Chapter 1

CRT GLASS

Glass formulations (melts) for cathode ray tubes (CRTs) produce some of the highest quality glassware available. This glassware equals or exceeds the finest crystal in lead content and comes very close to being defect free in both contaminant-induced artifacts and optical properties. A glass plant is a 24-hour-a-day, 7-day-a-week operation. The raw materials are relatively inexpensive, but the energy required to sustain tons of molten glass accounts for most of the operating cost. Glass tanks, which are a substantial capital investment, are rated by the tons of glass poured in 24 hours. A small tank would be rated at 10–20 tons and is best suited for smaller-sized glassware to maintain a balance between parts/hour and optimum flow rate.

Molten glass is drawn from the center third of the vertical axis to feed the molds. The top third contains contaminants being burned off, while the bottom third contains heavier particles of raw material that will not melt plus particles from the wear and tear of the firebricks. A continuous pour must be maintained at the tank's rated capacity to maintain the middle third at the proper level within the tank. Once a specific melt formula is established, a usable product can be produced. Glass poured before stability on a new tank is achieved is crushed (collet) and cycled back into the tank at up to 20% of the total raw material. Once a tank is pouring glass, it is preferable to run it without interruption on high-volume parts. But since CRTs come in many sizes, there is a need to change molds. To avoid downtime, glass tanks have multiple taps going to forming stations (turrets with four to six mold sets are typical), so that glass can be poured on two or more stations while the molds are being changed on another station. The mold sizes must be balanced for rate of pour and tonnage to keep the tank flowing within its capacity.

All cathode ray tubes are made from three parts to make a finished CRT as shown in Fig. 1.1: the faceplate, funnel, and neck tubing. (Glass manufacturers refer to the faceplate as a panel.) To transition a tank from one melt to another, such as going from 30 to 42% transmittance, the molds for faceplates must be changed over to funnels or some other glassware that is not critical for optical properties. When the transition is completed, the faceplate molds are phased back in.

The treatment of color and monochrome glassware diverges from this point, based on CRT processing, not the melt. Color CRTs start with two subassemblies, the faceplate and a funnel neck that are flame sealed together. Monochrome CRT processing starts with one piece called a bulb that consists of the faceplate, funnel, and neck tube all flame sealed together. This is how they would arrive at their respective CRT plans for processing.

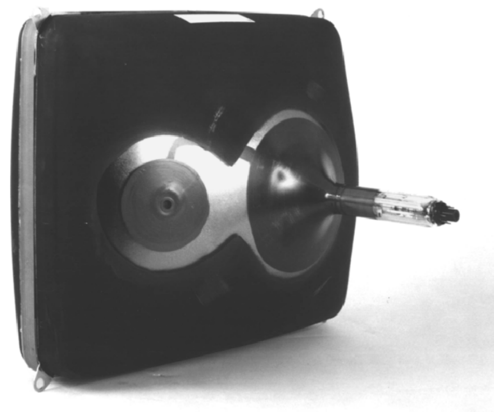

Figure 1.1 Monochrome CRT.

1.1 Color Glass

The basic building block for glass is one or more oxides of silicon, boron, or phosphorus with certain basic oxide additives. A specific glass melt is identified by what differentiates it from other melts. Color display faceplates are typically made from a lead-free barium–strontium melt. This formula provides nonbrowning characteristics along with a high anode voltage capacity of 24 to 32 kV and is highly absorbent of x rays. The barium–strontium color melt is only utilized for the faceplate. The funnel and neck reverts to a clear potash–soda lead glass that must be physically compatible with the barium–strontium for thermal expansion properties. The potash–soda lead has high x-ray absorbing characteristics. Table 1.1 lists color and monochrome glass melt properties.

