

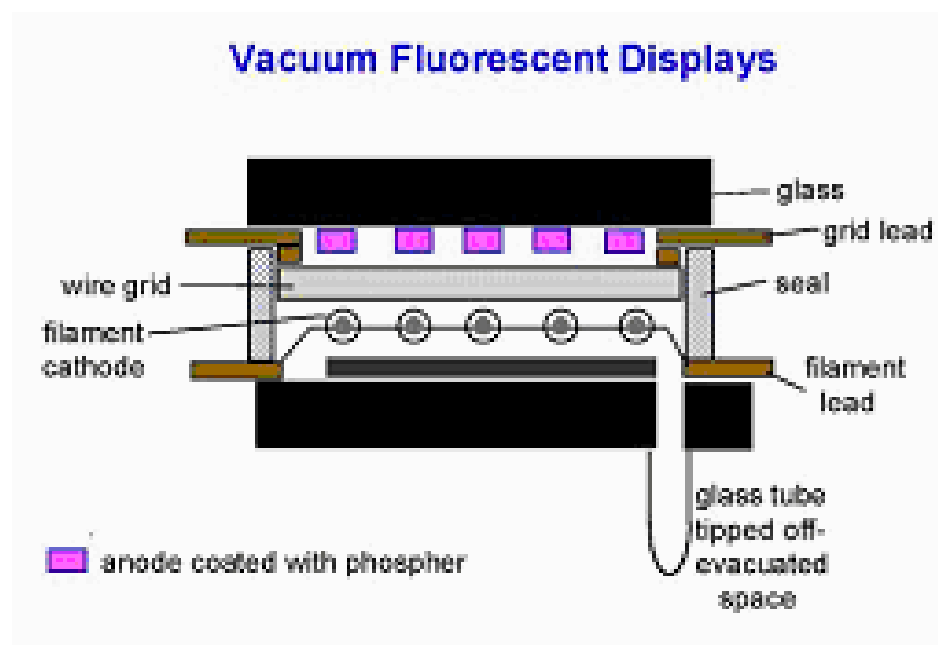
## Vacuum Fluorescent Displays

### 3.1. Introduction

A vacuum fluorescent display (VFD) is commonly called a flat CRT since it utilizes multiple cathodes and a matrix deflection system. In a sense, a VFD is a hybrid display device intermediate between the conventional electron tube and the well known CRT. The basic structure of a VFD are triode structures with patterned, transparent anode substrates and low voltage phosphors in an evacuated envelope. Both alphanumeric characters and matrix addressed VFDs are available, predominantly in low resolution. The vast majority of VFDs are of the character type (microwave ovens and video cassette recorders) or low information dot matrix panels. High resolution VFDs never really penetrated the marketplace.

### 3.2. Basic Physics of Operation

The underlying physics of operation of a VFD is the following. Refer to the figure below.

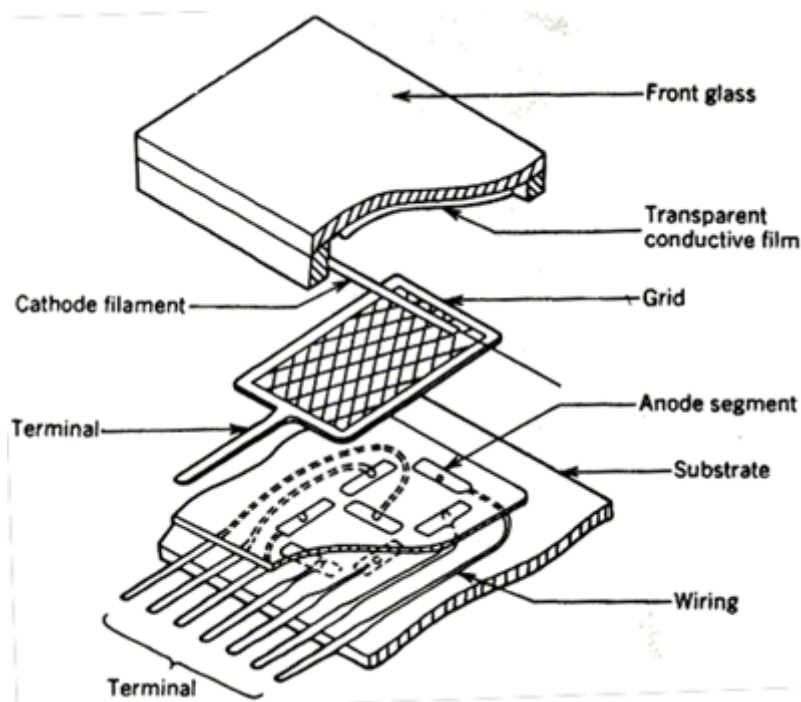


A cathode filament is heated to approximately 600 degrees Celsius to facilitate the emission of thermal electrons. A voltage in the range of 10 - 50 Volts is supplied to the anode while a simultaneous voltage is applied to the grid of that selected segment. Electrons from the filament are accelerated by the grid and sent to the phosphor coated anode. Chemical elements in the phosphor material are excited as the energy from the electrons bombarding the phosphor are transferred to these

