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Computer Display Industry and Technology Profile

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1.0 Introduction

Since World War II, cathode ray tube (CRT) electronic displays have played an increasingly important role in our lives, with televisions and personal computers being the primary applications. In the 1970's, the liquid crystal display (LCD) became popular in wristwatches and calculators. In the early 1980s, Epson introduced the first portable computer with a monochrome LCD display, followed soon by LCD monitor displays from Tandy and Toshiba. These electronic displays are commonly referred to as flat panel displays (FPDs).

There are now a number of flat panel displays (FPDs), each providing particular advantages for a given application. Appendix A[1] provides an overview of LCD and other FPD technologies. The LCD is by far the most common type of FPD, and currently is the only FPD used in commercial computer monitors, which includes laptop monitors. Computer monitors constituted approximately 54.7 percent of the $13.9 billion LCD market in 1997, and are predicted to increase to 67.4 percent of the $31.5 billion market in 2001.[2] LCDs comprised 87.6 percent of all FPD applications in 1997, and are expected to drop only slightly to 85.8 percent in 2003.[3] LCDs have greatly increased in number, type, and applications, including growth in the desktop monitor application. LCD desktop monitors, although not yet numerous in the commercial sector, appear to be a likely replacement technology for CRTs. Therefore, the potential for high market penetration and an increased LCD material volume is significant.

Concern over the environmental impact associated with the manufacture, use, and disposition of electronic products has emerged in recent years. These concerns have been driven in part because computer manufacturing requires the use of some toxic materials that may pose occupational and environmental risks. Concern has also been raised by the

[1] Socolof, M.L., et al., *Environmental Life-Cycle Assessment of Desktop Computer Displays: Goal Definition and Scoping,* (Draft Final), University of Tennessee Center for Clean Products and Clean Technologies, July 24, 1998.

[2] Stanford Resources, presentation at the 1998 United States Display Consortium (USDC) Business Conference, San Jose, CA.

[3] Ibid.

growing numbers of consumer electronic products in the marketplace, creating an increasing volume of end-of-life (EOL) materials and some calls for changes in EOL management, especially in Europe. Producers, customers, legislators, regulators, and municipalities are interested in examining the resources used to produce and use these products, and in reducing environmental impacts throughout the entire computer product life cycle, especially during disposition at EOL.

In the consumer realm, CRT displays in televisions and computers dominate in terms of material volume, while LCDs found in household equipment (e.g., microwaves, stereos) and consumer items (e.g., watches, cell phones, pagers) dominate in terms of number of displays. Looking at all electronic displays in terms of material volume, it is helpful to analyze three categories separately. The largest displays (>40-inches) are generally in projection format, and thus consume relatively small material volumes; they are also produced in relatively small unit volumes. The smallest displays (<5-inches) are produced in large volumes (over 1.6 billion units in 1998), but tend to be part of larger systems (appliances, stereos) and so are a relatively small part of the overall material volume. It is in the middle sizes (5- to 40-inches) that the display material volume is a large fraction of the system, and unit volumes are significant.

In order to assess environmental impacts of both CRTs and LCDs during manufacturing, use, and disposition stages, the United States Environmental Protection Agency Design for the Environment (DfE) Program formed a voluntary partnership with the display industry. The goal of the DfE Computer Display Project is to study the life cycle environmental impacts of CRT and LCD desktop computer displays, and generate data that will assist the display industry to make environmentally informed decisions and identify areas for improvement. The selection of these two types of displays was based on potential end-of-life material volume, widespread use, and the ability to compare two display types with the same functional unit—desktop computer application.

The purpose of the Computer Display Industry and Technology Profile is to provide an overview of the CRT and LCD computer monitor markets and technologies. Section 2.0 presents a market profile based on currently available data. The profile is not an exhaustive market assessment, and does not intend to imply preference to one technology type. Section 3.0, Technology Profile, presents an explanation of the basic operation and manufacturing of CRTs and thin-film transistor (TFT) -LCDs to readers relatively unfamiliar with the topic.

2.0 Industry Market Profile

2.1 Computer Monitors: Volume and Technology Trends

Virtually a one-to-one ratio exists between the number of computers and the number of displays in the marketplace. Because the world market for computers has grown so rapidly, a corresponding increase in displays can also be expected. Sales of personal computers (PCs) are expected to continue to grow beyond the year 2000. Many PCs will be desktop systems. ADI Corporation estimated worldwide demand for PCs at 66 million units in 1996, growing to 86.63 million in 1998, and over 100 million in 2000.[4] Desktop applications make up most of these sales.

The United States has been a major market for computers. The U.S. Bureau of the Census estimates that in 1993, 43.2 percent of the U.S. working population used a computer at work, compared with 34.8 percent in 1989 and 23.2 percent in 1984. Also in 1993, 22,605,000 households owned a home computer, up from 13,683,000 in 1989, and 6,980,000 in 1984.[5]

2.1.1 CRTs

The computer monitor has been one of the two largest applications for CRTs; the other has been television. According to a report published by Fuji Chimera Research, the 1995 worldwide market for monitor CRTs was 57.8 million units, 28 million of which (48.5 percent) were consumed in North America.[6] According to the same source, 1996 worldwide CRT monitor demand increased to 67.1 million units.[7] Stanford Resources reports that the CRT monitor market reached 84.2 million units in 1997 (25.6 million in the United States), and anticipates a worldwide growth to more than 100 million units in 2002, reaching 113.5 million in 2003.[8]

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4 *Nikkei Microdevices' Flat Panel Display 1997 Yearbook,* Nikkei Business Publications, Inc., p. 98.

5 "Computer Use in the United States: October 1993," U.S. Bureau of the Census, Current Population Reports, Special Series P-23.

6 *The Future of Liquid Crystal and Related Display Materials,* Fuji Chimera Research, 1997, p.12.

7 Ibid.

8 Stanford Resources, Inc., web site.

In order to keep pace with more demanding computer applications, CRTs have been continually improved: larger screen sizes, higher resolution (for Windows, Macintosh OS, and Web-page font challenges), and higher luminance (for videos). This improvement is likely to continue, as the market moves away from sales of smaller (14-inch and 15-inch) monitors, toward 19-inch and 21-inch monitors. Features that were once accompanied by a high price tag are becoming more standard. Reduced dot pitch; color matching; flatter, lighter weight, touch-sensitive screens; and digital cameras are some of the new offerings at lower prices. This is due, in part, to an increased number of CRT suppliers in the marketplace and improvements in technologies, such as aperture grille, Invar shadow mask, and the flatter Trinitron CRT.

The marketplace is seeing other changes in CRTs, such as shorter necks that reduce the depth by at least three inches on a 17-inch monitor. DisplaySearch reports that while a wider deflection yoke angle enables this development, it causes problems with focusing, which may require more circuitry to resolve. A number of companies have recently released new monitors, many in the 17-inch and 19-inch range.

2.1.2 LCDs

Although market analysts predict growth in the CRT monitor market through the first few years of the 21st century, it is widely anticipated that after that point, LCDs will begin to erode the CRT stronghold. Although the portable computer is currently the major application for LCDs, industry analysts expect this technology to increasingly penetrate the desktop monitor market, particularly in the 15-inch to 20-inch range. Industry experts anticipate that by 2000, LCDs will have captured 5.4 percent of the monitor market. The United States is a primary market for LCD monitors, and will grow into an even stronger market by the end of the century. NEC estimates that the United States will receive over half of the forecasted 6.4 million LCD monitors shipped in 2001 (see Figure 2-1). DisplaySearch also forecasts that the United States will constitute 30 percent of the worldwide LCD monitor market in 2001, with total LCD monitor sales of 7.7 million units. DisplaySearch predicts a worldwide LCD monitor market of $4.2 billion by 2000.[9]

[9] *DisplaySearch Monitor*, April 1997.

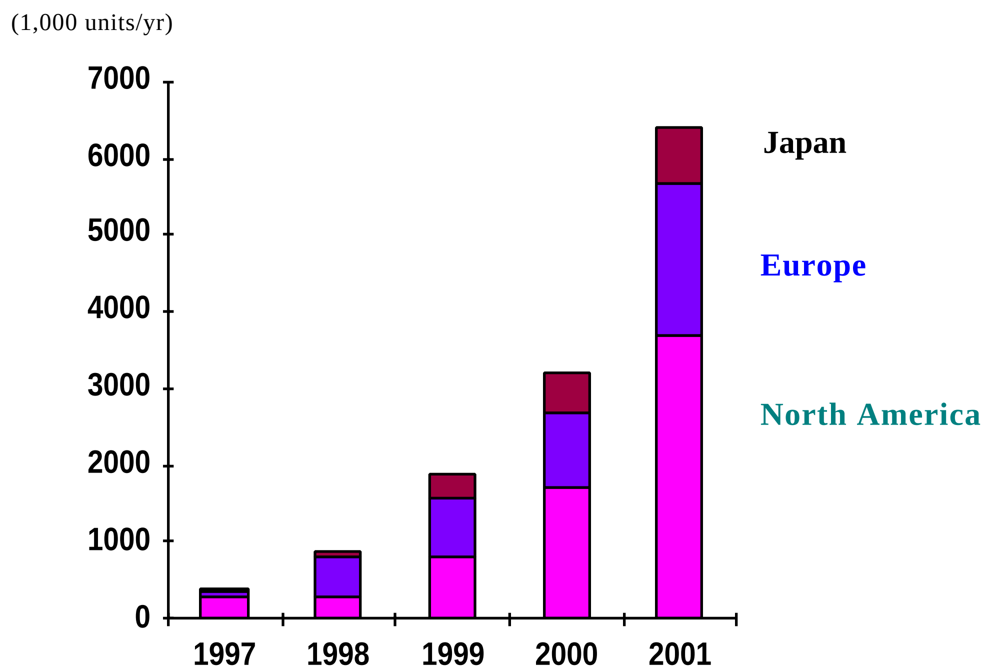

Figure 2-1: LCD Monitor Forecast[10]

LCD monitors are primarily active-matrix LCD (AMLCD), most of which are thin-film transistor (TFT) structures. Super-twisted nematic (STN), a passive-matrix LCD (PMLCD) technology, competes in some areas with AMLCD. Although some monitors are based on an STN structure, STN-LCDs are primarily found in electronic organizers and measurement devices. While STN-LCDs offer a cost advantage over TFT-LCDs, prices for the latter technology have been dropping. DisplaySearch reports that the TFT market will grow from $4.87 billion in 1996 to $13.7 billion in 2000, whereas the STN market is expected to drop slightly from $4.3 billion to $4.2 billion during the same time period.[11]

At Computex Taipei '97, a leading computer exhibition, over 20 companies displayed more than 100 models of LCD monitors.[12] A number of companies promoted both AMLCD and PMLCD monitors. More recently, DisplaySearch reported that over 180 LCD monitors are marketed by 50-some companies, 81 percent of which use thin-film TFT-LCD technology,

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[10] *Nikkei Microdevices' Flat Panel Display 1998 Yearbook*, Nikkei Business Publications, Inc., p. 80.

[11] *DisplaySearch Monitor*, April 1997.

[12] *Information Display*, Official Publication of the Society for Information Display, October 1997, p. 37.

and 19 percent of which use STN technology.[13] According to DisplaySearch, TFT-LCD monitor shipments will grow from 1.1 million in 1998 to 13.1 million in 2002.[14] Between 1998 and 2001, the 15-inch display is expected to make up the greatest share of these monitors.[15]

Currently, the greatest obstacle facing LCDs in the desktop monitor market is not competition from other LCD technologies, but a high price tag relative to that of CRTs. TFT-LCD monitors currently cost several times that of a CRT monitor, with a 15-inch unit costing $1200. There are indications that the price of TFT-LCDs will continue to decrease, prices have already dropped to $900. Most of the LCD monitor sales have been to the medical and financial community, but expectations are that the customer base will spread when a 3:1 cost ratio with CRTs is reached, and even more so as prices continue to decline. Surveys indicate that given a 1.5:1 cost ratio of FPDs to CRTs, 30 percent of consumers would opt for the FPD. DisplaySearch reports that low prices by Korean LCD suppliers will likely bring prices of 15- and 18-inch LCD monitors down to a 2X price ratio with 17" and 19" CRTs by the end of 1998.

2.2 Manufacturing Locations and Suppliers

2.2.1 CRTs

The majority of CRT display fabrication takes place outside of the United States. In 1997, Asia (excluding Japan) produced 54 percent of all color TVs and 79 percent of all CRT monitors.[16] DisplaySearch reports that Japan supplies between 10 and 15 percent of CRTs produced worldwide, primarily 17-inch and larger. The greatest concentration of CRT manufacturers is in Taiwan, where 33.6 percent of total world production took place in 1996.[17] South Korea and China are also becoming major sites for CRT monitor production. Most color CRT monitors and small TV CRTs (less than 19 inches) are produced outside the United States. Due to the cost of transporting heavier displays, some TV CRTs, 19 inches and larger, are produced in the United States. It is possible that a

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13 Presentation by DisplaySearch at the USDC Business Conference*: Enabling New Display Markets*, Display Works, January 20, 1998, San Jose, CA.

14 DisplaySearch FPD Equipment and Materials Analysis and Forecast, Austin, Texas, June 1998.

15 Ibid.

16 *The Future of Liquid Crystal and Related Display Materials,* Fuji Chimera Research, 1997, p. 12.

17 *Stanford Resources, Inc.,* web site.

similar situation will arise with larger CRTs monitors.[18] See Table 2-1 for regional production figures for CRT monitors.

	1994	1995	1996	1997	1998	2000
Europe	3,500	3,850	4,300	4,800	5,300	6,000
North America	800	1,000	1,200	1,500	1,800	2,400
Asia	41,000	45,650	53,000	60,000	65,000	75,000
Japan	5,300	6,080	7,100	8,000	9,000	10,000
So-Central America	800	1,200	1,500	1,900	2,500	3,200
Total	51,400	57,780	67,100	76,200	83,600	96,600

Table 2-1: Color CRT Monitors Production by Region (,000 units)[19]

As is the case with most commodity goods, CRT monitors are distributed by the manufacturer via different routes. They may be sold under the manufacturer's name through retail channels, or to original equipment manufacturers (OEMs) or other system retailers, such as Dell Computers. Major manufacturers and retailers include Acer, Apple, Compaq, CTX, Dell, Digital, Eizo, Hitachi, Hewlett Packard, IBM, Iiyama, LG, MAG, Mitsubishi, NEC, Nokia, Panasonic, Samsung, Sharp, Siemens Nixdorf, Sony, Toshiba, and Viewsonic.

Figure 2-2 shows the 1997 market share in the United States per CRT monitor brand name. In this table, some manufacturers (such as Sony) will be under-represented, as the monitors they manufacture for other companies may carry the brand name of the other company (e.g., Sony monitors manufactured for Dell). Figure 2-3 provides data on the 1996 industry market share for main color CRT monitor-tube manufacturers.

[18] Reported at the Glass Roundtable meeting, February 6, 1997, University of Texas at Austin.
[19] *The Future of Liquid Crystal and Related Display Materials,* Fuji Chimera Research, 1997.

