Lecture 2
Display Hardware

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CS 302 – Computer Graphics

Objectives

- You will have an in-depth understanding of the architecture of the graphics hardware output device.

Topics

- The Frame Buffer
- The Cathode Ray Tube
- The Liquid Crystal Display

The Frame Buffer

- The light on the screen generated by the beam of electrons in our CRT fades quickly – in 10 to 60 microseconds.
- In order to keep a picture on the screen for a while, the picture needs be redrawn before it disappears off the screen. This is called ***refreshing*** the screen.

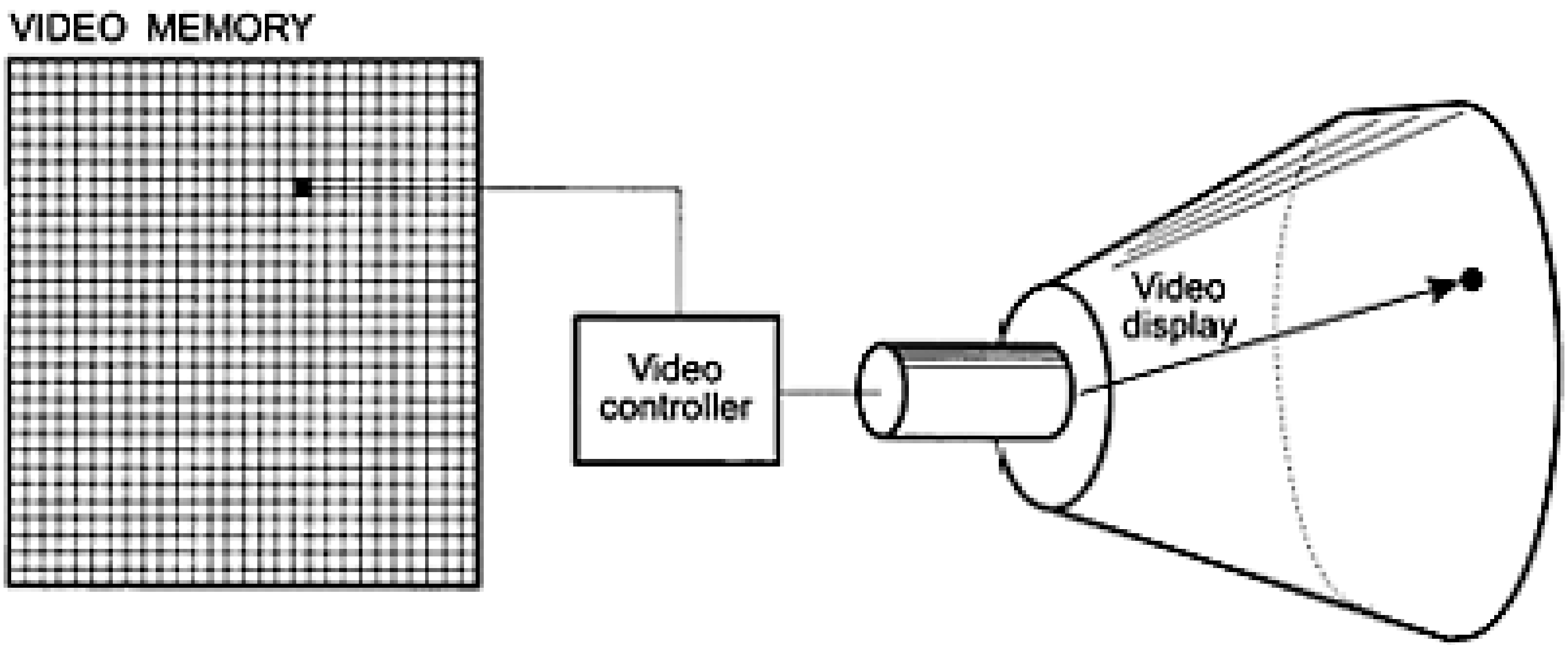
The Frame Buffer (cont.)

- Most display systems use raster scan technology to perform the refresh process. In this technology, the electron beam is directed discretely across the screen, one row at a time from left to right, starting at the upper left corner of the screen. When the beam reaches the bottommost row, the process is repeated, effectively refreshing the screen.
- The scanning cycle takes place 50 to 70 times per second.

The Frame Buffer (cont.)

- In the memory-mapped implementation of raster-scan technology, an area of RAM is devoted to recording the state of each individual screen pixel.
- The area of memory reserved for the screen display is usually called the *frame buffer* or the *video buffer*.

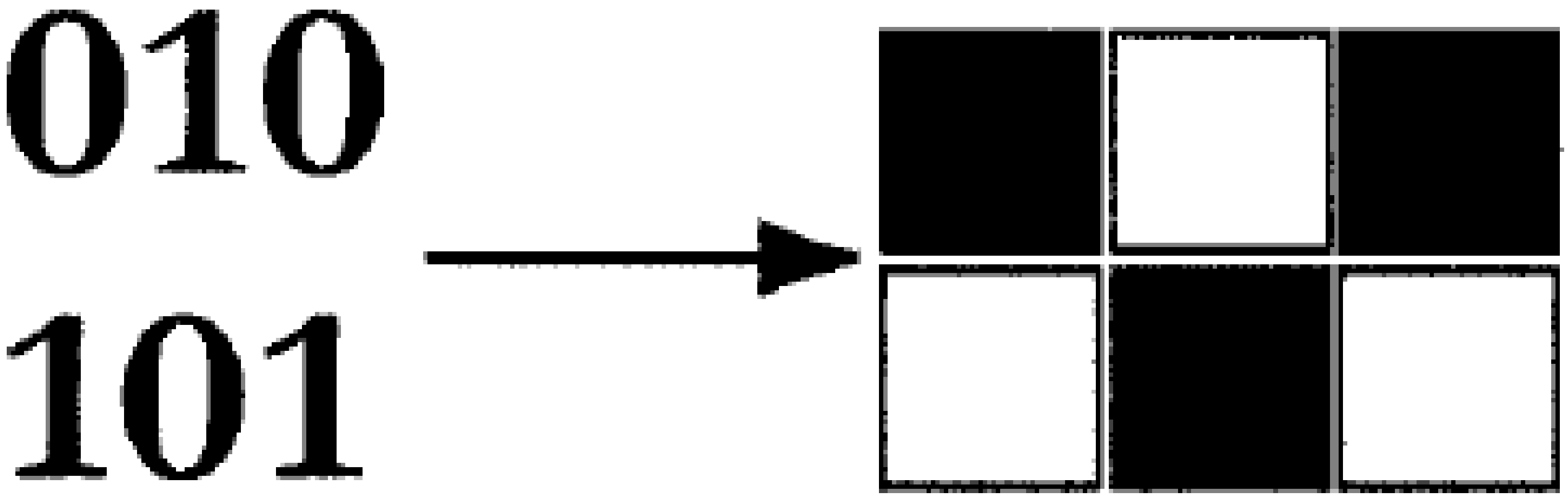
The Frame Buffer (cont.)



The Frame Buffer (cont.)

- The simplest color-coding scheme consists of using a single bit to represent either a white or a black pixel. Conventionally, if the memory bit is set, the display scanner renders the corresponding pixel as white. If the memory bit is cleared, the pixel is left dark.

The Frame Buffer (cont.)



Frame buffer

Pixels in the display

Monochrome display: frame buffer for turning pixels on and off

The Frame Buffer (cont.)

- Refreshing the screen is performed using the information stored in the frame buffer. You can think of frame buffer as a two dimensional array. Each element of the array keeps the intensity of the pixel on the screen corresponding to that element.

