OLED Fabrication for use in Display Systems and Comparison with LCD and PLASMA

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ABSTRACT

Popular LCD you commonly see used with computers, LCD TVs have a slim design and a flat viewing surface, but have been fine tuned for video display. Recent advances in flat panel LCD technology now allow for larger screens, wider viewing angles, and higher-quality video images. LCD Televisions are also competition for trendy plasma tv technology. There are two main types of fabrication currently in use for OLED’s. The first, small molecule OLED technology, requires vacuum deposition and typically uses a glass substrate. The second, which utilizes a deposition technique derived from ink-jet printing can be applied to a variety of substrates including flexible ones. The use of flexible displays generates much interest in the consumer market because of the possibility of new applications. This paper will focus on some of the many different approaches to OLED fabrication as well as techniques involved in producing full color displays. The use of flexible displays generates much interest in the consumer market because of the possibility of new applications. Organic light emitting diode (OLED) displays have been attracting more attention because of their various advantages including simple structure, self-emitting, fast response time and wide viewing angle. In the last decade, the focus of research is on improvement of efficiency and reliability for commercial applications [1]. Conventional multi-layer white organic light emitting diode (OLED) devices have a structure of stacked three primary color emissive layers (EMLs) with at least three emissive dopants. This method induces different degradation rates and phase segregation among different dopants and differential color aging. OLEDs with a single emissive dopant material in an EML are employed to avoid these disadvantages. six different methods for white OLEDs with a single emissive dopant, i.e., using (1) simultaneous emission from the host material in the EML, (2) excimer, (3) mixed-ligand molecule, (4) phosphor-sensitized fluorescent material, (5) exciplex, and (6) dual emission using excimer and exciplex. OLED and LED lighting are both solid-state technologies and offer overlapping value propositions per market segment. They will therefore compete directly in many instances. LED lighting has come a long way and offers a better performance than OLEDs, and that at a lower cost. OLED lighting will therefore only gain market success if it clearly defines its unique selling points and carves out initial market niches. In this paper we will be examining OLED Fabrication for Use in Display Systems and comparison with LCD and PLASMA

Keywords: Organic light-emitting diode, Organic LED, OLED, LCD, PLASMA.

INTRODUCTION

How LCD TV panels works

An LCD TV is sometimes referred to as a "transmissive" display — light isn't created by the liquid crystals themselves; a light source (bulb) behind the panel shines light through the display. A white diffusion panel behind the LCD redirects and scatters the light evenly to ensure a uniform image. The display consists of two polarizing transparent panels and a liquid crystal solution sandwiched in between. The screen's front layer of glass is etched on the inside surface in a grid pattern to form a template for the layer of liquid crystals. Liquid crystals are rod-shaped molecules that bend light in response to an electric current — the crystals align so that light cannot pass through them. Each crystal acts like a shutter, either allowing light to pass through or blocking the light. The pattern of transparent and dark crystals forms the image. It's the same display technology behind your digital watch but way more sophisticated.
This how the plasma display works. The plasma display’s computer first charges the electrodes that intersect at the particular cell to ionize the gas in that cell. It does this thousands of times in a small fraction of a second, charging each cell in turn. When the intersecting electrodes are charged, it created the voltage difference between them and electric current flows through the gas in the cell. The current creates a rapid run of charged particles and makes the gas atoms to release ultraviolet photons. The released ultraviolet photons then interact with the phosphor material inside the cell. When an ultraviolet photon hits a phosphor atom in the cell, it makes one of the phosphor’s electrons jumps to a higher energy lever and makes the atom to heat up. When the electron falls back to its normal level, it releases energy in form of visible light photon. The phosphors in plasma display create colored lights when they are excited and the three-phosphor color blend together to create the image. By varying the pulses of the current flowing through the different cells, the control system can creates hundreds of different combination of red, green and blue (The plasma).

