36.4: A 5-in. CRT for High Luminance and High Resolution Projection Display

Jianbo Cheng

Department of Opto-electronic Technology,
University of Electronic Science and Technology of China, Chengdu 610054, China

Qiong-Hua Wang

School of Optics/CREOL, University of Central Florida, Orlando, FL 32816-2700

Zulun Lin

Department of Opto-electronic Technology,
University of Electronic Science and Technology of China, Chengdu 610054, China

Abstract

We have developed 5-in. projection CRTs using multi-crystal material $MgAl_2O_4$ as the phosphor screen substrate. An experimental 50-in. rear-projection TV incorporating the projection tubes achieved more than 1600 TV lines of horizontal resolution and 1800 lumens of brightness.

1. Introduction

In a conventional projection CRT, the curved glass used as the phosphor substrate suffers from low thermal conductivity. The cathodoluminescence of phosphor powder exhibits a thermal quenching effect at high temperature due to the heat generated from high density electron beam. As a result, the display brightness is limited. The output luminance of a 9-in. projection CRT is less than 1200 lm.

Previously, we have reported 2-3in.YAG projection CRTs and HDTV projectors which have the performances of high luminance, high resolution and longevity [1, 2]. However, YAG is a mono-crystal material that is not only expensive but also difficult to scale up to 5 inches.

In this paper, we report on the novel 5-in. multi-crystal material $MgAl_2O_4$ (abbreviated as M) projection CRTs with high brightness and high resolution.

2. Structure and Fabrication

The schematic structure of the M projection CRT is shown in Figure 1. The phosphor screen consists of a flat M faceplate as the substrate and phosphor powder as the cathodoluminescent material. M is a multi-crystalline material and can be easily manufactured at reasonably low cost. Meanwhile, the diameter of M projection CRT is 5 inches which is bigger than YAG projection CRT. M's thermal conductivity coefficient is about 10X higher than that of glass (λ=0.13w.cm^{-1}.K^{-1} vs. λ=0.01w.cm^{-1}.K^{-1} for glass at room temperature). Other favorable properties are high melting point, high transparency, good mechanical and insulation strength. Therefore, it is an attractive candidate for CRT faceplate.

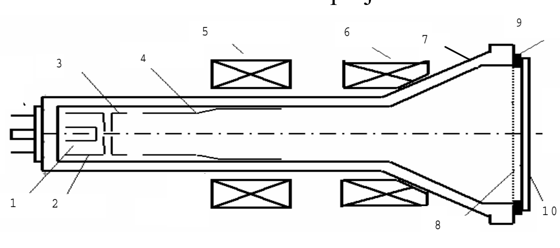

Figure.1 Schematic diagram of M projection CRT

1. cathode, 2. grid (G1), 3. G2, 4. G3 (pre-focus), 5.electromagnetic focusing yoke, 6.deflection yoke, 7.glass envelope 8. phosphor layer, 9. low temperature frit glass, 10.M faceplate.

2.1 Seal of M-to-Glass

As shown in Fig. 1 the joint between M screen and glass is realized by using low temperature frit glass.

Since M is multi-crystalline material, its expansion coefficient is small (75×10^{-7}°C^{-1}). No vacuum-electronic glass with comparable value is available. Thus, we have to develop a new envelope glass and low temperature frit glass that matches well with M.

The sealing process includes the low temperature frit glass cream's concoction, coating and baking. Figure 2 shows the curve of temperature vs. time for the baking. A helium mass spectrometer leak detector is used to measure the leakage of the seal. The leakage is less than 2×10^{-13} Pa.m^3.s^{-1} and the joint mechanical strength is hard.

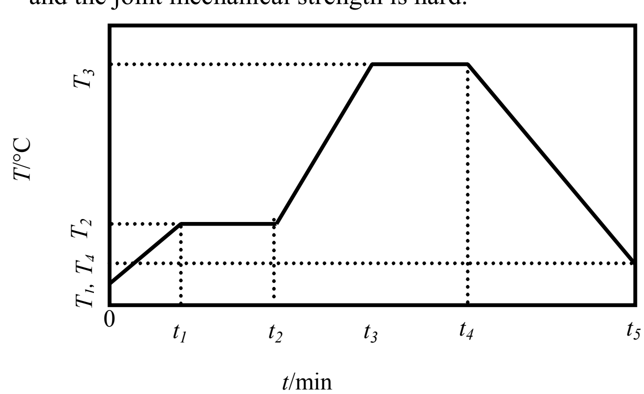

Figure.2 The curve of temperature vs. time for the baking

 ISSN/0002-0966X/02/3302-1084-$1.00+.00

2.2 Screening

We adopted centrifugal sedimentation method to prepare phosphor screen. The flow chart of fabrication is shown in Figure 3. The bulb of M projection CRT is set in bucket of centrifugal apparatus after mixing the sedimentation solution and phosphor particles. The motor rotates to produce a centrifugal acceleration of about $2\times10^3 m/s^2$. As a result, the phosphors are firmly deposited on M substrate with high density and without pinholes.