The additives (tints) used in color glass enhance the contrast by changing the overall transmittance percent and provide selective transmittance for high color purity (e.g., improved flesh tones on television). Transmittance levels are defined at screen center at 10.16 mm of thickness with a light source of 546 nm. This measurement standard applies to all glass melts. The standard melts for color have transmittances of 86%, 73%, 57%, and 46%. For faceplates thicker than 10.16 mm at screen center, the percent will be lower. An example is the standard 21-inch flat square (FS) diagonal faceplate used in most diagnostic-grade displays: It has 57% glass, yielding a transmittance of 55% owing to the thicker wall.

The progression from the early days of color CRTs with 35–40-inch radius faceplates to the newer FS (60–68-inch radius) and True Flat screens has introduced a variable into luminance uniformity. The FS faceplate has a wedge shape from the center to the edge that causes a 7% change in transmittance for color glass. If the center is at 55%, then the edge of the active video is down to 48%. The transition is gradual and difficult to see unless specific test conditions

Table 1.1 Melt properties of color and monochrome glass.

Glass Properties	
Color CRT Panel Glass	
PT-28C PT-28HG PT-28S PT-28T	Lead-free barium–strontium glass Nonbrowning, high strain point and high x-ray absorbing properties Four types of transmittance: 86%, 73%, 57%, 46% at 10.16 mm, 546 nm Compatible for sealing with color funnel glass
Color CRT Panel Glass with High Color Purity and Contrast Characteristics	
PT-28C PT-28X	Neodymium-doped lead-free barium–strontium glass Nonbrowning, high strain point and high x-ray absorbing Two types of transmittance: 86%, 60% at 10.16 mm, 546 nm Compatible for sealing with color funnel glass
Color CRT Panel Glass for Projection	
PC-28	Lead-free barium–strontium glass Ultra nonbrowning, high strain point and high x-ray absorbing properties High transmittance: 90% at 10.16 mm, 546 nm Compatible for sealing with color funnel glass
Black and White CRT Panel and Funnel Glass	
ST-5KHL ST-5DHL	Tinted barium–lead glass with x-ray absorbing properties Two types of transmittance: 42%, 30% at 10.16 mm, 546 nm
Color CRT Funnel Glass	
FT-22H	Clear potash–soda lead glass High strain point, high x-ray absorbing properties and electrical resistivity
Color CRT Neck Tube	
L-35	Clear potash–soda lead glass High strain point, high x-ray absorbing properties and electrical resistivity Compatible with color funnel glass
Black and White CRT Neck Tube	
L-29	Clear potash–soda lead glass High electrical resistivity and x-ray absorbing (lower strain point than L35)

Source: Glass codes are from Nippon Electric Glass Co., Ltd. Codes are specific to the glass manufacturer. An alternative glass source designation for monochrome in standard tint is T42 and in a dark tint is T30, corresponding to ST-5KHL and ST-5DHL, respectively.

are used. The curvature of the glass on the outside and inside is not a single radius, so the rate of change in transmittance is not the same in all directions. The main benefit of a flatter faceplate is the improved reflective characteristics. Less illuminance is directed back toward the eye because the larger radius has a reduced lens effect. Older 30-inch radius CRTs concentrated illuminance and were referred to as having a headlight effect. The flatter generation reflects more incident illuminance below the level of the eye.

1.2 Monochrome Glass

A tinted barium–lead glass with x-ray absorbing characteristics though is used in both the faceplate and funnel glass. Anode capacity is limited to approximately 21 kV at a diagonal size of 21 to 23 inches. Smaller diagonal sizes would have to operate at lower anode voltages. The lead in monochrome glass is what turns brown when the glass is exposed to high-energy x rays. Keeping the anode voltage below 21 kV and limiting the beam currents prevents this from becoming a failure mode. In general, the cathode will be depleted before glass browning becomes an issue on large CRTs. The image quality for diagnostic reading would also be questionable long before glass browning was observed.

Glass melts for monochrome are 42% (standard) and 30% (dark) at 10.16 mm thickness and 546 nm. A clear monochrome melt has been used in the past at 90%, but the benefits are minimal when color glass in the same bulb size is available.

