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.

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

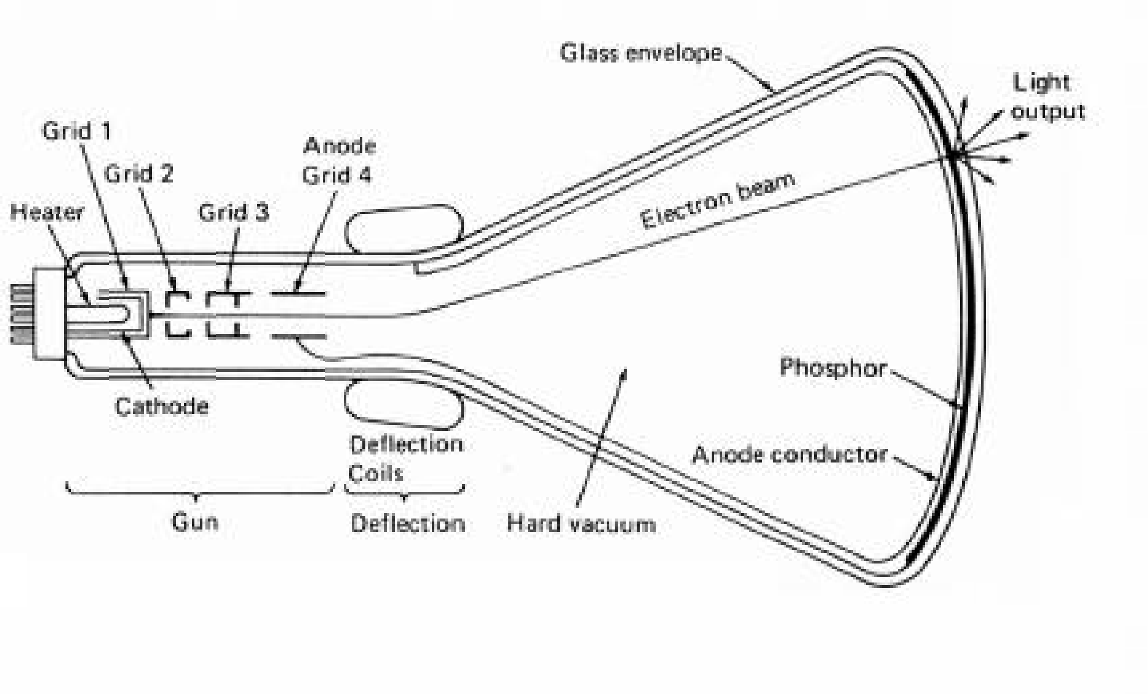

Figure 3-1: Cathode Ray Tube Fundamentals

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.

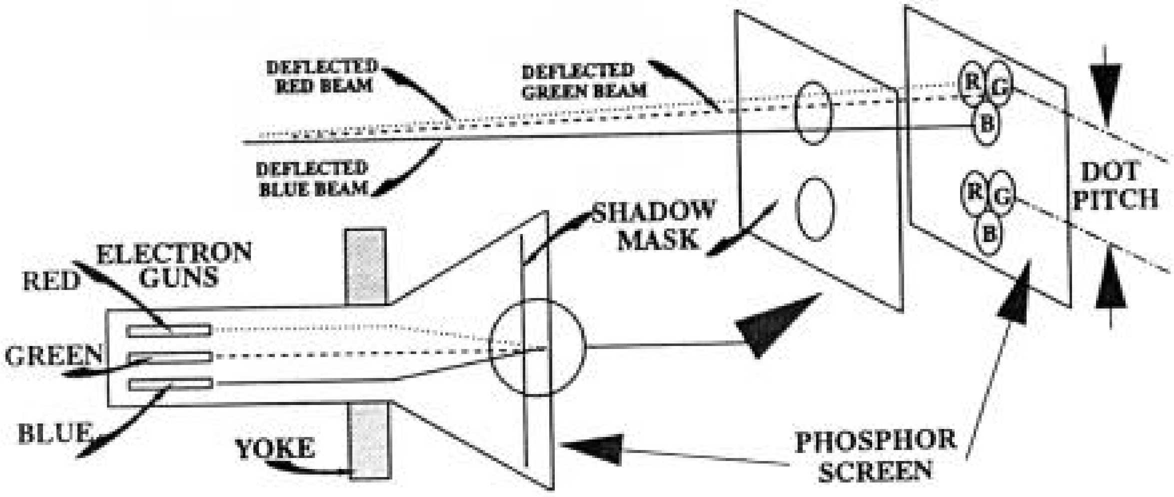

Figure 3-2: Shadow Mask Color CRT[24]

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.