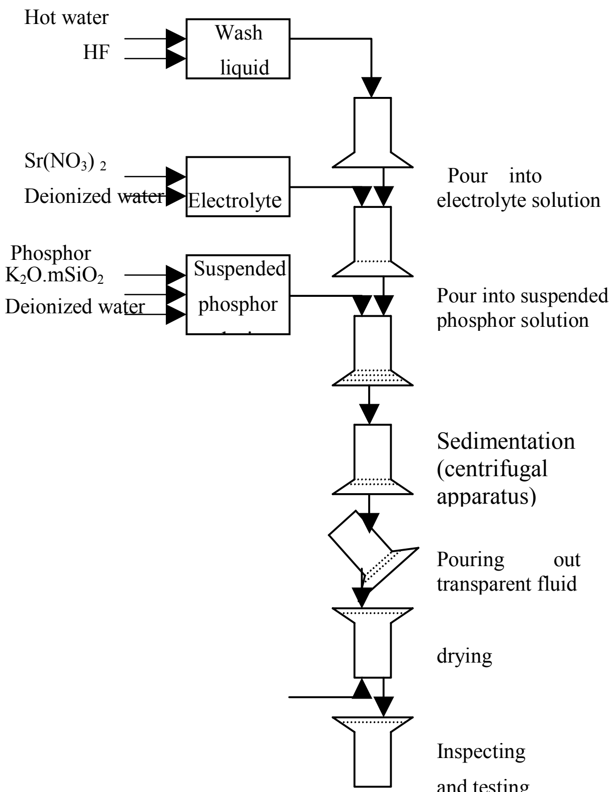

Figure.3 Flow chart showing the fabrication of M phosphor screen

2.3 Electron Gun

In order to improve the resolution of the 5-in M projection CRT, we have optimized the design of the electrostatic-electromagnetic focusing electron gun. As shown in Figure 1, cathode K, the G_1 grid and the G_2 grid form the cathode lens producing crossover, meanwhile the G_2 and G_3 grids compose the pre-focusing lens to reduce spherical aberration in the focusing action of the main lens. To further reduce the crossover size r_c, and get shaper spot at phosphor screen, we increased the voltage of G_2 from the conventional 0.6kV to 15kV. According to formula (1), the higher the G_2, the higher the crossover potential V_c:

$$r_c = \sqrt{\frac{V_z}{V_c + V_z}}\, r_k \frac{\sin\theta}{\sin\alpha} \qquad (1)$$

Here, r_c represents the radius of the crossover, r_k is the real

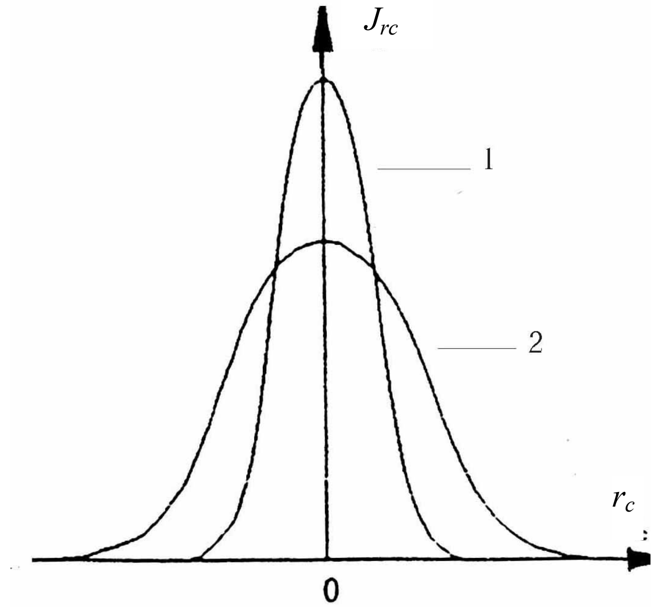

Figure.4 Current density distribution at crossover

1. $V_{G2} = 1.5$ kV 2. $V_{G2} = 0.6$ kV

emitting radius of the cathode G_1, V_c is the crossover potential, V_ε presents the primary velocity of electron, θ is the primary emitting angle of electron, and α is the convergence angle of electron. Obviously, a higher V_c leads to a smaller r_c. Meanwhile, the electron beam current density J_{rc} at the crossover is given by the following expressions:

$$J_{rc} = J_{max} \exp[-\frac{eV_c}{KT}\frac{\sin^2\alpha}{r_k^2} r_c^2] \qquad (2)$$

$$J_{max} = J_o \frac{eV_c}{KT} \sin^2\alpha \qquad (3)$$

where J_0 is the emitting current density of the cathode primarily determined by the cutoff voltage and geometry of the cathode lens. From the Expressions (2) and (3), we can see that the higher V_c is, the larger J_{max} is and the more quickly J_{rc} decreases with the increase of r_c. Therefore J_{rc} has more concentration of current density distribution as illustrated in Figure 4. For a higher V_c, the magnification of the focusing lens becomes a little larger. However, the screen voltage (29~32kV) is high enough to reduce the influence greatly.