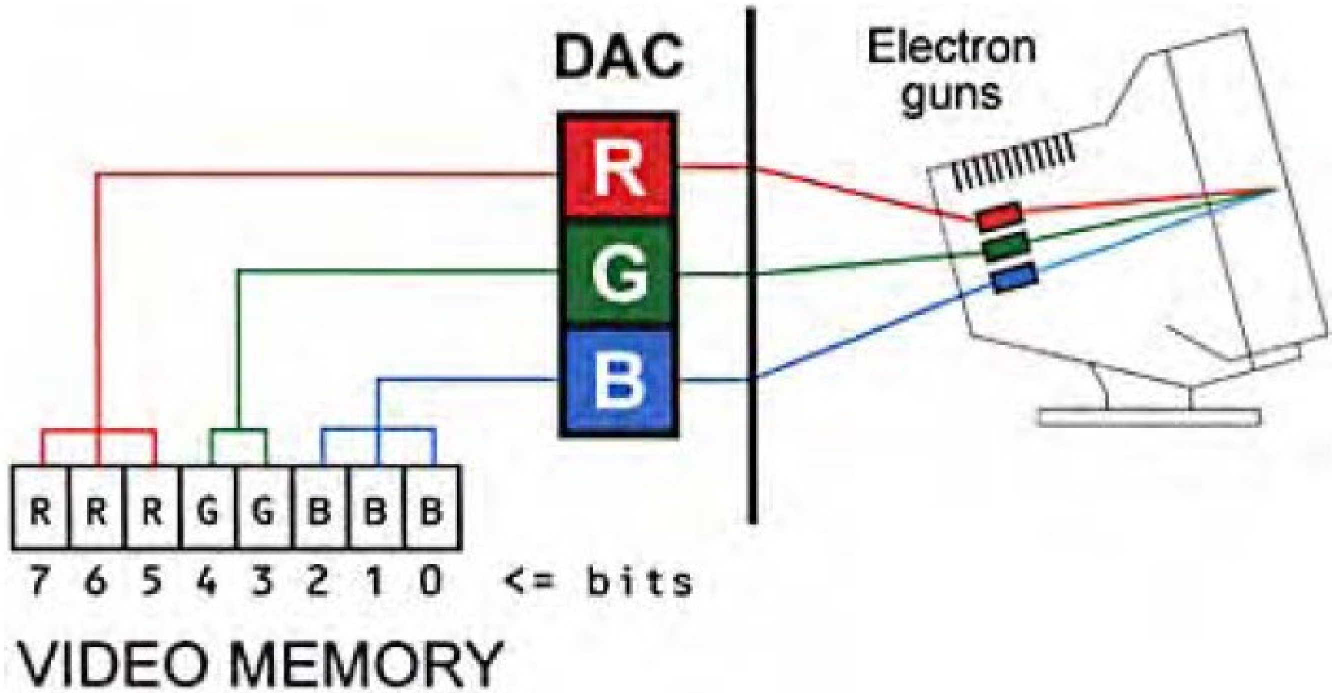
The Frame Buffer (cont.)

- Implementing color pixels requires a more elaborate scheme. In color systems the CRT is equipped with one electron gun for each color that is used to activate the pixels. Usually there are three color-sensitive electron guns: one for red, one for green, and one for blue.

The Frame Buffer (cont.)

- Data for each of the three colors must be stored separately. One approach is to have a separate memory map for each color. A more common solution is to devote bit fields or storage units to each color. For example, if one memory byte is used to encode the pixel's color attributes, three bits can be assigned to encode the red color, two bits to encode the green color, and three bits for the blue color.

The Frame Buffer (cont.)



Color Figure 1

The Frame Buffer (cont.)

- In Color Figure 1, one memory byte has been divided into three separate bit fields.
- Each bit field encodes the color values that are used to render a single screen pixel. The individual bits are conventionally labeled with the letters R, G, and B, according to the color they represent.

The Frame Buffer (cont.)

- Since eight combinations can be encoded in a three-bit field, the blue and red color components can each have eight levels of intensity.
- In this example we have used a two-bit field to encode the green color; therefore it can only be rendered in four levels of intensity.
- The total number of combinations that can be encoded in 8 bits is 256, which is also the number of different color values that can be represented in one memory byte.

The Frame Buffer (cont.)

- The color code is transmitted by the display controller hardware to a *Digital-to-Analog converter* (DAC), which, in turn, transmits the color video signals to the CRT.

The Frame Buffer (cont.)

Advantages of Raster Scan Display

- low cost
- color capability
- easy programmability

The Frame Buffer (cont.)

Disadvantage Raster Scan Display

- Grainy physical structure of the display surface that results from the individual screen dots.
- The dot pattern causes lines that are not vertical, horizontal, or at exactly 45 degrees to exhibit a staircase effect.
- Raster-scan systems also have limitations in rendering animation. Two factors contribute to this problem: 1) all the screen pixels within a rectangular area must be updated with each image change; and 2)in order to ensure smoothness, the successive images that create the illusion of motion must be flashed on the screen at a fast rate. These constraints place a large processing load on the microprocessor and the display system hardware.

