure on the COF at the target pressure, temperature, and duration. A buffer material between the bonding head and the COF is used to improve COF attachment. In general, the buffer film is made of teflon or silicone, as is shown in **Figure 5.11**.

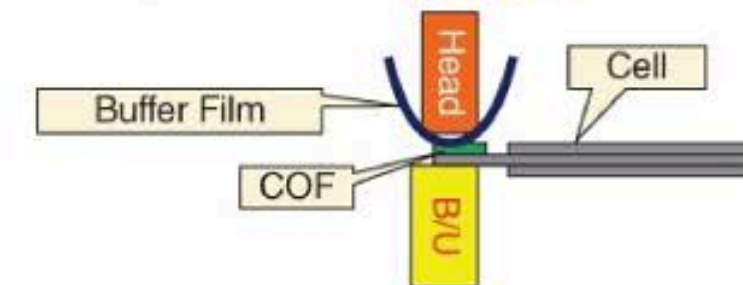


Figure 5.11 ACF main bonding step.

5.3.1.5 Lead Check

This is an in-line optical testing process that follows right after the main bonding step, aimed at two key objectives. One is to verify the alignment between the COF and cell electrode leads, for proper connections. The other is to check if enough number of conducting particles have been pressed between each electrode for achieving a proper electrical resistance of the bond (**Figure 5.12**).

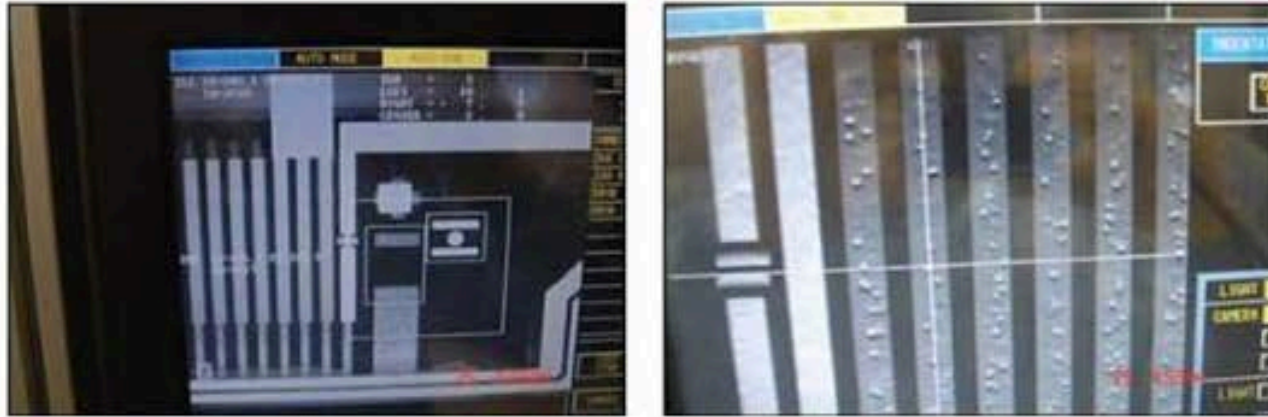


Figure 5.12 Lead check [2].

5.3.1.6 Silicone Dispensing

At this stage, silicone resin is dispensed on the cell lead bonding area to protect cell leads from corrosion and ambient moisture (Figure 5.13).

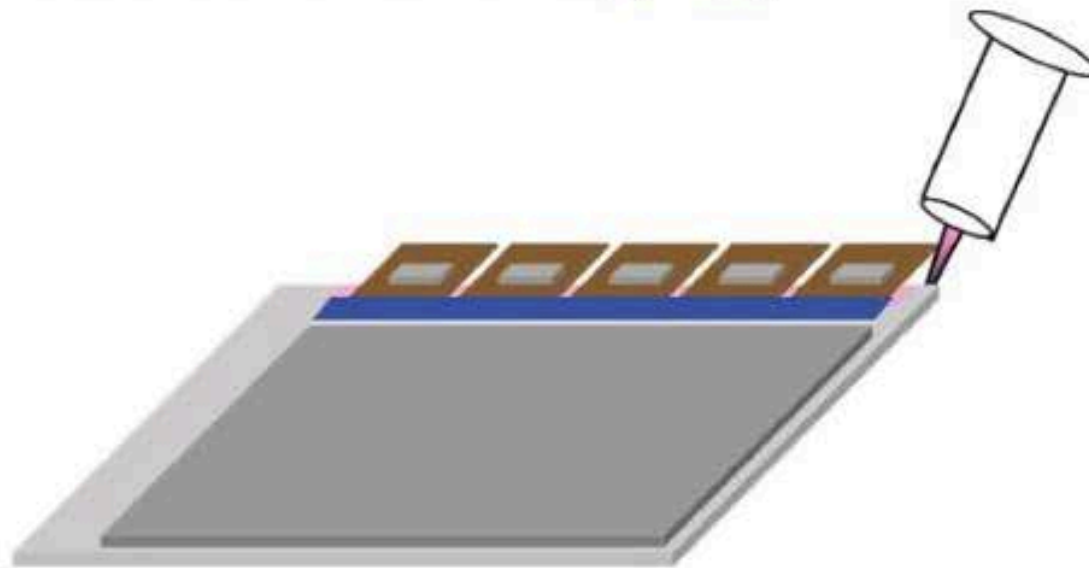


Figure 5.13 Silicone dispensing.

5.3.2 PCB Bonding

During this process, the PCB is attached to the COF surfaces. As before, ACF is first laminated onto the PCB electrode pad array, and then the COFs are bonded on to the PCB by a pressing head, as shown in Figure 5.14.

