

Figure 4.1 A simplified LCD cell showing each of the major components.

4.1 LCD Basics

The basic display using liquid crystals is composed of six main components: a polarizing filter, a glass plate that has a transparent electrode pattern, the liquid crystal material, a clear common electrode on glass, a polarizer whose axis is crossed compared to the first polarizer, and either a reflective surface or a light source. Without the liquid crystal between the polarizers, the crossed polarizers would block out the light, making the screen appear dark. Adjusting the voltages on the electrodes changes the amount of twist in the liquid crystal and varies the amount of light passing through. While most of the components of the LCD might be familiar, we will provide a brief overview of each component. A simplified design of a liquid crystal cell is shown in Fig. 4.1.

The structure of the LCD includes the alignment layers in contact with the liquid crystal, the electrical contacts composed of indium-tin-oxide (ITO) (which are transparent), glass layers, and polarizing films. The order of the layers on the glass is shown in Fig. 4.1 as ITO–glass–alignment layer; however, this ordering can be glass–ITO–alignment layer, which can reduce overall capacitance. Display cells have a reflector on the rear side that allows the displays to be used with ambient light. The next sections expand on the function related to each of these components as they apply to the LCD cell.

4.1.1 Polarization revisited

Polarization is a fundamental property of light and, in fact, all oscillating waves. Light waves are actually electromagnetic waves that have both an electric and a magnetic component. The electromagnetic component is a transverse wave and can be thought of as a string vibrating orthogonally to a line joining both ends. The electromagnetic wave is considered to be unpolarized if it is vibrating in more than one plane and is polarized if the

vibrations occur in a single plane. In light, polarization is tied to the electric field rather than the magnetic field.³

The main polarization forms are linear and circular polarization. Light vibrating in a single plane is referred to as linearly polarized, or, if the plane rotates at the optical frequency, it is referred to as circularly polarized or, sometimes, elliptically polarized.¹

Unpolarized light can be converted to polarized light, often, with a loss of intensity. Consider the string introduced above, vibrating in many planes and viewed on end through a thin slit. Every so often, the full oscillation of the string fills the view of the slit; however, the remainder of the time, the slit blocks the view of the string. If the string were a light wave and could pass through the slit, the slit would be acting as a polarizer.

When using two polarizers with their polarizing axes aligned, the light passing through the first polarizer will also be able to pass through the second polarizer. If the angle between the two polarizers is changed, there will be a reduction in the amount of light that can pass through the second polarizer. Complete blocking of the light will occur when the two polarizers are 90 deg to each other.⁴

For the light to pass through two crossed polarizers, something would have to be placed between the polarizers to transform the polarization from one plane to another. This effect is illustrated in Fig. 4.2, where a pair of