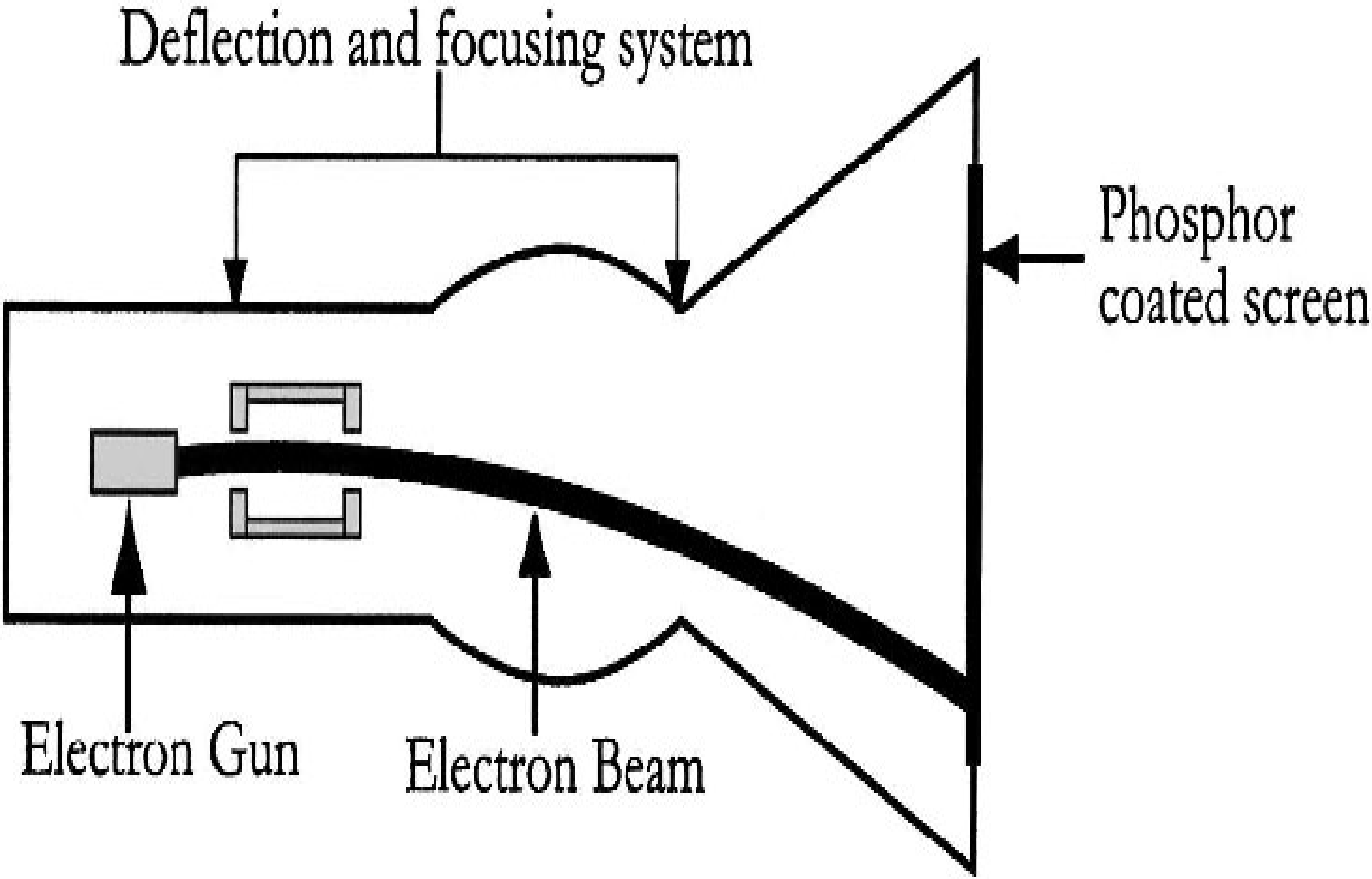
Computer Display Systems

- The computer display, or the monitor, is a very important device on the computer. It provides visual output from the computer to the user. In the Computer Graphics context, the display is everything. Most current personal computers and workstations use **Cathode Ray Tube (CRT)** technology for their displays.

Cathode Ray Tube (CRT)

- A CRT consists of:
  - An electron gun that emits a beam of electrons (cathode rays)
  - A deflection and focusing system that directs a focused beam of electrons towards specified positions on a phosphorus-coated screen
  - A phosphor-coated screen that emits a small spot of light proportional to the intensity of the beam that hits it
- The light emitted from the screen is what you see on your monitor.

Cathode Ray Tube (cont.)



Cathode Ray Tube (cont.)

- The point that can be lit up by the electron beam is called a **pixel**. The intensity of light emitted at each pixel can be changed by varying the number of electrons hitting the screen.

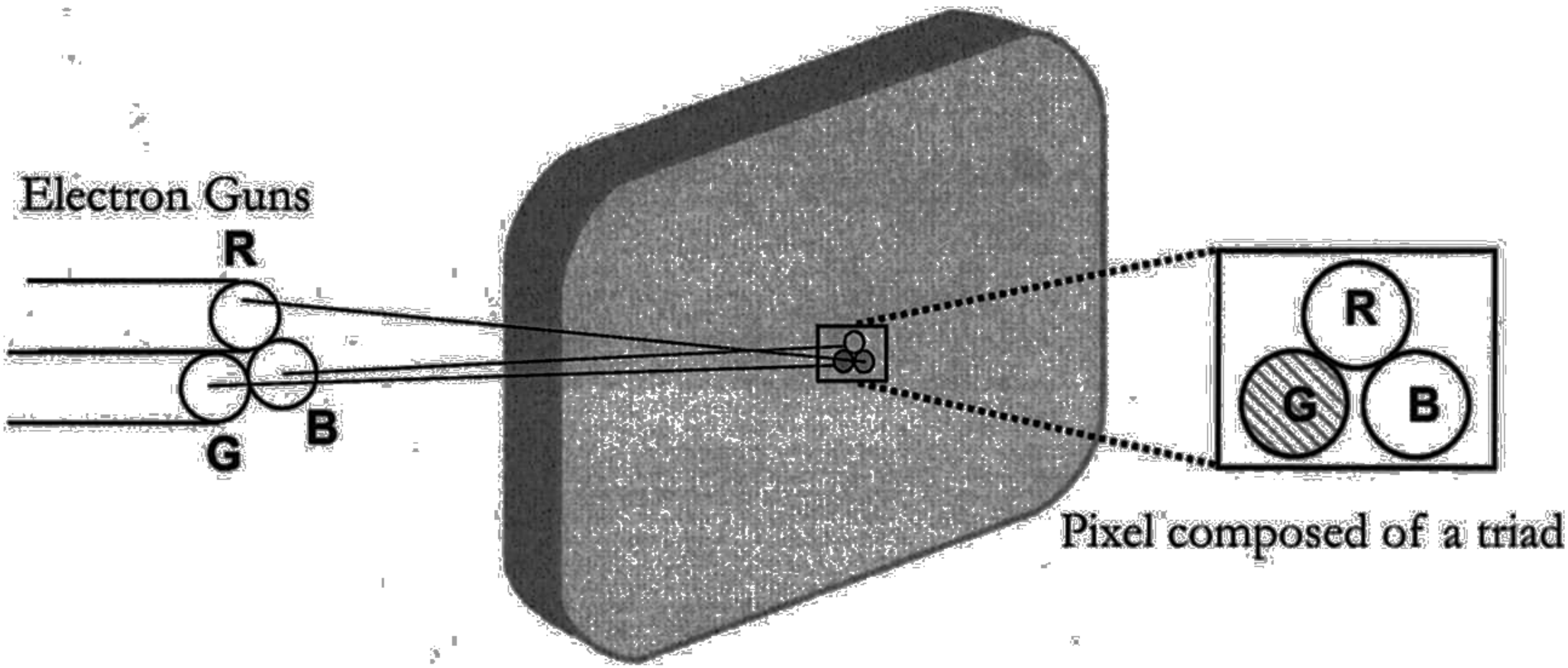
Cathode Ray Tube (cont.)

- A higher number of electrons hitting the screen will result in a brighter color at the specified pixel. A grayscale monitor has just one phosphor for every pixel. The color of the pixel can be set to black (no electrons hitting the phosphor), to white (a maximum number of electrons hitting the phosphor), or to any gray range in between. A higher number of electrons hitting the phosphor results in a whiter-colored pixel.

Cathode Ray Tube (cont.)

- A color CRT monitor has three different colored phosphors for each pixel. Each pixel has red, green, and blue-colored phosphors arranged in a triangular group. There are three electron guns, each of which generates an electron beam to excite one of the phosphor dots.

Cathode Ray Tube (cont.)