Like color, monochrome started out with 35–40-inch radius (1R bulbs for black and white television, B&W TV) faceplates that had a fairly uniform wall thickness from center to edge. Flat square bulbs are also poured with monochrome glass melts (also called flat profile, depending on the source). With standard tint glass and the same wedge-shaped profile, the 21-inch FS faceplate will now cause a 15% drop in center-to-edge transmittance; the standard 42% tint glass yields 34% at screen center in this bulb design. This represents the worst-case example of luminance nonuniformity that is due to the thickness of the glass.

The neck tube for monochrome glass is also a clear potash–soda lead glass, but with slightly different coefficients in order to be compatible with the barium–lead funnel. The high electrical resistivity of the neck glass is important in containing the anode voltage around the electron optics (also called a gun mount in the CRT industry).

1.3 Glass as an Insulator

An operating CRT is a large capacitor with stored energy. The glass is the dielectric material separating the opposing charges. The inside is charged to a positive voltage (anode potential) and the outside is tied to chassis ground points. As a dielectric, glass is not conductive, but it will allow a surface charge to be established. The first B&W TVs had no aluminum backing on the inside surfaces and the TV took a long time to produce luminance by today's standards; i.e., it took time to build up the anode voltage as a surface charge. The outside surface of the funnel, the other half of the capacitor, is coated with Aquadag to provide conductivity to ground; Aquadag contains graphite particles in a paintlike (water-based) vehicle. The application of Aquadag solved a high-voltage stability and capacity shortcoming when high-voltage circuits were all tubes. The Aquadag helped stabilize what would otherwise have been fluctuations in anode potential, causing fluctuations in luminance and picture size.

Today there is aluminum backing on the inside of monochrome CRTs that provides a conductive surface on the funnel. Color utilizes a conductive funnel coating that can be sprayed on. Both color (typically) and monochrome use aluminum backing for the phosphor screen. In addition to conductivity, it provides a protective layer for the phosphor, a heat sink, and a reflective surface to direct luminance outward. Aquadag still provides the ground plane on the outside, but is not needed to support modern high-voltage power supplies that are more robust and stable.

Glass can lose its dielectric properties with excessive heat and thus lead to a failure of the CRT. This is not very common because modern display designers are very conscious of heat management. One of the major heat sources within a display is the deflection yoke, and its design involves more than geometry and focus integrity. It must also run as cool as possible to avoid elevating the glass temperature under the yoke. The yoke is positioned where the neck and funnel glass come together. The yoke coils are over the thinner neck glass and joint (splice) with the funnel. Design engineers must measure the glass temperature when testing any new yoke design.

At 75°C, the ion mobility of the glass structure begins to increase, which reduces the insulating characteristics. Most CRT manufacturers would recommend that the "glass" temperature remain below 90°C and preferably below 85°C. Above 100°C, the properties have changed sufficiently to risk arcing from the anode potential to the yoke windings. Arcing erodes the glass and, if allowed to continue, will punch a hole through the neck glass, venting the CRT to the atmosphere. Above 120°C, the glass has lost most of its insulative properties and arcing will be heard as a "tick-tick-tick" sound.

1.4 Usable Area

The glass plant and the CRT manufacturer use a variety of dimensions, all of which are correct if they are applied in context. Glass plants define a bulb by the outside dimensions of the faceplate (panel) between opposite (diagonal) corners. The screen area is the surface area available for phosphor to be applied as defined by the glass plant. Not all standards are acceptable in all countries, and bulbs may also be designated with a "V" following the dimension, which denotes the viewable diagonal measure. For instance, what is called a 21-inch diagonal CRT in one country would be a 20V in another.

The actual area available to present information is the "active video area," which the display manufacturer will specify. This is the area that counts because two display manufacturers may use the same CRT but provide different active video areas. The difference can be significant and may be caused by a number of design compromises.