Because they use red, green and blue color filters in place of phosphor dots, LCD panels are completely immune to image burn-in. LCD TVs use the most advanced type of LCD, known as an "active-matrix" LCD. This design is based on thin film transistors (TFT) — basically, tiny switching transistors and capacitors that are arranged in a matrix on a glass substrate. Their job is to rapidly switch the LCD's pixels on and off. In a color TV's LCD, each color pixel is created by three sub-pixels with red, green and blue color filters. One of the biggest challenges for LCD TV manufacturers has been the speeding up of "pixel response" time (how fast an individual pixel's color can change without blurring) to ensure that fast-moving objects don't exhibit "motion lag" or ghosting. It's especially critical for larger-screen LCD TVs where much of the viewing will be DVD movies and/or HDTV. An important difference between plasma and LCD technology is that an LCD screen doesn't have a coating of phosphor dots (colors are created through the use of filters). That means you'll never have to worry about image burn-in, which is great news, especially for anyone planning to connect a PC or video game system. LCD TVs are extremely energy-efficient, typically consuming 60% less power than comparably-sized tube-type direct-view TVs!

PLASMA VS. LCD –OR O-LED, which is better?

The following are some advantages of each technology and how those advantages relate to each other- for different uses:
**LCD Features:**

1. LCD has almost no static image screen burn-in factors to consider. LCD (liquid crystal diode) technology uses essentially a fluorescent backlight to send light through its pixel design, which contains liquid crystal molecules and polarizing substrate to give form to light and color. The "liquid" crystal in an LCD is actually used in its solid state.

2. LCD by contrast has to increase the power voltage to make pixels darker. Thus, the higher the voltage surging into and through the pixel, the darker the LCD pixel. Though there are improvements in LCD contrast and black level, even the best producers of LCD technology.

3. LCD manufacturers claim figures between 50,000 and 75,000 hours for LCD monitors/TVs. An LCD can last as long as the backlight (and backlight bulbs can actually be changed out). This is because the light is passing through a prism effect of the liquid crystal to produce the light and color. It's a substrate so there is nothing to effectively burn out.

4. In LCD, controlling light waves at different speeds to allow them to pass through long thin crystal molecules is a more difficult template for producing accuracy and vibrancy in color. Color information benefits from the smaller pixel design of most LCD monitors, but would not be as impressive as plasma at the same size pixel level.

5. LCD is a backlit technology with crystal molecules deflected at angles to give color and definition. As such, there is nothing to pressure the unit at altitude and no real limitations. This explains the use of LCD screens as the primary viewing screen for the airlines in flight video material.

6. LCD displays static images from computer extremely effectively and with full color detail, no flicker, and no screen burn in.

7. With LCD there can be a "trailer" effect during fast pace scenes from video as the technology is much slower reacting to color changes. This results from the light prisms that must be produced from controlling voltages applied to "bend" the light. The higher the voltage applied to the crystal, the darker the image in that section of the LCD panel. This is also the reason for the lower contrast levels.

8. LCD substrate material is difficult to produce in larger sizes without pixel defects.

9. By using a type of fluorescent backlighting system for light production, LCD has much lower voltage requirements than its plasma counterpart.

**PLASMA Features:**

1. Plasma technology does have static image screen burn-in factors to consider. Static images will begin to "burn-in" the image displayed in a short period of time, approximately 15 minutes in some cases. Though the "burn-in" can generally be "washed" out using gray images or continual full color ranges over several hours, burn-in is a significant factor and hindrance to the plasma technology.

2. Plasma technology has come a long way in developing higher contrast images. Plasma technology simply blocks the power emitted (through complicated internal algorithms) to specific pixels in order to form dark or black pixels. While sometimes hurting gray scaling, this technique does produce dark blacks.

3. Plasma by contrast uses a small electric pulse for each pixel to excite the rare natural gases argon, neon and xenon (phosphors) used to produce the color information and light. As electrons excite the phosphors oxygen atoms dissipate. These rare gases actually have a life and fade over time. Manufacturers of plasma place a time stamp of 25,000 to 30,000 hours on the life of these phosphors and thus, the display itself. They cannot be replaced. There is no phenomenon of "pumping" new gases into a plasma display.

4. The plasma pixel design produces the most vibrant colors of any type of display in my opinion. Chromaticity coordinates are much more accurate on good plasma panels than on LCDs.

5. Since the plasma display element on a plasma TV is actually a glass substrate envelope containing rare natural gases, thinner air causes increased stress on the gases inside the envelope. This increases the amount of power required to run and cool the plasma which causes louder buzzing or fan noise. These problems usually start to occur at around 6500 feet.

6. Plasma will get the nod here because of the excellent performance with fast moving images, high contrast levels, color saturation, and brightness.

7. Though both panels are difficult to produce in large panels, plasma has proven the easier of the two as manufacturers have produced plasma panels in the 60" to 63" range. While these displays are still very costly, they have proven that they operate effectively and reliably.