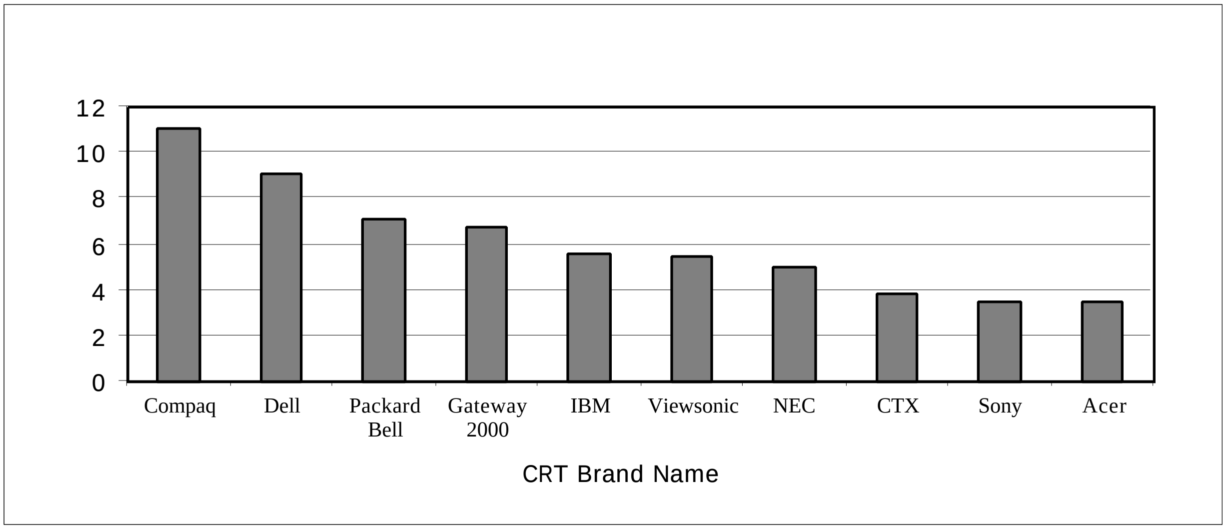


Figure 2-2: CRT U.S. Market Share (Percent) by Brand Name[20]

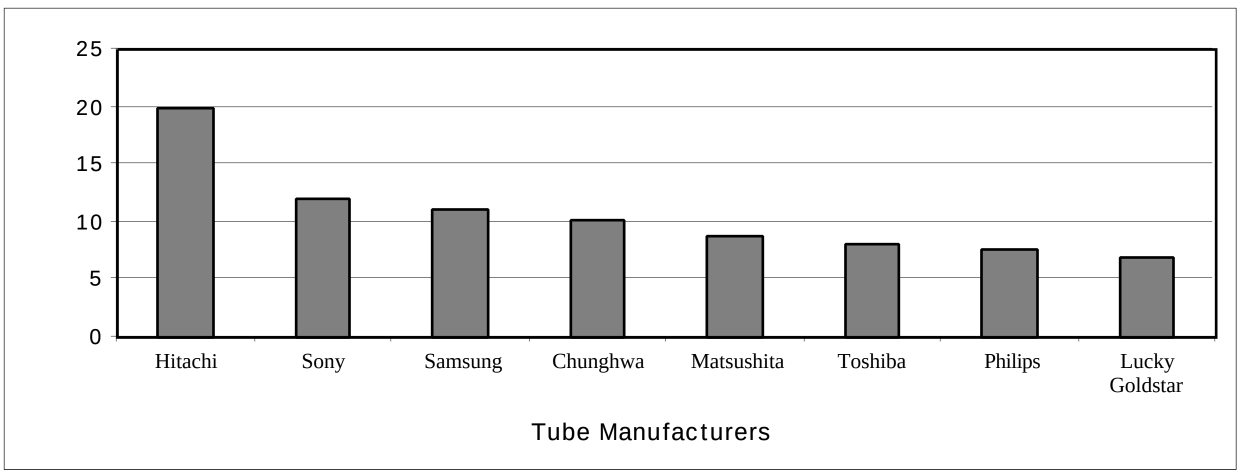


Figure 2-3: Worldwide Market Share (Percent) of Color CRT Tube Manufacturers[21]

20 Source: Stanford Resources, 1997 data.

21 Source: Stanford Resources, 1996 data.

2.2.2 CRT materials and subassemblies

The majority of CRTs (TVs and monitors) and CRT-related components and materials are manufactured outside of the United States. The major materials, components and subassemblies are as follows:

- Faceplate
- Funnel
- Neck
- Phosphors
- Frit
- Aquadag
- Lacquer coating
- Shadow mask assembly
- Electron gun assembly
- Deflection yoke
- Deflection amps
- Centering magnets
- Printed wiring boards (PWBs)
- Anti-static/anti-glare coating

For a more extensive listing, see the CRT process flow and bill of materials in Appendices A and B, respectively .

There are approximately 100 CRT manufacturers worldwide.[22] In the United States, there are five CRT glass manufacturing plants, producing approximately 600K tons of product annually: Thomson, Techneglas (two sites), and Corning (three sites, with one being a joint venture with Sony). Glass is imported from Asahi, NEC, Samsung, Schott, and Philips.

Sony is the only manufacturer of color monitor tubes in the United States, although they, along with Hitachi, Matsushita, Philips, Thomson, Toshiba, and Zenith, do produce TV-tubes in the United States. Aydin, Compaq, Display Tech, Digital Equipment Corporation, IBM, Modicon, NCR, and Unysis assemble computer displays domestically.

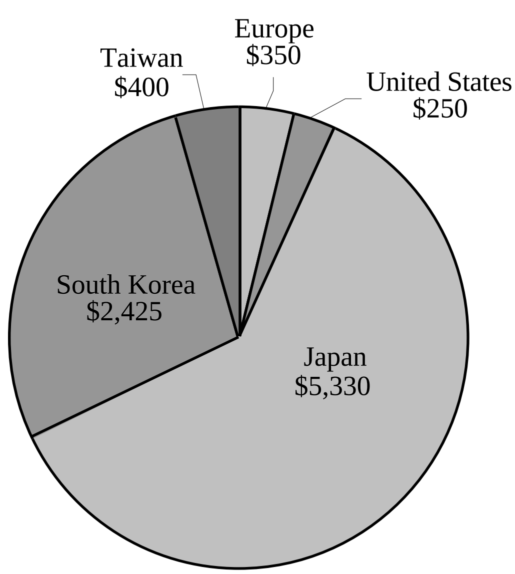
Techneglas, in addition to being a major North American manufacturer of panel and funnel glass, is a large producer of frit, planar dopants, and glass resins. Phosphors are supplied internally from vertically integrated manufacturing facilities and by foreign manufacturers (primarily in Japan).

[22] *Electronic Engineering Times*, December 1, 1997, num. 983, p. 27.

The remainder of the components and subassemblies are produced primarily in Asia. Although shadow masks for TVs are produced in United States, no United States manufacturer has established a high-volume, high-resolution shadow mask facility for monitors. Nippon Printing and Dai Nippon Screening are primary producers in Asia. Electron guns are made from precision metals parts, a significant portion being manufactured by Premium Allied Tube. Insulator glass used in the gun assembly is supplied by Corning Asahi Video and Techneglas. Deflection yokes and amps are produced primarily in the United States, Canada, and Taiwan, and there are a couple of domestic producers of centering magnets.

2.2.3 LCDs

The number of LCD suppliers is significantly lower than the number of CRT suppliers, primarily due to the high capital cost of manufacturing FPDs. As shown in Figure 2-4, Japan leads in AMLCD investment, followed by South Korea. More recent data from DisplaySearch shows that LCD capital investment by Japanese and Korean companies will decrease significantly in 1998 to $676 million, down from $3.85 billion the previous year.



Source: POSTECH

Figure 2-4: Capital Investment in AMLCD Production 1994-1996 ($millions)

In 1995, Japan manufactured 94.7 percent of all LCDs, followed by Korea at 3.5 percent and Taiwan at 1.7 percent; 0.1 percent were produced outside of these regions. By 2005, Japan is forecasted to lead LCD production, with 75 percent. Korea is expected to increase its share to 12.9 percent, and Taiwan to 11.9 percent; 0.2 percent will be produced elsewhere.

Korean and Taiwanese LCD manufacturers have been able to enter this market partially due to strategic relationships with Japanese companies. Samsung Electronics has established technical cooperation with Fujitsu for TFT-LCDs. LG (Lucky Goldstar) Electronics jointly developed technology with Alps Electric. CPT is in technical cooperation with Mitsubishi for TFT-LCDs. Chunghwa Picture Tubes has a partnership with Toshiba for STN-LCDs and is searching for a partner in TFT development. In addition, IBM and Acer are working together on TFTs, as are Toshiba and Walsin Linwa.

2.2.4 LCD materials and subassemblies

The LCD manufacturing process, particularly for TFT-LCD, is more complex in terms of types of materials and process steps than is the CRT process. The following list has been abbreviated to provide only the major materials, components, and subassemblies. For a more complete listing, refer to Appendices C and D for the TFT-LCD process flow and bill of materials, respectively.

- Front glass panel
- Color filter materials
- Indium tin oxide
- Back glass panel
- Liquid crystal materials
- Transistor metals
- Alignment material
- Etchants
- Photoresists
- Developing solution
- Sealer
- Spacers
- Polarizing material
- Driver ICs
- Backlight units
- PWB

Almost all of the materials, components, and subassemblies for LCD monitors are made in Asia. The exceptions are backlights and some driver integrated circuit (IC) devices, which are produced in North America or Europe.

3.0 Technology Profile

3.1 CRT Operation and Components

The cathode ray tube (CRT), whose basic components are shown in Figure 3-1, uses high voltages to move electrons toward a display screen. The electrons are emitted from a cathode and concentrated into a beam with focusing grids. The beam is accelerated toward the screen, which acts as an anode, due to a conductive coating. The screen is also coated with a luminescent material (a phosphor), typically zinc sulfide. This phosphor converts electromagnetic radiation (the kinetic energy of the electrons) into light—a phenomenon called phosphorescence.[23]   The *cathode ray* is essentially an electric discharge— the stream of electrons— in a vacuum tube.

The beam passes through either horizontal and vertical deflection plates (mutually perpendicular pairs of electrodes) or magnetic deflecting coils in the deflection yoke. Voltage is applied to these plates (or coils) to control the position of the beam and its line-by-line scanning across the screen.

Video signal (information to be displayed on the screen) is applied to the electrode (cathode) and is contained in the electron beam. This video signal, which controls the current to the electron-beam, is applied in synchronization with the deflection signals. The result is two-dimensional information displayed on the screen.

[23] The materials that phosphoresce are referred to as phosphors. Phosphors do not contain phosphorous.

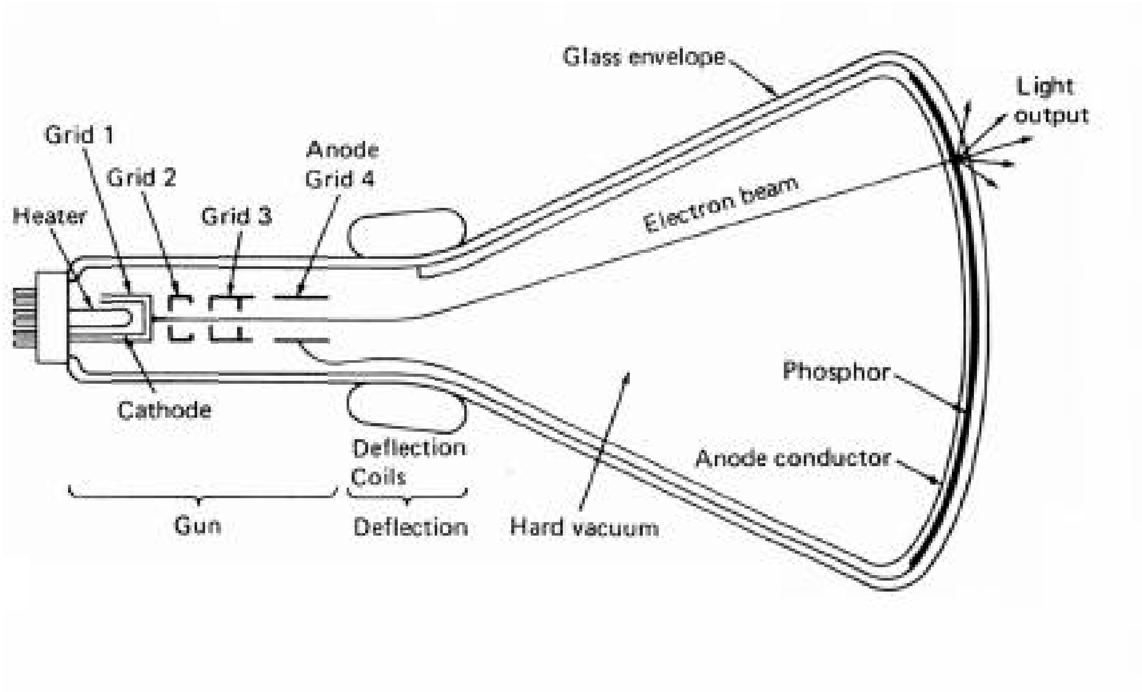


Figure 3-1: Cathode Ray Tube Fundamentals

Color images are made possible through several techniques. The most common technique is the use of a shadow mask, widely used in consumer TVs and monitors (see Figure 3-2). This technique requires three electron guns, which emit electrons that then pass through an aperture—a shadow mask—before hitting the screen. Different phosphorescing colors are obtained by adding materials to the zinc sulfide coating on the screen. The beam impacts the screen at precise locations, striking only one of three colored regions: a red, green, or blue area, and emits visible light. When this point source of light strikes the corresponding dot, a shadow of the mask falls on the inside of the screen. The three beams are controlled (deflected) by one yoke, enabling the three beams to strike the corresponding dots simultaneously, and requiring only one focus control.

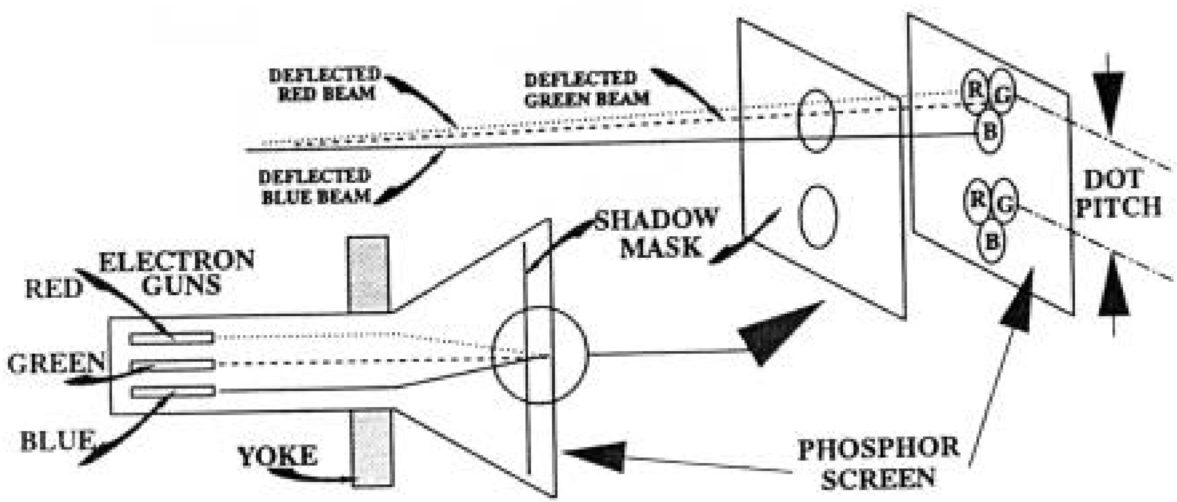


Figure 3-2: Shadow Mask Color CRT[24]

The most common alternative to the shadow-mask technique is the Trinitron, which uses an aperture grill (rather than a shadow mask) that is composed of parallel, colored stripes, (rather than dots). A grid positioned in front of the stripes directs the beam to the appropriate color. Although the Trinitron design offers certain performance and warrants investigation, the scope of this operational and manufacturing description is limited to the shadow mask structure.

3.2 CRT Manufacturing Process[25]

The traditional CRT glass manufacturing process is comprised of the following main categories of activities:

- Glass fabrication
- Faceplate (screen) preparation
- Shadow mask fabrication/assembly
- Funnel preparation

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24 Castellano, J.A.,*Handbook of Display Technology*, Academic Press, Inc., 1992, pg. 42,

25 *Environmental Consciousness: A Strategic Competitiveness Issue for the Electronics and Computer Industry,* MCC, 1993.