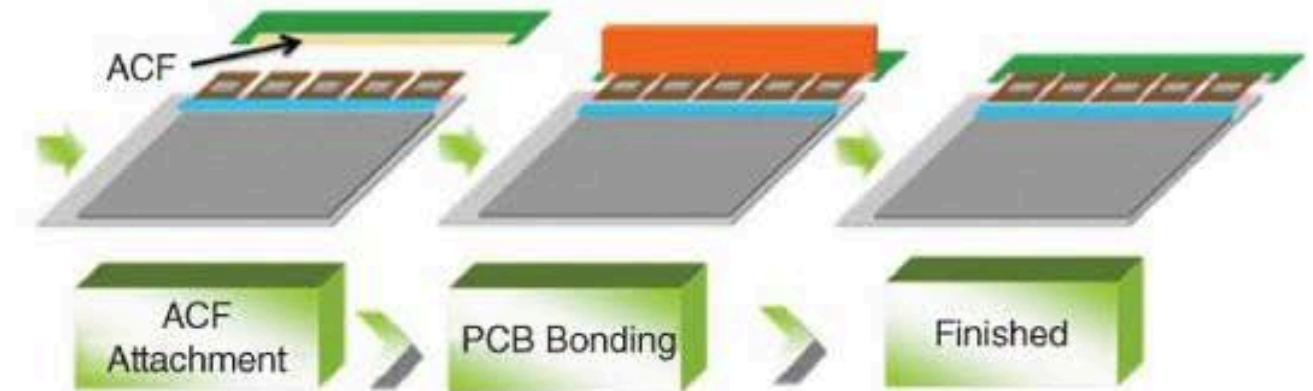


Figure 5.14 Procedures for PCB bonding.

5.3.3 PCB Test

This process checks both functional and visual quality of PCB bonding to prevent unqualified panels flowing down to the module assembly line. Mostly, it is tested by a sampling protocol. In recent years, one kind of business models is to sell PCB-bonded panel (open cell) to customers directly without mechanical parts assembly. For the open cell business, SKD (semi knock down, means sub-module) test will be done instead of PCB test. Instead of sampling, SKD test will do 100% checking with additional test items and images. Typical major defects found during this process are non-proper PCB bonding, particles, line defects, and so on. Figure 5.15 shows some typical defects found by PCB test.

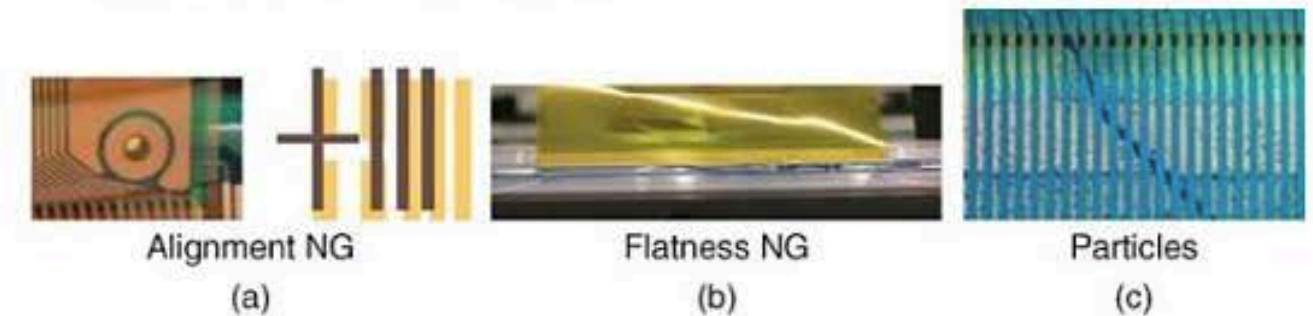


Figure 5.15 Some typical defects found by PCB test: (a) poor alignment, (b) poor flatness, and (c) particle contamination.

5.3.4 Press Heads: Long Bar or Short Bar

Two kinds of press heads are used for ACF bonding: long bar and short bar. In the case of long bar, a single pressing head is used for the entire side of the panel, allowing simultaneous bonding of multiple COFs. It is convenient to use with the benefits of no limitation on the number of COFs and on the COF pitch. The main

drawback, however, is that it is difficult to adjust the flatness of the bar for obtaining uniform pressing forces on each COF. Using a head with long bar also induces more wasting of ACF tape.

On the other hand, bonding heads with a short bar can more easily achieve uniform pressure for each COF, but have limitations on the pitch and the number of COFs. In general, the structure of the short bar machine is more complicated compared with the long bar machine, as shown in Figure 5.16.

