Structure Operating and Manufacturing of AMLCD Devices

Kada BENCHIKH, Belabbes SOUDINI and Rachid ALLAM

Abstract: This paper provides a state of the art review of Active Matrix Liquid Crystal Display (AMLCD) technology. After a short presentation of market dynamics in display technologies and the interest of LCDs in this field, we develop in more details the structure, operating and manufacturing process of AMLCD devices. The review is illustrated with recent achievements made in the field. Improvements and derivates of the devices are described, limitations inherent to technology and design are mentioned.

Keywords: LCD, pixel, TFT, active matrix, color filter, time multiplexing

1. INTRODUCTION

As the information society develops, demands for various types of display devices increase. Accordingly, many efforts have been made to research and develop various flat display devices such as LCD (Liquid Crystal Display), PDP (Plasma Display Panel), OLED (Organic Light Emitting Diode), and FED (Field Emission Display).

Flat display panel market has generated 74 billion USD in 2005 and should be more than 100 billion USD at the end of 2008. Further, LCD market has been of 60 billion USD in 2005. The trends in 2010, for example, will be of 30 million and 100 million display devices for PDP and LCD respectively.

Among various flat display devices, LCD devices have been used most widely replacing CRTs (Cathode Tube Ray) because of its advantages, such as excellent picture quality, light weight, thin profile and lower consumption. At the present time, CRT devices trend to disappear by overgoing recent display technologies concurrence; OLED devices are used newly including only the small size displays; PDP devices are used for large size displays which are very expensive and LCD devices are in top growth covering all display ranges and upsetting PDP devices for large sizes. Moreover LCD manufacturer are making 8th generation plates (40” to 52”) then reducing the costs for 30% [1]. Particularly, AMLCD devices are used in an increasingly wide variety of products, including consumer electronic, computer monitors, televisions and other communication devices.

A large number of papers related to AMLCD devices have been published and the rate of publications are still growing regularly. We will try to contribute, in this way, with a synthesis work.

It should be understood that the figures, in this paper, are merely schematic and are not drawn to scale. In particular certain dimensions, such as the thickness of layers, have been exaggerated while other dimensions have been reduced.

2. STRUCTURE

Fig.1 shows the structure of a conventional active matrix liquid crystal display device [2], [3], [4], [5] comprising a display panel, a plurality of picture elements (pixel) arranged in a matrix form. Only a few of the picture elements are shown for simplicity whereas in practice, the total number of picture elements (m×n) in the display area may be 200,000 or more. The
pixel array consists of \( m \) rows (1 to \( m \)) and \( n \) columns (1 to \( n \)). Each picture element is associated with a respective switching device such as a thin film transistor (TFT). The gate electrodes off all TFTs associated with pixels in the same row are connected to a common row conductor as gate line. Similarly the same electrodes associated with all pixels in the same column are connected to a common conductor as data line. The drain electrodes of the TFTs are each connected to a respective transparent pixel electrode. The gate lines, data lines, TFTs and pixel electrodes are carried on one transparent plate. A second transparent plate carries the common electrode to all the pixels. The first and second transparent plates are spaced and a liquid crystal is disposed therebetween. Each of the pixel electrodes together with the liquid crystal and the common electrode define a pixel of a LCD device. A pixel is formed at the intersection of a gate line and a data line so as to cross each other. Each pixel electrode has a necessary capacitance [6], [7] between the pixel electrode and the storage capacitance line. This capacitance serves as a storage capacitance. The gate lines are supplied successively with gate signals by a gate driver controlled by regulator timing pulses from a timing and control unit. Video information signals (data) are supplied to the data lines from a data driver. The data driver is supplied with video signals from a video processing unit and timing pulses from the timing and control unit in synchronism with row scanning.