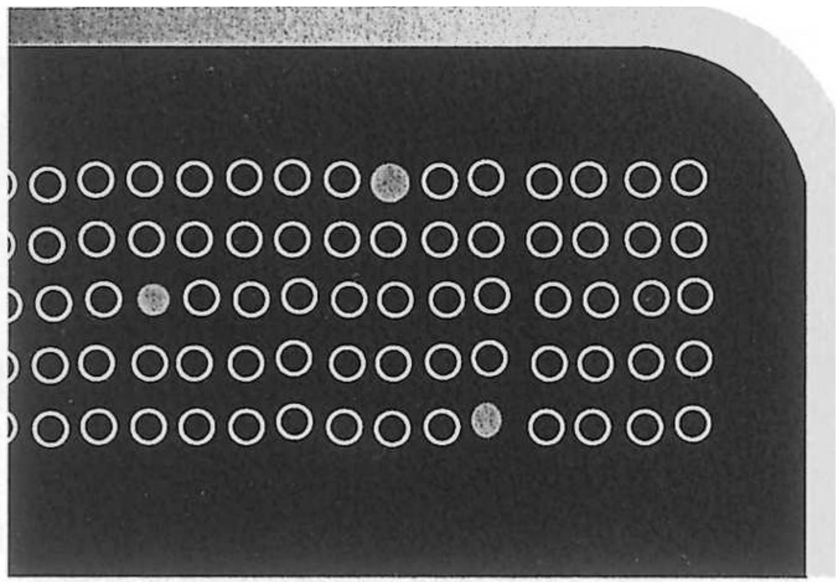


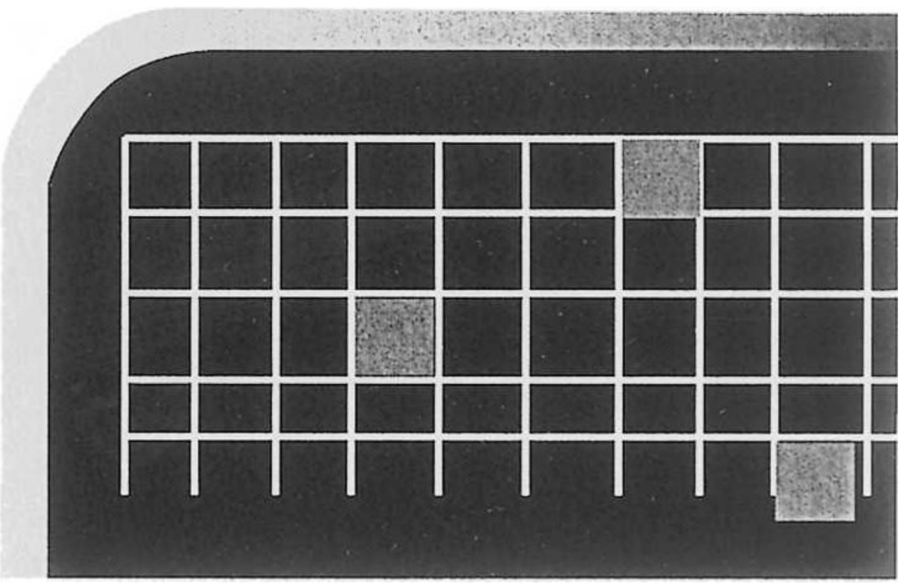
Cathode Ray Tube (cont.)

- Because the dots are close together, the human eye fuses the three red, green, and blue dots of varying brightness into a single dot/square that appears to be the color combination of the three colors.

Cathode Ray Tube (cont.)

- Conceptually, we can think of the screen as a discrete two-dimensional array (a matrix) of pixels representing the actual layout of the screen.

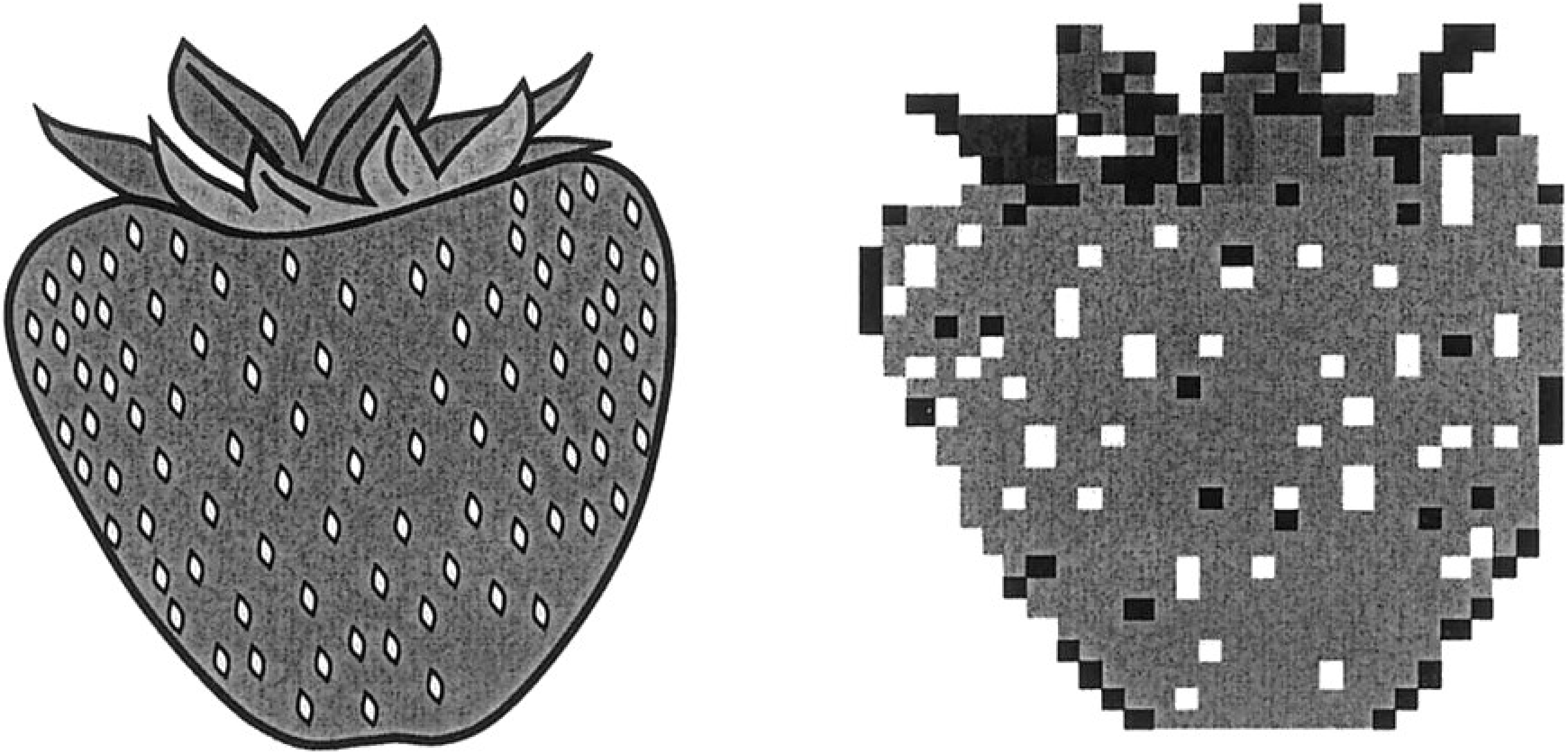




Cathode Ray Tube (cont.)

- The number of rows and columns of pixels that can be shown on the screen is called the screen resolution.
- On a display device with a resolution of 1024 x 768, there are 768 rows (scan lines), and in each scan line there are 1024 pixels. That means the display has 768 x 1024=786,432 pixels! That is a lot of pixels packed together on your 14-inch monitor. Higher-end workstations can achieve even higher resolutions.

Cathode Ray Tube (cont.)



The same image at different resolutions

Cathode Ray Tube (cont.)

- The Figure shows two images displayed in different resolutions. At lower resolutions, where pixels are big and not so closely packed, you can start to notice the "pixelated" quality of the image as in the image shown on the right. At higher resolutions, where pixels are packed close together, your eye perceives a smooth image. This is why the resolution of the display (and correspondingly that of the image) is such a big deal.

Cathode Ray Tube (cont.)

- You may have heard the term dpi, which stands for dots per inch. The word dot is really referring to a pixel. It is also known as pixels per inch (ppi). The higher the number of dots per inch of the screen/image, the higher the resolution and hence the crisper the image.

Cathode Ray Tube (cont.)

- The modern computer display based upon CRT technology employs the **raster scanning** of electron beams.

Cathode Ray Tube (cont.)