- Bulb joining
- Electron gun fabrication
- Final assembly

3.2.1 CRT glass fabrication

Raw materials are converted to a homogeneous melt at high temperatures and then formed into the glass panel (see Figure 3-3). Sand is the most common ingredient and must be chosen according to high quality, high purity, and grain-size standards. The sand and soda ash can be sourced within the western United States, whereas limestone may come from the coast of the Bahamas. Other raw materials such as boron (used as anhydrous borax or boric acid) come from California or Turkey.

Dry blending mixes the raw materials, and small amounts of liquid may be added for wet blending. The batch is then preheated to temperatures approaching that of the furnace and charged into the furnace, where melting and other reactions (dissolution, volatilization, and redox) take place. The next phase, fining, removes bubbles chemically and physically from the molten glass melt. The most commonly used fining agents are sulfates, sodium or potassium nitrates, and arsenic or antimony trioxides. The melt is then conditioned, or homogenized, and then cooled prior to fabrication. After forming, the glass must be prepared to withstand upcoming chemical, thermal, and physical activities and to meet high quality standards for optical glass. These activities include some, or all, of the following: beveling, chamfering, grinding, polishing, and annealing at 350-450 degrees Celsius. In some cases, breakage occurs during the manufacturing process, in which case the broken glass—*cullet*—can be reintroduced into the batch melt.

3.2.2 Faceplate preparation (pattern)

The CRT faceplate, also referred to as a panel or screen, is coated with a conductive material and a luminescent material (the phosphors). The conductive coating, an aquadag, acts as an anode, attracting the electrons emitted from the electron guns. The coating is composed of electrically conductive carbon particles, with silicate binders suspended in water. It is deposited by painting, sponging, spinning, or spraying, and then baked to increase durability.

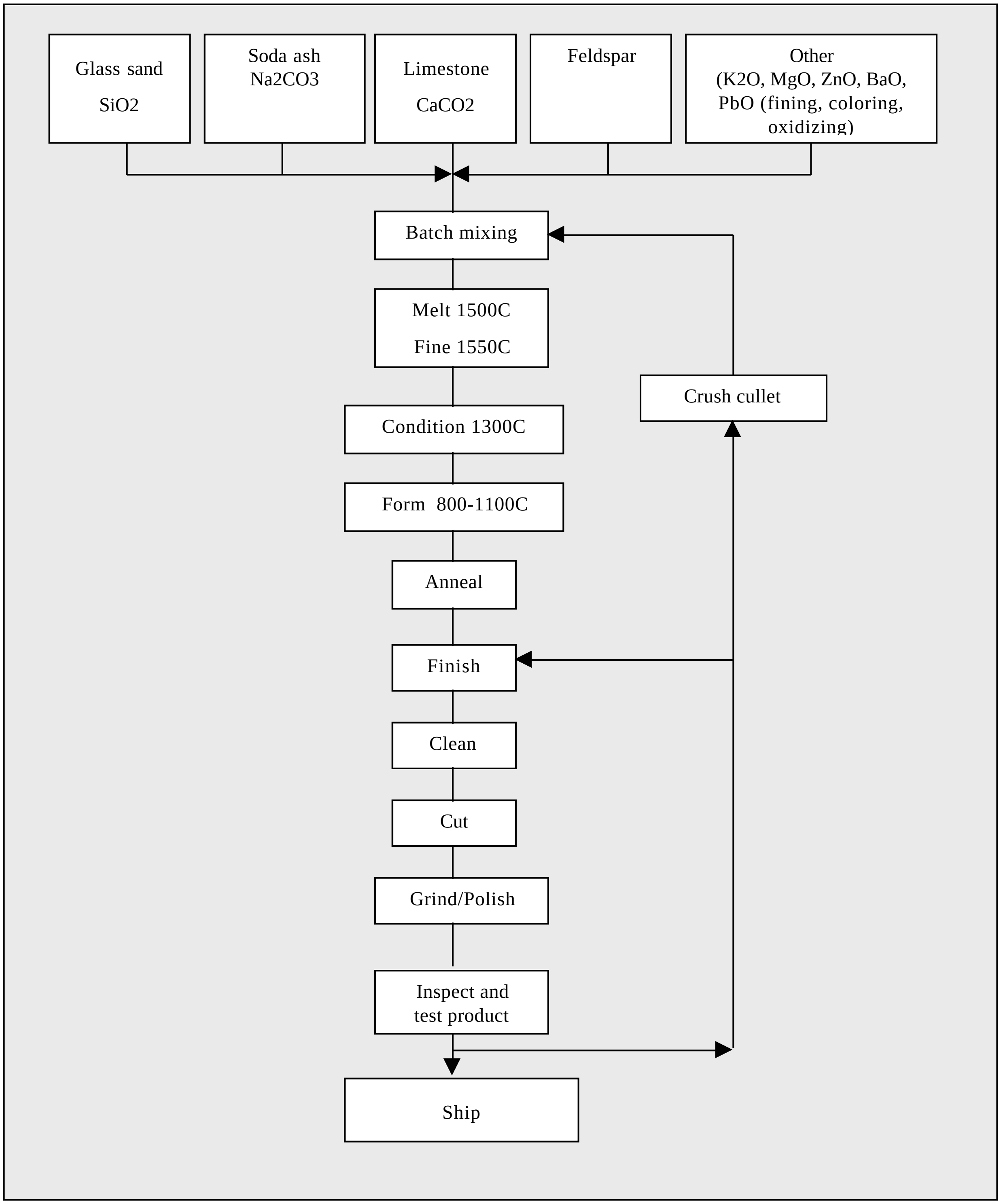

Figure 3-3: Glass Manufacturing Process Flow[26]

26 Encyclopedia of Chemical Technology, 3rd Edition, vol 11, 1980, p. 847.

The luminescent phosphor and contrast-enhancing materials are applied to the inside surface of the faceplate in aqueous solutions, using spin coaters. These coatings are patterned by photolithography, using polyvinyl alcohol (PVA) photoresists and near-ultra-violet exposure lamps. Exposure of the photoresist material from light passing through the apertures in the shadow mask creates a pattern of dots (or stripes) where the red, green, and blue phosphors will be placed in subsequent steps. These phosphor materials are powders that are applied one at a time in dichromate-sensitized PVA slurries (a thin paste that has solids suspended in liquids).

The pattern is developed by rinsing with a solvent to wash away the unexposed resist. Next, a coating of contrast-enhancing material (grille dag) is applied and dried. A lift-off process digests the resist that remains between the glass and the grille material. The digested resist lifts off the glass, carrying away unwanted grille material on top of it and opening windows in the black grille material. In subsequent coating and photolithographic steps, the red, green, and blue phosphors are deposited in these windows. The result is a patterned luminescent screen with the emissive elements separated by the non-reflecting grille material.

The grille dag and phosphor deposition processes leave a non-uniform screen surface. To level this surface, lacquer is applied as an extrusion film, or it is sprayed onto the screen and then dried. A layer of aluminum is then evaporated onto the screen to enhance reflection.

3.2.3 Shadow mask fabrication and assembly to faceplate

The shadow mask foil is a thin structure made of aluminum-killed steel that is etched with the appropriate pattern of round apertures (may also be slits or slots). It is patterned through a series of photolithographic steps. The mask foil is coated with a casein type resist (a food industry by-product) and exposed with ultraviolet (UV) lamps. The design is developed and the apertures etched away with a ferric chloride solution.[27]

The ferric chloride etchant is reduced by the dissolving iron, producing ferrous chloride from both the etchant and the dissolving iron. The etchant is regenerated using chlorine, producing by-product chemicals and ferric chloride.

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[27] The etch process for monitors takes place in Europe or the Pacific-Rim countries. No United States manufacturer has established a high volume, high-resolution shadow mask etching facility.

The mask, which is flat when delivered to the CRT manufacturer, is first curved to approximately the shape of the faceplate in a large hydraulic press. In the CRT, it is supported on a heavy frame, which is typically manufactured by metal cutting, welding and stamping. Springs are welded to the formed frame and the shadow mask is welded on while the parts are held in an alignment fixture. The parts are then oven-blackened to increase the brightness capability of the finished CRT.

3.2.4 Funnel preparation

The funnel provides the back half of the vacuum shell and electrically connects the electron gun in the neck of the CRT and the faceplate to the anode button (a metal connector button in the funnel provided for attachment of the power supply). The conductive coating on the inner surface is an aquadag; similar to the type used on the screen. The major difference is the graphite particle size and the addition of electrical conductivity modifiers. Silicate binder concentration may be higher, and iron oxide may be added, to reduce the conductivity.

Funnel dag is applied by sponge, flow coating, or spraying, and is then baked to evaporate the solvent in the dag. The surface of the dry funnel that will be mated with the faceplate (screen, panel) is coated with a frit (solder glass). This frit is a low melting temperature glass powder made of lead oxide, zinc oxide, and boron oxide, which is mixed with nitrocellulose binder and amyl acetate vehicle to form a paste (with the consistency of toothpaste). It is typically formulated so that the final melting temperature is significantly higher than the original melting temperature, thereby allowing it to be reheated in repair and recovery processes.

3.2.5 Bulb joining

The panel and shadow mask assembly and internal magnetic shield are joined together by clips to form a faceplate assembly. This assembly is placed on the fritted funnel in a fixture that carries the two halves in precise alignment through a high temperature oven, where the frit is cured (hardened). The resulting assembly is a vacuum tight bulb, ready to receive the electron gun and to be evacuated to become a finished CRT.

3.2.6 Electron gun fabrication and assembly

The electron gun is composed of a number of electrostatic field-shaping electrodes made of 300 and 400 series steels. These steels are similar to those used in other industries, but have higher purity requirements and contain iron (Fe), nickel (Ni), and chrome (Cr). The electron gun metals are typically annealed hydrogen fired before being assembled and attached to insulating glass support pillars. The pillars, made of a borosilicate glass, are heated to their softening temperature and pressed over tabs on metal electrodes. After the pillars cool, they captivate the electrodes, making a monolithic structure. This structure is mounted to a glass stem that will be joined to the neck portion of the bulb assembly by melting. The glass stem is provided with electrical feed-though pins, which carry the electrical connections from the external circuitry to the electrodes.

Hidden within the lower end of the gun are three cathodes consisting of hollow nickel tubes, with one end closed and coated with an electron emitting material, typically a mixture of barium, strontium, and calcium carbonates. A tungsten wire heater, coated with a layer of insulating aluminum oxide, is placed in the center of the cathode tube.

Additional ribbon conductors are welded between the upper electrodes and the remaining pins in the stem. Finally, the upper cup of the gun, steel centering springs, and a vacuum getter ring on a long wand are welded on. Additional parts are added at this stage, such as anti-arcing wires, magnet pole pieces, or magnetic shunts, depending upon the design. This finished electron gun assembly is ready for sealing to the bulb.

3.2.7 Final assembly

The frit-sealed bulb assembly and the electron gun assembly are joined by fusing the stem and neck tubing together in a gun-seal machine that melts the two glasses together. During this fusing operation, the two pieces are fixtured into precise alignment. Typically, the neck is slightly longer than necessary and the excess glass is "cut off" by the sealing fires, falls into a reclaim container, and is returned directly to a glass company to be remelted and reformed into a new neck.

Figure 3-4: CRT Manufacturing Process

After joining, the entire CRT is attached to a vacuum exhaust machine that carries the assembly through a high-temperature oven while exhausting the air from inside the CRT. The combination of high temperature while pumping the air out of the CRT produces a high vacuum inside. After cooling, the vacuum getter is vaporized and the evaporated metal (barium, zinc) coats the inside surface of the CRT. This film absorbs the residual gases inside the envelope and reduces the gas pressure inside the CRT to its final operating pressure.

The electron emissive cathode material, which was initially sprayed on the nickel cathode cap as a carbonate, is first converted to an oxide by electrically heating the cathode to high temperature. The surface metal oxides are then reduced to a monolayer of metal by emitting an electrical current from the cathode while it is at high temperature. The resulting surface emits large quantities of electrons that can be controlled by voltages applied to the electrodes of the gun.

The final CRT manufacturing stage is electrical test and visual inspection. Having passed these tests, the CRT faceplate is fitted with a steel implosion band for safety. The band compresses the CRT, thereby increasing the strength of the glass, making the tube more resistant to implosion. A flow-chart description of the CRT manufacturing process is shown in Figure 3-4.[28]

3.3 Active-Matrix LCDs

3.3.1 Thin-film transistor (TFT) structures

Computer displays need very fast response speed, high contrast, and high brightness to handle the information content and graphic demands. One way to achieve this speed is by having a switch at each pixel, which is the basis for active-matrix addressing. This switch can be a transistor or a diode (Appendix A). This profile will cover only the transistor structure, which basically consists of a gate, source and drain, and channel. Electrons flow through the channel between the source and drain when voltage is applied to the gate. There is an insulating layer between the gate and the source/drain region, referred to as a dielectric.

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[28] Socolof, M.L., et al., *Environmental Life-Cycle Assessment of Desktop Computer Displays: Goal Definition and Scoping,* (Draft Final), University of Tennessee Center for Clean Products and Clean Technologies, July 24, 1998.

The transistors are patterned on the rear panel of the display, on a base of amorphous silicon (a-Si) or polysilicon (poly-Si). Currently, most flat panel displays (FPDs) use a-Si, although poly-Si does offer some performance advantages in smaller displays. These advantages have not overcome the fact that the technique for depositing thin-film a-Si is very well understood and established. Therefore, most TFT-LCDs are currently based on a-Si, which is the subject of this profile.

TFT a-Si devices are typically characterized as *staggered*, which refers to the fact that the pixel electrodes are on opposite panels (one on the front and one on the rear). More recently, a new design has emerged in the marketplace, called in-plane switching (IPS). This profile will cover the manufacturing processes for the bottom-gate etch stop (E/S)—a staggered structure—and the in-plane switching (ISP) design. Most TFT-LCD monitors are based on the E/S transistor structure, although NEC and Hitachi have released monitors using IPS.

3.3.2 Twisted-nematic TFT-LCD operation

Whereas the E/S or IPS designation relates to the addressing mechanism for each pixel, the principle behind light transmission of the display is related to characteristics of the liquid crystal (LC). This profile covers the operation of twisted nematic (TN) technology, which is used in most computer monitors.

All LCDs work on the same principle: information on the screen is displayed via an array of pixels, controlled by voltage and the orientation of the LC molecules. LC materials are organic compounds that align themselves in the direction of an electric field and have the properties of both solid crystals and viscous liquids. There are almost 400 different types of LC compounds in use for displays. Generally, they are polycyclic aromatic hydrocarbons, or halogenated aromatic hydrocarbons.

The following section describes one way in which light is transmitted or blocked from transmission in a TN-LCD. Figure 3-5 illustrates this process.

Light, which in a TFT-LCD originates from the backlight source or unit, passes through a polarizer before striking the rear panel. This polarizer blocks the transmission of all but a single plane of lightwave vibration. This polarization orientation is parallel to the orientation of the LC molecules and perpendicular to the polarizer plane on the opposite panel. The orientation of the LC is determined by the rubbing direction of the polyimide alignment layers, to which the closest molecules appear to be anchored. The layer on one panel is rubbed at 90 degrees to the other, thereby causing the LC molecular chain to twist 90 degrees between the two panels.

With no voltage applied, the twisted LC structure is fixed. Therefore, light entering from the rear and travelling through the LC cells follows the twist and arrives at the front panel in a plane parallel with this polarizer. As a result, the light is transmitted. When voltage is applied, an electric field is set up between electrodes, one on each of the two panels. The LC molecules align themselves in the direction of the electric field, thereby destroying the twist. The light travels through the cells, arriving at the front panel in a plane perpendicular to the rear polarizer, and is blocked. The field strength will determine how much of the light is blocked, thereby creating a grayscale.