Fig. 2 shows a cross-sectional view of an AMLCD panel. The device comprises [8], [3], [9], [7] a pair of glass or like transparent substrate facing each other and spaced apart by a spacer provided therebetween along the edges. Liquid crystal may be sealed between substrates. Alignment layers, made of polyimide, are formed on the transparent substrates. Formed on the inner surface of lower substrate is a plurality of driving electrodes. TFT layer is formed contiguous to driving electrodes. The drain of the TFT forms the pixel electrodes and the TFT serves as switching elements. Then a color filter with a black matrix and common electrode are sequentially formed on the inner surface of the upper transparent substrate. Three different types of color filters, for example, red filter, green filter and blue filter are formed on the upper transparent substrate in correspondence with the driving electrodes. Further, a transparent passivation layer (not shown) may be added on the color filter and then the common conductive electrode is formed on
the passivation layer for driving the liquid crystal. There is a construction where the common transparent electrode is formed directly onto the color film without the passivation layer. The coloring materials may be deteriorated or damaged when the common electrode is formed. This disadvantage is avoided by forming the passivation layer. Transparent spacers are scattered in the liquid crystal layer held by the two transparent substrates in order to keep the thickness (4 to 9 µm) of the liquid crystal layer uniform. Moreover, a sealing material (not shown) is applied to the surrounding section of the liquid crystal display panel except for a liquid crystal injection port. Furthermore, two polarizing films are respectively set on the substrates. Thereafter, liquid crystal is injected through the liquid crystal injection port, and the liquid crystal injection port is closed with an end-sealing material. Then, packaging members such as a data driver, a gate driver, a control circuit and a backlight are installed, thereby completing the liquid crystal display device. The backlight, for transmission-type LCD, emits an incident light to produce an image by controlling the transmittance of the incident light.

Fig. 2. Cross-sectional view of an AMLCD panel.

Fig. 3 shows an example of the cross-sectional view in the active region of the AMLCD panel. A gate electrode, a gate insulating film, a semiconductor layer, a n+Si layer to be the source and drain electrodes, a metal layer, an interlayer insulating film, and a transparent conductive layer to be the pixel electrode are formed in this order on an insulating substrate. The pixel electrode is connected to the drain of the TFT. In this structure, the interlayer insulating film is formed between the gate line (the same layer as the gate electrode) and the pixel electrode and between the data line and the pixel electrode. Therefore, the pixel electrode can be arranged to overlap the data line. It is known that such an arrangement can improve the aperture ratio, and reduce an alignment defect of liquid crystal by shielding the electric field resulting from the data line.

Fig. 4 shows a structural example of a color filter [10],[7]. Three different types of color filters are formed on a glass substrate, for example, red filter, green filter and blue filter corresponding to the three primary colors. The color filters are arranged as a mosaic, delta or stripe pattern. Any color may be achieved by the primary colors mixing principle. In the case of color display one pixel
is formed by three sub-pixels, i.e., red, green, and blue pixels. For example a panel for displaying a matrix consisting of 800 horizontal pixels and 600 vertical pixels, the number of sub-pixels displayed on one gate line is 2400. The color filter includes a black matrix layer which is a light-blocking layer closing gaps between adjacent color filters. Furthermore, with the provision of light-blocking layer to close the gaps between adjacent color filters, there is no possibility of transmission of undesired light through the gaps between adjacent color filters. Then the black matrix layer serves to avoid blurring of the color at the filter boundary. This promotes the improvement of the contrast and color purity, and hence the image quality.

3. MANUFACTURING PROCESS

TFT switching elements are usually realised with amorphous silicon (a-Si) or polycrystalline silicon (poly-Si) and processing temperatures under 300°C are used. Silicon thin film layer is formed on transparent substrate by Low Pressure Vapor
Chemical Deposition (LPCVD) [8], [11], [5]. Recently, the trend in LCD devices is to higher resolutions at larger sizes. The driving circuits should use thin film transistors having a high mobility as switching devices for high speed switching of video signals. A method for overcoming the switching problem is to use a poly-Si TFT instead of a-Si TFT [5]. More particularly, the poly-Si TFTs are used in the driving circuits, which are integrated into the LCD panel. Also, active layers of the TFTs in the pixel, such as the semiconductor layer, are made of poly-Si, thereby preventing image blur due to slow switching in the pixels. Channel length may be reduced, then decreasing the turn-on time of TFTs and increasing the drain current [9].

Gate electrode, source electrode and drain electrode are made of a metal such as aluminum (Al), chromium (Cr) or molybdenum (Mo) [9], [5]. The driving electrodes and common electrode are made of a transparent conductive material like ITO (Indium Tin Oxide) so as to pass light through there [12], [7]. Driving electrodes have a thickness of 3 to 500 angstroms [9]. Semiconductor layer has a thickness of 0.1 to 0.5 microns. Gate insulating film is made of SiO2 by oxidizing the silicon surface [7] or consists of SiNx and has a thickness of 0.5 micron or below [9]. Suitable insulating film is transparent and has a low dielectric constant. For instance, it is of SiO and has a thickness of 5000 angstroms to 1 micron. Transparent substrate is made from material such as glass, pyrex, quartz or like having comparatively high melting point.