In this case, the raster scan (for monochrome CRT) works in the following manner:

1. The electron beam is initially directed towards the top left-hand corner of the display screen.
2. Electro-magnets are used to move the electron beam horizontally across the screen. As the electron beam travels from the left to the right-hand side of the screen, it excites the phosphor coating (which is bonded to the rear of the screen) and this gives rise to the production of a visible line

Cathode Ray Tube (cont.)

3. The electron beam is rapidly moved back to the left-hand side of the screen – to a position slightly below its original location. Since the electron beam is moved so quickly to this position, it does not have the chance to significantly excite the phosphor, and therefore does not give rise to a visible line.

Cathode Ray Tube (cont.)

4. From this new position the electron beam is again swept horizontally across the screen. This gives rise to another visible line, which is slightly below the first line referred to previous step.
5. The process is repeated; this gives rise to a set of horizontal lines drawn on the display screen.

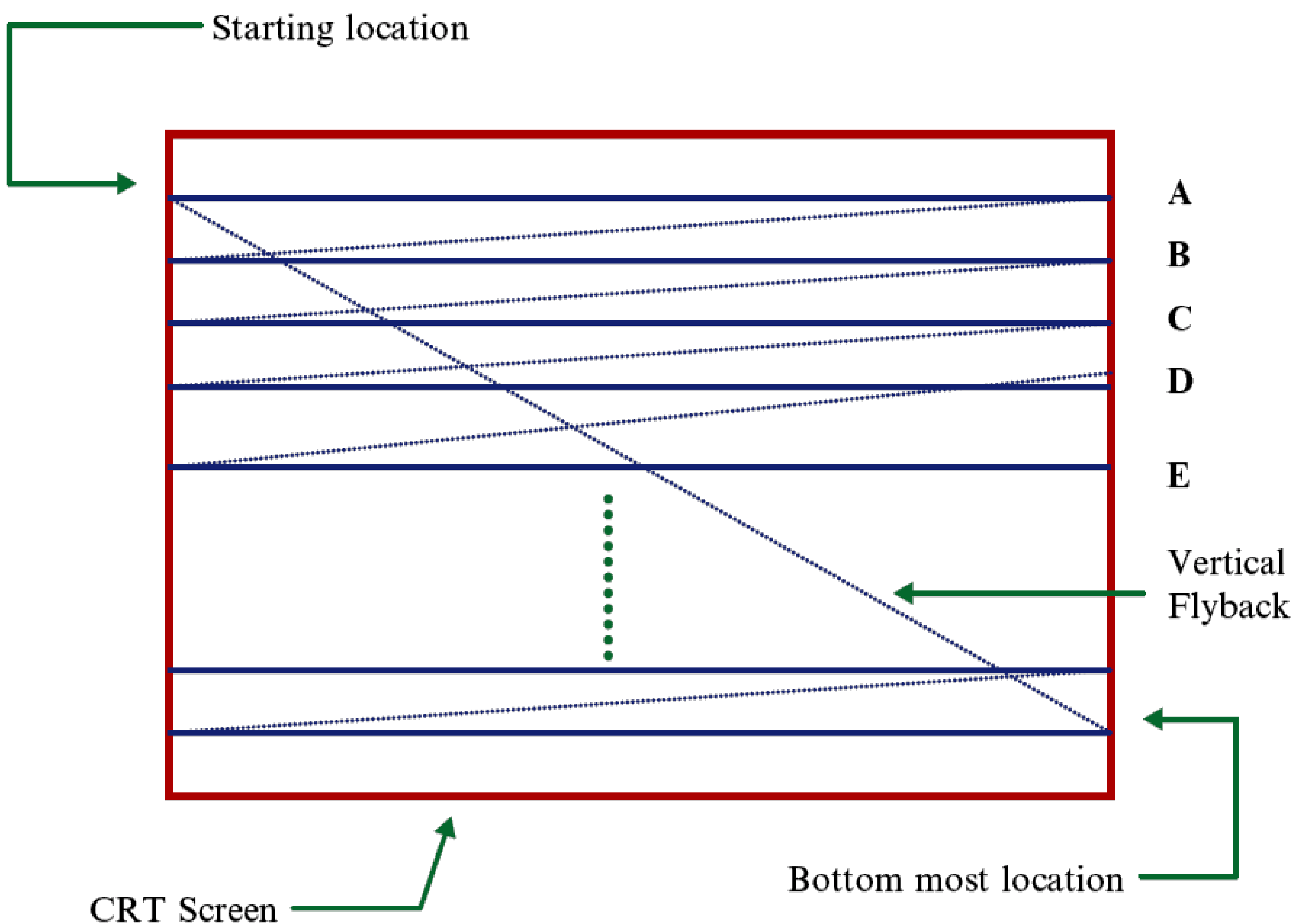
Cathode Ray Tube (cont.)

6. When the electron beam finally reaches the bottom right-hand corner of the screen, it is rapidly returned to the top left-hand corner. This is known as the vertical flyback. If the deflection occurs quickly enough then this vertical flyback does not give rise to a visible diagonal line across the screen.

Cathode Ray Tube (cont.)

7. The technique outlined above enables the entire screen to be scanned, and a set of horizontal scan lines are produced. The light output from the excited phosphor rapidly decays and therefore so as to avoid the flicker problems discussed in the previous section, the display must be regularly refreshed (this involves rapidly repeating steps 1 to 6).

Cathode Ray Tube (cont.)



Cathode Ray Tube (cont.)

- The generation of color images is somewhat more complex and is underpinned by the fact that we can generate any color within the visible spectrum by mixing together sources of red, green, and blue light in appropriate proportions.
- The color CRT employs three electron beams that are simultaneously scanned across the surface of the screen in the manner outlined in points 1 to 7 above. Three different types of phosphor are deposited on the surface of the screen. One of these gives rise to the emission of red light, the second green, and the third blue.