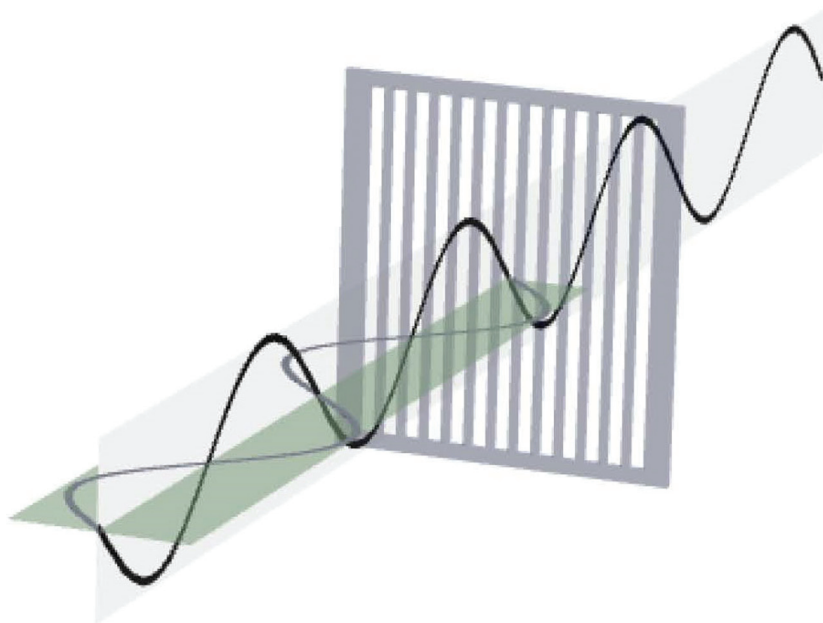


Figure 4.2 Illustration of the “picket fence” model demonstrating how either a single or a pair of aligned polarizers work to pass a single polarization of light.

aligned polarizers and an incoming unpolarized light source allows only a single polarization to pass through.

4.1.2 Twisted nematic effect in liquid crystals

The development of the twisted nematic effect changed liquid crystals from an interesting material to the commercially viable display technology that has virtually replaced all other approaches. The strength of this technology is the combination of optical performance and low-operating-power requirements. The latter is very important in mobile devices and is the result of the LCD not requiring any significant current flow and using low voltage levels.

In a twisted nematic liquid crystal device, the director rotates through an angle from one side of the cell to the other, typically with the exit polarization 90 deg from the input. Light entering a liquid crystal cell with its electric field vector parallel to the director of the liquid crystal will remain parallel to the director as it passes through the cell in a waveguiding effect known as adiabatic following.⁵ When light enters parallel to the director, the setup is known as O-mode operation and provides an exit beam with polarization 90 deg to the input beam. This waveguiding effect also occurs for light entering the cell perpendicular to the director, known as E-mode operation.

The liquid crystal material operates by transitioning between two states controlled by the applied electric field. When there is no electric field, the molecules in the liquid crystal align to provide a light path that rotates the polarization vector of the light. When the electric field is on, the molecules align with the field and do not affect the propagation of light, providing a direct path for the light. This interesting effect is controlled by alignment films on the electrodes that create a preferred alignment of the liquid crystal molecules. As such, a twist can be introduced in the light path that will guide the light between the two polarizers.⁶ The off state is then defined as the state in which light can pass through the liquid crystal. In the on state, the light path in the liquid crystal is not modified and passes straight through, but then is blocked by the second polarizer. This is the principle behind the black segments of a traditional seven-segment LCD. Figure 4.3 illustrates the changes to the liquid crystal that allow the polarized light to pass through.

4.1.3 Backlighting

Liquid crystals do not generate light of their own, so another means of providing light is required to allow the screen to be viewed. The light source can either be ambient light or an artificial light source located behind or to the side of the screen.⁷ In the case of a display using ambient light, a reflector is required to take the incoming light and reflect it back to the viewer; however, such reflectors are also useful in side-lit or back-lit displays.

Ambient light will normally be located in front of the screen, on the side of the viewer. This light can be maximized by placing a reflector behind the LCD

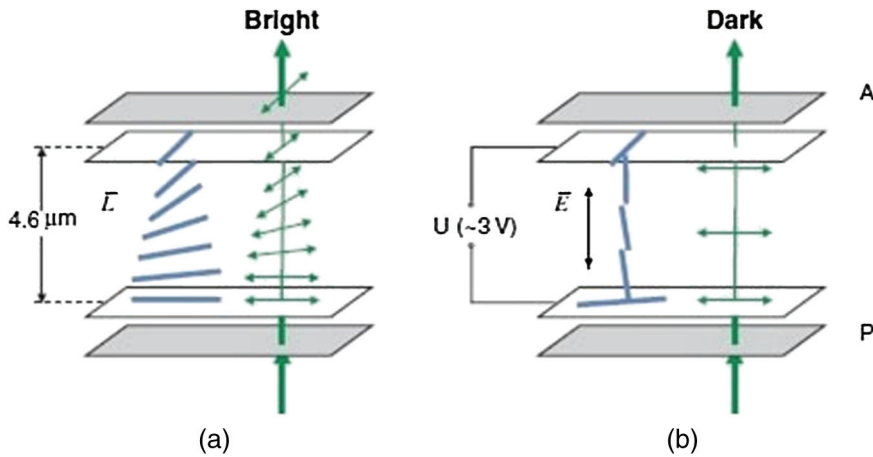


Figure 4.3 Illustration of the twisted nematic cell in which (a) the cell is off and (b) the cell is on. A and P indicated analyzer and polarizer, respectively.