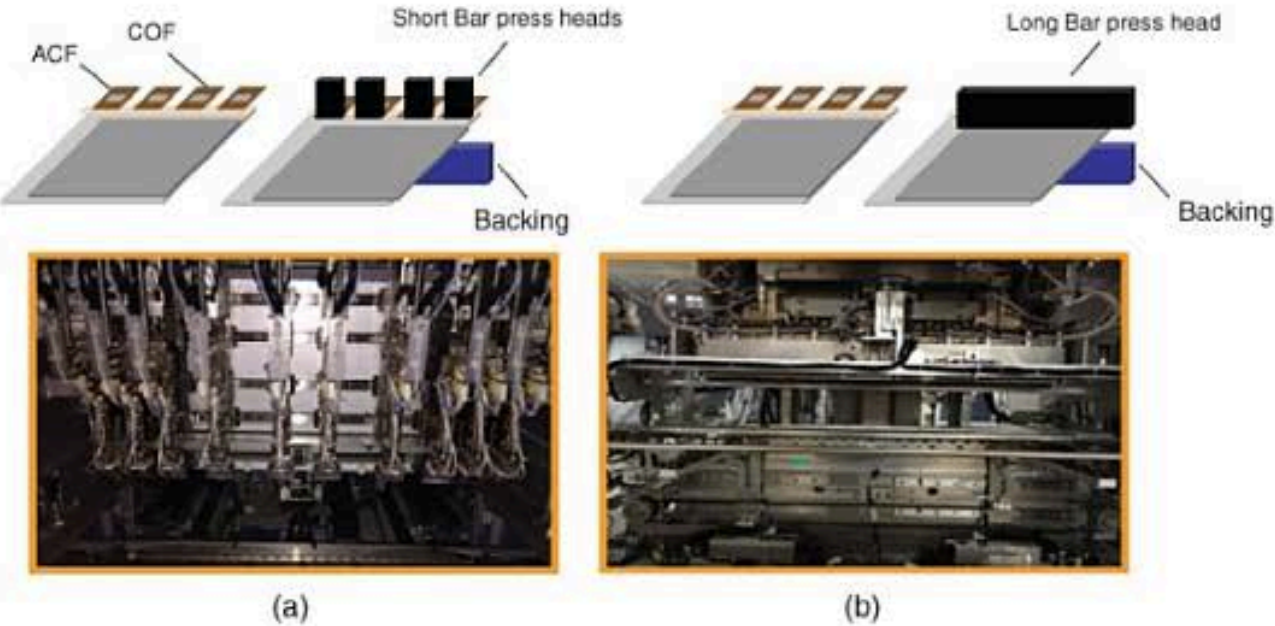


Figure 5.16 COF bonding: press head options: (a) array of short bars for each COF, and (b) long bar for pressing across entire panel edge [1].

5.4 Introduction to Small-Panel JI Process

For small TFT-LCD panels, the chip-on-glass (COG) process is generally used. JI processes for small panels are similar to large panels, with a typical flow shown in Figure 5.17.

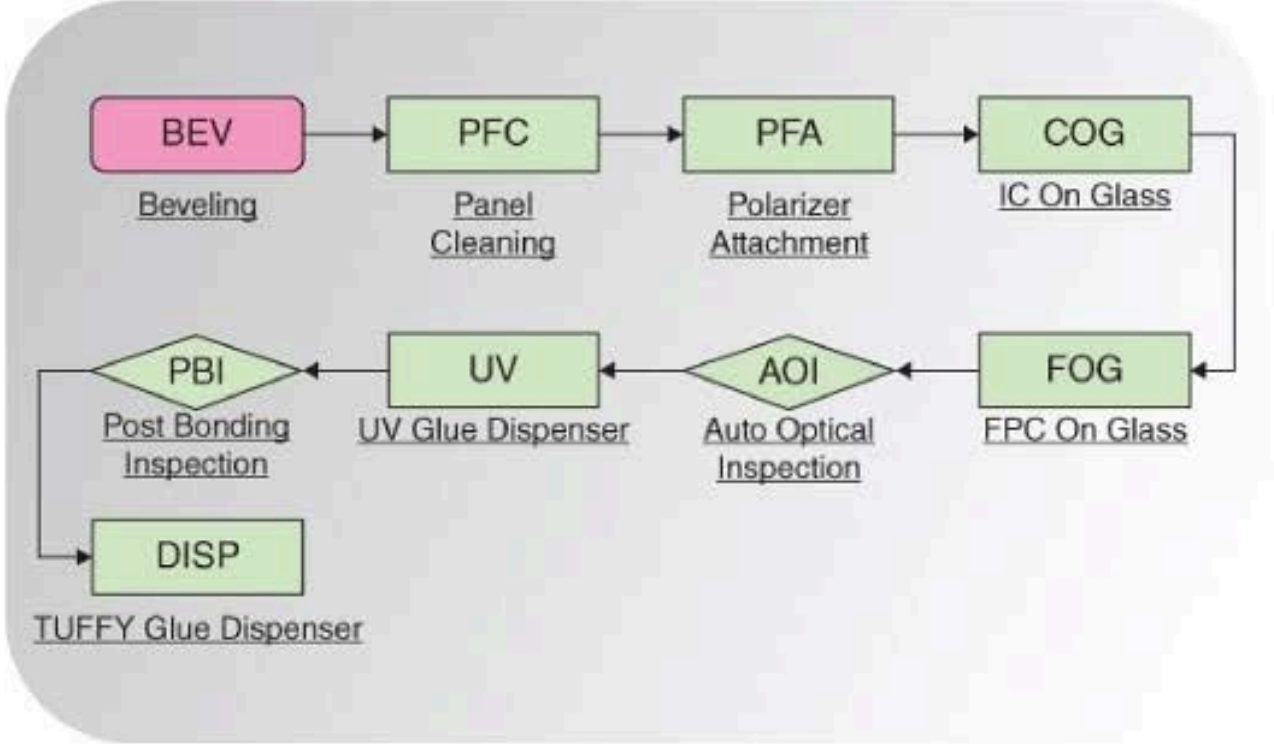


Figure 5.17 Typical process flow for small-panel JI process [1].

5.4.1 Beveling

To avoid glass chipping during handling, the JI process usually requires beveling all the glass corners at the beginning. In some occasions, beveling on edges is also required.

5.4.2 Panel Cleaning

After glass beveling, a cleaning step is required to prepare for subsequent polarizer attachment and COG bonding processes. DI water and clean room cloth are typically used. Sometimes solvent is used for more thorough cleaning.

5.4.3 Polarizer Attachment

The JI process for small panel LCM usually includes polarizer attachment, as shown in Figure 5.18. This process attaches polarizer sheets to the top (color filter) and bottom (TFT) surfaces of the TFT-LCD panel. Particle control is important for this process to ensure successful bonding. Particles may originate from facility environment, clean cloth, glass chipping, polarizer material itself, and inner parts of the assembly machine.

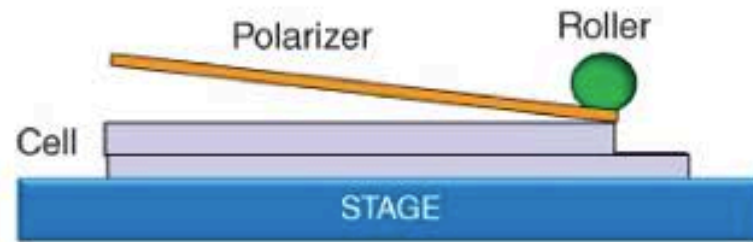


Figure 5.18 Polarizer attachments.