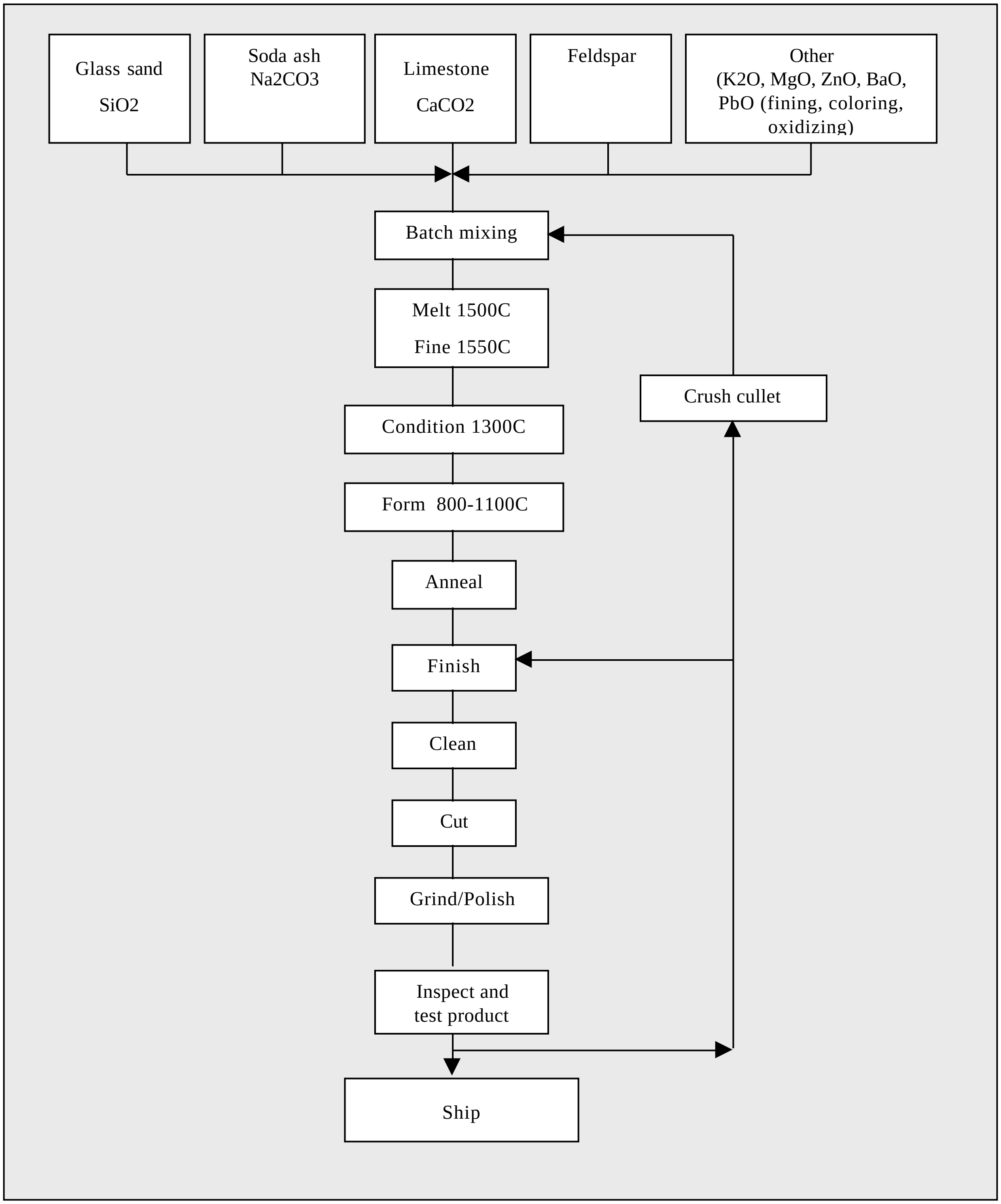

Figure 3-3: Glass Manufacturing Process Flow[26]

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[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.