The video should not be extended fully into the corners and edges of the CRT. The bezel opening surrounding the CRT should be sized to deny this option to the user. Optical distortions will occur as the active video area reaches the inside transition radius at the edges (the inside radius of the faceplate wraps around to the side, called the skirt). The image will follow the curvature and be outside of the display's ability to maintain geometry and focus. In this same area is a characteristic feature of the molding process called suck-up. It is caused during the mold release phase and it leaves a ridge of glass like a bead in varying degrees that will behave the same as a lens. The active video area should always be defined to avoid these problems by remaining clear of the transition radius.

1.5 Contrast Enhancement

The darker the tint (i.e., the lower the transmittance percentage), the greater the contrast enhancement potential. However, this gain must be judged against the increase in drive required to achieve equal luminance and the impact on beam size. The de facto standard diagnostic display is a 21-inch FS bulb using color glass melt at 55%. This does not provide a desirable level of contrast enhancement, so a secondary tinted panel of 62% or 90% is bonded to the faceplate. The net transmittance becomes 34% and 50%, respectively. These panels should also have an antireflective coating to further enhance contrast. For a standard 21-inch FS monochrome melt at 34%, a 90% panel nets 30% transmittance and meets most requirements.

The ambient conditions for a workstation influence the choice to be made. In high ambient conditions the display must overcome more illuminance. The 62% panel would make this more difficult, while the 90% would permit greater luminance. In a dark reading room the darker panel would provide a better balance.

Contrast enhancement by the CRT faceplate works on a simple principle. The luminance energy from the phosphor passes through the faceplate only once, being attenuated by the stated percentage. For ambient light, some is reflected at the surface of the glass and observed as glare while the balance enters the glass to be reflected by the inside glass surface and phosphor screen, thus being attenuated twice, on the way in and on the way out. Secondary reflections within the glass would be attenuated multiple times.

1.6 X-Ray Compliance

Color and monochrome glass have different operating limits owing to the glass melt characteristics. Regardless of melt, the limit for all CRT displays that must not be exceeded is 0.5 mR/h throughout the useful life of the tube when it is operated within regulation limits of a hypothetical power supply with a 5-MΩ internal impedance. The CRT manufacturer is required to publish International Standards Organization (ISO) exposure rate limit curves for each CRT configuration at a maximum anode voltage and 250 μA of anode current.

A 21-inch FS monochrome melt has an absolute maximum of 24.5 kV anode voltage.[1] The recommended operating range for a typical configuration is 18 kV to 21 kV. At 21 kV, the anode current could be as high as 1200 μA and be within the 0.5 mR/h limit. A 340 cd/m^2 (100 fL) display would peak at just over 300 μA, one-fourth of the limit. The 21-inch FS color counterpart has a maximum of 37 kV anode voltage.[2] The recommended operating range for a typical configuration is 25 kV to 28 kV. At 28 kV, the anode current is off the chart in excess of 2000 μA and within limits. The performance increase using color glass at 340 cd/m^2 would reduce the beam current below the monochrome FS, which is again well under the ISO limit curves. The faceplate provides an excellent barrier to x-ray energy and typically yields the lowest readings on the CRT; the neck area is the highest in most designs and operating conditions.

Compliance with the ISO limit curves is the responsibility of the display manufacturer; it must certify the proper use of the CRT in the display's design. Testing is conducted through recognized independent laboratories and reported to the Department of Health and Human Services (DHHS) in the United States and in accordance with the Federal Performance Standards for Television Receivers (21 *CFR*, Subchapter J). The measurements are done in accordance with the EIA publication No. RS-501 (current version). Display manufacturers also verify compliance on production units in accordance with good manufacturing procedures and the agencies they are tested under.

References

1. Clinton Electronics Corporation, CRT model A57.
2. Clinton Electronics Corporation, CRT model A18.