5.4.4 Chip on Glass (COG) Bonding

This process bonds driver ICs onto the cell glass using ACF as well. As shown in [Figure 5.19](#), the procedures for ACF attachment are similar to large panels. At first, ACF film is laminated onto the connecting electrodes on the glass. Then ICs are loaded and pre-bonded for precise positioning and temporary bonding. Finally, the main bond process is performed at particular temperature, pressure, and time duration. During this process, the alignment and missing of driver IC are the main inspection goals.

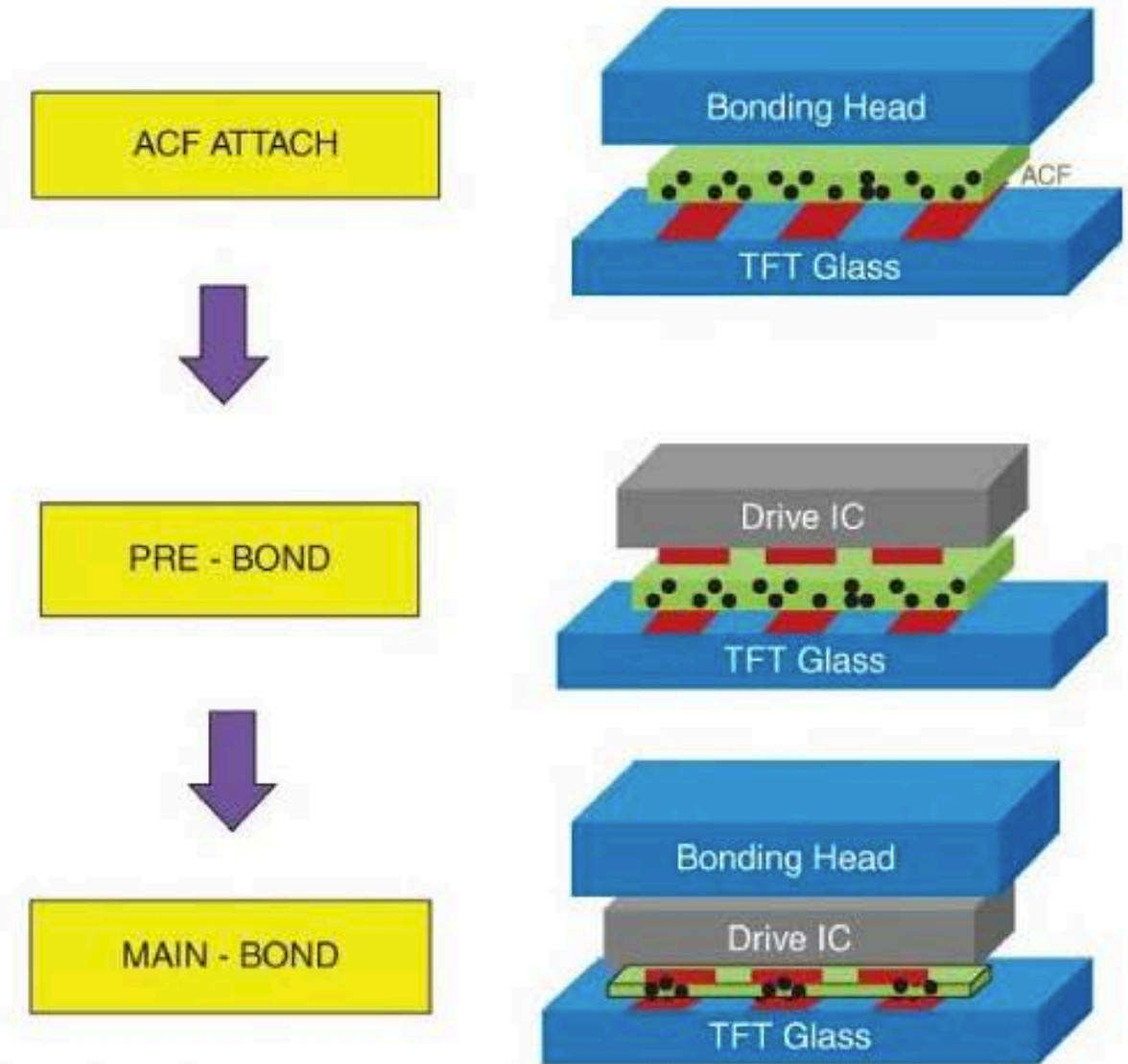


Figure 5.19 Chip on glass (COG) bonding.

5.4.5 FPC on Glass (FOG) Bonding

This process bonds FPC onto TFT glass. As shown in [Figure 5.20](#), similar to large panels, three sub processes are included: ACF lamination, FPC pre-bond, and FPC main bonding.

