Miniature CRTs having High Brightness, High Resolution, Light in Weight and Very Low Power Consumption

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Unique monochrome 0.6" CRTs, based on a new gun concept and a phosphor screening method, have been developed. The phosphor screen emits a white cathodoluminescence which has a high brightness of more than 2,000 cd/m² along with a high resolution of 700 TV lines horizontally and consumes less than 2 watts of power. The tube itself weighs 6 grams, and the total weight of the entire unit, including the CRT, yoke, driver board assembly with socket, is only 30 grams. These units can be utilized wherever brightness, resolution, weight, size, power consumption and price where the major factors for varied applications whether current and in the future.

Key words: miniature CRT, helmet mounted display, phosphor screen, electron gun, resolution

I INTRODUCTION

CRTs have a great advantage as a video projector for (i) television broadcasting and VCR (entertainment), and (ii) information that has been processed by computers. This is because CRT display, as compared to other display devices, have the advantages in brightness, resolution, real time imaging, less power consumption and a relatively low production cost. But some of disadvantages of large CRTs are (a) large glass envelope volume and (b) the weight factor of glass, yoke, etc., for addressing a sharply focussed electron beam onto the phosphor screen. But these disadvantages can be eliminated by projection of video images from a small CRT onto large screen.⁽¹⁾ This approach is very evident today, as seen in large screen TV by using 5" to 7" CRTs as a base for projection onto HDTV screens.⁽²⁾ This same concept is applicable to the display devices using

miniature CRTs and the projection of their displays onto screen of 5" or smaller.⁽³⁾

To accomplish this mode of miniature video projection, the CRT phosphor screen should emit a brilliant cathodoluminescence (CL); e.g. more than 1,500 cd/m², with a sharply focused electron beam (e.g. less than 20 μ m diameter, which is 1/10 of an ordinary CRT with 0.2 to 0.3 mm line width). The brightness of a phosphor screen in a CRT will be increased with incident electrons exciting the phosphor particles per unit time; e.g. anode voltage multiplied by electron beam current and irradiation duration. The miniature CRTs have limitations associated with anode voltages. The anode voltage should be below 10 kV due to electrical discharge (break down) between the anode terminal and parts, especially the deflection yoke. Therefore, to obtain a high brightness, one would consider increasing the electron beam current. But this assumption

creates another problem in that the diameter of the electron beam bundle expands exponentially with an increase in the electron beam current.⁽⁴⁾ Consequently, it is necessary to reduce the cathode current as low as possible to obtain a sharply focused electron beam, which would render a brighter emitting phosphor screen.

These objectives necessitated a selection of phosphor with a white emission $Y_2O_2S:Tb$ (JEDEC CODE P45) which has a high energy conversion (double), that of $Y_3Al_5O_{12}:Tb$ (JEDEC CODE P53), aside from having a low threshold voltages (900V).⁽⁵⁾ With this combination, it is possible to display monochrome video images on a 0.6" CRT screen with a brightness of more than 2,000 cd/m² along with a resolution of 700 TV lines (beam size be approximately 14 μm), and a low power consumption of less than 2 watts, while maintaining a very light weight of 6 grams.

II PHOSPHOR SCREENS

It has been reported that the phosphor screen in the helmet mounted miniature CRTs heats up to an elevated temperature (nearly 100 °C) in operation. To circumvent the loss of brightness at high drive, the P53 phosphor ($Y_3Al_5O_{12}:Tb$) was chosen for maintaining linearity in brightness under high screen current densities,⁽⁶⁾ by many for miniature Helmet Mounted Displays. This gave rise to a number of questions regarding many parameters of tube operation, including beam spot size, power consumption, heat, and safety by the electron beam irradiation of the screen.

To verify this heating effect, calculations were made on the irradiation power impinging on the phosphor particles in (a) 0.6" CRT (with 20 μm diameter of electron beam) and (b) 19" CRT for TV use (with 0.3 mm diameter

of electron beam), under NTSC operation conditions. The scanning time of a horizontal line is determined by the broadcasting system, and it is 63.5 μsec , independent on screen sizes. Since the screen size of a 0.6" CRT is too small (12 mm horizontally), one would assume that the phosphor particles would emit a notable amount of heat from the relatively slow scanning electron beam bombardment.

In addition, the irradiation duration time of 20 μm electron beam on the phosphor particles in 0.6" screen is 106 nsec ($t = 20 \times 10^{-4} \times 63.5 \times 10^{-6} / 1.2 = 106 \times 10^{-9}$ sec) which is double of 50 nsec by the 0.3 mm diameter beam in 19" screen ($t = 300 \times 10^{-4} \times 63.5 \times 10^{-6} / 38 = 50 \times 10^{-9}$ sec). If the electron beam at 6 kV with 1 μA (beam density of 0.3 A/cm² = $1 \times 10^{-6} / 3 \times 10^{-6}$ cm²) is irradiated onto a phosphor screen in 0.6" CRT for 106 nsec, the power dumped on the phosphor particles is 2×10^{-4} watts (= $0.3 \times 6 \times 10^3 \times 1.06 \times 10^{-7}$) that is comparable with the power of 19" CRT (2.1×10^{-3} watts) operated with 30 kV, 1 mA (beam density of 1.4 A/cm²). From this, it is assumed that the phosphor screen in a 0.6" CRT could possibly heat up only a few degree C during operation. Actual data from this experiment showed a rise of from 3 to 5 °C on the phosphor screen in a 0.6" CRT. From these findings, we chose the $Y_2O_2S:Tb$ phosphor, which emits a white cathodoluminescence, with a high energy conversion efficiency (about 20 % by our measurement), instead of the heat resisting phosphor (P53) with an 8 % efficiency. The $Y_2O_2S:Tb$ phosphor screen maintains its efficiency as the mean particle size is reduced to 2.5 μm (as measured by a microscope). And the new application of these small particles gives rise to a high resolution of images on the phosphor screen. The overall brightness is further increased (about 20 to 30 %) by removing small particles

