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DISPLAYS

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A short review is given on new display technologies such as plasma, liquid crystals, light emitting diodes, electroluminescence and electrochromism. It is stated that thin or thick film or hybrid techniques are essential for all the different types of display. Comparing the performance data of displays the advantages, disadvantages, appropriate applications and future developments are described. Finally the display market and its growth are discussed briefly.

1. INTRODUCTION

In the field of new optoelectronic displays many physical principles are used and various different technologies are employed. Probably the only feature common to all display technologies is that thin or thick film or hybrid techniques are essential for all the different types of display. These techniques are used for both the manufacturing of the display-cell and for assembling with the driving circuitry.

Let us first classify the optoelectronic displays according to a simple but important consideration for the user: the availability (Table I). The present paper will review the state of the art and recent developments with commercially established displays and with engineering models.

Cathode ray tube (crt) displays, which are still predominant among display devices with a medium to high information content are not treated in this review. The only vacuum devices mentioned are vacuum fluorescent displays which are flat triode tubes with electrons exciting phosphors at the anode.

Under research and development are displays using a variety of physical effects, such as electrolytic, electrophoretic, magnetic, ferroelectric, electrostatic and piecoelectric. Which of these approaches will finally be adopted depends on the solution of remaining problems.

TABLE I
State of the art of display technology (availability)

Commercially established	Engineering models	Under research and development
CRT displays Vacuum fluorescent displays Plasma displays Liquid crystal displays LEDs	Electroluminescence Electrochromic	Utilization of large variety of physical effects

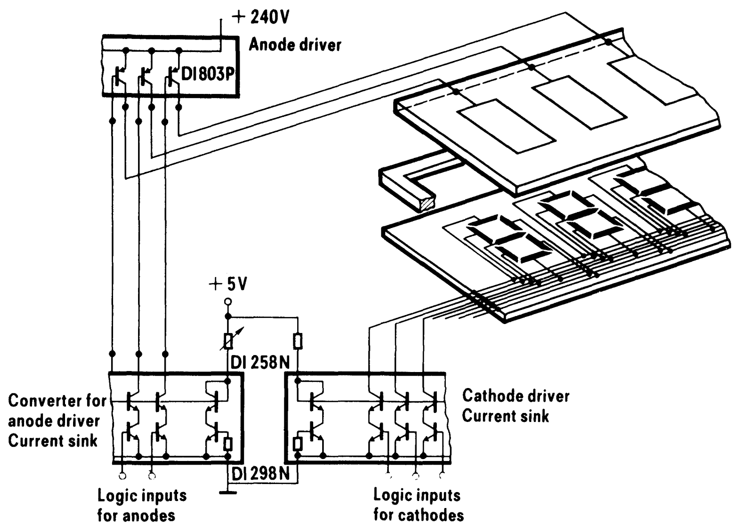

FIGURE 1 Seven segment dc multiplexing plasma display.

2. PLASMA DISPLAYS

Plasma displays use numerous short gas discharge paths between two glass plates for the display of alphanumerics. The discharges are always triggered at the intersection of two selected conductors.

The numeric display shown in Figure 1 is intended for applications where only a relatively small information content is required. The segmented cathodes are deposited, for instance, in thick film technology on a substrate.[1] The transparent anodes (ito = indium tin oxide) are on the front panel. The two substrates are glass sealed using a common spacer frame.

As the gas discharge is either on or off half selection is readily possible and the addressing is done in a multiplexing mode.

Also driven in a multiplexing mode are dc[2] and ac[3,4] matrix displays intended for a higher information content. In Figure 2 the general configuration of an ac plasma panel is shown. The conductors are either made in thick film technology or, preferably, because of the high resolution required, in thin film technology.[2] Typical are 512 horizontal and 512 vertical lines with a pitch of 0.4 mm. The conductors are coated with a dielectric film that stores capacitive charge thus storing whatever information is written in, thereby obviating the need for an external memory.

AC plasma matrix displays offer a number of technical and ergonomic advantages such as complete freedom from flicker. But they are still too expensive – due mainly to their rather complicated drive circuitry.

3. LIQUID CRYSTAL DISPLAYS

At present, all practical liquid crystal displays (lcd) use twisted nematic cells (tnc),[5] the construction of which is shown in Figure 3.