8. Plasma by contrast has the challenging requirement of powering hundreds of thousands of transparent electrodes to provide light and excite the encased phosphors of each cell.
OLED Features:

Light-emitting diodes (LEDs) have been encroaching on the long established domain of incandescent and fluorescent lighting due to their long life, intensity, and power efficiency. Certain limitations, however, have restrained LEDs from supplanting conspicuous application, particularly difficulty and cost of production. Organic Light Emitting Diodes (OLEDs) show promise of replacing liquid crystal displays (LCDs) and other lighting appliances, due to their low cost, ease of fabrication, brightness, speed, wide viewing angle, low power consumption, and contrast. The edge gained by OLEDs will facilitate further LED market permeation. An OLED (organic light-emitting diode) is a light-emitting diode (LED) in which the emissive electroluminescent layer is a film of organic compound which emits light in response to an electric current. This layer of organic semiconductor is situated between two electrodes. Generally, at least one of these electrodes is transparent. OLEDs are used to create digital displays in devices such as television screens, computer monitors, portable systems such as mobile phones, handheld games consoles and PDAs. A major area of research is the development of white OLED devices for use in solid-state lighting applications [2; 3; 4]. Bottom or top distinction refers not to orientation of the OLED display, but to the direction that emitted light exits the device. OLED devices are classified as bottom emission devices if light emitted passes through the transparent or semi-transparent bottom electrode and substrate on which the panel was manufactured. Top emission devices are classified based on whether or not the light emitted from the OLED device exits through the lid that is added following fabrication of the device. Top-emitting OLEDs are better suited for active-matrix applications as they can be more easily integrated with a non-transparent transistor backplane. Also Silicones deliver high thermal and photo stability compared to organic materials, such as epoxies or plastics. This stability is an important consideration as LED designers increase the amount of drive current in their devices and decreases the overall size of lighting fixtures. Combined, these trends are pushing LED temperatures to 150°C and higher, which can cause conventional epoxies and plastics to turn yellow and physically degrade over time. In contrast, silicones have demonstrated reliable optical and physical performance at temperatures reaching 200°C and higher. This range helps ensure next-generation LEDs can meet and exceed the lumen maintenance requirements of challenging packaging applications. Traditionally, the view among many veteran LED designers and manufacturers was that phenyl silicones came with certain limitations when it came to thermal stability — but no more. Breakthroughs in phenyl-based silicone chemistry now enable optical silicone encapsulants to perform with exceptional reliability in the latest generation of chip-on-board LED architectures.

The TFT array attached to the bottom substrate on which AMOLEDs are manufactured, are typically non-transparent, resulting in considerable blockage of transmitted light if the device followed a bottom-emitting scheme [5].

1- Lower cost

OLEDs can be printed onto any suitable substrate by an inkjet printer or even by screen printing [6], theoretically making them cheaper to produce than LCD or plasma displays. However, fabrication of the OLED substrate is more costly than that of a TFT LCD, until mass production methods lower cost through scalability.

2- Lightweight and flexible plastic substrates

OLED displays can be fabricated on flexible plastic substrates leading to the possible fabrication of flexible organic light-emitting diodes for other new applications, such as roll-up displays embedded in fabrics or clothing. As the substrate used can be flexible such as polyethylene terephthalate (PET) [7] the displays may be produced inexpensively.

3- Wider viewing angles and improved brightness

OLEDs can enable a greater artificial contrast ratio (both dynamic range and static, measured in purely dark conditions) and a wider viewing angle compared to LCDs because OLED pixels emit light directly. OLED pixel colors appear correct and unshifted, even as the viewing angle approaches 90° from normal.

4- Better power efficiency and thickness

LCDs filter the light emitted from a backlight, allowing a small fraction of light through. So, they cannot show true black. However, an inactive OLED element does not produce light or consume power, thus allowing true black [8]. Dismissing the backlight also makes OLEDs lighter because some substrates are not needed. This allows electronics potentially to be manufactured more cheaply, but, first; a larger production scale is needed, because OLEDs still somewhat are niche products [9]. When looking at top-emitting OLEDs, thickness also plays a role when talking about index match layers (IMLs). Emission intensity is enhanced when the IML thickness is 1.3–2.5 nm. The refractive value and the matching of the optical IMLs property, including the device structure parameters, also enhance the emission intensity at these thicknesses [10].
5- Response time

OLEDs also can have a faster response time than standard LCD screens. Whereas LCD displays are capable of between 1 and 16 ms response time offering a refresh rate of 60 to 480 Hz, an OLED theoretically can have a response time less than 0.01 ms, enabling a refresh rate up to 100,000 Hz. OLEDs also can be run as a flicker display, similar to a CRT, in order to eliminate the sample-and-hold effect that creates motion blur on OLEDs [11].