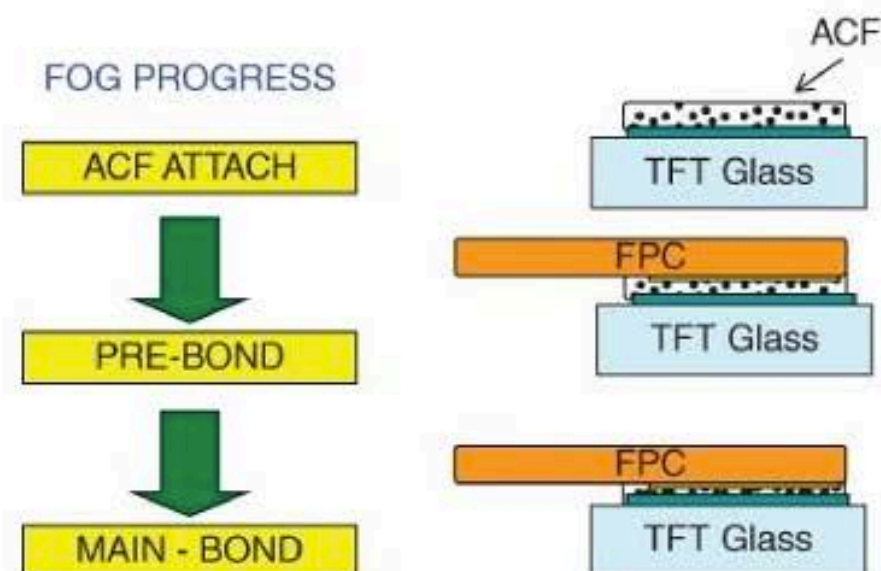


Figure 5.20 FPC attachment.

5.4.6 Optical Microscope (OM) Inspection

This procedure checks the bonding status of IC and FPC. Detected bonding failures usually are misalignment, insufficient conducting balls between electrodes, improper press-crack of conducting particles, contaminant particles trapped in the bond, and so on (Figure 5.21).

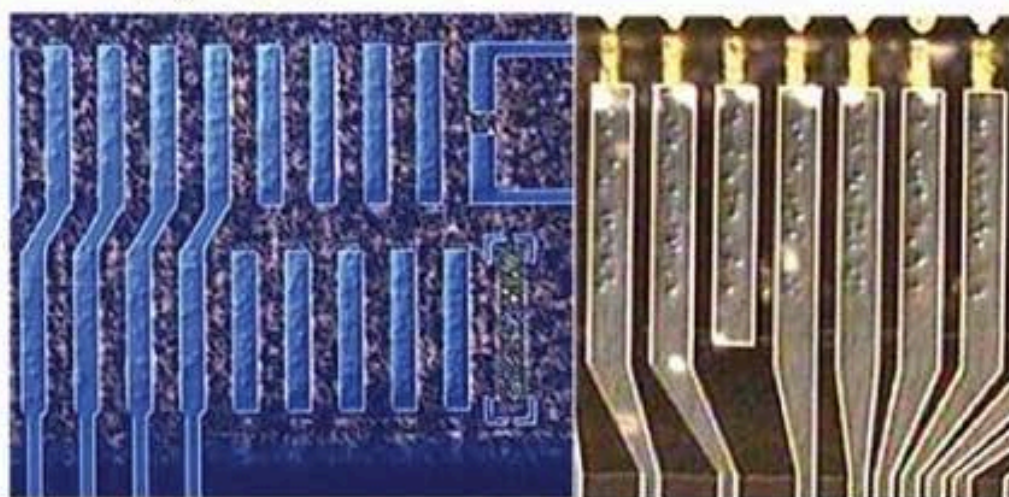


Figure 5.21 Example of OM inspection [3].

5.4.7 UV Glue Dispense

As shown in Figure 5.22, UV or other kind of glue is dispensed between FPC and the edge of panel glass to increase mechanical robustness of the bond and prevent FPC from damage.

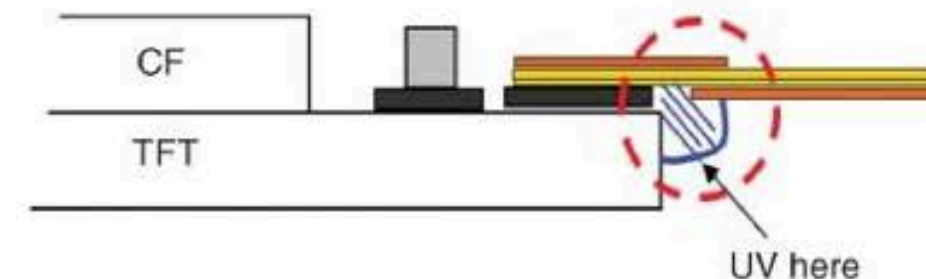


Figure 5.22 Example of glue dispensing.

5.4.8 Post Bonding Inspection (PBI)

This process inspects functional defects and sorts out failed panels before assembling with the backlight unit. Defects found here usually are dot pixel defects, line defects, abnormal display, and so on (Figure 5.23). This test requires connecting the module to equipment with customized interface for providing power and testing signals. In addition, panels with cosmetic defects like cracks, scratches are also sorted out. For some applications, JI-finished panels will be shipped to customers directly without backlight. In that case, more detailed inspections have to be done before packing. The inspections are similar to those introduced in Chapter 16.