The liquid crystal is sandwiched as a thin film with a thickness of typically 10 μm between two glass plates whose inner surfaces are coated with a transparent electrode film

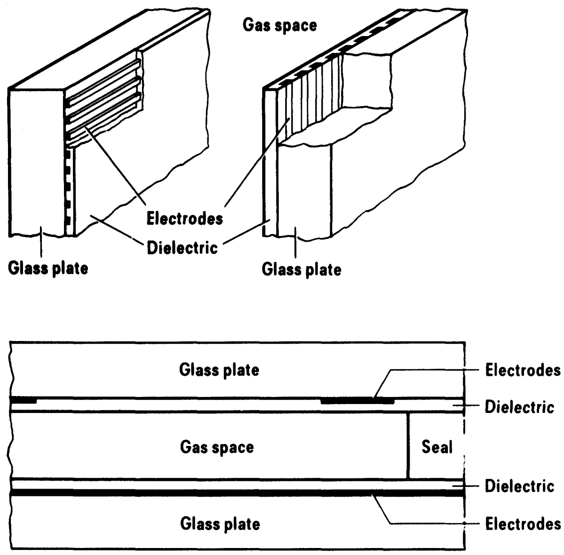

FIGURE 2 AC plasma display.

of indium tin oxide (ito), into which the geometrical structures required for the display are etched. Thick film painting or photolithography are used for masking, depending on the resolution required. The liquid crystal molecules are arranged parallel to the two substrates, their orientation twisting by 90° from substrate to substrate. The uniform orientation of the liquid crystal molecules at the substrate surfaces is achieved either by rubbing an organic film or by oblique evaporation of SiO.

The cell placed between two crossed polarizors is transparent because the liquid crystal molecules rotate the polarization plane of the light by 90°. An applied electric field will orient the molecules parallel to the electric field so that no rotation of the polarization plane occurs and the display will absorb light. With this mode of operation dark alphanumerics appear on a light background. As lcds operate in a field effect mode the electric current is extremely small and resistances of the electrodes (ito) are rather large. The most frequently applied technique for providing contact to lcds is therefore via defor-

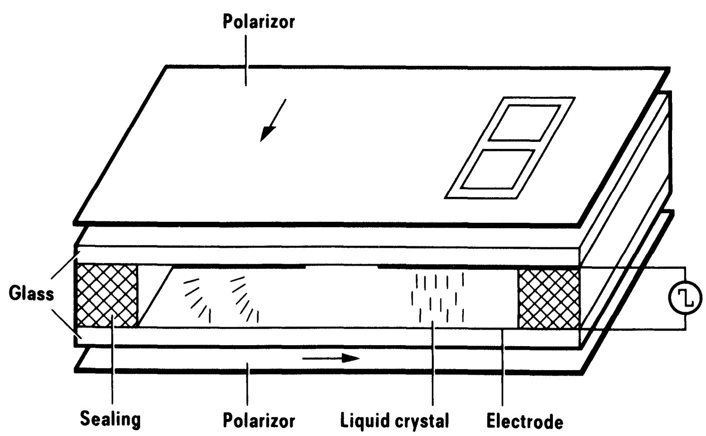

FIGURE 3 Liquid crystal display (twisted nematic).

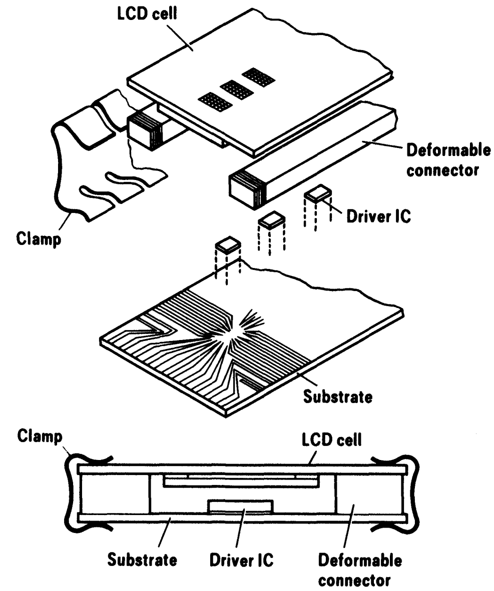

FIGURE 4 LCD cell/hybrid driver substrate assembly.

mable connectors. Figure 4 shows the assembly of a sophisticated dot matrix lcd and the driver substrate carrying the integrated CMOS-circuits.[6] The driver substrate is usually a PC board but it may also be a thick film multilayer.