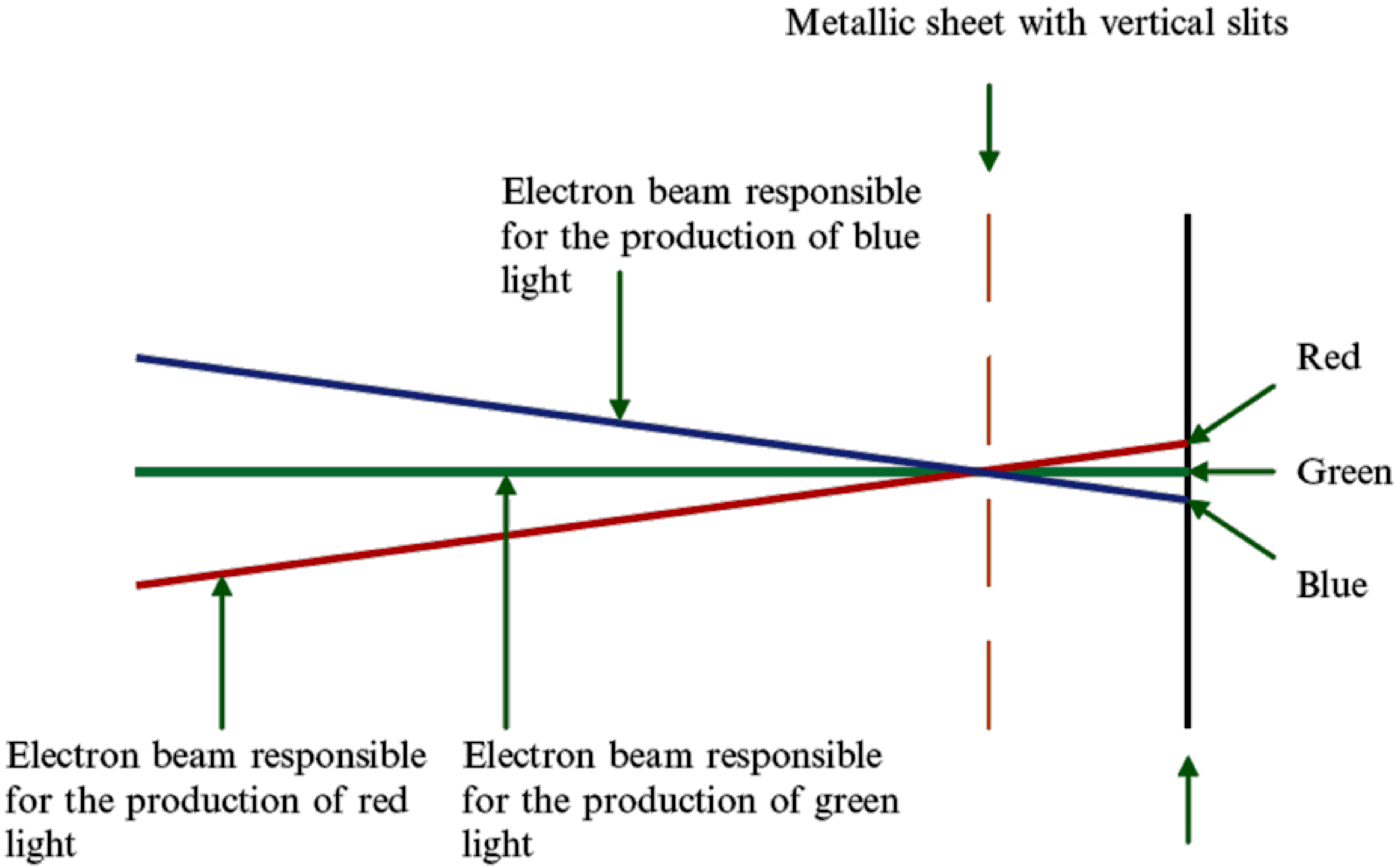
Cathode Ray Tube (cont.)

- Complexity in the implementation of the color CRT arises when we consider how we can lay out these three phosphors on the screen’s surface and ensure that each can only be ‘addressed’ by a single electron beam (e.g. the electron beam responsible for the production of red light should only be able to address the red phosphor). This is achieved by inserting a thin sheet of metal which lies just below the CRT screen.

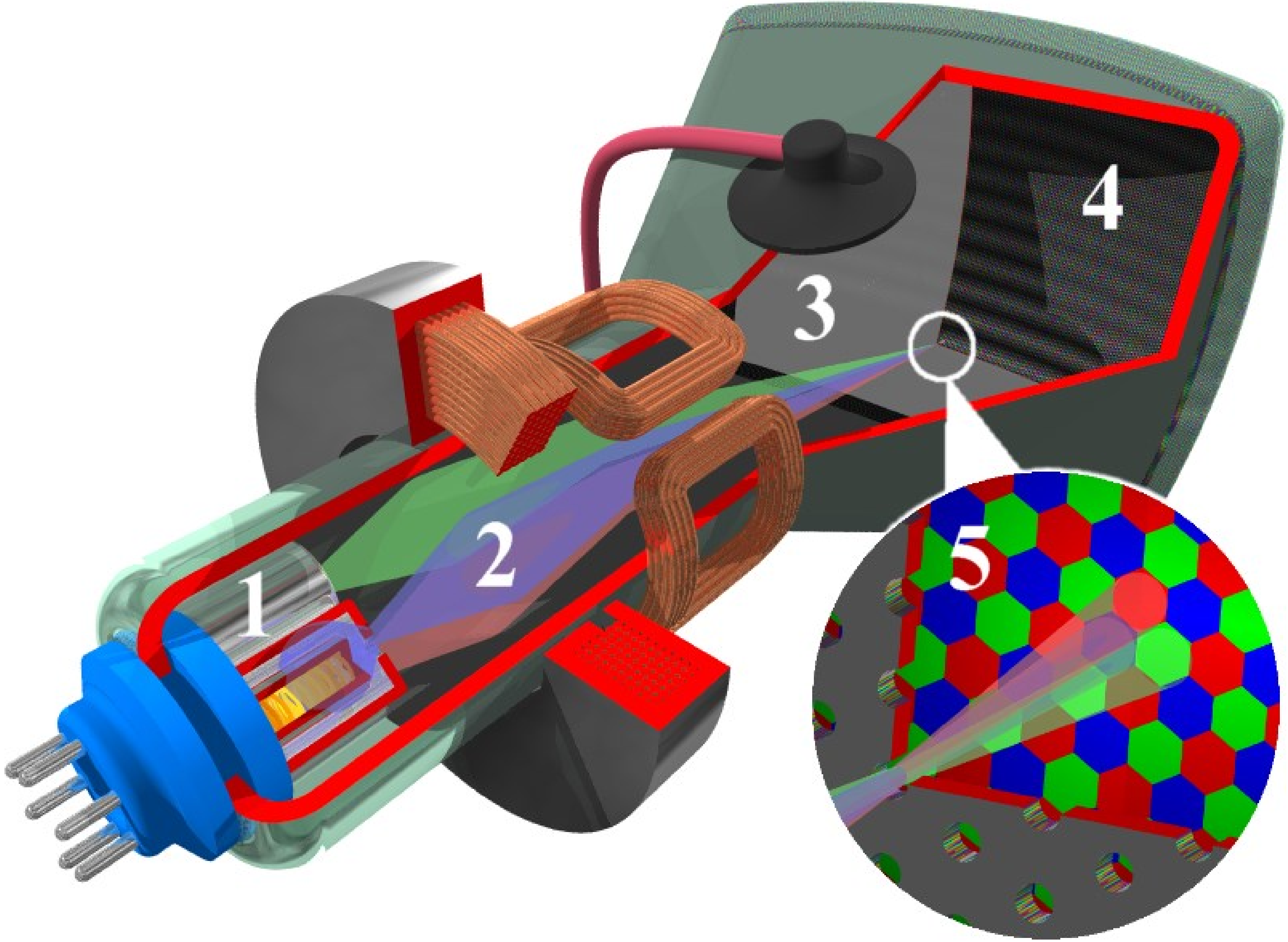
Cathode Ray Tube (cont.)

- This sheet of metal comprises a set of narrow, vertical strips, and the phosphors deposited on the inner face of the CRT are arranged as a series of vertical stripes. The trajectory of the electron beams is such that they intersect and cross over in the region of the slits and subsequently impinge on the screen. By accurately aligning the location of the slits with the stripes of the three phosphors it is possible to ensure that each electron beam is only able to ‘write’ to a phosphor of a certain color.

Cathode Ray Tube (cont.)



Cathode Ray Tube (cont.)



Liquid Crystal Display

Liquid Crystal Display

- First discovered in 1888, liquid crystals are liquid chemicals whose molecules can be aligned precisely when subjected to electrical fields--much in the way metal shavings line up in the field of a magnet. When properly aligned, the liquid crystals allow light to pass through.

Liquid Crystal Display (cont.)