Fig. 1 Brightness of $Y_2O_3:Sb$ phosphor screen as a function anode current.

of less than $1\mu m$ from the phosphor powder, we used this phosphor powder in following experiment. Fig.1 shows the screen brightness as a function of the electron beam current. A brightness of $2,000\text{ cd/m}^2$ is of obtained from the screen without any appreciable rise (approximately a few degree C). Thus, the electron beam current was reduced to $10\mu A$ from $100\mu A$ of the typical helmet mounted miniature CRTs by using P53 phosphor.

III ELECTRON GUN

The resolution of the images on phosphor screen is predominantly determined by the diameter of electron beam striking the phosphor screen.⁽⁵⁾ The electrons emitted from the cathode are focused by use of either external magnets or internal electrostatic plates attached to the gun in typical CRTs.

The electron beam in typical CRTs is usually focused by grid cup, which restrict the number of electrons emitted by the cathode due to the aperture size in order to obtain a beam spot size smaller than $30\mu m$, as shown in Fig. 2. These intercepted electrons impinge upon the surface metal of the grids and generate heat,

Fig. 2 Beam currents detected at anode I_a , gride I_{g3} , and cathode I_k .

Fig. 3 Resolution of 0.6" CRT screen as a function of screen brightness.

mechanical deformation, etc., which gives rise to astigmatism, aperture erosion, gas and poor resolution.

To eliminate these problems, a modified version of an electron gun was designed which consists of two focusing parts; prefocusing and mainfocusing. The prefocusing is done by cathode control grit G_1 , and accelerating grid G_2 . By using this type of prefocusing arrangement, all of the electrons emitted the

cathode flow into main focusing section. The main focus is accomplished by utilizing rare earth permanent magnets. This is possible since the electron beam is accelerated with the constant anode voltage of the CRT.

Two magnets, rather than one, are used on an electron beam of $10\ \mu\text{A}$ to obtain a diameter less than $20\ \mu\text{m}$ on phosphor screen. This beam diameter narrates 600 horizontal TV lines ($= 12\text{ mm}/20 \times 10^{-3}\text{ mm}$). Actual measurements showed 700 TV lines of resolution (Fig. 3), denoting the size of the electron beam is approximately $14\ \mu\text{m}$. An effort to further reduce the line width and increase the contrast ratio also attempted using Fiber Optic Flat Plates (FOP). This was tried with a 50 % optical transmission FOP which reduced the brightness by 1/2, with little, if any effect on enhancing the contrast ratio, as compared to a typical glass face plate. This indicated that little if any improvements are observed if the light output of the tube is less than $1,000\text{ cd/m}^2$.

IV POWER CONSUMPTION, FRIT SEAL AND WEIGHT

The attention was then focused on the power consumption as well as a weight reduction. It is evident that the CL of a phosphor screen is generated by the electron beam which consumes little energy; e.g. 60 mW for 6 kV at $10\ \mu\text{A}$ of current. The most energy is consumed in the operation by the electronics drive board for the deflection yoke and anode high voltage.

The power consumption by the deflection yoke can be lowered if the distance between the magnetically focused electron beam and yoke is shortened. Since the electron beam size is less than $50\ \mu\text{m}$, this distance may be significantly reduced by miniaturizing the prefocus electron gun. But this

miniaturization required ultra high precision in the gun parts assembly and gun stuffing or insertion. This problem was overcome only through the use and redesign of precision machinery utilized in wrist watches and quartz oscillators assembly technology. Based on this experiments the diameter of electron gun was reduced to 2 mm. The outside diameter of the neck tubing was reduced also to 6 mm. With these reductions in size, the length was also shortened. Since the gun insertion required no pump-down tip off, a new method of frit technology was developed to seal both ends of the tube during the evacuation pump-down. This resulted in lowering the total weight of the tube to only 6 grams. Fig. 4 shows a photograph of the 0.6" CRT developed. The total weight of the entire unit, including the CRT, yoke, and driving board assembly with socket, is only 30 grams.

V CONCLUSION

By these efforts and redesigns, it was possible to develop a miniaturized 0.6" CRT that exhibits a high brightness along with high resolution at much lower power consumption levels and lower weight. These miniature 0.6" CRTs may hold a great competitive potential against all other small display devices; i.e. LCD, EL, plasma display, emitting diodes, to list a few. These CRTs can be useful in virtual reality display, palmtop computers, medical instruments as well as helmet mounted projection displays.

Fig. 4 Photograph of developed 0.6" CRT.

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