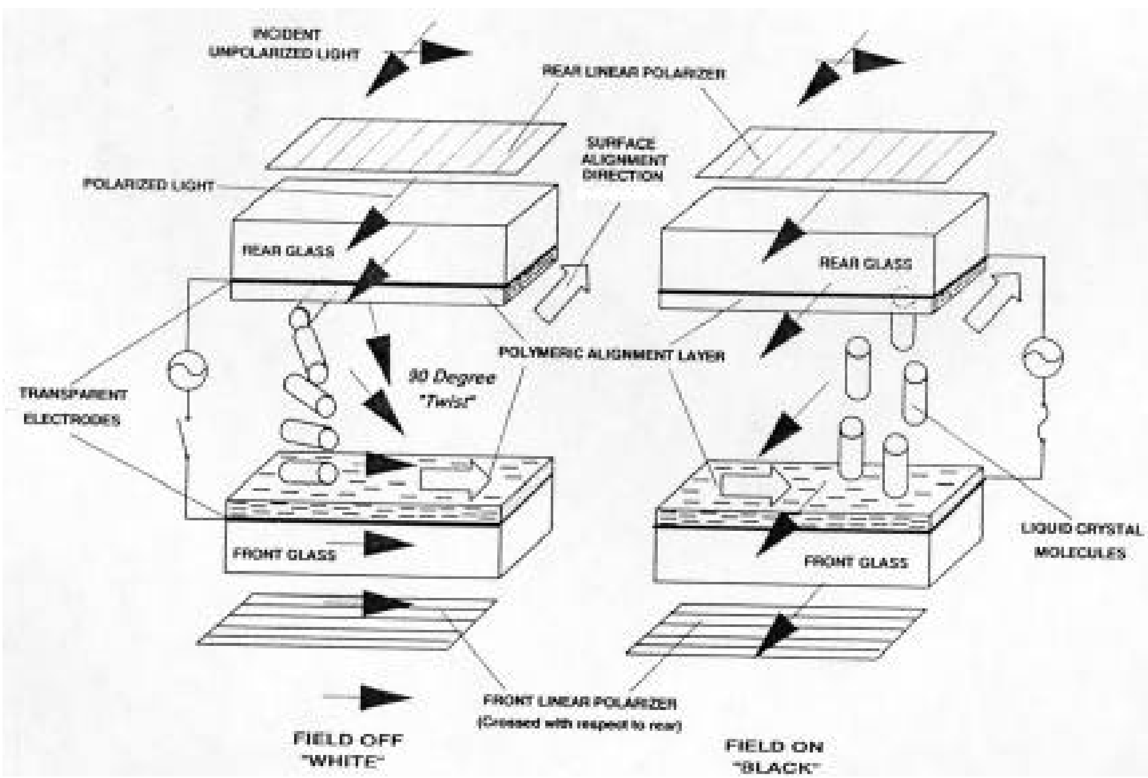

Figure 3-5: TN Field-Effect LCD Operating Principles[29]

[29] Castellano, J.A., *Handbook of Display Technology*, Academic Press, 1992.

Addressing occurs when the pixels are manipulated with voltage to turn off and on, creating an image on the display screen. The active-matrix LCD uses direct addressing, which requires a switch (the TFT) and a capacitor at each pixel. The TFT is controlled by electrodes, which are the gate and source/drain regions on the transistor. The pixel is addressed by controlling current to the TFT, allowing the transistor to turn on and off. When voltage is applied, there is a short delay while LC molecules align themselves, resulting in a slightly opaque pixel. Also, the capacitor holds the charge for a short period of time after the voltage is removed and the molecules must reorient themselves to their original, 90-degree twist. These delays allow the display to scan the pixels and activate the appropriate ones for the desired image.

The above description is for a black and white display—black, when light is blocked, and white when all wavelengths of incident light is transmitted. Full color results when each pixel is divided into three subpixels— red, green, and blue (RGB). Color filters, which absorb all but a range of wavelengths of the incident light, are used to create the subpixel color. By combining the subpixels, a wide range of color is possible.

3.4 TFT-LCD Manufacturing

The following sections discuss TFT-LCD manufacturing and display assembly processes. This section is designed to provide an overview of these processes only. For available details on equipment and materials used, refer to the TFT-LCD process flow in Appendix D.

3.4.1 Glass fabrication

Molten glass is prepared into flat substrates by the float or fusion draw process. The distinguishing difference between the technologies is the chemical type of the glass required and the degree of flatness. Soda lime glass is acceptable for some LCDs, and borosilicate for others. Whatever the glass material, strict controls are necessary during the glass fabrication process in order to obtain optical quality glass with satisfactory mechanical properties.

The float method of forming glass uses a flat surface, a *bed*, onto which molten glass (the melt) flows. The glass floats on the source of the bed, made of molten tin, becoming flat (sides are parallel) and smooth. In the glass fusion process, the homogeneous melt is drawn downward into a uniform sheet of glass. The speed of the drawing process determines the glass sheet thickness.

After fabrication, the glass sheets are trimmed to the desired size and prepared to withstand upcoming chemical, thermal, and physical activities and to meet high quality standards of optical glass. These activities include some, and perhaps all, of the following: beveling, chamfering, grinding, polishing, and annealing at 350-450 degrees Celsius.

3.4.2 Front panel patterning

Prior to patterning the front panel, the substrate must be clean. The glass is cleaned with physical, chemical, or dry techniques. The list of cleaning methods covers all types that may occur in the LCD panel process. Not all of these cleans occur immediately after the glass manufacturing stage.

Physical cleaning encompasses brush scrubbing, jet spray, ultrasonic, and megasonic methods. The chemical means include cleaning with organic solvents, a neutral detergent, process-specifics cleans according to manufacturing step (etching, stripping, etc.), and pure water cleans following chemical treatment. Dry cleaning processes use ultraviolet ozone, plasma oxide (to clean photoresist residue), non-oxide plasma, and laser energy (limited to localized needs rather than full-surface cleans). Because organic contamination and particulates are significant factors in reduced manufacturing yield, all three methods play important roles at different stages in the process.

3.4.2.1 Deposit ITO

Before creating the necessary layers on the front panel, the glass is physically cleaned, typically using the ultrasonic method. Next, the transparent electrode material, indium tin oxide (ITO), is sputtered onto the substrate. This creates the front panel (common) electrode.

3.4.2.2 Pattern color filter

Next, the black matrix is deposited and patterned, which creates a border around the color filter for contrast. Currently, most TFT-LCDs use a sputtered (physical vapor deposition, or PVD) chrome as the black matrix material, although the trend may be headed toward the use of black resin. The color filters are patterned onto the substrate in succession (RGB), either by spin coating the filter material or by electrodeposition. In each case, the pattern is transferred via the photolithographic process described in Table 3-1. Spin coating is more common than electrodeposition, and the same alternatives to the spin coater mentioned above may be adopted. If a black resin is used for the matrix, it will be applied after the color filter formation, rather than before, as is the case with chrome matrix. The color filter process results in a non-uniform substrate, thereby requiring a planarization step before moving on to the alignment layer creation. The surface is planarized with a layer of polyimide.

3.4.2.3 Deposit alignment layer

The last material to be added to the front panel is the alignment layer, a polyimide that is applied by roll coating and then rubbed to the desired molecular orientation.

3.4.2.4 Inspect and test

The substrate is finally inspected for visual defects and tested.

3.4.3 Rear Panel Patterning

3.4.3.1 Clean and inspect

The rear glass substrate must be cleaned and inspected prior to the detailed and costly patterning processes. Typically, as with the front glass panel, this is accomplished with an ultrasonic water clean.

Coat
Photoresist, a photo-sensitive polyimide resin, is deposited on the substrate, typically using a spin coater. The spin coater dispenses the photoresist into the center of the substrate that is rotating. The centrifugal force resulting from the rotation causes the resist to spread across the substrate toward the edge. This method wastes approximately 90-95 percent of the photoresist material, as most is spun off of the substrate. Several alternative coating techniques have been, or are being, developed.

Prebake
After the photoresist is patterned, the substrate is baked to reduce the moisture content in the photoresist.

Expose
After prebaking, the substrate is ready to be patterned. This is accomplished by placing a mask with the desired pattern on top of the substrate and exposing the photoresist to light of a specific wavelength.

Develop
Depending on the type of photoresist used, specific areas (either those exposed, or those masked) are removed with a developing solution, leaving behind a pattern.

Clean
After developing the pattern, the substrate is cleaned in water to remove chemical residue and then dried.

Bake
The photoresist may be baked once again in order to remove moisture and harden the resist before the upcoming etch step.

Etch
The substrate is now etched to remove the material that was deposited onto the entire substrate and patterned. In this case, the black matrix material (chrome) not covered by photoresist is etched away, leaving a distinct, desired pattern. Depending on the materials to be removed and the linewidth requirements, a wet or dry etch is used. Wet etch involves a solvent immersion or spraying followed by a water clean. Dry etch is a plasma-based reactive ion etch.

Strip/Clean/Inspect
The photoresist is then completely removed from the substrate and cleaned (with water), dried, and inspected. The stripping solution is a solvent, typically either N-methyl pyrrolidinone (NMP) or trimethylamine hydrochloride (TMAH), depending on the type of photoresist.

The patterning process is similar for all standard photolithograhic patterning in semiconductor and LCD manufacturing. The etchants and etching equipment used, however, will vary depending on the material being patterned. A plasma etch may be used for final resist cleaning.

Table 3-1: Standard Photolithographic Patterning Process

3.4.3.2 Pattern TFTs

The rear panel is where the transistors are created, which requires many more steps than the front panel. The transistors are made up of the regions illustrated in Figure 3-6 and discussed below. Each region requires the full photolithographic patterning process. Detailed process flow spreadsheets are provided in Appendix D.

Gate

The gate metal, typically aluminum, is sputtered onto the substrate and patterned. The aluminum may be dry or wet etched.

Gate dielectric/channel/etch stop

The gate SiNx (or SiOx) dielectric, a-Si channel, and SiNx etch stop layer are deposited in succession in a chemical vapor deposition tool. The a-Si is patterned and dry etched.

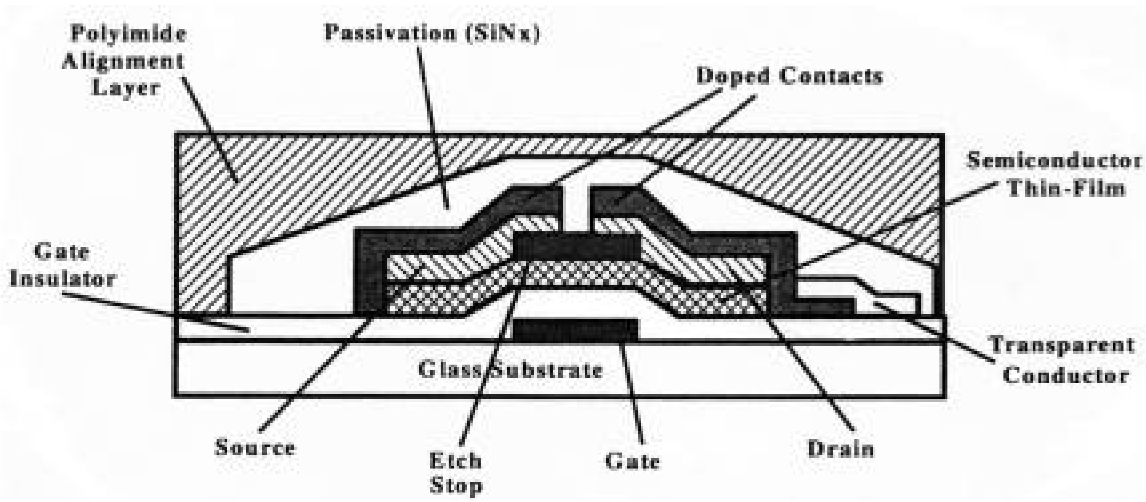

Figure 3-6: Etch/Stop Structure TFT

TFT island

A doped a-Si layer is deposited using CVD, patterned, and dry etched.

Pixel electrode

The pixel electrode is formed by sputtering ITO. The ITO layer is annealed (to reduce film stress) and patterned, using either wet or dry etch.

Contact hole and source/drain metal

A contact between the doped (n+) a-Si layer and the source/drain metals (deposited in the next step) is formed by patterning a hole and etching to expose the n+a-Si. Next, the source/drain metal is sputtered (metal type) and patterned, using either wet or dry etch.

3.4.3.3 Deposit passivation layer/test/inspect

The surface must receive a passivation layer of SiNx for protection, after which the device is inspected and electrically tested.

3.4.3.4 Deposit alignment layer

The substrate is cleaned prior to rubbing to ensure a particulate and contaminant-free surface. Contamination is detrimental to the success of the rubbing process. The thin polymer alignment layer is deposited onto the glass surface by spin coating or printing, and then baked to remove moisture. It is then "rubbed" with fabric in the direction desired for LC orientation. The very fine grooves resulting in the layer help the LC molecules align properly. The rubbing mechanism is typically a cloth on a belt that is attached to a roller, which moves across the substrate, rubbing as it advances. The substrate is then cleaned before moving to the next step.

3.4.4 Front Panel Patterning-IPS

The fabrication of the front panel for the IPS mode display is the same as that described above with one exception: no ITO electrode is formed on the front panel.

3.4.5 Rear Panel Patterning-IPS

The structure described in the following section is a top-gate IPS TFT. The manufacturing advantage is the reduction in the number of mask (patterning) layers from six or seven to potentially four. In the IPS mode, the electrodes are on the same panel. Therefore, the electric field is set up between the pixel and the common (counter) electrodes on the rear panel (see Figure 3-7), rather than between the front and rear of the display (as is the case in the typical TN structure). The LC used in this mode aligns itself horizontally, unlike the vertical alignment of the TN.

Light shield metal

Figure 3-7 illustrates an IPS-mode TFT with a bottom-gate structure. Some IPS designs create the gate at the top of the transistor. In this case, there is a risk of exposing the a-Si layer to backlight energy. This exposure could generate leakage (unwanted) current. Therefore, a layer of chrome is sputtered to act as a light shield. The light shield is patterned and either wet or dry etched.

Dielectric

A passivation layer of SiOx may be deposited through a CVD process. It may be eliminated, as channel protection can be provided by the SiNx layer deposited as part of the island formation.

Source/drain metal

The source/drain metal is sputtered, patterned, and wet etched. This metal can be aluminum (Al)-based, titanium (Ti), molybdenum (Mo), chrome (Cr), tungsten (W), molybdenum/tantalum (Mo/Ta), or Mo/W. The etch process is typically dry (see process flow in Appendix D for etchant chemistry).