- Liquid Crystal is a substance that behaves like both a liquid and a solid. The molecules in liquid crystals can move past each other relatively easily, much like molecules in a liquid. However, all the molecules in a liquid crystal tend to be oriented in the same manner, much like the molecular arrangement in a solid crystal. Liquid crystals retain their dual liquid and solid nature only over a certain range of temperatures and pressures. **(Microsoft ® Encarta ® 2008.)**

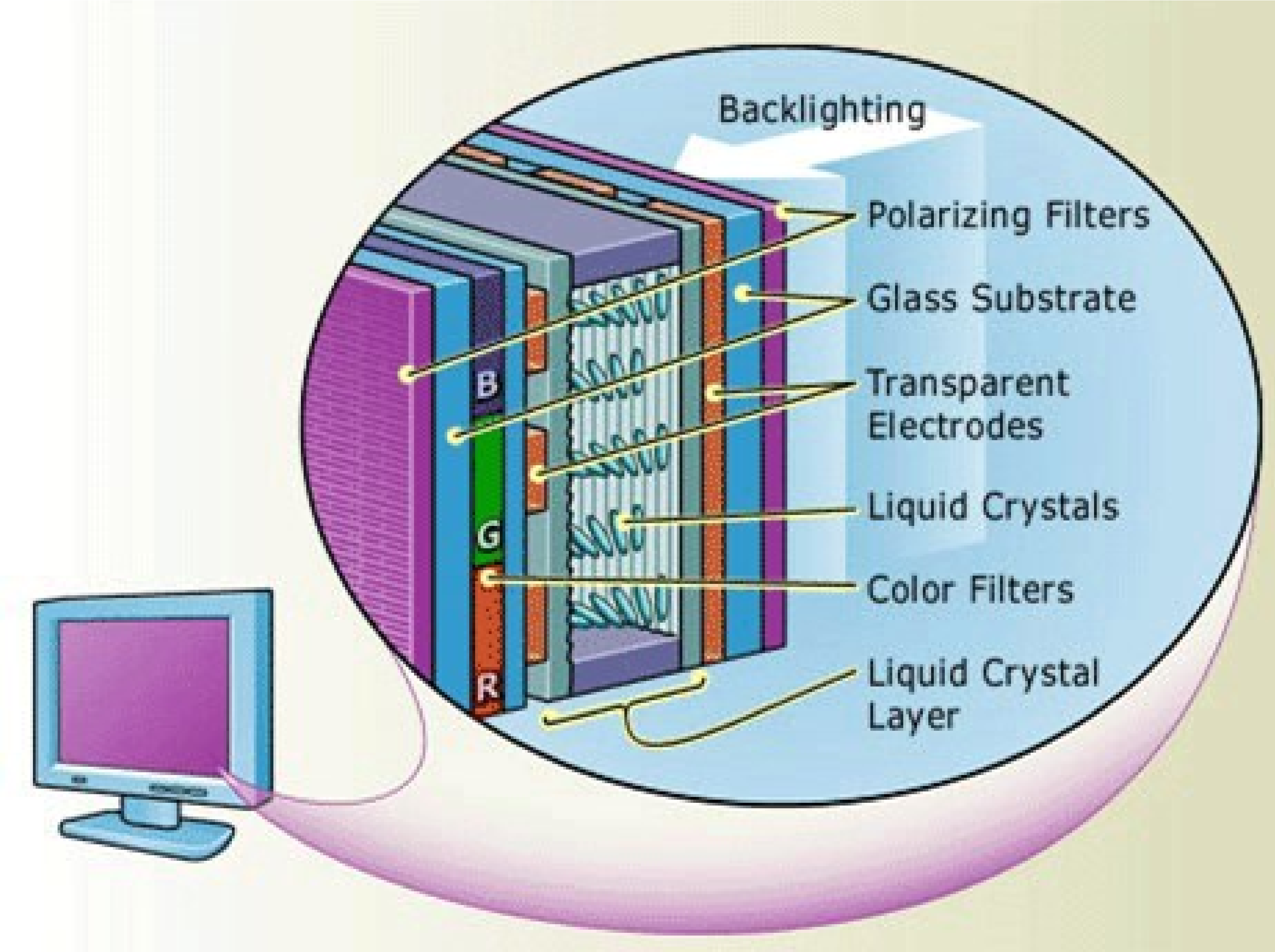
Liquid Crystal Display (cont.)

- At sufficiently high temperatures or low pressures, the orientational order relaxes into random molecular rotations, causing a liquid crystal to become an ordinary liquid. At sufficiently low temperatures or high pressures, molecules in a liquid crystal cease being able to easily move by each other, and the liquid crystal freezes into an ordinary solid. **(Microsoft ® Encarta ® 2008.)**

Liquid Crystal Display (cont.)

- LCD is a display technology developed in 1963 at the David Sarnoff Research Center in Princeton, NJ, that is quite amazing. Sandwiched between polarizing filters and glass panels, liquid crystals are rod-shaped molecules that flow like liquid and bend light like crystal. The orientation of the filters and panels determines how light passes through the crystals. **(http://www.pcmag.comencyclopedia _term/0,2542,t=lcd&i=45973,00.asp)**

Liquid Crystal Display (cont.)



Liquid Crystal Display (cont.)

- Because it takes such little power to move crystal molecules, LCD-based digital wristwatches began to flourish in the 1970s along with myriad other monochrome displays. By the 1990s, color LCDs helped the sales of laptops to boom, and in 2003, LCD computer monitors outsold CRTs for the first time, making LCD the predominant electronic display technology.

Liquid Crystal Display (cont.)

Characteristics of LCD

- Takes up less space, consumes less power, and produces less heat than traditional cathode-ray tube monitors.
- Lack of flicker and low glare reduce eyestrain.
- Much more expensive than CRTs of comparable size.

Liquid Crystal Display (cont.)

- LCDs have many advantages over cathode-ray tube monitors. They offer crisp text and no annoying flicker, which means they can help reduce eyestrain. Because they're usually less than ten inches thick, desktop LCD monitors take up much less space than their traditional CRT counterparts. The downside: The color quality of LCD displays typically can't compare with that of CRTs, and the high price tags of desktop LCDs mean they're still a luxury for most.

Liquid Crystal Display (cont.)

- Whether on a laptop or a desktop, an LCD screen is a multilayered, sideways sandwich. A fluorescent light source, known as the ***backlight***, makes up the rearmost slice of bread. The backlight itself is a cold cathode. Depending on how expensive the display is, there will be either a single cathode at the top, or one at the top and one at the bottom, or two at the top and two at the bottom for optimum brightness and clarity.

Liquid Crystal Display (cont.)

- Each pixel is made up of three sub-pixels, which have red, green and blue filters in front of them, just as each pixel on a CRT has RGB phosphors. The subpixels are made up of a group of liquid crystal molecules. These molecules are suspended between transparent electrodes and are mashed between two polarizing filters.