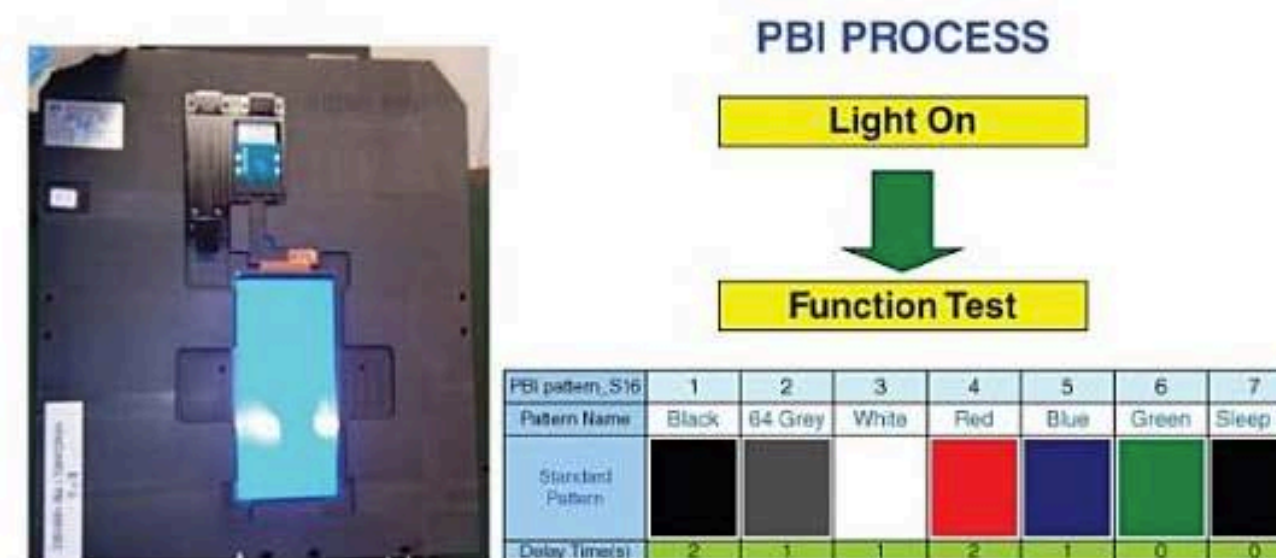


Figure 5.23 Example of PBI [3].

5.4.9 Protection Glue Dispensing

This process dispenses protection glue onto the top of exposed conductors of TFT and ICs. Fast curing silicone glue is usually used. Purpose for the glue dispensing is

to prevent ICs and circuits from moisture corrosion, dust, and also for shielding leakage light (Figure 5.24).

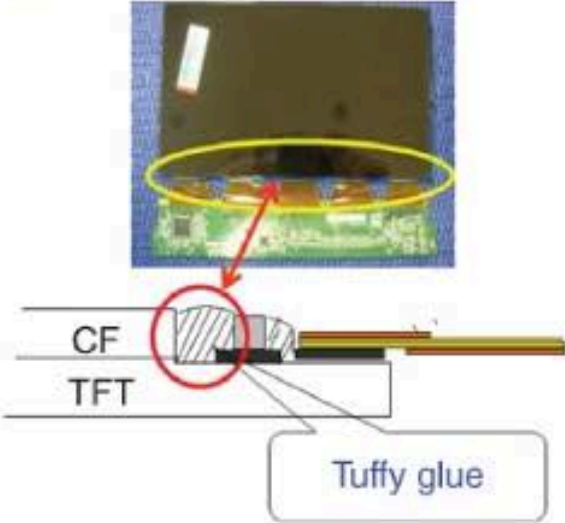


Figure 5.24 Protection glue dispensing.

5.5 LCD Module Assembly

The module assembly process in itself is not complicated. Figure 5.25 shows the assembly procedures for small panels (smart phone), while Figure 5.26 shows the same for large panels (TV).

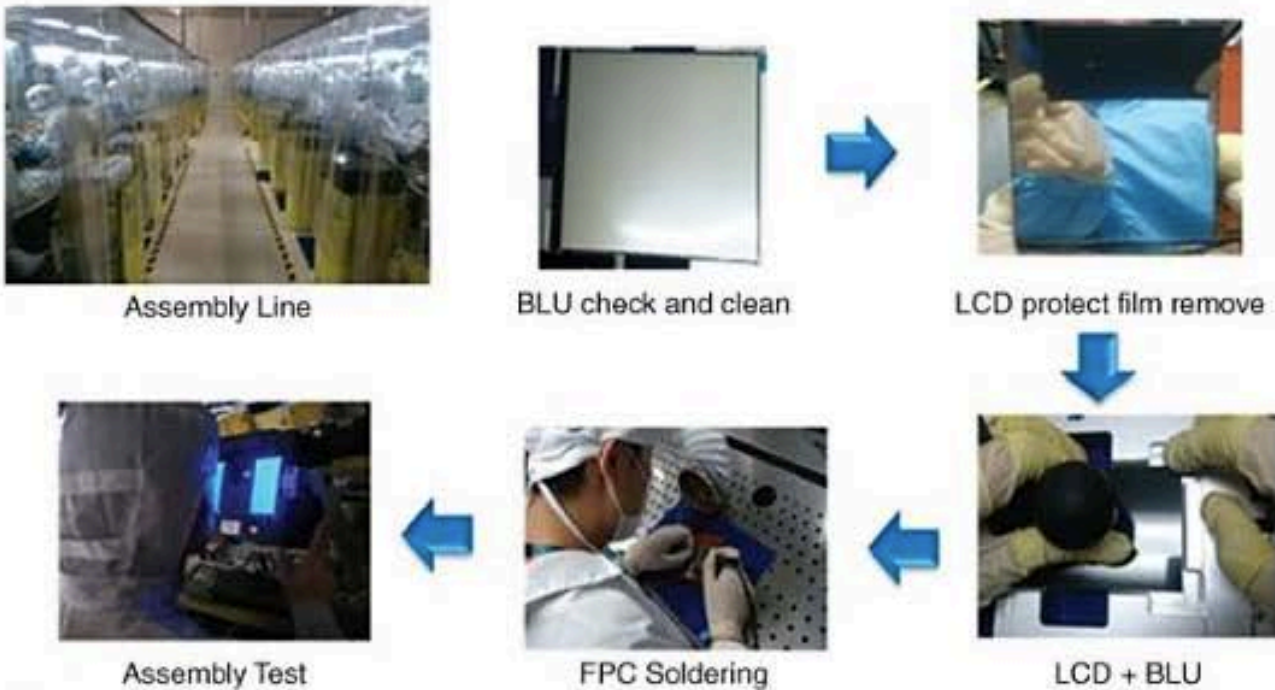


Figure 5.25 Small panel module assembly process [1].