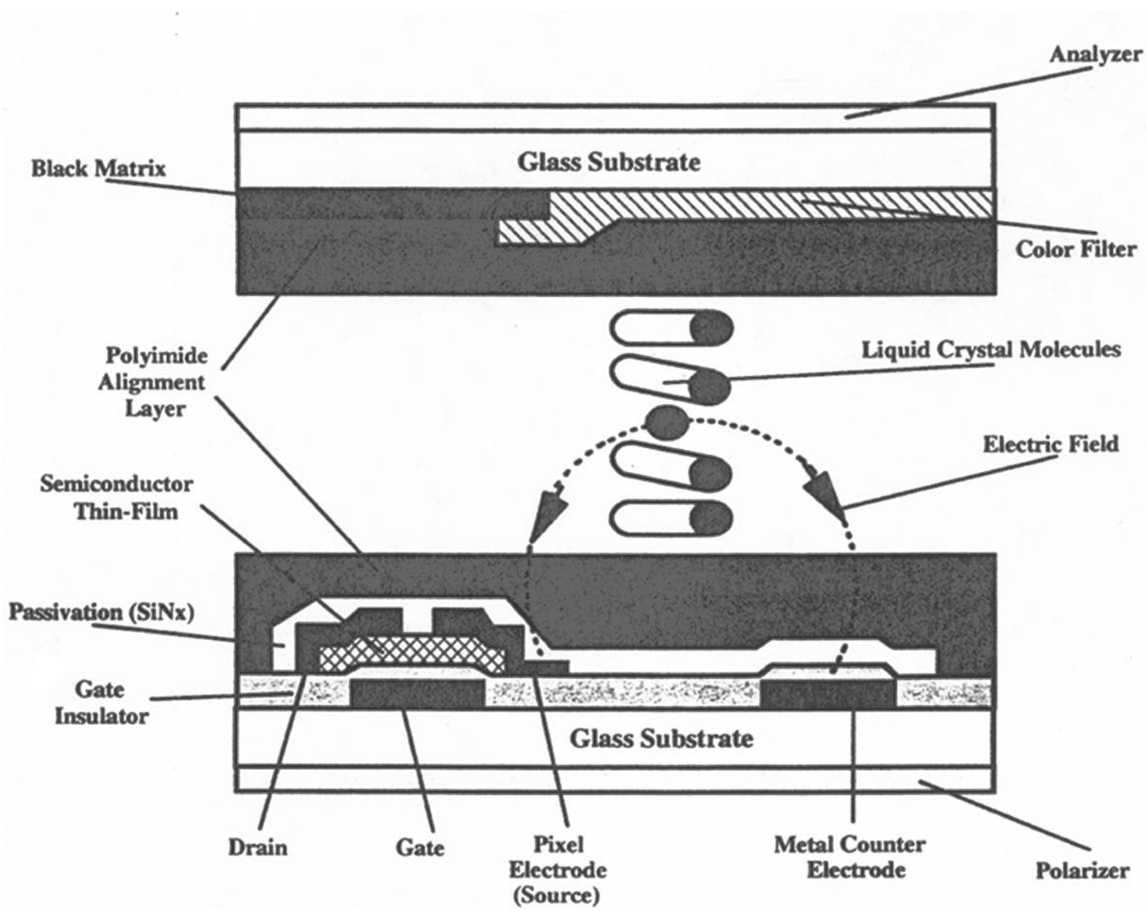

Figure 3-7: Hitachi IPS TFT

Island

The TFT island is created similarly to that for the E/S structure. A single-chamber CVD process is used to deposit a doped (n+) a-Si, a-Si, SiNx combination. The a-Si layer is patterned and dry etched.

Gate, pixel, common electrode

The gate, pixel, and common electrodes are all formed on the rear panel substrate simultaneously, and then patterned in a single mask step. The metal is commonly wet etched.

As with the traditional TN-based rear panel process, following the TFT formation the substrate is coated with an alignment layer and rubbed.

3.4.6 Display cell and final module assembly

At this stage of the process, the color filter substrate (top glass) and TFT substrate (rear glass) are joined with seal material, and liquid crystal (LC) material is injected into the small space in between. Polarizing films are added to the outside of each substrate and the driver electronic PWBs are attached. Finally, the backlight unit is added to complete the display module, the remainder of the electronics is attached, and the entire unit is tested.

3.4.6.1 Seal panels

At this point, the color filter substrate and TFT substrate are ready to be assembled. First, an adhesive seal material is applied, usually by either silkscreening or screen printing. A hole is left in the seal for later LC material injection. After the adhesive is applied, it is cured in order to outgas solvents in the material and achieve partial cross-linking of the polymer. This makes the material less tacky (B-stage material), which allows the plates to touch during alignment.

Before sealing the two substrates (accomplished by lamination), spacers are deposited on one of the substrates to maintain a precise cell gap (between 5-10 micrometers) between the two surfaces. These spacers are either glass or plastic. The substrates are then aligned and laminated by heat and pressure to complete the cross-linking of the polymer.

3.4.6.2 Inject LC

The LC material is injected into the gap produced by the spacer. The hole that was left open for this injection is sealed with the same type of resin and cured.

3.4.6.3 Attach polarizers

The last step in the display cell assembly is the polarizer attachment. The polarizers are typically in rolls or precut sheets, and are applied to the outside of each glass panel with the help of an adhesive layer that is already on one side of the polarizer. The module is cleaned before moving on to inspection and test.

3.4.6.4 Inspect and test

The display module is inspected and functionally tested. The most common display failures can be traced back to particulates and problems with the cell gap.

3.4.7 Module Assembly

3.4.7.1 Attach backlights

The light source for the TFT-LCD is a backlight unit, which is usually a cold cathode fluorescent tube (CCFT). A typical desktop unit has four backlights, which are placed around the edges of the display. A light pipe projects the light across a diffuser screen to provide uniform illumination. If the IPS TFT structure is used, eight backlights are required.

3.4.7.2 Attach electronics

After the cell is inspected and the printed wiring boards (PWBs) are cleaned, the electronics are attached to complete the display module.

Driver chips are attached either on the glass substrate (*chip-on-glass, or COG*) or near it with tape automated bonding (TAB) on flex circuit (*chip-on-film, or COF*). Alternatively, the chips may be mounted on PWBs (*chip-on-board, COB*). The use of TAB bonding for COF device attach is most common. The controller PWB is attached as are other passive components and packaging hardware.

3.4.7.3 Final test and ship

Once all interconnects are attached, the unit goes through a final electrical test and is shipped.

Appendix A

Flat Panel Display Technologies[30]

Technology	Description	Applicability to DfE Project
Liquid Crystal Displays (LCD)	A liquid crystal material, acting like a shutter, blocks, dims, or passes light unobstructed, depending on the magnitude of the electric field across the material.[31] A backlight provides the light source.	Included in the DfE Computer Display Project life-cycle study. Descriptions of the subtechnologies and whether or not they are included in the study are presented below.
(1) Passive matrix (PMLCD)	Liquid crystal (LC) material is sandwiched between two glass plates, which contain parallel sets of transparent electrical lines (electrodes) in a row and column configuration to form a matrix. Every intersection forms a pixel, and the voltage across the pixel causes the LC molecules to align and determines the shade of that pixel.[32]	Traditionally for low-end applications (e.g., calculators, wrist watches). Higher end applications use a super-twisted nematic (STN)[33] construction. The liquid crystal material is twisted between 180 and 270 degrees, which improves the contrast between the "on" and "off" states, resulting in a clearer display than with the twisted nematic (twisted only 90 degrees.[34] However, cost and performance issues limit this technology from wide application in the desktop market, therefore, it will not be evaluated in the study.
(2) Active matrix (AMLCD)	Similar to the PMLCD, except an electronic switch at every pixel provides faster switching and more shades. The addressing mechanism eliminates the viewing angle and brightness problems suffered by PMLCD. Requires more backlight than PMLCD due to the additional switching devices on the glass (at each pixel). Various switching types are listed below:	Provides vivid color graphics in portable computer and television screens.[35] This technology meets the functional unit specifications in this study. Specific subcategories are described below.

30 Socolof, M.L., et al., Environmental Life-Cycle Assessment of Desktop Computer Displays: Goal Definition and Scoping, (Draft Final), University of Tennessee Center for Clean Products and Clean Technologies, July 24, 1998.

31 Office of Technology Assessment, *Flat Panel Displays in Perceptive*, OTA-ITC-631, Washington, DC: U.S. Government Printing Office, September, 1995.

32 Ibid.

33 Traditional light modulating methods for LCD technologies include twisted nematic (TN), super-twisted nematic (STN), double STN, triple STN, and film-compensated STN. The STN is the current standard for high-end PMLCD applications.

34 Office of Technology Assessment, *Flat Panel Displays in Perceptive*, OTA-ITC-631, Washington, DC: U.S. Government Printing Office, September, 1995.

35 Ibid.

Technology	Description	Applicability to DfE Project
	AMLCD Switch Types:	
	(2a) Thin-film transistor (TFT): The transistor acts as a valve allowing current to flow to the pixel when a signal is applied. The transistors are made of various materials including: amorphous silicon (a:Si), polycrystalline silicon (p:Si), non-Si[CdSe].[36] Two different TFT light modulating modes are twisted nematic (TN) and in-plane switching (IPS).[37] In comparison to the TN mode, the IPS mode requires more backlight but fewer manufacturing steps.	The current standard AMLCD switching mechanism for computer displays is a:Si TFT. Polycrystalline Si is not suitable for larger than about 5" displays. Both the TN and IPS a:Si TFT AMLCD technologies are analyzed in the DfE project.
	(2b) Diode matrix: The diode acts as a check valve. When closed, it allows current to flow to the pixel charging it. When opened, the pixel is disconnected and the charge is maintained until the next frame.[38]	The diodes are found to short easily and must be connected in series to achieve long life usability. The diode displays are also limited in size to smaller than that of the functional unit defined for the DfE study.
	(2c) Metal-insulator metal (MIM): The MIM is a diode type switch using metal-insulated-metal fabrication techniques.[39]	Temperature sensitive, which creates gray scale nonuniformities. They are also size-limited, like other diode type displays and therefore not included in the study.
(3) Active-addressed LCD	Hybrid of passive and active matrix. The pixels are addressed using signals sent to the column and row as determined using an algorithm encoded into an integrated circuit (IC). The IC drives each row of pixels more or less continuously and drives multiple rows at one time.[40]	Employed in notebook and desktop monitors >12.1". However, they need special drivers[41] have slow response times, and their contrast worsens as panel size increases. Therefore, this technology does not meet the specifications of the functional unit and is excluded from evaluation in the DfE study.
(4) Plasma-addressed liquid crystal (PALC)	The pixel is addressed using row electrodes, which send the signal, and column gas channels, which conduct a current when ionized.[42]	PALC displays are in development to be used as large low cost displays. Production of the displays have not yet occurred and they are not included in the study.

[36] Castellano, J., *Handbook of Display Technology,* Stanford Resources, Inc., San Jose, CA., 1992.
[37] *DsiplaySearch FPD Equipment and Materials Analysis and Forecast,* Austin, TX, 1998.
[38] Castellano, J., *Handbook of Display Technology,* Stanford Resources, Inc., San Jose, CA., 1992.
[39] Office of Technology Assessment, *Flat Panel Displays in Perceptive*, OTA-ITC-631, Washington, DC: U.S. Government Printing Office, September, 1995.
[40] Ibid.
[41] Ibid.
[42] Ibid.

Technology	Description	Applicability to DfE Project
(5) Ferroelectric LCDs (FLCD or FELCD)	The pixel is addressed using positive or negatives pulses to orient the crystals. The positive pulse allows light to pass (light state) and the negative pulse causes the blockage of light (dark state).[43] A ferroelectric liquid crystal is bistable and holds its polarization when an electric field is applied and removed.[44] They are also called surface stabilized ferroelectric (SSF) LCDs.	Has high resolution with very good brightness, but limited color palette.[45] Limited color palette does not meet color specification of functional unit.
Plasma Display Panels (PDP)	An inert gas (e.g., He, Ne, Ar) trapped between the glass plates emits light when an electric current is passed through the matrix of lines on the glass. Glow discharge occurs when ionized gas undergoes recombination. Ionization of atoms occurs (electrons are removed), then electrons are recombined to release energy in the form of light. Full color plasma displays use phosphors that glow when illuminated by the gas.[46]	Established technology. Good for large screens (e.g., wall-mounted televisions), but are heavier and require more power than LCDs.[47] Designed for large screens and are larger displays than specified for desktop applications. Therefore, not included in the study.
Electroluminescent Displays (EL)	A phosphor film between glass plates emits light when an electric field is created across the film.[48] EL uses a polycrystalline phosphor (similar to LED technology, which is also an electroluminescent emitter, but uses a single crystal semi-conductor). ELs are doped (as a semiconductor) with specific impurities to provide energy states that lie slightly below those of mobile electrons and slightly above those of electrons bound to atoms. Impurity states are used to provide initial and final states in emitting transitions.[49] Also referred to as thin-film EL (TFEL). Variations: AC thin-film EL (AC-TFEL), active matrix EL (AMEL), DC EL, organic EL.	Lightweight and durable. Used in emergency rooms, on factory floors, and in commercial transportation vehicles.[50] Problems found in the power consumption and controlling of gray levels. Targeted toward military, medical, and high-end commercial products; therefore not included in the scope of the DfE project.

[43] Castellano, J., *Handbook of Display Technology*, Stanford Resources, Inc., San Jose, CA., 1992.
[44] Peddie, Jon, *High Resolution Graphics Design Systems*, McGraw Hill, New York, NY, 1994.
[45] Ibid.
[46] Office of Technology Assessment, *Flat Panel Displays in Perceptive*, OTA-ITC-631, Washington, DC: U.S. Government Printing Office, September, 1995.
[47] Ibid.
[48] Ibid.
[49] Peddie, Jon, *High Resolution Graphics Design Systems*, McGraw Hill, New York, NY, 1994.
[50] Office of Technology Assessment, *Flat Panel Displays in Perceptive*, OTA-ITC-631, Washington, DC: U.S. Government Printing Office, September, 1995.

Technology	Description	Applicability to DfE Project
Field Emission Displays (FED)	Flat CRT with hundreds of cathodes (emitters) per pixel (form of cathodeluminescent display); eliminates single scanning electron beam of the CRT. Uses a flat cold (i.e., room temperature) cathode to emit electrons. Electrons are emitted from one side of the display and energize colored phosphors on the other side.[51]	Not commercially available, but anticipated to fill many display needs.[52] Could potentially apply in all LCD and CRT applications. High image quality as with CRT, but less bulky and less power use than with CRT. A number of roadblocks to this technology taking over the AMLCD market include proven manufacturing processes (problems found in the reliability and reproducibility of the devices), efficient low-voltage phosphors, and high voltage drivers. The technology is targeted toward military, medical and high-end commercial products and not included in the DfE study.
Vacuum Fluorescent Displays (VFD)	Form of cathodeluminescent display that employs a flat vacuum tube, a filament wire, a control grid structure, and a phosphor-coated anode. Can operate at low voltages, because very thin layers of highly efficient phosphors are coated directly onto each transparent anode.[53]	VFDs offer high brightness, wide viewing angle, multi-color capability, and mechanical reliability. Used in low information content applications (e.g., VCRs, microwaves, audio equipment, automobile instrument panels). No significant uses seen for computer displays.[54]
Digital Micromirror Devices (DMD)	Miniature array of tiny mirrors built on a semiconductor chip. The DMD is used in a projector that shines light on the mirror array. Depending on the position of a given mirror, that pixel in the display reflects light either onto a lens that projects it onto a screen (resulting in a light pixel) or away from the lens (resulting in a dark pixel).[55]	Just beginning to be used mainly as projection devices, and has not been developed for use that would match the functional unit of the DfE study.[56]

[51] Office of Technology Assessment, *Flat Panel Displays in Perceptive*, OTA-ITC-631, Washington, DC: U.S. Government Printing Office, September, 1995.
[52] Ibid.
[53] Peddie, Jon, *High Resolution Graphics Design Systems*, McGraw Hill, New York, NY, 1994.
[54] Ibid
[55] Office of Technology Assessment, *Flat Panel Displays in Perceptive*, OTA-ITC-631, Washington, DC: U.S. Government Printing Office, September, 1995.
[56] Ibid.

Technology	Description	Applicability to DfE Project
Light Emitting Diodes (LED)	The LED device is essentially a semiconductor diode, emitting light when a forward bias voltage is applied to a p-n junction. The light intensity is proportional to the bias current and the color dependent on the material used. The p-n junction is formed in a III-V group material, such as aluminum, gallium, indium, phosphorous, antimony, or arsenic.	For low information display applications, which makes it not capable of meeting the requirements of the functional unit of the study. Color, power, and cost limitations prevent the emergence into the high information display market.[57]
Electrochromic Display	Open-circuit memory using liquid electrolytes.[58] Non-emitter (as LCDs), as opposed to emitters (e.g., EL, FED, PDP).	Outstanding contrast and normal and wide viewing angles, open-circuit memory. Complex and costly, involving liquid electrolytes, poor resolution, poor cycle life, lack of multicolor capability, etc. Not suitable for computer displays in past; however, new technology may be promising.[59]
Light Emitting Polymers	Developing technology (Holton 1997).[60]	Developing technology.