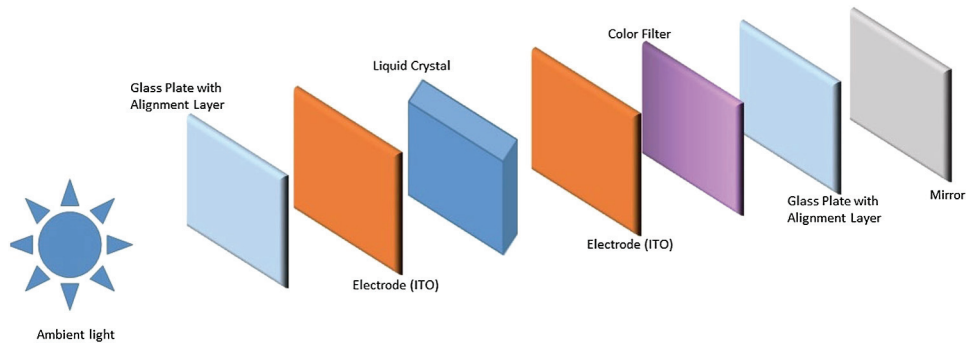


Figure 4.4 A typical front-illuminated display, in which the light source is located on the left and the display is viewed from the left.

to reflect the unpolarized ambient light toward the viewer, as shown in Fig. 4.4.

Artificial light sources can take many forms, such as conventional light-emitting diodes, electroluminescent panels, incandescent light bulbs, or cold, hot or external electrode fluorescent lamps. Electroluminescent panels provide uniform illumination of the display; however, the other sources require the use of a diffuser to provide well-distributed, uniform light for the display. White light is preferred for larger displays, and, typically, colored lighting is only used in small, single-purpose displays.

4.2 Liquid Crystal Operating Modes

The three main operating modes for LCDs are (1) the in-plane switching mode, (2) the vertical-alignment mode, and (3) the twisted nematic mode,

which is currently the most often used. While other operating modes do exist, their commercial viability has not yet been shown. The quest for higher-speed operation and improved viewing angles has led to the development of new and improved operating modes.

4.2.1 Twisted nematic mode

In the basic operation of the twisted nematic mode, the amount of twist of the liquid crystal controls the amount of light that is allowed to pass. When no voltage is applied across the liquid crystal, the twist allows light to pass through the crossed polarizers. Applying a voltage removes the twist from the liquid crystal, directly affecting how much light can pass, and resulting in a change in the intensity of light seen.

The twisted nematic mode is one of the most practical operating approaches and is responsible for making LCD technology viable, particularly for mobile, battery-operated displays. The low operating voltages and extremely low current flow have led to the popularity of LCDs and have almost completely removed the need for cathode ray tubes.

The twisted nematic mode provides good response time and brightness in a structure that is simple to construct. When manufacturing a color display with a large number of pixels, the liquid crystal material is injected between thin films of transistor layers. Such transistor layers provide the data and gate bus structure for the display and pixel electronics. Finally, a black matrix and colored filter layers are added, as well as a common electrode layer. The crossed polarizers complete the LCD. This is illustrated in Fig. 4.3.

The key to the operation of the twisted nematic liquid crystal device is the placement of the alignment layers on the conducting contacts on either side of the liquid crystal material. This forces the 'twist' in the material that allows light to pass through without an applied electrical potential. An applied voltage changes the orientation of the liquid crystal, blocking light from passing.⁷

The twisted nematic liquid crystal technology was developed in the 1960s⁸ but has only recently become a major part of display technology, due in large part to the needs of the mobile computing market. However, the twisted nematic display is not without its issues. It has a long response time to signal changes and works best in a narrow viewing angle. Additionally, it is often noted that color reproduction is not considered very high quality, at least when compared to older cathode ray tube displays.