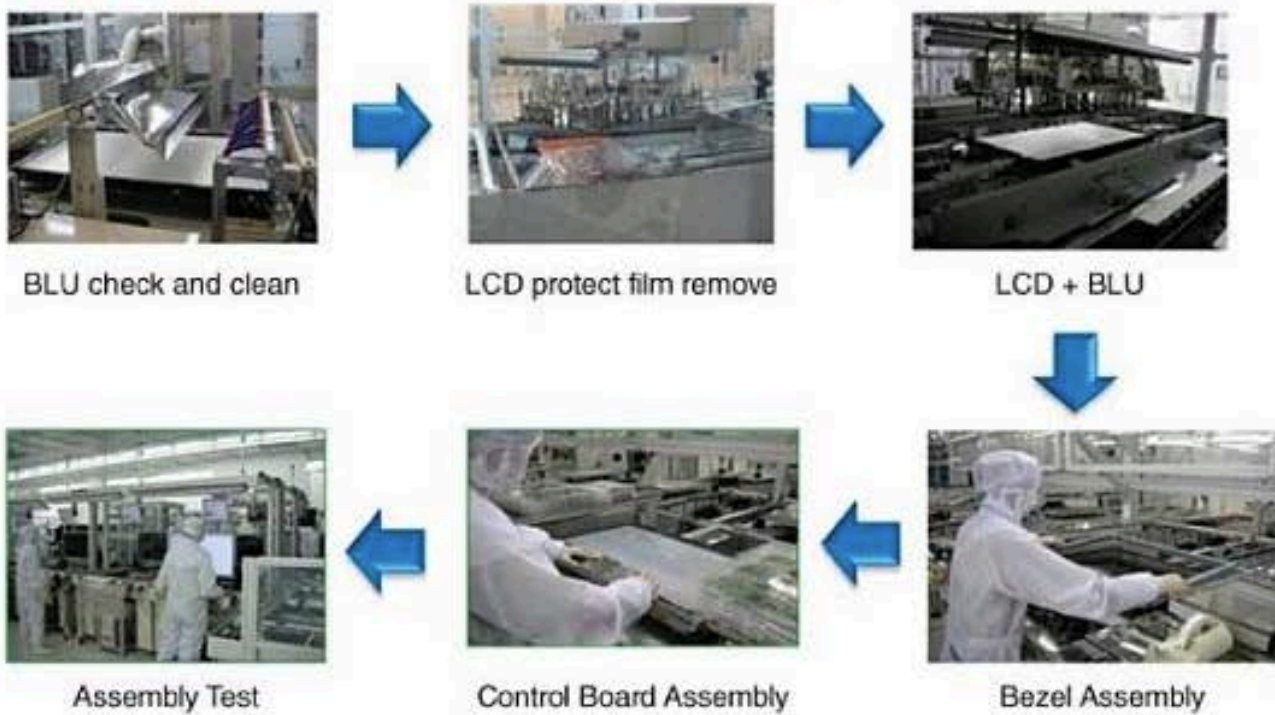


Figure 5.26 Large-panel module assembly process [1].

Since backlight particles represent one of the major defects of LCD module, cleaning and double-checking the BLU quality at the beginning of the assembly

process is sometimes necessary. Furthermore, the environment cleanness, especially at the stage of combing BLU with LCD cell, is one of the key factors for successful module assembly. When removing the protection film on both LCD panel and backlight unit, the speed to rip off the film is also critical—if too fast, it may induce high-static electric voltage and damage the panel circuit or electronic parts. The induced static electric voltage may also attract the particles in the air or on any objects nearby and cause particle defects.

In the early stage for some LCD makers, fully automatic module assembly lines had been used for years. In recent years, thin and narrow border frame design becomes a stylish trend to display modules. Some of the automatic processes, screw fastening for example, cannot meet the requirements for variation and flexibility in assembly by design. They are replaced by human hands and the assembly line becomes semi-automatic.

On the other hand, the small panel assembly lines at most module assembly makers used to be almost entirely based on manual labor in the past. However, mobile phone LCMs have evolved to narrow border or borderless designs as required by customer, and thus combining the LCD panel with BLU presently requires precise positioning and assembly. Assembly by human hand and eyes become critical and not achievable. Thus, such LCM assembly lines have become more and more automatic.

5.6 Aging

Aging is an optional process after LCD module assembly and before final test for shipping. The assembled LCD modules are placed in a high temperature environment for several hours (e.g., 60 °C for 5 hours).

The purpose for aging is to screen out potential defects of circuit parts, potential problems of mechanical and optical parts, and to stabilize the liquid crystal distribution. The process is costly (electricity usage) and time consuming. Since the design and manufacturing of LCD modules have been mature for recent years, this process has become optional for some customers. Figure 5.27 shows some types of aging lines. The design of the aging line depends on panel size and aging condition requirements.



Figure 5.27 Examples of aging lines [1].

5.7 Module in Backlight or Backlight in Module

In recent years, due to the continuously dropping street price of display modules, the profit margin for LCD and component makers becomes critical. It causes all the makers reconsidering the possibility of redistribution of the value chain.

Figure 5.28 shows the LCD module production flow with different combinations. Originally, LCD panel makers produce LCM by themselves with backlight modules input from BLU makers. The BLU makers procure all the components including optical parts and mechanical parts to assemble into backlight modules. This kind of business model induces additional cost that can be avoided. For example, repeated loading and unloading, repeated packing and unpacking, repeated inspection, cost of shipment, cost of over specification, and so on.