[57] Castellano, J., *Handbook of Display Technology,* Stanford Resources, Inc., San Jose, CA., 1992.
[58] Peddie, Jon, *High Resolution Graphics Design Systems*, McGraw Hill, New York, NY, 1994.
[59] Ibid.
[60] Holton, W.C., "Light-emitting polymers: increasing promise," *Solid State Technology*, vol. 40, no.. 5, p. 163, May 1997.

Appendix B

CRT Manufacture

Process step	Equipment	Process Material/Chemical	Notes
Fabricate glass			
Mix batch			
Melt			
Fine			
Condition			
Form panel			
Anneal			
Finish			
Clean			
Cut			
Grind and polish			
Inspect			
Test			
Pattern panel glass			
Clean			
Etch		acid	
Apply (contrast) grille material	spin coat	aquadag (polyvinyl alcohol)	1
Dry aquadag			
Apply green phosphor slurry	spin coat	slurry mixture: water, wetting agents, polyvinyl alcohol	
Dry phosphor	IR lamp		
Expose green phosphor	near-UV lamps		
Develop		water	
Dry			
Apply blue phosphor slurry	spin coat	ZnS:Ag	
Expose blue phosphor	near-UV lamps		
Develop		water	
Dry			
Apply red phosphor slurry	spin coat	Y_2O_2S:Cu	
Expose red phosphor	near-UV lamps		
Develop		water	
Dry			
Apply lacquer leveling film	spin coat or spray	polymer	
Apply reflective layer	evaporate	aluminum	1000 angstroms

Process step	Equipment	Process Material/Chemical	Notes
Prepare funnel			
Coat inside of funnel (dag)	sponge, flow coat, or spray	aquadag	2
Dry coating	evap oven		
Apply frit		Pb glass frit (PbO, ZnO, BO), nitrocelluose binder, amyl acetate	
Harden	evap oven	remove amyl acetate	
Manufacture shadow mask		rolled iron or Invar metal	
Etch hole pattern		etchant: ferric chloride solution	
Clean		water	
Anneal			
Draw to face plate contour			
Blacken mask and side pieces			
Weld side pieces			
Anneal magnetic shield	oven		
Blacken shield	oven		
Manufacture electron gun			3
Hydrogen fire metals			
Fixture metal parts			
Heat glass pillars			4
Press pillars over tabs on electrode			
Mount to glass stem			
Join stem to neck	melt		
Insert cathodes into support pins			
Insert heater			
Manufacture electron gun			
Weld assembly to support pins			
Weld ribbon conductors			
Weld centering springs, getter			
Add additional parts			5
Assemble mask to panel		aluminum-killed steel	
Coat shadow mask back side		bismuth oxide	
Curve shadow mask	hydraulic press		
Weld springs (brackets) to frame			
Weld mask			
Position shield on brackets			

Process step	Equipment	Process Material/Chemical	Notes
Join bulb and gun			
Attach panel to funnel	clips		total layer <.002 inch
Cure frit			> 440 °C
Seal gun to bulb			fuse base to funnel neck
Exhaust/finish assembly			
Cut excess neck glass			
Evacuate	vacuum exhaust		6
Heat tube			350 °C
Notes:			
(1) Electrically conductive carbon materials (graphite) w/silicate binders in water suspension.			
(2) Aquadag with addition of electrical conductivity modifiers, higher concentration of silicate binder, and possibly iron.			
(3) 300/400 series steels (contain Fe, Ni, Cr); borosilicate glass insulation; Ni cathode; mix. of Ba, Sr, Ca carbonates emitter material; W wire heater coated with Al oxide.			
(4) Glass pillars heated to softening temperatures.			
(5) Arcing wires, magnet pole pieces, magnetic shunts.			
(6) Excess neck glass is reused by glass companies.			

Appendix C

NEC CRT: Detailed Bill of Materials

NEC JC-1549VNA

Sub No. Entry No.	Name	Qty.	Material	Weight (grams)	Total (grams)
Bill of Materials for: NEC JC-1549VNA					
1.1	chassis	1	PS	1624.9	1624.9
1.2	right hand shield	1	steel	499.2	499.2
1.3	left hand shield	1	steel	417.4	417.4
1.4	top shield	1	steel	64.5	64.5
1.5	insulator pad	1	polyester	27.2	27.2
1.6	back shield	1	steel	190.5	190.5
1.7	shield brackets	4	brass	4	16
1.8	screws	46	zinc plated steel	1.6	73.6
1.9	swivel base large	1	PS	272.2	272.2
1.10	rubber feet	4	silicone rubber	0.5	2
1.11	brackets	4	brass	1	4
1.12	swivel base small	1	PS	109.9	109.9
1.13	base shield	1	steel	1079.5	1079.5
1.14	base bracket	2	PS	46.4	92.8
1.15	shadow mask	1	steel	626	626
1.16	anode connection	1	steel	3.3	3.3
1.17	anode cap	1	rubber	16.4	16.4
1.18	anode cap insert	1	steel	3.6	3.6
1.19	glass	1	glass	5511.1	5511.1
1.20	bracket 1	1	steel	46.4	46.4
1.21	bracket 2	1	steel	90.7	90.7
1.22	bracket 4	1	steel	246.7	246.7
1.23	xy control 1	1	PC	9.4	9.4
1.24	xy control 2	1	PC	6.2	6.2
Bill of Materials for: Neck assembly					
2.1	base neck	1	PS	66.9	66.9
2.2	top neck	1	PS	15.9	15.9
2.3	neck ring large 1	1	PS	15	15
2.4	neck ring small 1	1	PS	4.5	4.5
2.5	neck ring small 2	1	PS	4	4
2.6	meck ring large 2	1	PS	14.5	14.5
2.7	ferrite magnet	1		295.6	295.6
2.8	Cu attached to magnet	1	copper	134.5	134.5
2.9	Cu attached to neck	1	copper	108.9	108.9
2.10	extraneous copper	1	copper	0.4	0.4
2.11	insulating rings	4	polysulphone	4.1	16.4
2.12	brass ring	1	brass	2.1	2.1
2.13	rubber gaskets	2	rubber	6	12
2.14	screw with washers	4	zinc plated steel	2.9	11.6

Sub No. Entry No.	Name	Qty.	Material	Weight (grams)	Total (grams)
2.15	neck clamp	1	steel	4.4	4.4
2.16	brackets	4	brass	1.2	4.8
Bill of Materials for: Gun					
3.1	gun	1	steel	19.4	19.4
3.2	brackets	2	PC	2.9	5.8
3.3	attachment to glass	1	plastic	2.9	2.9
3.4	attachment to board 1	1	polycarbonate	4.2	4.2
3.5	attachment to board 2	1	polycarbonate	10.9	10.9
3.6	connectors	2	aluminum	0.4	0.8
3.7	screws	4	zinc plated steel	0.9	3.6
3.8	shield	1	steel	79.4	79.4
3.9	PWB board 194 mm x 122 mm	1	4 layer		
3.9a	heat sink	4	aluminum	17.6	70.4
3.9b	SOP	1			
3.9c	resistors	117			
3.9d	capacitors	60			
3.9e	transistors	27			
3.9f	resistors	4	7W		
3.9g	variable resistors	9			
3.9h	jumpers	7			
3.9i	connector 12 pin	1			
3.9j	connector 6 pin	1			
3.9k	connector 2 pin	2			
Bill of Materials for: Power board					
4.1	flyback transformer	1		320.8	
4.1a	wire	1	440 mm		
4.1b	connector 2 pin	1			
4.1c	wire	2	172 mm		
4.1d	wire	1	194 mm		
4.1e	magnet	1	ferrite magnet	101.6	101.6
4.1f	steel pin	1	steel	3.8	3.8
4.1g	rubber cap	1	rubber	1	1
4.1h	misc. potting material	1	silicone	176.2	176.2
4.1i	copper wire	1	copper	38.2	38.2
4.2	PWB additional 194mm x 95 mm	1	4 layer		
4.2a	capacitors	47			
4.2b	SOP	9			
4.2c	transistors	12			
4.2d	resistors	149			
4.2e	jumpers	6			
4.2f	wire	5	156 mm		
4.2g	connectors 5 pin	2			
4.3	PWB (x controller)		2 layer		
4.3a	PWB	1	114 x 20 mm		

Sub No. Entry No.	Name	Qty.	Material	Weight (grams)	Total (grams)
4.3b	inductor	1	copper	5.4	5.4
		1	baclite	4.6	4.6
4.3c	wire	2	156 mm		
4.3d	3 pin connector	1			
4.4	PWB (y controller)		2 layer		
4.4a	PWB	1	35 x 74 mm		
4.4b	wire	2	156 mm		
4.4c	3 pin connector	1			
4.4d	resistor	1			
4.5	knobs sm	5	PS	2.8	14
4.6	knobs lg	2	PS	4.4	8.8
4.7	aluminum shielding	1	aluminum	136.3	136.3
4.8	heat sink 1	1	aluminum	20.7	20.7
4.9	heat sink 2	1	aluminum	38.9	38.9
4.10	heat sink 3	1	aluminum	15.2	15.2
4.11	edge bracket	1	steel	87.2	87.2
4.12	wire	12	32 mm		
4.13	connector 12 pin	2			
4.14	PWB power, 349.5 x 245 mm	1	4 layer		
4.14a	fuse	1			
4.14b	variable resistors	1			
4.14c	resistors	251			
4.14d	capacitors	165			
4.14e	transistors	28			
4.14f	SOP	8			
4.14g	diode	1			
4.14h	junpers	25			
4.14i	inductor	1	baclite	6.8	6.8
		1	copper	9.6	9.6
		1	ferrite	7.6	7.6
	insulating tape	1	polyester	0.6	0.6
4.14j	inductor	1	baclite	8.7	8.7
		1	copper	26.8	26.8
		1	ferrite	139.5	139.5
4.14k	copper tape	1	copper	2.4	2.4
4.14 l	inductor	1	baclite	9.5	9.5
		1	copper	12	12
		1	ferrite	8.5	8.5
	insulating tape	1	polyester	4.8	4.8
4.14m	inductor	1	baclite	5.7	5.7
		1	copper	7.2	7.2
		1	ferrite	5.1	5.1
	insulating tape	1	polyester	0.5	0.5
4.14n	inductor	1	baclite	3.8	3.8
		1	copper	4.8	4.8
		1	ferrite	3.4	3.4

Sub No. Entry No.	Name	Qty.	Material	Weight (grams)	Total (grams)
	insulating tape	1	polyester	0.4	0.4
4.14 o	inductor	2	ferrite magnet	17.9	35.8
		2	copper	1.8	3.6
4.14p	inductor	2	baclite	5.4	10.8
		2	copper	4.6	9.2
		2	ferrite	4.2	8.4
4.14q	connector 15 pin	2			
4.14r	connector 3 pin	2			
4.14s	connector 5 pin	4			
4.14t	connector 6 pin	1			
4.14u	connector 2 pin	2			
4.14v	connector 4 pin	1			
4.14w	wire	4	296 mm		
4.15	power switch	1	PS	5.2	5.2
4.16	power cord receptacle	1	ABS	34	34
4.17	power cord	1	475 mm length	292.7	292.7
Bill of Materials for: PWB attached to power board by cable connector					
5.1	PWB, 82 x 30 mm	1	4 layer		
5.2	SOP	1			
5.3	resistors	2			
5.4	capacitors	4			
5.5	transistors	1			
5.6	connector 5 pin	1			
Bill of Materials for: PWB attached to power board by solder connector					
6.1	PWB, 53 x 52 mm	1	2 layer		
6.2	SOP	1			
6.3	resistors	24			
6.4	capacitors	10			
6.5	transistors	6			
6.6	connector 13 pin	1			
6.7	jumpers	4			
Bill of Materials for: PWB attached to power board by solder connector					
7.1	PWB, 44 x 96 mm	1	2 layer		
7.2	SOP	2			
7.3	resistors	37			
7.4	capacitors	11			
7.5	transistors	5			
7.6	connector 11 pin	1			
7.7	jumpers	2			
				Weight Total	11636.8

Appendix D

TFT-LCD Manufacture

Glass Panel

Process Step	Equipment	Material/Chemical	Notes
Fusion Method		barium borosilicate, aluminoborosilicate; 0.7mm thick	e.g., Corning 7059: 49% SiO_2, 10% Al_2O_3; 15% B_2O_3; 25% BaO; 1% other
Mix			
Melt glass			
Fine			
Condition			
Flow glass			
Draw glass			
Cut glass	band, wire, or circular blades		
Bevel/chamfer/heat glass			
Grind (may be eliminated)		sand, garnet, corundem, silicon, carbide, boron carbide, or diamond	
Polish (may be eliminated)			
Chemical finishing		potassium nitrate	
Clean (physical)	brush, scrub, ultrasonic, or megasonic		
or Clean (chemical)		organic solvent; neutral detergent; or chemical clean; and water	
or Clean (dry)	ultraviolet ozone; plasma oxide; plasma non oxide; or laser		
Anneal (back panel only)			350-400°C
Float method		barium borosilicate or aluminoborosilicate; 0.7mm thick	e.g., Corning 7059: 49% SiO_2, 10% Al_2O_3; 15% B_2O_3; 25% BaO; 1% other
Mix			
Melt			
Fine			
Flow glass	molten tin bed	float on bed of molten tin in chemically controlled atmosphere	
Cool glass		still on molten tin	
Cut glass			
Bevel/chamfer/heat glass			
Grind (may be eliminated)			
Polish (may be eliminated)			
Chemical finishing		potassium nitrate	
Clean (physical)	brush, scrub, ultrasonic, or megasonic		
or Clean (chemical)		organic solvent; neutral detergent; or chemical clean; and water	
or Clean (dry)	ultraviolet ozone; plasma oxide; plasma non oxide; or laser		
Anneal (back panel only)			

Front Panel Pattern-TN

Process Step	Equipment	Process Material	Ancillary Material	Notes
Clean glass	Ultrasonic clean/spin rinse dryer		IPA, water, nitrogen	
Deposit ITO	PVD		Indium tin oxide	
Coat photoresist	Spin coater		Polyimide	
Bake	Oven			
Expose	Stepper			
Develop	Developer		TMAH	
Clean	Spin rinse dryer		Water	
Bake photoresist	Oven			
Etch ITO	Plasma etcher		Cl_2; HBr; He; O_2	Wet etch: HCL
Strip photoresist	Developer		TMAH	
Clean	Spin rinse dryer		Water	
Deposit black matrix material	Sputter	Chrome		Alternative: black resin & photo process
Coat photoresist	Spin coater		Polyimide	
Bake	Oven			
Expose	Stepper			
Develop	Developer		TMAH	
Clean	Spin rinse dryer		Water	
Bake	Oven			
Etch Cr	Wet bench			
Strip photoresist	Wet bench		TMAH	
Clean	Spin rinse dryer		Water	
Inspect				
Apply (R) color filter material	Extrude/spin or slit/spin coater	0.8-2.0 um acryl epoxy resin, Sbq-PVA	Same as process material	Pigment-dispersion method, 99% TFTs
Bake	Oven			
Expose	Stepper			
Develop	Developer		TMAH	
Clean	Spin rinse dryer		Water	Negative resist; extra strip not required
Apply (G) color filter material	Spin coater	Pigment-diffused acryl epoxy resin	Same as process material	
Bake	Oven			
Expose	Stepper			
Develop	Developer		TMAH	
Clean	Spin rinse dryer		Water	
Apply (B) color filter material	Spin coater	Pigment-diffused acryl epoxy resin	Same as process material	
Expose	Stepper			
Develop	Developer		TMAH	
Clean	Spin rinse dryer		Water	
Planarize	Coat	Polyimide		

Process Step	Equipment	Process Material	Ancillary Material	Notes
Deposit alignment layer	Roll coat	Polyvinyl alcohol; polyesters; poly- siloxanes; polyamic acid solution		
Bake	Oven			
Rub	Rubbing machine			
Inspect	Microscope			
Test				