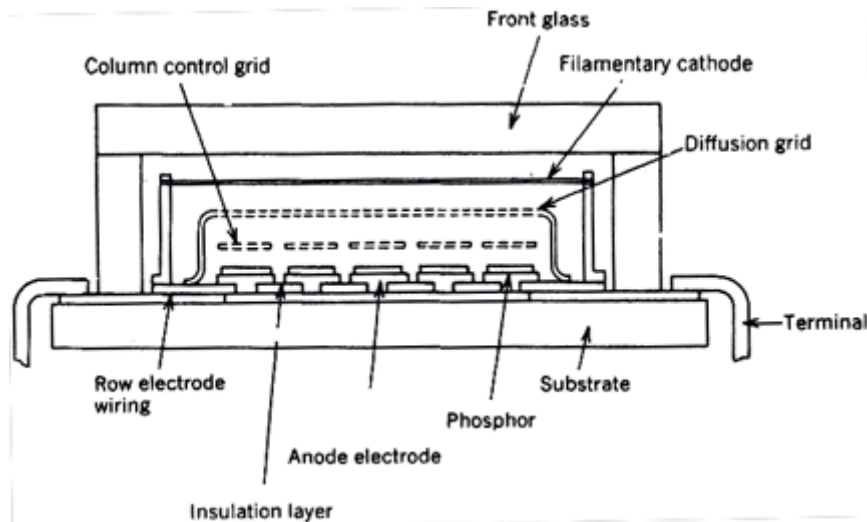
atoms, raising their electrons to a higher energy level where they remain for a very short period of time. When the electrons relax to their ground state, energy is released in the form of visible light. The monochrome colors are blue-green. The display can be driven by direct addressing methods or multiplexing.

### 3.3. Basic Display Configuration

VFDs are flat CRTs that can be direct or matrix addressed. The basic structure of a numeral display is shown below.



It consists of a cathode filament, a grid, a set of anode segments (with associated wiring) and a front glass plate on a transparent conductive film. All components are sealed in a vacuum element. The character selection is accomplished by applying a voltage to the appropriate segments resulting in the phosphor on those segments emitting light. A multicharacter assembly can be created by combining a number of elements and this can be selectively energized by switching the grid voltage in conjunction with selecting the proper segments on the switched character. This is a multiplexing feature. A matrix addressable VFD is shown below.



Each dot (pixel) is selected by driving the proper row and column electrodes, where the row is the anode and the column is the grid.

### 3.4. Optical Performance

The equation for luminance for a VFD can be expressed as:

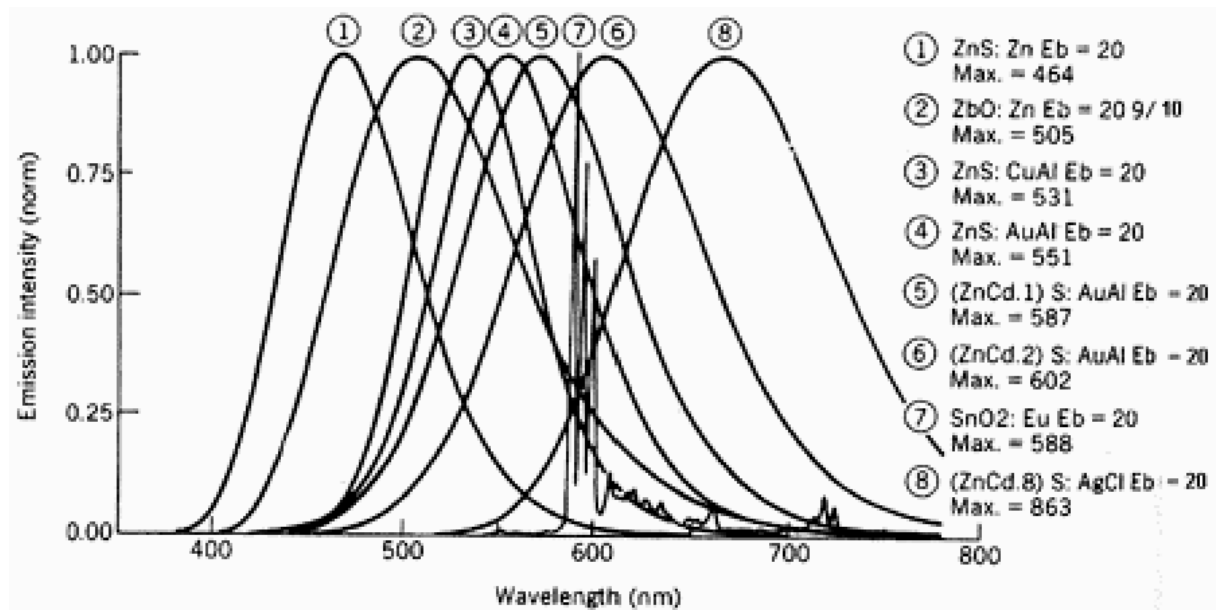
$$L = 3.2 V_p J_p D_u n$$

where  $V_p$  is the anode voltage,  $J_p$  is the anode current density,  $D_u$  is the duty cycle and  $n$  is the luminous efficiency of phosphor.

The equation for luminance versus voltage is expressed as:

$$L = \frac{n D_u G}{1+k} V_p^{(n+1)}$$

where  $G$  is the permeance,  $k$  is the distribution rate which is defined as grid current / anode current and  $n$  is a constant (typically 1.7). The emission spectrum and constituents of phosphor are shown below.



Multicolor displays are made using spatial color synthesis techniques.

### 3.5. VFD Trends

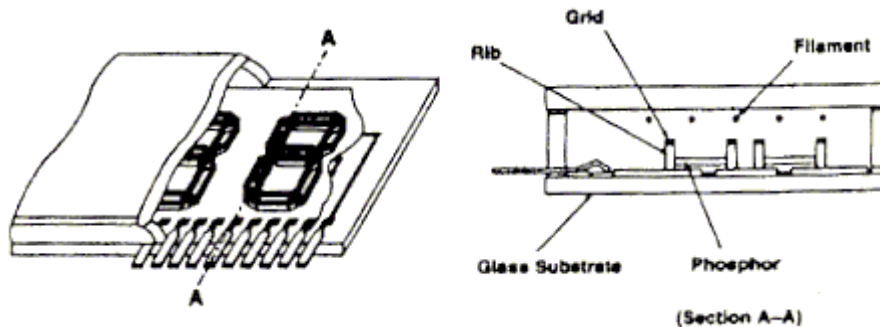
As mentioned earlier, VFD technology is relatively mature. The technology trends of VFDs include driving methods, the structure and materials for high integrity display and large areas.

### 3.6. Chip in Glass

As the segment density increases, the number of lead wires will obviously increase, causing a structural problem with the direct-drive (static) drive scheme. Chip-in-Glass (CIG) technology was developed as a means to avoid this lead wire problem. The CIG has driving IC mounted inside the vacuum element. The figure below shows the CIG VFD configuration.



deforming owing to excessive grid power dissipation. This technology was adapted from the plasma display community. The rib-grid structure is shown below.



### 3.9. Large Size VFD Panel

As the size of a VFD increases, reinforcement is needed. The provision of spacers as inner supports and the use of thick glass are as reinforcement measures. VFDs are being used more and more as information boards.

### 3.10. Lighting Elements

A lighting element VFD is used for large size display devices installed indoors and outdoors. This application started with large screens, such as the one at the Tsukuba Expo in Japan. Lighting VFDs usually require high voltages,  $\sim 10$  kV, to create luminance  $> 1500$  cd/m<sup>2</sup>.

### 3.11. VFDs for Heads-up Displays (HUD)

There have been more development efforts to create heads-up displays in the automobile industry. This application utilizes a virtual image that is displayed in front of your windshield. The idea is to put information in the driver's field of view, such as a speedometer, without creating annoying artifacts so that the driver need not look away to view his/her display. This display keeps the driver's eyes on the road thereby improving safety and reducing eye fatigue. Because of severe losses associated with the optical stack needed to create a virtual image and brightness of the background, heads-up displays need to be at least 5 times as bright as is required for other applications. This creates a design challenge for both the luminance efficiency of the phosphor and electrodes (high power efficiency and dissipate heat generated). A successful VFD for heads-up display / HUD applications was demonstrated with  $35 \times 10^3$  with a 3000 hour lifetime. The VFD HUD implemented rare earth oxide dopants to the electron emitting material for the oxide cathode and the use of silicon compounds for the protection of the phosphor thereby providing a heat sink.

### 3.12. Conclusions

VFD technology is mature and will continue to hold a small market share in the display market. Despite the development to move them to higher resolutions, their biggest market will be smaller, low resolution display applications.

### 3.13. Phosphor

The phosphor materials used in VFD applications are different than those used in CRTs. The VFD phosphorous must be low voltage, low resistant, and to have the ability to withstand heat treatment and contamination during the manufacturing process.

### 3.14. Advanced Techniques

To move VFDs to higher resolution, researchers are considering low temperature polysilicon thin-film-transistor (TFT) technology. An example of a TFT VFD is shown below.