![OLED Structure](http://programming4.us/multimedia/8254.aspx)  
O-LED structure (source: http://programming4.us/multimedia/8254.aspx)

![Demonstration of a flexible OLED device](image)

Demonstration of a flexible OLED device
This report is divided into two parts: (a) technology and (b) market assessment. The first offers a comprehensive yet detailed overview of both LED and OLED lighting, going through fabrication processes, material compositions, technology roadmaps, and key players. The device attributes of each technology are also critically assessed, examining parameters such as color warmth and controllability, flexibility, efficiency, surface emission, lifetime, wafer size, and luminaries design. The second section offers a blunt market assessment. Detailed cost projection roadmaps are developed, factoring in estimated cost evolution of the integrated substrates, encapsulation layers and materials. Changes in system configuration and material composition required to enable the cost roadmaps are outlined. We also factor in production costs including capital and labor. Values are expressed in units of $/unit and $/klm. The value proposition of OLEDs for all market segments is critically analyzed. For each assessment, IDTechEx Research examines parameters such as light quality, form factor, technology mix diversity, price sensitivity, light controllability, lifetime and light intensity. The report also rigorously compares the performance of OLED and LED devices using the above parameters. IDTechEx Research then develops detailed market forecasts. Here, we estimate the market share of OLEDs per lighting market segment, calculate the total lighting area per sector, estimate the lumen output per segment, and forecast the equivalent number of units sold per sector. Combining all our analysis, we forecast the monetary value of the market at module level per market segment.

The relative monetary contribution of each lighting market segment to the total OLED market between 2013 and 2023 Exact values are available upon request(Source: IDTechEx)
We forecast the market will grow to 1.3 billion USD in 2023 and initially grow at a rapid rate of 40-50% annually, although the initial market base is very small. We contextualise our assessment by expressing our market forecast in units of equivalent 60W incandescent bulbs. We assess the implications of our market forecast for the global capital investment and production capacity. We compare the market size to that of LEDs (including automotive, backplane and residential) at module level. Production capacities are compared too to further set out forecasts in prospective. Our methodology is clearly laid out in the report, as are all our underlying assumptions.

CONCLUSION

OLED displays are an exciting new display technology that offers improved performance as well as novel applications. Full color displays using OLEDs are in the position to replace LCDs in the small scale display market. OLEDs offer a decreased manufacturing cost, a brighter, more vibrant display, as well as a larger viewing angle. A lower power consumption makes OLED perfect for portable devices which rely on battery power. The ink-jet printing method used with OLEDs is sure to spark display applications never before possible with either LCD or Plasma.

The LCD is currently the display of choice in small devices and is also popular in large-screen TVs. Regular PLASMA often form the digits on digital clocks and other electronic devices. OLEDs offer many advantages over both LCDs and PLASMA:

- The plastic, organic layers of an OLED are thinner, lighter and more flexible than the crystalline layers in a PLASMA or LCD.
- Because the light-emitting layers of an OLED are lighter, the substrate of an OLED can be flexible instead of rigid. OLED substrates can be plastic rather than the glass used for PLASMA and LCDs.
- OLEDs are brighter than PLASMA. Because the organic layers of an OLED are much thinner than the corresponding inorganic crystal layers of a PLASMA, the conductive and emissive layers of an OLED can be multi-layered. Also, LEDs and LCDs require glass for support, and glass absorbs some light. OLEDs do not require glass.
- OLEDs do not require backlighting like LCDs (see How LCDs Work). LCDs work by selectively blocking areas of the backlight to make the images that you see, while OLEDs generate light themselves. Because OLEDs do not require backlighting, they consume much less power than LCDs (most of the LCD power goes to the backlighting). This is especially important for battery-operated devices such as cell phones.
- OLEDs are easier to produce and can be made to larger sizes. Because OLEDs are essentially plastics, they can be made into large, thin sheets. It is much more difficult to grow and lay down so many liquid crystals.
- OLEDs have large fields of view, about 170 degrees. Because LCDs work by blocking light, they have an inherent viewing obstacle from certain angles. OLEDs produce their own light, so they have a much wider viewing range.
Here are six basic things that users should know about the TV screen using new technology.