Rear Panel Pattern-TN

Process Step	**Equipment**	**Product Materials**	**Ancillary Materials**	**Notes**
Clean bottom glass	Ultrasonic or brush		IPA, nitrogen, water	alkali-free likely future material
Inspect				
Deposit gate metal	PVD	One of the following: Al, Al + barrier, Al + metal, Al alloy		Ti/Al/Ti possible future metal layers
Coat photoresist	Spin coater		Polyimide	90- 95% wasted on traditional spin coater
Bake	Oven			
Expose	Stepper			
Develop	Developer		NMP	
Clean	Spin rinse dryer		Water	
Bake photoresist	Oven			
Etch gate metal	Plasma etcher			or wet etch + clean
			Al: $C1_2$+$BC1_3$/$C1_2$	
			Al+barrier: Cl_2; BCl_3; N_2; CF_4	
			Al+metal: Cl_2; BCl_3; N_2; CF_4	
			Al alloy (Zr, Cu, Nd, Y): Cl_2; BCl_3; N_2; CF_4	
Strip photoresist	Developer		NMP	
Clean	Spin rinse dryer		Water	
Inspect				
Deposit dielectric material	PECVD	SiO_2 or SiN		
Deposit channel material	PECVD	a-Si		
Deposit etch stop layer	PECVD	SiNx		
Coat photoresist	Spin coater		Polyimide	
Bake	Oven			
Expose	Stepper			
Develop	Developer		NMP	
Clean	SRD		Water	
Bake photoresist	Oven			
Etch SiNx	Plasma etcher		CHF_3; CF_4	
Etch a-Si	Plasma etcher		CF_4; O_2	
Etch SiNx	Plasma etcher		CF_4; O_2 or Cl_2	
Strip photoresist	Developer		NMP	
Clean	SRD		Water	
Deposit ohmic contact material	PECVD	Doped Si (n-type: As,P)		
Coat photoresist	Spin coater		Polyimide	
Bake	Oven			
Expose	Stepper			

Process Step	Equipment	Product Materials	Ancillary Materials	Notes
Develop	Developer		NMP	
Clean	SRD		Water	
Bake photoresist	Oven			
Etch doped a-Si	Plasma etcher		$C1_2$ or CF_4+O_2 or SF_6+HCL	
Strip photoresist	Developer		NMP	
Clean	Spin rinse dryer		Water	
Deposit ITO	PVD	Indium oxide/tin oxide		
Anneal	Oven			
Coat photoresist	Spin coater		Polyimide	
Bake	Oven			
Expose	Stepper			
Develop	Developer		NMP	
Clean	SRD		Water	
Bake photoresist	Oven			
Etch ITO	Plasma etcher		Cl_2+ HBr; He; O_2; CH_4+H_2	or wet etch + clean
Strip photoresist	Developer		NMP	
Clean	SRD		Water	
Coat photoresist	Spin coater		Polyimide	
Bake	Oven			
Expose	Stepper			
Develop	Developer		NMP	
Clean	SRD		Water	
Bake photoresist	Oven			
Etch n+ a-Si (contact)	Plasma etcher		Cl_2	
Deposit source/drain metal	PVD	One of the following: Al, Al + barrier, Al + metal, Al alloy Ti, Mo, Cr, W, MoTa, or MoW		
Coat photoresist	Coater		Polyimide	
Bake	Oven			
Expose	Oven			
Develop	Stepper			
Clean	Developer		NMP	
Bake photoresist	Spin rinse dryer		Water	
Etch metal	Plasma etcher		Al etch: $C1_2$+$BC1_3$/$C1_2$	or wet etch + clean
			Al+barrier: Cl_2; BCl_3; N_2; CF_4	
			Al+metal: Cl_2; BCl_3; N_2; CF_4	
			Al alloy (Zr, Cu, Nd, Y): Cl_2; BCl_3; N_2; CF_4	
Strip photoresist	Developer		NMP	
Clean	SRD		Water	
Deposit passivation layer	PECVD	SiNx	CF_4+O_2	
Coat photoresist	Coater		Polyimide	
Bake	Oven			
Expose	Oven			

Process Step	Equipment	Product Materials	Ancillary Materials	Notes
Develop	Proximity printer			
Clean	Developer		NMP	
Bake photoresist	SRD		Water	
Etch SiNx	Plasma etcher		O_2, N_2, He, SiF_6, CHF_3 (mixture)	
Strip photoresist			NMP	
Clean	SRD		Water	
Deposit alignment material	Roll coater	Polyimide, 500 to 1000 A		
Bake	Oven			
Rub	Rubbing machine			
Electrostatic discharge				
Test	SRD		Water	

Front Panel Pattern-IPS

Process Step	Equipment	Process Material	Ancillary Material	Notes
Clean glass	Ultrasonic clean/SRD		IPA, water, nitrogen	
Deposit black matrix material	Sputter	Chrome		Alternative: black resin & photo process
Coat photoresist	Spin coater		Polyimide	
Bake	Oven			
Expose	Stepper			
Develop	Developer		TMAH	
Clean	Spin rinse dryer		Water	
Bake	Oven			
Etch Cr	Wet bench			
Strip photoresist	Wet bench		TMAH	
Clean	Spin rinse dryer		Water	
Inspect				
Apply (R) color filter material	Extrude/spin or slit/spin coater	0.8-2.0 um acryl epoxy resin, Sbq-PVA	Same as process material	Pigment-dispersion method, 99% TFTs
Bake	Oven			
Expose	Stepper			
Develop	Developer		TMAH	
Clean	Spin rinse dryer		Water	Negative resist; extra strip not required
Apply (G) color filter material	Spin coater	Pigment-diffused acryl epoxy resin	Same as process material	
Bake	Oven			
Expose	Stepper			
Develop	Developer		TMAH	
Clean	Spin rinse dryer		Water	
Apply (B) color filter material	Spin coater	Pigment-diffused acryl epoxy resin	Same as process material	
Expose	Stepper			
Develop	Developer		TMAH	
Clean	SRD		Water	
Deposit alignment layer	Roll coat	Polyvinyl alcohol; polyesters; poly-siloxanes; polyamic acid solution		
Bake	Oven			
Rub	Rubbing machine			
Inspect	Microscope			
Test				

Rear Panel Pattern-IPS

Process Step	Equipment	Product Materials	Ancillary Materials
Clean substrate	Brush, disk, US, or MS		
Inspect			
Deposit light shield metal	PVD	Cr	
Coat photoresist	Coater		Positive photoresist
Bake	Oven		
Expose	Stepper		
Develop	Developer		NMP
Clean	Spin rinse dryer		Water
Bake	Oven		
Etch Cr	Plasma etcher	Cl_2;O_2	
Strip	Plasma asher	Cl_2;O_2 (or wet bench)	
Clean	Spin rinse dryer		
Inspect	AOI		
Deposit dielectric	CVD	SiO_2	
Deposit source/drain metal	PVD	One of the following: Al, Al + barrier, Al + metal, or Al alloy	
Coat photoresist	Coater		
Bake	Oven		
Expose	Stepper		
Develop	Developer		NMP
Clean	Spin rinse dryer		Water
Bake	Oven		
Etch			Al etch: $C1_2$+$BC1_3$/$C1_2$
			Al+barrier: Cl_2; BCl_3; N_2; CF_4
			Al+metal: Cl_2; BCl_3; N_2; CF_4
			Al alloy (Zr, Cu, Nd, Y): Cl_2; BCl_3; N_2; CF_4
Strip			NMP
Clean			Water
Create island		SiNx, a-Si, n+ a-Si	
Coat photoresist		n+ a-si	
Expose			
Develop	PVD		
Clean			
Bake			
Etch island	Plasma etcher		CF_4; O_2; Cl_2
Strip			
Clean			
Inspect			

Process Step	Equipment	Product Materials	Ancillary Materials
Deposit gate electrode	CVD	Al, Al+barrier, Al+metal, or Al alloy	
Deposit pixel electrode	CVD	Al, Al+barrier, Al+metal, or Al alloy	
Deposit common electrode	CVD	Mo, Ta, MoTa, MoW, Al/Cr, or Ti/Al/Ti	
Coat photoresist	Coater		
Bake	Oven		
Expose	Stepper		
Develop	Developer		
Clean	Spin rinse dryer		
Bake	Oven		
Etch metal(s)	Wet bench		Al etch: $C1_2+BC1_3/C1_2$
			Al+barrier: Cl_2; BCl_3; N_2; CF_4
			Al+metal: Cl_2; BCl_3; N_2; CF_4
			Al alloy (Zr, Cu, Nd, Y): Cl_2; BCl_3; N_2; CF_4
			Ti: Cl_2; CF_4
			Mo: Cl_2; O_2; SF_6
			Cr: Cl_2; O_2
			W: Cl_2; O_2; SF_6
			MoTa: Cl_2; O_2; SF_6
Clean	Spin rinse dryer		
Strip	Developer		
Clean	Spin rinse dryer		
Deposit alignment layer	Roll coater	Polyimide, 500 to 1000 A	
Bake	Oven		
Rub	Rubbing machine		
Electrostatic discharge	Spin rinse dryer		Water
Test			

Display Cell Assembly

Process Step	Equipment	Process material/chemical	Notes
Apply seal	Screen printer	Epoxy resin, acrylic resin, etc.	
Cure	Oven		
Apply spacers	Spacer sprayer	Divinylbenzene-type resin or silica	
Inspection	Microscope		
Align and assemble plates			Each glass plate 1.1 mm thick
Cure	Oven		
Scribe and break			400 different types exist; more than one used
Inject liquid crystal	Vacuum/injection system	Polycyclic aromatic/halogenated hydrocarbon; cyanobiphenyl; phenylcyclohexane compound	0.8 mg/cm^2
Seal		Epoxy resin, acrylic resin, etc.	Sealing LC-injection hole
Cure	UV light source/oven		
Clean			
Attach front polarizer	Laminator	Polyvinyl alcohol-iodine	.2 - .3 mm cellulose triacetate; cellulose acetate butyrate-protective layer
Attach rear polarizer	Laminator	Polyvinyl alcohol-iodine	.2 - .3 mm cellulose triacetate; cellulose acetate butyrate-protective layer
Clean			
Inspect/test display			

Display Module Assembly

Process Step	Process material/chemical	Notes
Attach row drivers	PWB, TAB (polyimide film, sealing resin)	
Attach column drivers	TAB (polyimide film, sealing resin)	
Attach backlight	Glass fluorescent material, 20ppm Hg (notebook computer)	
Inspect		
Clean circuit boards		
Test		
Attach controller	TAB (polyimide film, sealing resin)	
Attach passive components		
Attach packaging hardware		
Attach interconnects		
Test unit		

Appendix E

Cannon FPD: Detailed Bill of Materials

Cannon FLCD 15C01

Appendix E
Cannon FPD - Detailed BOM

Sub No. Entry No.	Name	Qty.	Material	Weight (grams)	Formation Process	Features	Supplier	Finish (top)	Finish (bottom)
Bill of Materials for: Canon FLCD 15CD01									
1.1	Front bezel	1	ABS	150	inj. mold	31 brass inserts	Japan Synthetic Rubber Company	screened logo	conductive paint
1.2	LED light pipe	1	polycarb	<1	inj. mold				
1.4	Adjustment PWB	1	see subassy BOM						
1.5	scr M3, 4 pnh	3							
1.7	Knob	2	ABS	1.7	inj. mold			as molded	
1.9	Power supply PWB	1	see subassy BOM						
1.10	Power switch bezel	1	ABS	4.2	inj. mold			as molded	
1.11	scr M3, 4 pnh	7							
1.14	LCD subassy	1	see subassy BOM						
1.15	Backlight assy	1	see subassy BOM						
1.16	scr M3, 4 pnh	2							
1.17	scr M3, 4 pnh	18							
1.19	Cable clamp	1	nylon	<1	inj. mold			as molded	
1.20	Power supply cover	1	steel	25	progressive die stamp			electro-galvanized	
1.21	scr M3, 10 pnh	2							
1.22	insulator	1	polyester	10	die cut				
1.23	Hitachi PWB	1	see subassy BOM						
1.24	scr M3, 4pnh	6							
1.26	NFX controller	1	see subassy BOM						
1.27	scr M3, 4 pnh	6							
1.30	Rear cover assy	1	see subassy BOM						
1.31	scr M3, 10 pnh	9							
1.32	Power supply assy	1	see subassy BOM						
1.33	scr M3, 10 pnh	4							
1.34	Base/stand	1	see subassy BOM						
Bill of Materials for: LCD subassy 1.14									
4.1	Plastic frame	1	PC-GF30	150	inj. mold	6 brass inserts			
4.2	Gasket	1	silicone rubber	n/a	dispensed				
4.3	Brightness enhancer	1	polyester	10	extruded, die cut		3M	microembossed	
4.4	scr M3, 4 pnh	6							
4.6	Large gasket	1	silicone rubber	n/a	dispensed				
4.7	Small gasket	1	silicone rubber	n/a	dispensed				
4.8	LCD panel assy	1	see subassy BOM						
4.9	Metal clip	4	Be Cu	1	stamped			Ni plate	
4.10	scr M3, 4 pnh	1							
4.12	Cable assy	1	see cable assy summary						
4.13	Hold-down clip	1	Be Cu	1	stamped			Ni plate	
4.14	scr M3, 4 pnh	1							

Appendix E

Cannon FPD - Detailed BOM

Sub No. Entry No.	Name	Qty.	Material	Weight (grams)	Formation Process	Features	Supplier	Finish (top)	Finish (bottom)
Bill of Materials for: Backlight assy 1.15									
5.1	Metal plate	1	steel	175	progressive die stamp			electro-galvanized	
5.2	Brass thd'd standoff	4	brass	2	screw machine				
5.4	scr M3, 4 pnh	4							
5.5	Foam gasket	4	foam rubber	<1	adhesive backed foam tape		3M	adhesive	
5.6	Nylon strain relief	1	nylon	<1	inj. mold				
5.8	Clear protector	1	plexiglass	75	inj. mold			etched both sides	
5.9	Opaque diffuser	1	polyester	10	extruded, die cut		3M	microembossed both sides	
5.10	Light pipe	1	polycarbonate	550	inj. mold				
5.11	Corner tape	4	aluminized mylar	<<1	extrude/roll form/ e-less plate		3M		
5.12	White reflector	1	polyester	15	extruded, die cut				
5.13	Light assy	4	see subassy BOM						
5.14	scr M3, 4 pnh	4							
5.16	Nylon clamp	6	nylon	1	inj. mold				
5.17	scr M3, 4 pnh	6							
5.19	Rear plate assy	1	see subassy BOM						
Bill of Materials for: Light assy 5.13									
5.13b	Cold cathode tube	1	glass, phosphor	8.7	complex				
5.13c	Shock cushion	2	silicone rubber	1.7	inj. mold				
5.13d	Cable assy	2	insulated Cu wire	4.4	complex	inj. molded connector			
Bill of Materials for: Rear plate assy 5.19									
6.1	Rear plate	1	steel	350	progressive die stamp	2 piece 18 spot welds		electro-galvanized	
6.2	Cable clamp	3	nylon	1.1	inj mold				
6.3	Plastic tube	2	polycarb	4.1	extrude/screw mach.				
6.4	scr M3, 10 pnh	2							
6.5	Flat cable toroid	6	hi-mu ferric	12	molded		Tokin		
6.6	Hold-down plate	2	steel	20.6	progressive die stamp			electro-galvanized	
6.7	scr M3, 4 pnh	4							
6.8	Caution label	1	paper	<<1				screen print ink	adhesive
Bill of Materials for: Rear cover assy 1.30									
9.1	Rear cover	1	ABS	325	inj mold		Japan Synthetic Rubber Company	as molded	conductive paint
9.2	BeCu fingers	6	BeCu	1	die stamped	heat staked to rear cover		Ni plate	
9.4	Cloth mesh	2	polyester	<1	woven	glued to rear cover			
9.5	Metal plate	1	steel	200	stamped	2 pressed in screw machine nuts		electro-galvanized	
9.7	scr M3, 4 pnh	4							