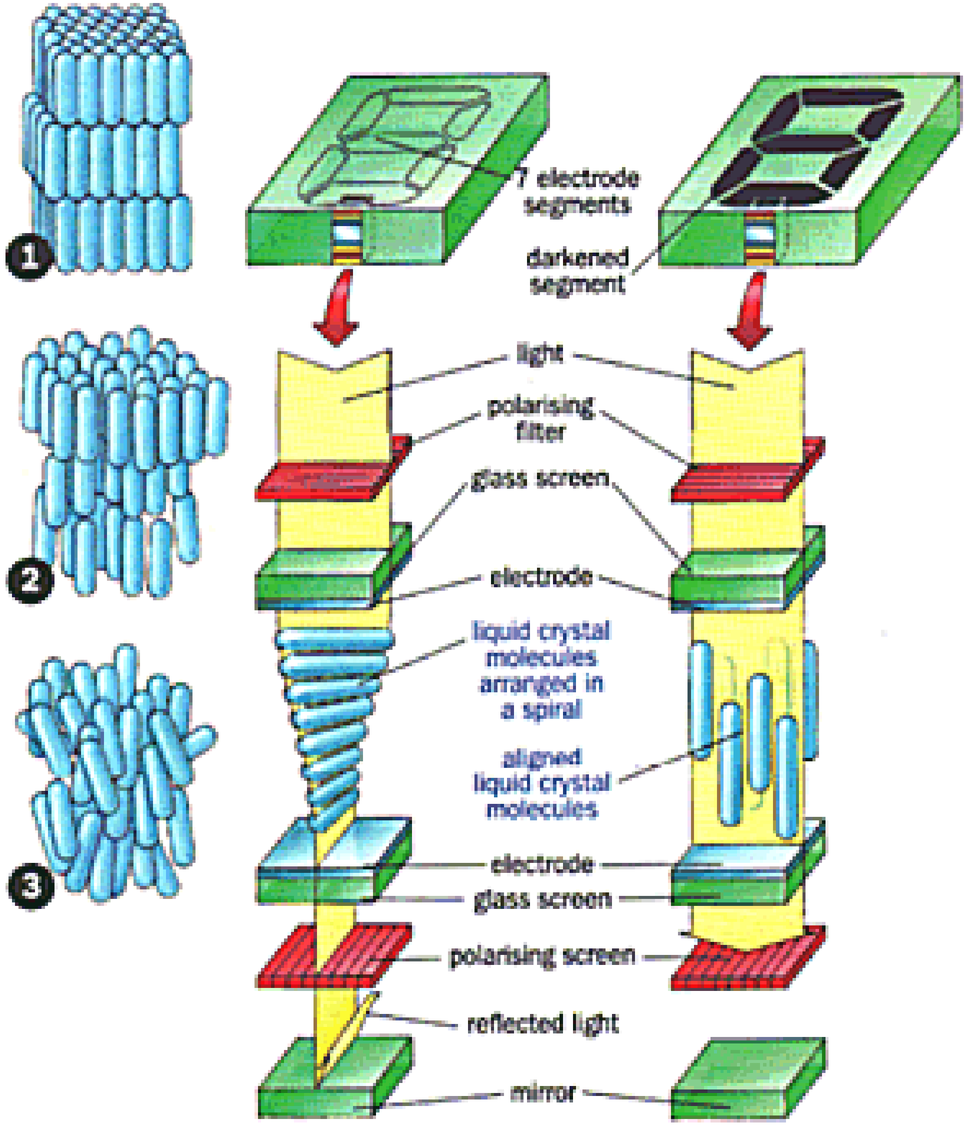
Liquid Crystal Display (cont.)

- The two filters are exact opposites of each other. As the light from the light source behind the first filter comes in, the filter effectively whites it out - which means that if it was to pass through the liquid crystals with no interaction, the filter on the other side would polarize it back to black, leaving no color being emitted.

Liquid Crystal Display (cont.)

- However, if the electrodes apply current to the liquid crystals they twist and change the way that the light is passed through, altering its polarization and this then results in the correct color coming out of the second polarizing filter and being displayed to the user.

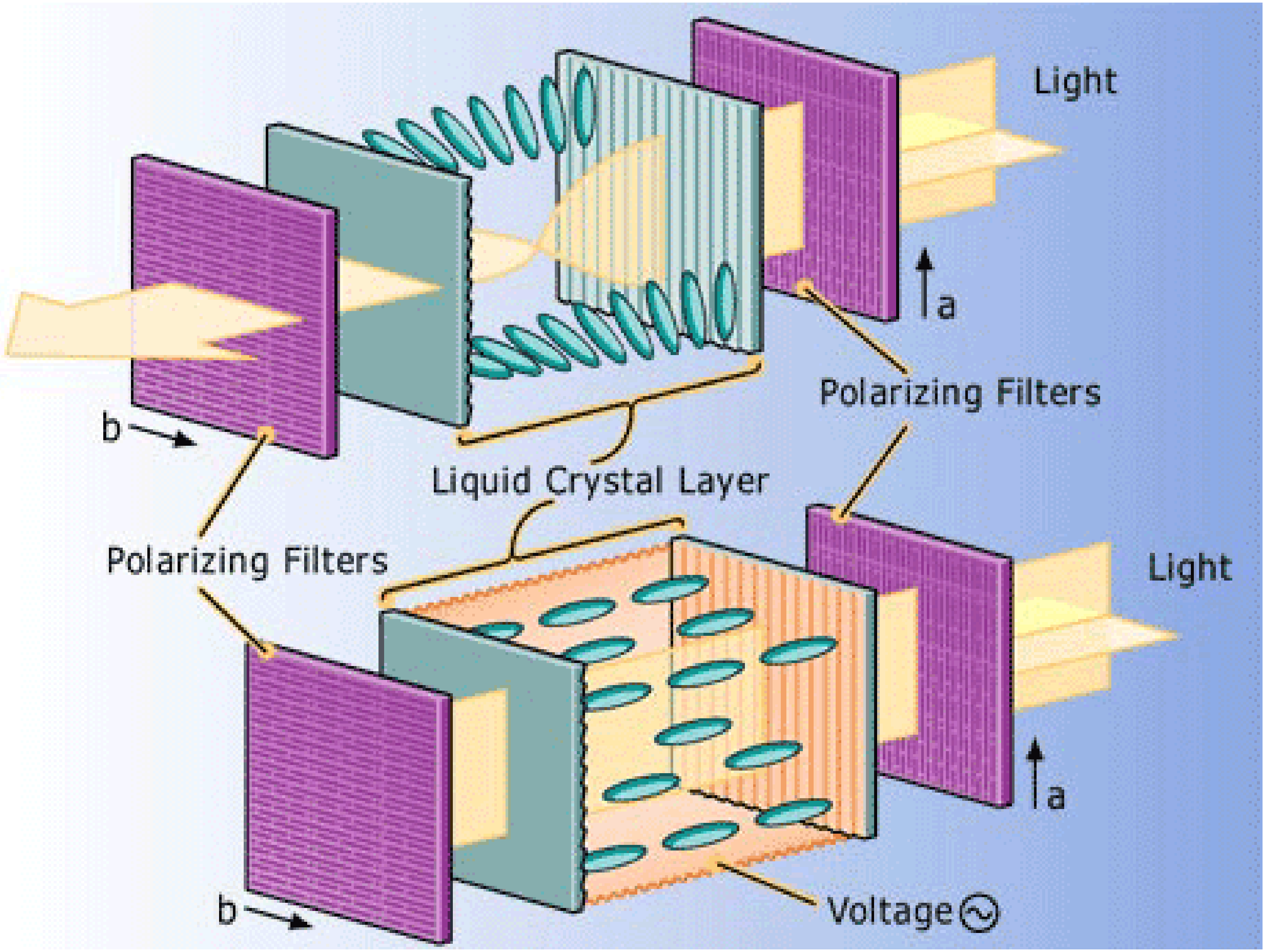
Liquid Crystal Display (cont.)



Liquid Crystal Display (cont.)

- In a color LCD panel, each pixel is made up of three liquid crystal cells. Each of those three cells is fronted by a red, green, or blue filter. Light passing through the filtered cells creates the colors you see on the LCD.
- Nearly all modern color LCDs--both in notebooks and for desktop monitors--use a thin-film transistor, also known as an ***active matrix***, to activate each cell.

Liquid Crystal Display (cont.)



Homework

- How does CRT based display systems perform raster scanning?
- What are the usual rates of refreshing the screen?
- How much time do the beam of electrons stay on the CRT screen?
- What is the purpose of having the frame buffer for most display systems?
- How does LCD draw each pixel of the image?