In some new areas of applications for lcds, particularly in automobile dashboards, the environmental conditions are very severe. Therefore development work is underway to mount the driver IC's directly onto the lcd. As the multiplexing capability of lcds is rather limited attempts are being made to drive lcds by an active matrix, which means that at each picture element there is a transistor which acts as a switch (Figure 5). With these transistor realized on a silicon substrate[7] the size of the display is limited and it has to be operated in a reflective mode. These disadvantages do not exist with thin film transistors (tft),[8] but tfts have not yet been developed to the point where fabrication can begin.

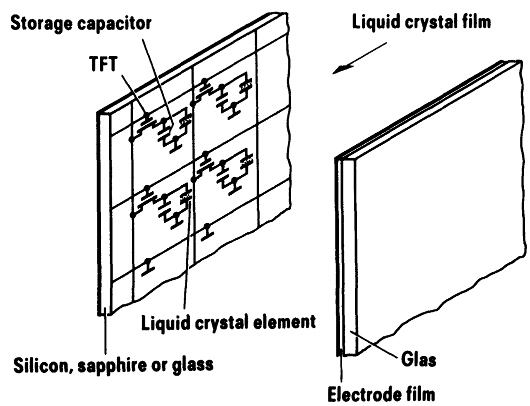

FIGURE 5 Configuration for directly driving the picture elements of a liquid crystal film via an active matrix.

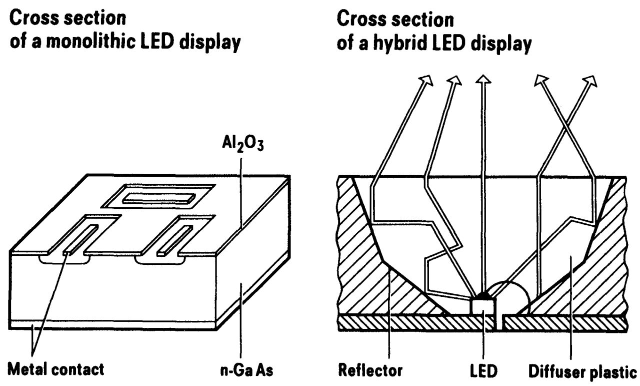

FIGURE 6 LED displays.

4. LED DISPLAYS

LED displays[9] are semiconductor devices which emit light by the recombination of electrons and holes in the pn junction of a semiconductor chip (Ga $As_{1-x}P_x$).

Alphanumeric displays are either of monolithic or hybrid design (Figure 6). The monolithic type is commonly used in small displays, for instance in pocket calculators. The semiconductor chip for one character has 7 or 16 segments or 5 × 7 dots, each of which can be separately driven. The front of the display is covered with a plastic lens for better readability. Hybrid displays as used, for instance, in measuring instruments have a separate led for each segment. A reflector and a diffuse scattering plastic direct the light such that a light bar appears.

LEDs are not well suited for large flat panels with a great number of picture elements, because of power and cost requirements. Nevertheless automatic fabrication techniques have been developed for devices such as that shown in Figure 7, which might be of importance for special applications. Displays with up to 38,000 picture elements have been built with such techniques.[10]

LED displays have found such widespread application because they operate with low voltages, possess IC compatability, allow multiplexing and are both reliable and rugged.

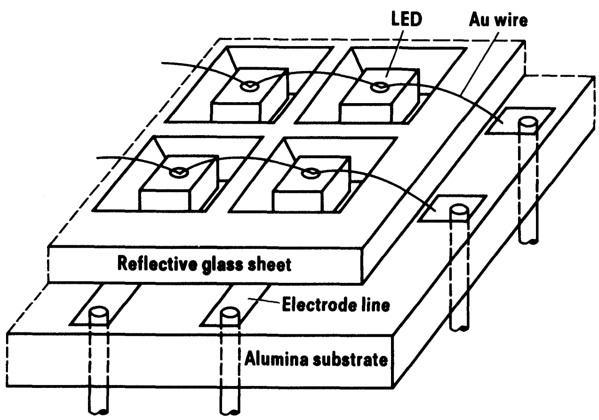

FIGURE 7 LED flat panel.

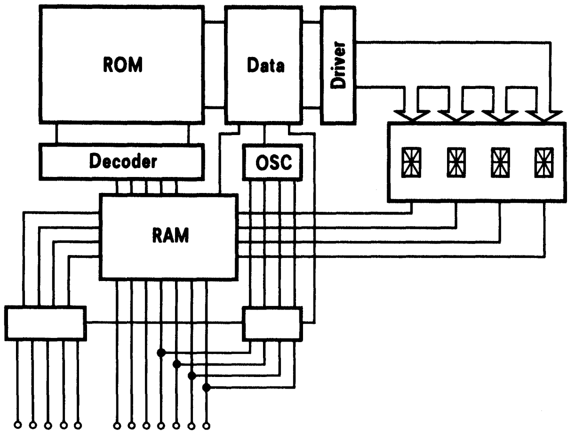

FIGURE 8 Intelligent LED display.