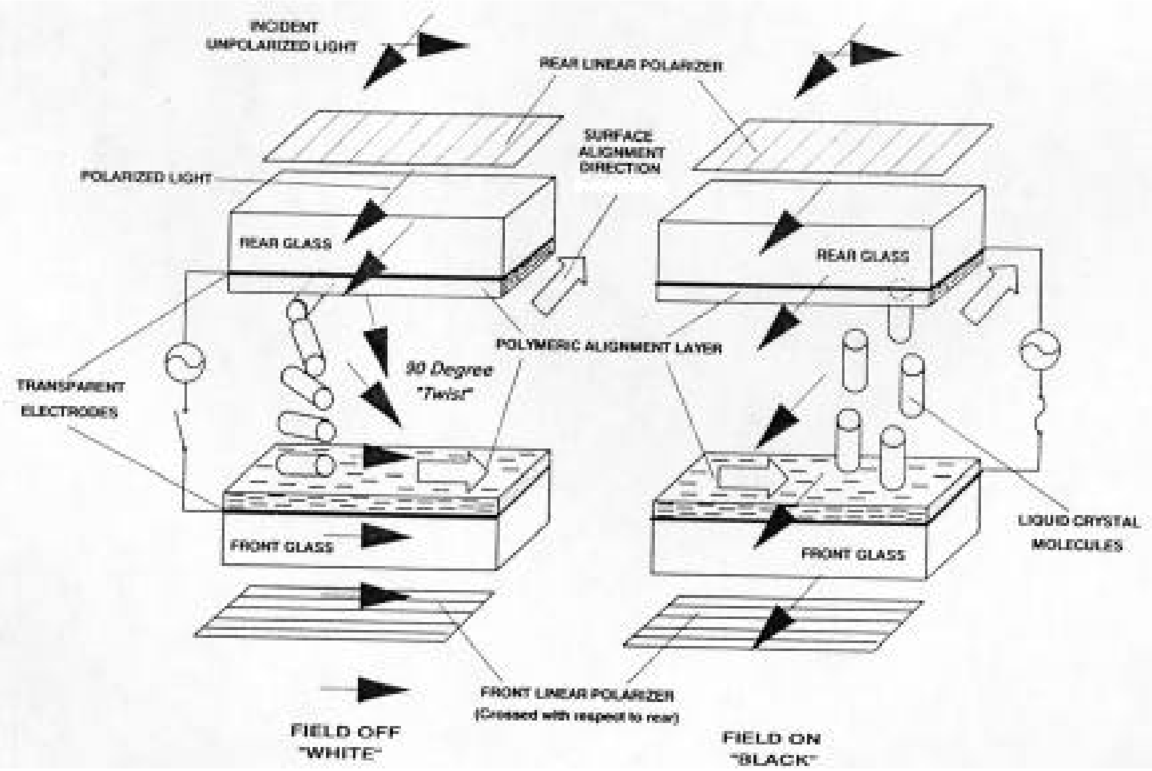

Figure 3-5: TN Field-Effect LCD Operating Principles[29]

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[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.