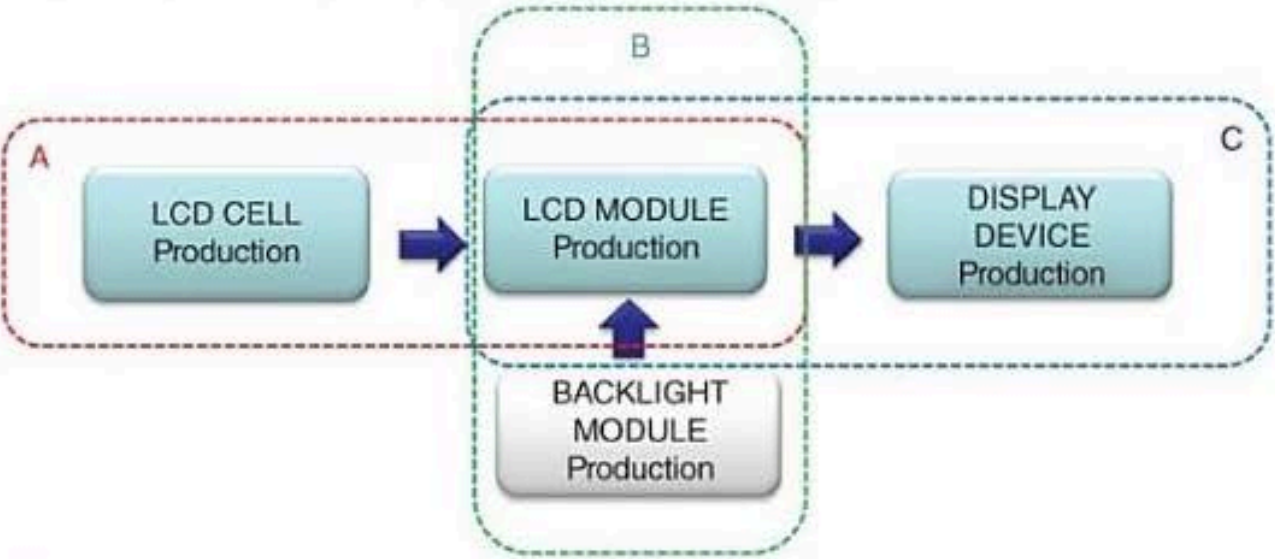


Figure 5.28 Different value chain combinations in LCM manufacturing.

To eliminate the extra costs and enlarge profit margins, in recent years makers have tried to combine the process in either upstream or downstream. Some LCD makers procure all backlight parts and assemble LCMs combining with the JI process. Some backlight makers procure open cells from cell makers as one of the components and manufacture LCMs. Some TV makers own backlight and mechanical parts (plastic, metal) manufacturing and make TV sets.

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- 3 Unpublished Mobile phone product inspection SOP of AU Optronics (Xiamen).

6
LCD Backlights

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6.1 Introduction

Unlike other display devices, TFT-LCD is a non-luminescent device. Therefore, a flat light source module, which is called as backlight unit (BLU), is required and must be assembled under the LCD panel (Figure 6.1(a)). The BLU supplies the LCD panel with bright, two-dimensionally uniform white light, thanks to which necessary output beam profile and uniform light distribution are realized over the display area.

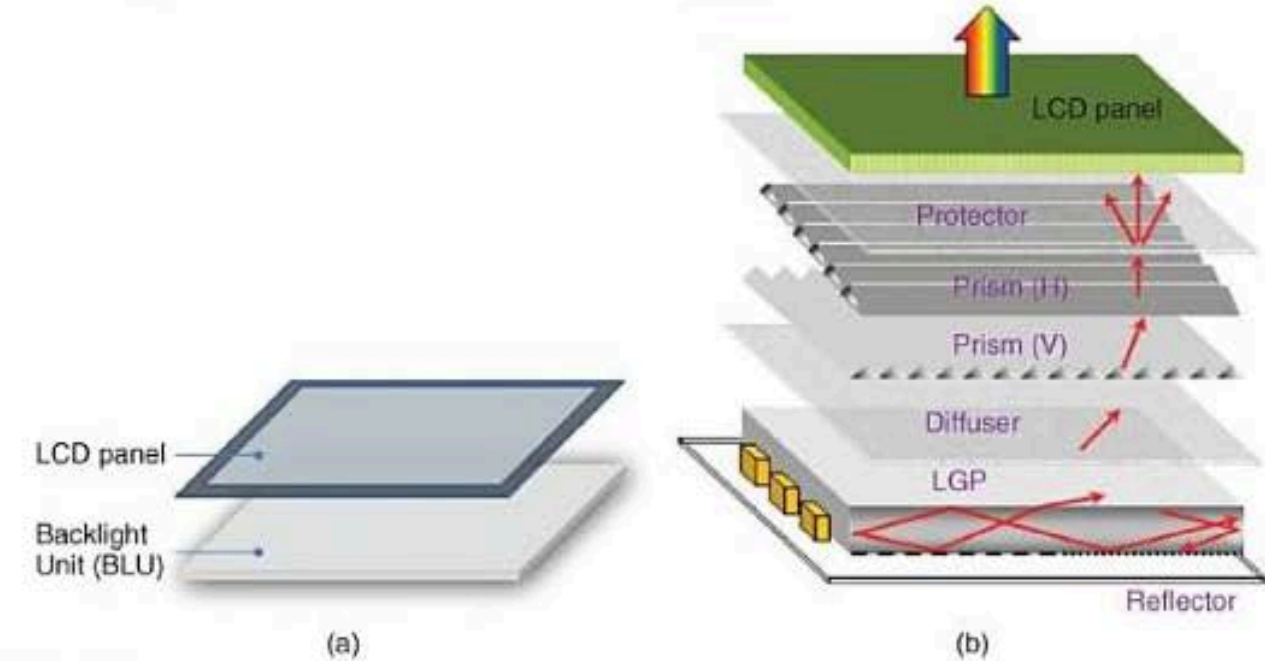


Figure 6.1 A schematic view of a backlight unit (a) and its components (b).

The BLU consists of several optical components, such as LED light source, light guide plate (LGP), and multiple optical films as shown in Figure 6.1(b) [1, 2]. Fluorescent lamps have been used as light sources in BLU during the past decades, but presently most LCD devices use LEDs. Depending on the location of LED, there are edge-lit type and direct-lit type BLU structures. Figure 6.1(b) shows the edge-lit type BLU, where several LEDs are located on the