Since orange, yellow and green leds are available in addition to the conventional red, multicolor displays are readily implanted with leds. Although blue leds have been realized in the laboratory their efficiency is still too low for practical purposes. Intelligent displays are a recent development trend. These are a combination of the display and the driving circuitry into one unit in which the lsi circuitry contains not only drivers and decoders but also memories (Figure 8). Such modules can readily be used together with a microprocessor.[11]

5. ELECTROLUMINESCENT DISPLAYS

Electroluminescent (el) displays rely for their operation on a physical mechanism similar to that of leds. Whereas the semiconductor used for leds is a single crystal, that used for el-displays is in polycrystalline form.

EL displays are classified according to their technology-powder or thin film and drive voltage–dc or ac. Most promising is the thin film ac version,[12] the basic design of which is shown in Figure 9. The vacuum deposited active film (eg manganese doped ZnS) is sandwiched between two similarly deposited insulating films (eg Y_2O_3) used primarily to protect it from moisture. The sandwich is stacked on a glass substrate with transparent conductors (ito). The back electrode is metallic (eg Al). The light emitted by ZnS:Mn is of yellow color. A commercialized ac el matrix display has 12 x 40 characters (engineering model). Although other colors can be realized by choosing other materials, the efficiency is inferior and too low for practical purposes. Development work is being done to improve it. Work is also underway to decrease the required operating voltage.

Progress concerning the quality of the ZnS-films has been achieved recently by applying a special evaporation process called atomic layer epitaxy.[13] Alternate layers of zinc and sulphur are evaporated onto a hot substrate so that monolayers of Zn or S are absorbed only. This leads to ZnS films free of defects.

6. ELECTROCHROMIC DISPLAYS

Electrochromic displays (Figure 10) use the transition from the transparent to a deep blue state which occurs when an electric current is passed through a material such as

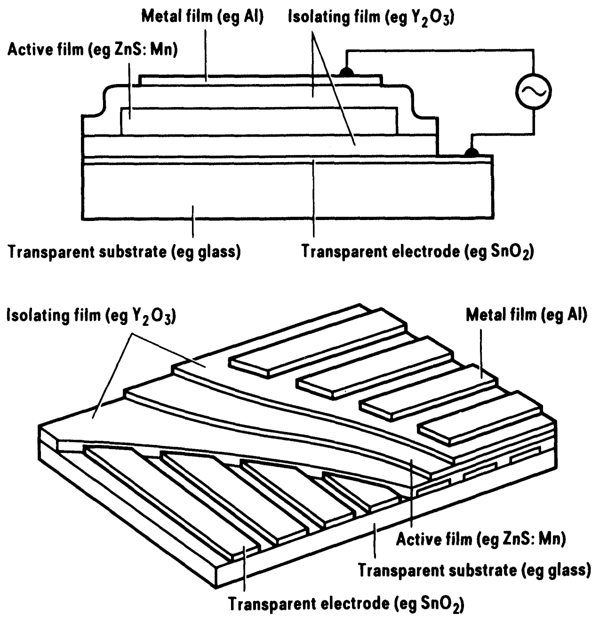

FIGURE 9 AC-electroluminescent-display.

deposited tungsten oxide.[14,15] The blue still persists after the current has been removed, which means that the display is capable of storing information. The transparent state is restored by reversing the polarity of the current.

The thin WO_3 film must be in physical contact with an electrolyte. The light absorp- is changed due to the formation of hydrobronze according to the reaction $nH^+ + WO_3 + e^- \rightarrow H_nWO_3$ where H^+ derives from the electrolyte and e^- from the transparent electrode.