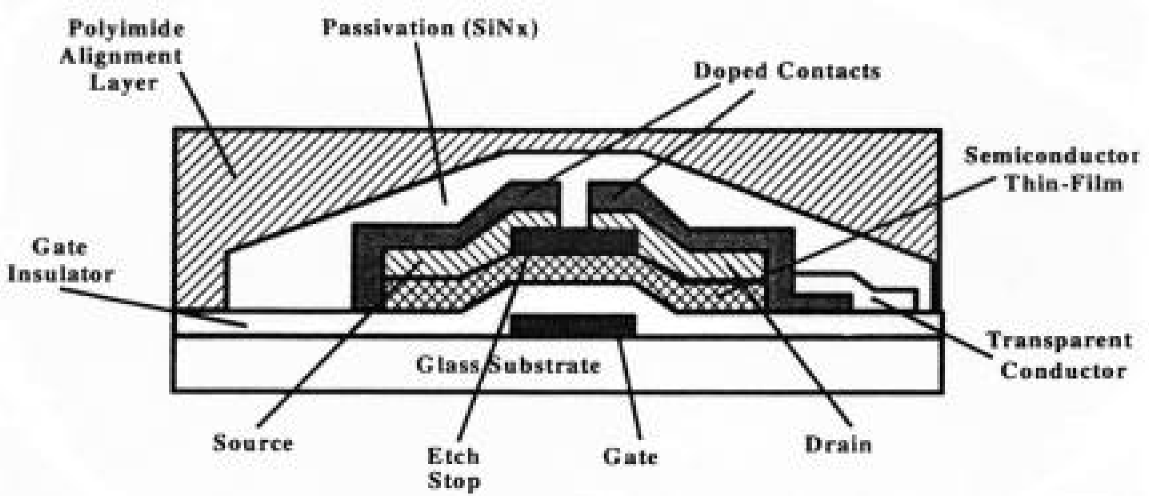

Figure 3-6: Etch/Stop Structure TFT

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).

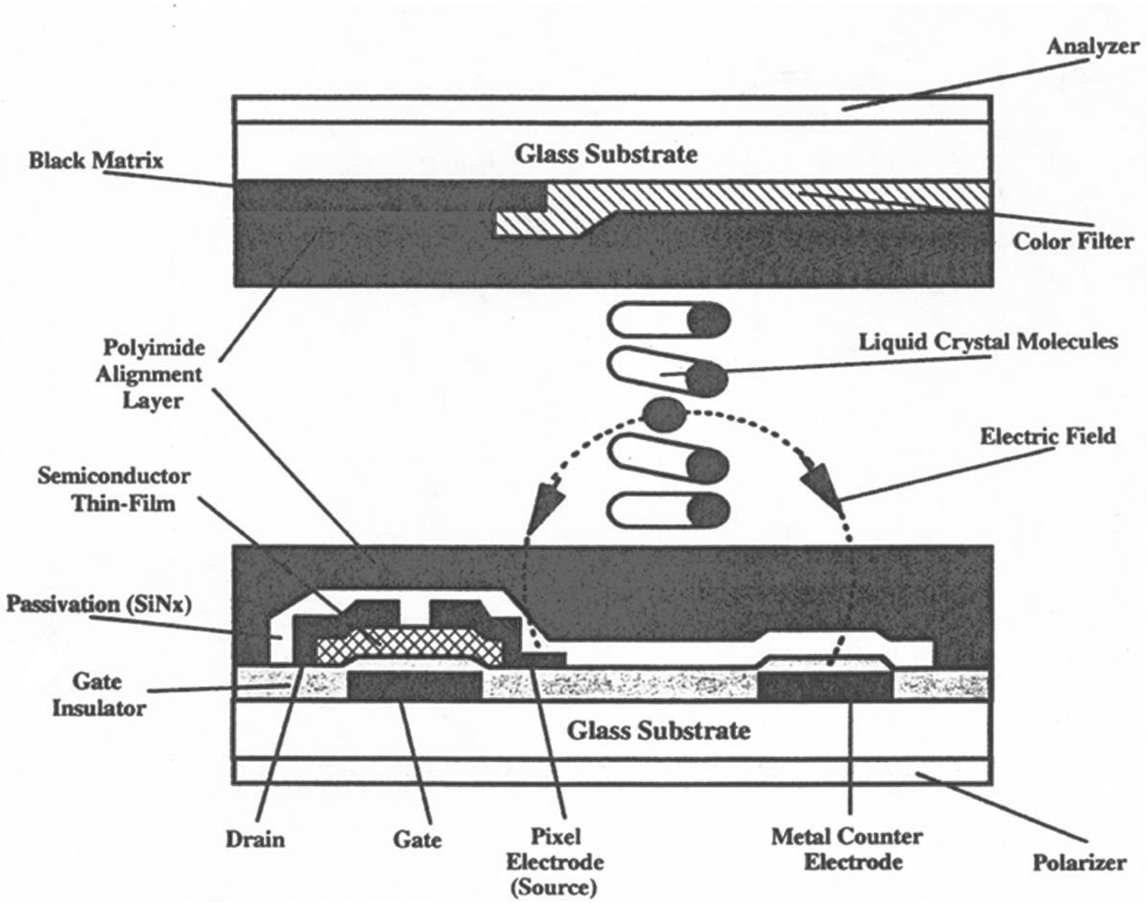

Figure 3-7: Hitachi IPS TFT

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.