The color filter manufacturing consists as follow. A water soluble organic resin layer, for example polyvinyl alcohol, gelatine, or the like, is formed on a transparent glass substrate. Then, the water soluble organic layer is colored with coloring materials of red, blue and green by printing these coloring materials in an arrangement having a predetermined pattern. As a result, each color filter is formed so as to be arranged in correspondence to each driving electrode (Fig.1). The color filter includes red portions, blue portions and green portions. In addition, a black matrix layer [3], [7] is provided between the color filters by coloring the boundary of each primary color with a black pigment. The black matrix layer [9] may be made of aluminum (Al), or chromium (Cr) with a thickness of 2000 to 3000 angstroms and may be formed by means of deposition or sputtering.

AMLCD devices may be manufactured from a stock of standard blanks and shaped individually as appropriate. A laser may be use in the cutting step of a preformed active matrix device. In AMLCD devices the plates are typically formed of glass, which can be reliably fractured along straight lines using a “scribe and break” technique. However, more complex and/or curved shapes may be more readily cut in glass and other suitable plate materials by utilizing laser scribing [4].

On the other hand, while developing ever larger LCDs several interconnect technologies have been used [12]. Two technologies nowadays are used: TAB (Tape Automated Bonding) and COG (Chip On Glass) which employs wire bonding directly to the display electrodes. Both require metal bumps on top of the IC surface.

COG technology bonds chips directly to the LCD electrodes, by means of bumps, usually grown galvanically on the bond pads of the IC. The extra processing is limited to growing of the bumps and to the bonding of the ICs to the LCD, but packaging of the ICs is removed from the normal production of these ICs. The disadvantage lies in the availability of a high performance bonding process, testability and quality assurance. However, film processing in the COG method requires small number of processes and low cost of materials, compared with the TAB method. Therefore, the COG method is preferably used for small-scale liquid crystal display devices in which smaller number of pixels and lower cost are required to be achieved.

TAB technology operate by growing or transferring bumps on ICs with peripheral contacts, attaching them to a flexible foil and applying the foil to the LCD. This interconnect technology has all the advantages of application flexibility, testability, quality
assurance, reliable low ohmic contacting and high production yield. TAB also has the advantage of reducing the LCD glass size as compared to COG, allowing for larger LCDs from the same substrate.

4. OPERATING

LCD effect is well known [13], [12], [2]. The Twisted Nematic Liquid Crystal (TN-LC) in AMLCD has been arranged so, that in rest both molecular axes parallel to the electrodes gradually rotate over 90° going from one plate to the other opposite plate, and the polarization angle of light passing through, with it. When an electrical field of sufficient strength is applied, the induced dipole LC molecules are aligned perpendicular to the plates, thereby losing the polarizations rotation properties.

The display panel is operated in conventional manner. Light from a light source disposed on one side enters the panel and is modulated according to the transmission characteristics of the picture elements.

Particularly [5], when a scanning voltage is applied to the gate electrode (Fig.1) through the gate line, the TFT is operated so as to apply a data voltage from the data line to the pixel electrode. The data voltage applied to the pixel electrode through the TFT generates a voltage difference between the pixel electrode and the common electrode. The voltage difference changes the arrangement of the liquid crystal between the pixel electrode and the common electrode such that light transmittance characteristics of the pixel are changed. Thus, a visual image can be created with the pixels of an LCD device according to data voltages applied to the pixels.

In other manner, when the TFT turns on, a voltage is applied through the data line to the capacitor and the liquid crystal driving electrode. Then, an electrical charge is stored by the capacitor between opposite electrodes. The electrical charge can be kept for a long time because the current leakage of the TFT and the liquid crystal material is negligibly small. Therefore, a principle duty ratio can be the time of electrical charge retention in the capacitor divided by the time necessary for inputting a data signal [8].

The display panel is driven using the time multiplexing principle as shown, for simplicity in the example of Fig. 5.