**OLED without LCD and Plasma backlight**

Structure of OLED screen generally includes back panel (Substrate) to shore the screen, pure Anode layer, the organic layers including conductive layer and emissive layer, then the above Cathode layer helps to create electrons when electricity goes through. OLED’s full name is Organic Light-Emitting Diode, it means the luminescent organic diode. While LCD and plasma need backlight, OLED requires no backlight because its pixels can emit light. LCD requires CCFL backlight (cold fluorescent) or LED, Plasma needs UV lamp to burn phosphors, creating the basic RGB colors.

**OLED has many advantages**

OLED screen does not use backlight so that it is very thin. With the self-emitting structure, OLED TV will be thinner, lighter, save more energy and perform better than any older TV technology. Each pixel can emit light or help the black representation reach perfect level, that’s why the screen contrast is extremely high.

**OLED is completely different from LED**

OLED and LED have similar operation mode but OLED TV and LED TV have completely different structure. LED TV is a concept that TV manufacturers created, it is still LCD TV but using LED lamp instead of CCFL of normal LCD TV. Meanwhile, OLED TV screen includes many pixels that can illuminate. Thus, OLED screen is energy efficient than LCD, LED and Plasma.

**RGB OLED and White OLED**

Current TV Technology is divided into two main branches, RGB OLED and White OLED. RGB OLED TV operates similar to plasma TV when each main pixel is divided into sub-pixel with three colors: green, blue and red.

White OLED is added a white sub-pixel, its pixel structure is similar to pixel RGB OLED. With the addition, the White OLED screen brings brighter images. Besides, White OLED screen is said to have higher lifetime than RGB OLED, the ability to hold color is better and is also consistent with more sizes. While RGB OLED is rated better on display and saves more energy.

**AMOLED** is a form of OLED

“AM” here means “Active Matrix” and is a common structure in electronic circuits of the device. An AMOLED includes anode layer, organic compound layer and the Cathode layer, the thin transistor film (TFT) in between helps form a matrix of pixels. TFT thin film layer acts as an electrical circuit to determine which pixel will be turned on to create the image. So that AMOLED brings good visibility, flexibility, it is consistent with the motion pictures, fit on the screens of mobile phones, computers or even TV. AMOLED is not different, it is a product of the OLED in general.

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**OLED TV is expensive but it will be popular**

Like any new technology, the first OLED TVs will be very expensive. Do not forget that the big size LCD and Plasma are very expensive before. With price is up to $8,000 for the first 55-inch models, there will be only 1% of customers in general can own the product. However, after a few years, OLED will become the main display technology and pass through LED or Plasma, which is general movement trend of the market.