Appendix E
Cannon FPD - Detailed BOM

Sub No. Entry No.	Name	Qty.	Material	Weight (grams)	Formation Process	Features	Supplier	Finish (top)	Finish (bottom)
9.8	Shoulder screw	2							
9.10	Insulator	1	polyester	20	die cut				
9.11	scr M3, 5 type B	4							
Bill of Materials for: Power supply assy 1.32									
10.1	Housing	1	steel	150	progressive die stamped	2 piece, 2 spot welds		electro-galvanized	
10.2	Insulator	1	polyester	24	die cut				
10.3	Power supply PWB assy	1	see subassy BOM						
10.4	Pwr switch	1	ABS/Cu	5.2	inj. mold		Matsushita		
10.5	Pwr cord recept.	1	ABS/Cu	34	complex, inj. mold	3 wire pigtail w/ ferrite choke			
10.6	scr M3, 4 pnh	4							
10.7	Heat sink	1	aluminum	60					
10.8	scr M3, 4 pnh	8							
Bill of Materials for: Base/Stand assy 1.34									
11.1	Upright	1	UP-GF14	450	inj. mold				
11.2	Bracket 1	1	steel	44	stamped			electro-galvanized	
11.3	Bracket 2	1	steel	52	stamped			electro-galvanized	
11.4	Bracket 3	1	steel	65	stamped			electro-galvanized	
11.5	Bracket 4	1	steel	175	stamped	2 piece, 22 spot welds		none	
11.6	Bracket 6	2	steel	10	stamped				
11.7	Axle	2	steel	15	screw machine				
11.8	Spring	2	steel	8					
11.9	Bushing	2	nylon	3	inj. mold				
11.10	Swivel bearing 1	1	stainless	68	stamped				
11.12	Swivel bearing 2	1	POM	31	inj. mold				
11.13	Bracket 7	1	steel	460	stamped			textured paint	
11.14	Base weight	1	steel	450	stamped				
11.15	Rubber feet	5	silicone rubber	<1	die cut			adhesive	
11.16	Cover 1	1	ABS	33	inj. mold				
11.17	Cover 2	1	ABS	27	inj. mold				
11.18	Cover 3	1	ABS	30	inj. mold				
11.19	Cover 4	1	ABS	35	inj. mold				
11.20	Cover 5	1	ABS	20	inj. mold				
11.21	Cover 6	1	ABS	95	inj. mold				
11.22	C-clip	4	steel	<1	stamped				
11.23	Lg washers	2	steel	3.6	stamped				
11.24	Sm washers	2	steel	<1	stamped				

Appendix E
Cannon FPD - Detailed BOM

Sub No. Entry No.	Name	Qty.	Material	Weight (grams)	Formation Process	Features	Supplier	Finish (top)	Finish (bottom)
Bill of Materials for: LCD panel Assembly 4.8									
12.1	AMLCD cell	1	glass, misc thin films	475	complex				
12.2	Row driver TAB	3	IC chip on polyimide tape	1	complex	2mm X 12 mm IC, 30mm X 15mm tape			
12.3	Column driver TAB	10	IC chip on polyimide tape	1	complex	1.5mm X 10mm IC, 20mm X 12mm tape			
12.4	Row driver input PWB	1	see subassy BOM						
12.5	Column driver input PWB	1	see subassy BOM						
12.6	Connection flex	1	Cu thin film on polyimide base	5	complex	35mm X 12cm			
			weight sub-total	5136.6					
Bill of Material Summary for Cables									
	21 individual wires, AWG 36, totaling 352 inches; 9 connectors with average of 5 connections each and 1.5 g weight each								
Bill of Materials for: NFX Controller 1.26									
PWB:	Trace	0.008	Space	0.008	Pitch	0.016			
	ViaID	0.012	ViaOD	0.024	Material	FR4			
	Thick.	0.062	#Layers	4	Weight	120			
Board Area in Sq Inches:	38.156	(total both sides)							
Components				All Dimensions in Inches					
Part Number	Qty	#IO	Type Pkg	Lead Pitch	Length	Width			
CG21503...Japan	1	208	QFP	0.02	0.375	0.35			
AD7224KR-1	1	20	SOP	0.05	0.095	0.085			
TD62595AFT9424K	1	18	SOP	0.05	0.08	0.075			
J47AD 74ACTQ244...National	6	20	SOP	0.05	0.065	0.06			
P39AK DS26C32ATM	5	16	SOP	0.05	0.075	0.055			
MC33174D XAG448...Motorola	2	14	SOP	0.05	0.1	0.065			
SM128 LM324M	1	14	SOP	0.05	0.065	0.055			
P41AD DS26C31TM	1	16	SOP	0.05	0.075	0.055			
AH6-0054-01 N335E3B	1	100	QFP	0.025	0.215	0.175			
	1	100	I.C. Socket	0.025					
	2	3	SOT-23	0.2					
	4	3	SOT-23	0.1					
	4	4	SOT	0.06					
403 592C	1	4	SOT	0.1					
SCC 357	1	4	SOT	0.1					
	3	6	SOT	0.025					
	16	3	SOT-23	0.075					

Appendix E

Cannon FPD - Detailed BOM

Sub No. Entry No.	Name	Qty.	Material	Weight (grams)	Formation Process	Features	Supplier	Finish (top)	Finish (bottom)
For SOT on line #19	1	0	Al heatsink Plate						
	12	2	Electro Cap						
	10	2	Electro Cap						
	2	3	Fuse						
20.000 MHz	1	4	Crystal						
20.000 MHz	1	2	Crystal						
	8	2	Diode						
	456	2	1206 chip cap						
	27	2	misc. Discrete						
	232	2	0805 chip resistor						
Socket type w/large metal bracket	1	25	Connector	0.05					
Ni-Zero-Insert-Flex	10	12	Connector	0.025					
Ni-Post	1	10	Connector	0.07					
Ni-Post	1	3	Connector	0.07					
Ni-Post	1	4	Connector	0.07					
Ni-Post	1	8	Connector	0.07					
Bill of Materials for: Hitachi PWB 1.23									
PWB:	Trace	0.01	Space	0.01	Pitch	0.02			
	ViaID	0.012	ViaOD	0.035	Material	FR4			
	Thick.	0.062	#Layers	4	Weight	205			
Board Area in Sq Inches:	39.781	(total both sides)							
Components				All Dimensions in Inches					
Part Number	Qty	#IO	Type Pkg	Pitch	Length	Width			
5B2 HA17339	1	14	SOP	0.1	0.095	0.065			
51CT00T TL1451A4Y	1	16	SOP	0.1	0.075	0.065			
	2	3	SOT-23	0.1					
	8	3	SOT-23	0.1					
	8	2	Capacitor						
Wire Type	8	2	Capacitor						
Wire Type	10	2	Capacitor						
Wire Type	2	2	Capacitor						
Wire Type	7	2	Capacitor						
	4	6	Transformer						
	8	4	Choke						
	8	9	Transformer						
Wire Type	14	2	Resistor						
Wire Type	2	2	Resistor						
Can Type	4	2	Capacitor						
Can Type	4	2	Capacitor						
Can Type	5	2	Capacitor						

Appendix E

Cannon FPD - Detailed BOM

Sub No. Entry No.	Name	Qty.	Material	Weight (grams)	Formation Process	Features	Supplier	Finish (top)	Finish (bottom)
Can Type	1	2	Capacitor						
	1	2	Fuse						
	1	3	Filter						
	1	3	Variable resistor						
Open case	1	3	Connector	0.1					
Open case	1	4	Connector	0.1					
Closed case	4	4	Connector	0.1					
Closed case	4	3	Connector	0.1					
	4	4	SOT	0.1					
	26	3	SOT	0.075					
	2	5	SOT	0.035					
	14	2	Misc. Discrete						
	19	2	1206 chip capacitor						
	75	2	0805 chip resistor						
Bill of Materials for: Adjustment PWB 1.4									
PWB:	Trace	0.02	Space	0.01	Pitch	0.03			
	ViaID	0.012	ViaOD	0.035	Material	FR4			
	Thick.	0.048	#Layers	2	Weight	27			
Board Area in Sq Inches:	9.2		(total both sides)						
Components				All Dimensions in Inches					
Part Number	Qty	#IO	Type Pkg	Pitch	Length	Width			
	3	4	Variable resistor	0.1	0.95	0.65			
	1	3	Trimmer pot	0.1	0.2	0.2			
	1	2	Axial leaded resistor	0.2					
	1	2	Pilot lite LED	0.1					
	1	4	Connector	0.1					
	1	6	Connector	0.1					
Bill of Materials for: Power supply PWB assy 10.3									
PWB:	Trace	0.05	Space	0.02	Pitch	0.07			
	ViaID	0.03	ViaOD	0.06	Material	Phenolic			
	Thick.	0.062	#Layers	1	Weight	240			
Board Area in Sq Inches:	31.5	(1 side only)							
Components				All Dimensions in Inches					
Part Number	Qty	#IO	Type Pkg	Pitch	Length	Width			
M51995P	1	16	DIP	0.1	0.9	0.2			
upc494C	1	16	DIP	0.1	0.9	0.2			
2903D	1	8	DIP	0.1	0.3	0.2			
PC123	3	4	DIP	0.1	0.2	0.2			
3050C	8	3	To-220	0.1	0.75	0.4			

Appendix E
Cannon FPD - Detailed BOM

Sub No. Entry No.	Name	Qty.	Material	Weight (grams)	Formation Process	Features	Supplier	Finish (top)	Finish (bottom)
Rectifier	1	4	SIP	0.2	1.1	0.8			
	4	2	L.g. electrolytic cap						
	8	2	Med e-lytic cap						
	6	6	Sm e-lytic cap						
	20	2	Radial tant cap						
	8	3	Sm transistor						
	22	2	Axial lead diode						
	45	2	Axial lead resistor						
	24	2	Wire jumper						
	3	2	Lg ferrite core toroid						
	1	8	Lg transformer						
	1	2	Fuse						
	1	2	Connector	0.1					
	1	8	Connector	0.1					
Bill of Materials for: Row driver input PWB 12.4									
PWB:	Trace	0.02	Space	0.01	Pitch	0.03			
	ViaID	0.012	ViaOD	0.035	Material	FR4			
	Thick.	0.032	#Layers	4	Weight	30			
Board Area in Sq Inches:	24	(total both sides)							
Components				All Dimensions in Inches					
Part Number	Qty	#IO	Type Pkg	Pitch					
	9	2	1206 chip capacitor						
	3	2	2515 chip capacitor						
	2	36	Connector	0.1					
Bill of Materials for: Column driver input PWB 12.3									
PWB:	Trace	0.02	Space	0.01	Pitch	0.03			
	ViaID	0.012	ViaOD	0.035	Material	FR4			
	Thick.	0.032	#Layers	2	Weight	40			
Board Area in Sq Inches:	18	(total both sides)							
Components				All Dimensions in Inches					
Part Number	Qty	#IO	Type Pkg	Pitch					
	20	2	1206 chip capacitor						
	10	2	2515 chip capacitor						
	2	36	Connector	0.1					
Total Product Weight				5798.6	Stand	3681.4			

Glossary

a:Si	Amorphous silicon
Active center	Location of the unpaired electron on a free radical, where reactions take place.
Alignment layer	A layer and/or surface treatment applied to the boundary of a liquid crystal cell to induce a particular director orientation. For example, a layer of polyimide buffed in one direction induces alignment parallel to the buffing direction, or a surfactant may be polymerized on a boundary surface to induce perpendicular alignment.
AMLCD	Active-matrix liquid crystal display
Amorphous	Irregular; having no discernible order or shape. In the context of solids, the molecules are randomly arranged, as in glass, rather than periodically arranged, as in a crystalline material.
Amorphous polymers	A glass-like structure with tangled chains and no long-range order.
Amphiphilic	A molecule with a hydrophilic head and a hydrophobic tail (i.e., a molecule that has one end that attracts water and one end that repels water).
Anisotropic	Having properties that vary depending on the direction of measurement. In liquid crystals, this is due to the alignment and the shape of the molecules. Dielectric anisotropy means different dielectric strengths along different axes, and refractive anisotropy means different refractive indices along different axes.
APCVD	Atmospheric pressure chemical vapor deposition
Aquadag	An aqueous conductive coating found on the faceplate.
Backbone	The main structure of a polymer onto which substituents are attached.
Biaxial	Possesses two directions along which monochromatic light vibrating in any plane will travel with the same velocity.
Birefringence	Also called double refraction. The property of uniaxial anisotropic materials in which light propagates at different velocities, depending on its direction of polarization relative to the optic axis.
Block polymers	Polymers composed of two or more connected sequences (blocks) of homopolymers.
BOM	Bill of materials
Buffing	To give the inner glass surfaces of a liquid crystal cell a texture, in order to align the liquid crystal molecules in a certain direction parallel to the surfaces.
CCFT	Cold cathode fluorescent tube
Chain polymer	A polymer in which the repetition of units is linear. The

	monomers are linked end to end, forming a single straight polymer.
Chiral Nematic	Similar to the nematic phase; however, in the cholesteric phase, molecules in the different layers orient at a slight angle relative to each other (rather than parallel, as in the nematic). Each consecutive molecule is rotated slightly relative to the one before it. Therefore, instead of the constant director of the nematic, the cholesteric director rotates helically throughout the sample.
COB	Chip-on-board
COF	Chip-on-film
COG	Chip-on-glass
Convergence	The ability of an electron beam to hit the correct phosphor dot.
Cross-linking	A process in which bonds are formed joining adjacent molecules. At low density, these bonds add to the elasticity of the polymer. At higher densities, they eventually produce rigidity in the polymers.
CRT	Cathode ray tube. A glass vacuum tube used in televisions and monitors.
Cullet	Broken glass from CRT
CVD	Chemical vapor deposition
DfE Program	EPA’s Design for the Environment Program
Dielectric	A material that is inserted between the plates of a capacitor to increase its effective capacitance.
Dot pitch	The vertical distance between the centers of adjacent pixels. Dot pitch is an important determinant in the clarity of a color monitor.
E/S	Etch stop
EOL	End-of-life
FPD	Flat panel display
Frit	Solder glass made of lead oxide, zinc oxide, and boron oxide, mixed with nitrocellulose binder and amyl acetate to form a paste.
Gate	Control terminal of a thin-film-transistor.
Grille dag	A coating of contrast-enhancing material applied to the faceplate.
IC	Integrated circuit
IPS	In-plane switching
Isotropic	Disordered and without any preferred direction.
ITO	Indium tin oxide
LCD	Liquid crystal display
Liquid crystal	A thermodynamic stable phase characterized by anisotropy of properties without the existence of a three-dimensional crystal lattice, generally lying in the temperature range between the solid and isotropic liquid phase.

Mesomorphic substance	Another term for a liquid crystal material.
MIM	Metal-insulator metal
Monochromatic light	Light composed of only one specific wavelength.
Nematic	Liquid crystals are characterized by long-range orientational order and the random disposition of the centers of gravity in individual molecules. Nematics may be characterized as the simplest spontaneously anisotropic liquids.
NMP	N-methyl pyrrolidinone
OEM	Original equipment manufacturer
p:Si	Polycrystalline silicon
Passivation	A thin-film protective layer that is applied to a glass substrate prior to LCD fabrication. It makes the surface "passive" in that no ions can migrate from the glass to the silicon film.
PECVD	Plasma-enhanced chemical vapor deposition
Phosphors	Luminescent materials
Photoresist	A photosensitive polyimide resin
PMLCD	Passive matrix liquid crystal display
Polyimide	A cyclopolymerized organic material capable of withstanding high temperatures (at least 300°C).
Polymer liquid crystals	Polymers that contain mesogen units and thus have liquid crystal properties.
PVD	Physical vapor deposition
PWB	Printed wiring board
Slurry	A thin paste that has solids suspended in liquids.
STN	Super-twisted nematic, a passive-matrix LCD technology
TAB	Tab automated bonding
TFT-LCD	Thin film transistor liquid crystal display
TMAH	Trimethylamine hydrochloride