This method [14] operates on a row at a time basis by scanning the gate lines sequentially with a gating (selection) signal so as to turn on each row of TFTs in turn and applying data (video) signals to the data lines for each row of pixels in turn as appropriate and in synchronism with the gating signals so as to build up a complete display picture. Using one row at time addressing all TFTs of the addressed row are switched on for a period determined by the duration of the gating signal corresponding to a row time or less during

![Fig. 5. Time multiplexing in AMLCD.](image-url)
which the video information signals are transferred from the data lines to the pixels. Upon termination of the gating signal, the TFTs of the row are turned off for the remainder of the field time thereby isolating the pixels from the data line and ensuring the applied charge is stored on the pixels until the next time they are addressed, usually in the next field period. Referring to figure 1 and figure 5, the gate lines are supplied successively with gating signals by a gate driver circuit comprising a digital shift register controlled by regular timing pulses from a timing and control circuit. In the intervals between gating signals, the gate lines are supplied with a substantially constant reference potential by the gate driver circuit. Video information signals are supplied to the data lines from a data driver circuit. The data driver is supplied with video signals from a video processing unit and timing pulses from the timing and control unit in synchronism with row scanning to provide serial to parallel conversion appropriate to the time multiplexing principle of the panel.

Data driver (Fig. 6), represents the next step in driver IC development for AMLCDs. Data driver is designed around few main functions [11]: data input, data storage, data conversion, data output and the shift register, realizing the serial to parallel conversion. Such functions are performed at the transitions of a clock pulse through the shift register during reading of data. A latch stores the assembled data, where a conversion to the appropriate voltage level occurs.

On the other hand, an exemplary driving method of a color LCD [7] is shown in Fig.7, wherein respective colors R, G, and B of the color filter are arranged in a mosaic pattern. In the video signal, the respective color signals VR, VG, and VB are multiplexed in synchronism with clocks Ø1, Ø2, Ø3. Thus it is necessary that the timing of these clocks Ø1, Ø2, Ø3 correspond with the arrangement of each color filter allocated to the pixel. Referring to Fig.6 and Fig.7, when selecting, for example, the first row, a signal VR is first supplied to the S1 output of the shift register (Fig.6) in synchronism with the clock signal Ø1. Second, a color signal VG is supplied to the S2 output in synchronism with the clock signal Ø2. Third, a color signal VB is supplied to the S3 output in synchronism with the clock signal Ø3. Thus, it is necessary to shift the clock signals Ø1, Ø2 and Ø3 going from one row to the next row in order to supply one of the three primary color signals to each driving electrode in correspondence with the three primary color filters arranged in the mosaic pattern.

![Circuit diagram of a data driver.](image)

**Fig. 6.** Circuit diagram of a data driver.
5. CONCLUSION

Some improvements have been achieved in AMLCD devices and are listed as follow. LCD color filters are sized to prevent incident light leakage between pixels by means of a black matrix. The signal lines may be formed in any number of layers that may have a grounding line in between some or all of the layer to reduce the non-active or non-display area of an AMLCD panel. Further, by reduction of the channel length as well as the on-resistance and parasitic capacitance of TFTs, the switching speed and drain current increase, so an image display of high contrast and satisfactory image quality can be obtained.

On other hand, recent innovations in plate formats, layer disposition steps and photolithography together with processing interconnect technology have positioned the AMLCDs as dominant leader in the display market, by a progressive decreasing of device costs, covering a wide variety of products such as portable devices and monitors for computers and TV.

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Kada BENCHIKH
Department of Electronics
University of Sidi-Bel-Abbes (Algeria)
E-mail: k_benchikh2002@yahoo.fr

Belabbes SOUDINI
Rachid ALLAM
University of Poitiers (France)
E-mail: allam_rachid@yahoo.fr

BIOGRAPHY

Kada BENCHIKH was born in Sidi-Bel-Abbes, Algeria, in 1955. He received the Eng degree in Electronic Engineering from USTO University (Algeria) in 1980, the MS degree in Microelectronic from University of Sidi-Bel-Abbes in 1992. He is currently professor of Electronic at the University of Sidi-Bel-Abbes. His current research interests includes display technologies, flat panel displays and microelectronic.

Belabbes SOUDINI was born in Sidi-Bel-Abbes, Algeria, in 1963. He received the Eng degree in Electronic Engineering from USTO University (Algeria) in 1988, the MS degree in Microelectronic from University of Sidi-Bel-Abbes in 1990 and the PhD from the University of Sidi-Bel-Abbes in 1995. He is currently professor of Electronic at the University of Sidi-Bel-Abbes. His current research interest includes materials sciences, microelectronic and optoelectronic.

Rachid ALLAM was born in Oujda, Morocco, in 1955. He received the Dipl. Eng degree in Electronic Engineering from USTO University (Algeria) in 1980, the Docteur-Ingenieur in 1984 from the University of Lille (France). Currently, he is professor of Electronics at the University of Poitiers (France). His current researchs concerns microwave mixers, nonlinear CAD and millimeter-wave MMICs.