The interest in electrochromic displays is great because they provide a high contrast image, allow a broad viewing angle range, require a supply voltage of only 2 V and possess

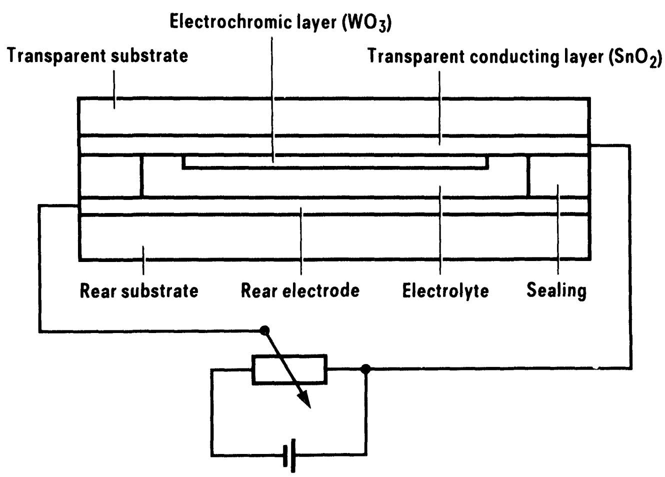

FIGURE 10 Underlying principle of electrochromic display.

TABLE II
Performance data of displays

Property	LED	Vacuum fluorescence	Plasma	LCD	Electro-luminescence	Electrochromic
Operating voltage (V)	2	24	approx 250 approx 50	3	200	2
Power (mW per numeric approx 12 mm in height)	140	100	50	0.005	75	5
Operating temperature range (°C)	−55 to +85	−10 to +55	0 to +60	−15 to +80	0 to +45	
Switching delay (s)	100 ns	<50 μs	10–20 μs	100 ms	1 μs	200 ms
Multiplex performance	very good	very good	very good	possible	very good	
Contrast	dependent on illumination			⩾10	depending on illumination	⩾10
Information content	small	small to medium	small to large	small to medium	medium	small
Surface area	small to medium	small to medium	small to large	small to large	medium	small to large

information storage capability. The lifetime problem has however not yet been satisfactorily solved and a multiplexing solution is also still needed.

7. COMPARISON OF DISPLAY PROPERTIES

Table II lists various significant properties of the above optoelectronic displays, so that comparisons can be made. It is obvious that leds and vacuum fluorescent displays are suitable for displays of moderate size that have to handle relatively little information. Plasma displays on the other hand can be used for handling a large amount of information, the operating voltage is, however, rather high. The outstanding properties of liquid crystal displays are their extremely low power consumption and the independence of their contrast of the ambient light conditions. A drawback of electroluminescent displays is their rather high operating voltage, whereas electrochromic displays cannot be multiplexed.

The requirements which have to be met by displays are so diverse that there can be no ideal all purpose display. The question of which is the best display can only be decided for each particular application. Consider for example just one feature of a display: its information content (Table III). It is obvious that the new optoelectronic displays will mainly be chosen for applications requiring only a small information content. Nevertheless there is a marked trend towards displays with a medium information handling capability. Among the new displays only plasma displays have so far found acceptance for applications in which large information content is required.

In the laboratory however a variety of approaches[16] are being explored for the development of data and video flat panels with high information content. Why is success so difficult in this sector? It is obviously difficult to meet the technical standards of cathode

TABLE III
Information content of displays

Information content	CRT displays	Vacuum fluorescent displays	LED displays	Plasma displays	LCD*	EL displays	EC displays
Small (up to approx 10 000 pixels)							
Medium (from approx 10 000 to approx 100 000 pixels)							
Large (from approx. 100 000 to approx 1 000 000 pixels)							

*Also a large information content in projection mode

ray tube displays in all points, quite apart from economic comparisons. This does not imply resignation. The day will come when flat color television panels become available. But before this is possible a number of physical, technological and economic problems must be solved.

Diagram 1 finally shows what we are talking about from the market point of view.[17] The world market for displays was 1350 millions of Deutschmark in 1978 and is expected to be 2800 Deutschmark in 1985.

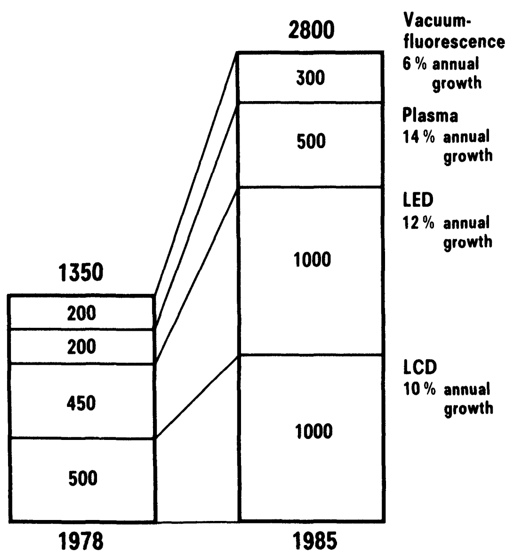

DIAGRAM I

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