Further information: Comparison of display technology

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CRT</th>
<th>LCD</th>
<th>Plasma</th>
<th>OLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brightness</td>
<td>Some compensate for ambient light</td>
<td>Very poor in direct sunlight without reflective design (battery powered devices); uneven backlighting in older models; low temperatures can cause dimming or blackout</td>
<td>Some panels are highly reflective, should be used in a dark environment for optimum picture quality</td>
<td>Poor in bright ambient light; white color dimmer than LCDs of same brightness</td>
</tr>
<tr>
<td>Contrast</td>
<td>Over 15,000:1 [12]</td>
<td>Over 1,000:1</td>
<td>Over 20,000:1</td>
<td>Over 1,000,000:1</td>
</tr>
<tr>
<td>Color</td>
<td>Excellent</td>
<td>Good on most newer models</td>
<td>Excellent</td>
<td>Vivid and wide gamut, blue OLED degrades faster than other colors so manufacturers may overdrive the blue LEDs to compensate, causing oversaturated colors organic materials decay over time (2011)</td>
</tr>
<tr>
<td>Color depth</td>
<td>Unlimited</td>
<td>Up to $68 \times 10^7$</td>
<td>$68 \times 10^7$ [13][14]</td>
<td></td>
</tr>
<tr>
<td>Black level</td>
<td>Excellent</td>
<td>Poor due to bleed through</td>
<td>Excellent</td>
<td></td>
</tr>
<tr>
<td>Ghosting and smearing</td>
<td>No ghosting or smearing artifacts; slightly blurry; halo may appear around objects with high contrast to background</td>
<td>Display motion blur on models with slow response time, and the elimination technique (strobing backlight) can cause eye-strain</td>
<td>None even during fast motion, advancements in 3D have eliminated phosphor trailing due to the use of fast-switching phosphors</td>
<td>None even during fast motion</td>
</tr>
<tr>
<td>Response time</td>
<td>1 ms typical [15; 16]</td>
<td>1–8 ms typical (according to manufacturer data), older units could be as slow as 35 ms$^1$ [17]</td>
<td>Sub-millisecond</td>
<td>Sub-millisecond</td>
</tr>
<tr>
<td>Frame rate</td>
<td>60–85 fps typically, some</td>
<td>60 or 75 fps typically; 60 fps typically,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental influences</td>
<td>Magnetic fields may cause distortion or shimmer, earth's magnetic fields may cause distortion</td>
<td>Low temperatures can cause slow response, high temperatures can cause poor contrast</td>
<td>High altitude pressure difference may cause poor function or buzzing noises [18]</td>
<td>UV exposure can damage, water can damage organic materials</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
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<td>--------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Flicker and eyestrain</td>
<td>Part of the screen always lit during refreshes; flicker noticeable at refresh rates below 85 Hz</td>
<td>Depends; as of 2013, most LCDs use PWM (strobing) to dim the backlight [20] which can cause severe eyestrain for some people [21; 22; 23] although the flicker isn't visible because it is normally done at 200 Hz or faster</td>
<td>Poor due to phosphor based but improving in newer models</td>
<td>Part of the screen always lit during refreshes due to multiplexing</td>
</tr>
<tr>
<td>Weight</td>
<td>Heavy, especially for larger units, a 20 inches (51 cm) screen weighs about 50 pounds (23 kg)</td>
<td>Light</td>
<td>Heavy, however, less weight gain per size increase</td>
<td>Very light</td>
</tr>
<tr>
<td>Size</td>
<td>Bulky depth, 7&quot; smallest possible for color screen, over 40&quot; is very heavy</td>
<td>Compact, can be manufactured almost any size and shape, very thin allowing mounted distance to user for less focusing-related eyestrain</td>
<td>Up to 150&quot; (3.8m) [24]</td>
<td>Compact, can be made in nearly any size or shape.</td>
</tr>
<tr>
<td>Energy consumption and heat generation</td>
<td>High [25]</td>
<td>Low [25] with CCFL backlight 30–50% of CRT, with LED backlight 10–25% of CRT</td>
<td>Varies with brightness but usually higher than LCD [26; 27; 28; 29]</td>
<td>Varies with brightness but usually lower than LCD (except when displaying a lot of white area)</td>
</tr>
<tr>
<td>Screen burn-in</td>
<td>Yes, the reason screensavers became popular</td>
<td>Discoloring may occur due to thermalization, but usually it is not permanent; dead or stuck pixels may occur in manufacturing or usage</td>
<td>Severe in early models, dead or stuck pixels may occur in manufacturing or usage</td>
<td>Yes, dead or stuck pixels may occur in manufacturing or usage</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Hazardous to repair or service due to high-voltage, requires skilled convergence calibration and adjustments for geographic location changes [30]</td>
<td>Difficult to replace backlight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is compatible with Light</td>
<td>Yes</td>
<td>No</td>
<td>Yes [31]</td>
<td>No</td>
</tr>
<tr>
<td>pens or guns</td>
<td>Electromagnetic radiation emission</td>
<td>Emits strong electromagnetic radiation in the audio-frequency to low-frequency RF range (from the electron beam deflection coils)</td>
<td>Emits very little electromagnetic radiation</td>
<td>Emits strong radio-frequency electromagnetic radiation</td>
</tr>
<tr>
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<td>-----------------------------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
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</tr>
<tr>
<td>Other</td>
<td>The LCD grid can mask effects of spatial and grayscale quantization, creating the illusion of higher image quality. Many newer models are powered by an external 12V power supply (for thinness), and could (with a special cable) be connected directly to the computer's power supply, possibly saving power, desk space and wall-outlet space.</td>
<td>Screen-door effects are more noticeable than LCD when up close, or on larger sizes; fragile and required to be upright to avoid screen collapse</td>
<td>No backlight needed, can be fabricated on flexible plastic substrates for flexible displays</td>
<td></td>
</tr>
</tbody>
</table>

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