4.2.2 In-plane switching mode

In-plane switching mode is a technology used to align liquid crystals in a plane parallel to the glass substrates so that, by changing the applied voltage, the orientation of the liquid crystal molecules can be changed or switched in the same plane. In-plane switching mode was developed to overcome some of

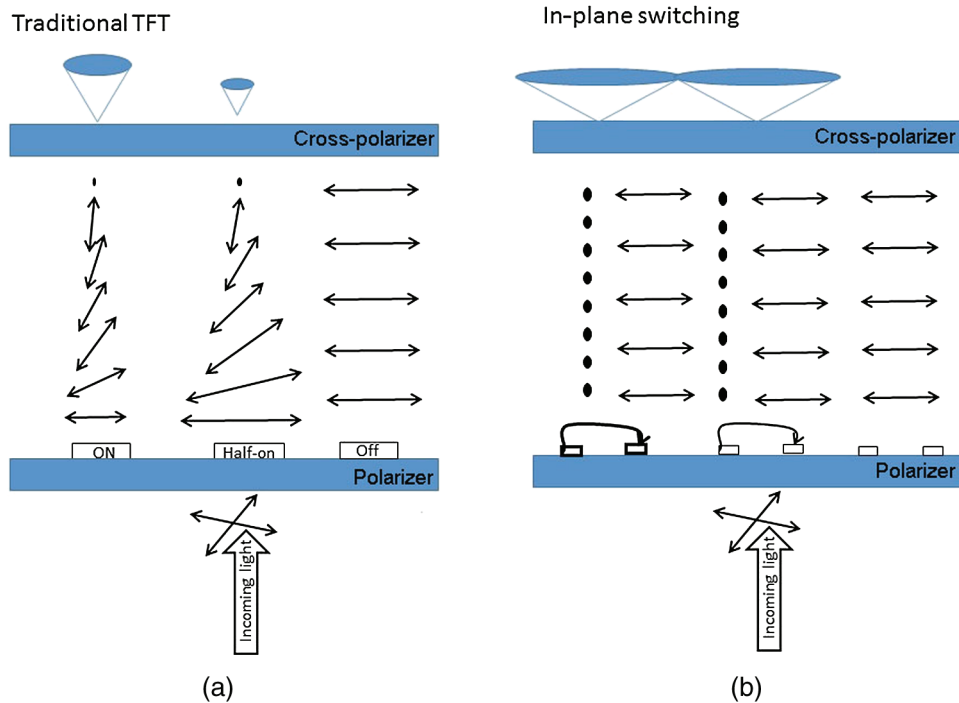


Figure 4.5 Schematic of a traditional LC cell using (a) thin film transistor (TFT) technology and (b) in-plane switching technology. The arrows below the displays show the direction of the incoming unpolarized light.

the problems encountered by twisted nematic LCDs, in particular, the narrow viewing angle. The in-plane switching mode operates by arranging and switching the molecules of the liquid crystal layer parallel to the glass plates, as shown in Fig. 4.5.

The basic idea of the in-plane switching mode display is that the polarizers are oriented in the same plane, and the switching effect is through the liquid crystal molecule's rotation around the axes perpendicular to its length. This is accomplished by the use of interdigitated electrodes on the conducting surface, as shown in Fig. 4.5. In-plane switching displays show good color from all viewing angles and work well in touch-sensitive screens because they do not lighten when pressed. The clarity of the image is improved over the twisted nematic displays, which have a better response time.

4.2.3 Vertical alignment mode

Vertical alignment mode liquid crystals naturally align in a direction perpendicular or vertical to the glass substrate. In this state, with no external voltage applied, there is no effect on the polarization of incoming light such that a darkened display is created when the cell is placed between crossed polarizers. The application of an electric field causes the crystals to tilt away