The pre-focusing lens enables the crossover image to be an imaginary image farther away the main focusing lens, so the divergence angle of electron beam is reduced, and the magnification decreased because of the longer actual distance of crossover imaginary image to the main lens.

An electromagnetic focusing system is used as the main lens. We developed large diameter (more than 50 mm) magnetic focusing yoke around the tube's glass neck. The optimum magnetic field distribution of electromagnetic focusing lens was achieved according to expanding field principle.

The electron gun's design has been optimized with the aid of electro-optics calculation and measurement. As a result, the electron gun realized 50% electron beam spot diameters of 65μm and 70μm at cathode currents of 0.5mA and 1.0mA, respectively.

3. Performance

The M projection CRTs are shown in Figure 5. Because of the M's high thermal conductivity and the help of liquid cooling, the M projection CRTs, to a great extent, avoid the phosphor's thermal quenching and "burning out" caused by the high density electron bombardment. These serious problems exist in conventional glass projection phosphor screen. Therefore, M phosphor screen can lead to a higher luminance and longer life than the glass phosphor screen.

Figure. 5 The M projection CRTs

3.1 Theory

As shown in Figure 1, M phosphor screen features M faceplate. According to thermodynamics, when phosphor screen is in thermal equilibrium the conducted thermal energy per unit area of phosphor screen faceplate unit time is

$$Q = \lambda \frac{\Delta T}{D} \qquad (4)$$

where λ is thermal conductivity of faceplate, ΔT is temperature difference of inside and outside of faceplate, D is thickness of faceplate. We know that at room temperature

$$\lambda_M = 0.13 \mathrm{W \cdot cm^{-1} \cdot K^{-1}} \qquad (5)$$

$$\lambda_{glas\ s} = 0.01 \mathrm{W \cdot cm^{-1} \cdot K^{-1}} \qquad (6)$$

Because the M's mechanical strength and insulation characteristics are good, the M faceplate is much thinner than glass

$$D_M = 2\mathrm{mm} \qquad (7)$$

$$D_{glass} = 10\mathrm{mm} \qquad (8)$$

Substitute Equations (5) (6) (7) (8) into Equation (4), for the same electron excitation power density, the relationship of the M and glass phosphor screen's temperature difference is

$$\Delta T_M = \Delta T_{glass}/65 \qquad (9)$$

For 1W/cm^2 electron excitation power density, when

$$\Delta T_{glas\ s} = 117□ \qquad (10)$$

Therefore

$$\Delta T_M = 1.8□ \qquad (11)$$

With the help of liquid cooling the M phosphor screen avoids to a great extent the phosphor's thermal quenching and "burning out" caused by high density electron bombardment existing seriously in conventional glass projection phosphor screen. Therefore the M phosphor screen can obtain higher luminance and longer life than glass phosphor screen.

3.2 Measurement

By experiment and test, The M projections CRTs have excellent linear luminance-current characteristics shown in Figure 6. The red, green and blue tubes have the luminance of 6.0×10^4 cd/m^2, 1.2×10^5 cd/m^2 and 8.2×10^3 cd/m^2 at a current of 1.0mA and a voltage of 32kV, respectively. The 50% screen spot diameter is 85μm. For 3-in. diagonal phosphor screen, the corresponding resolution reaches

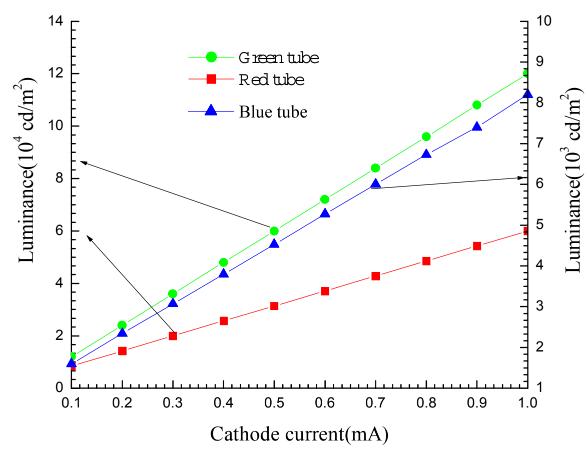

Figure.6 Luminance of red, green and blue M tubes

1600TV lines. The contrast ratio of the CRTs is 100□1.

The longevity for projection CRTs is a key factor. From the above analysis we know that the M phosphor screen's operation temperature is relatively low, and phosphor browning is little serious, thus the M projection CRT has a long life of 10000hour.

4. Application to 50-in. Projection TV

As shown in Figure 7, an experimental 50-in. rear-projection display system incorporating the M projection CRTs has been developed. Apart from the projection CRTs, a display system mainly includes an optical system and electronic circuits. The optical system consists of a projection lens, a mirror and a screen. The projection lens having 1∶1 F/number and 53.6mm focal length is a kind of hybrid lens composed of 2 pieces of plastic elements and 2 pieces of glass elements. The screen adopts layer screen structure including a fresnel lens, a horizontal lenticular lens and a vertical lenticular lens.

Fig. 7 A prototype 50 in. projection TV using present design.

Concerning the electronic circuits, we developed a multi-scanning system to present several mode pictures such as PAL, NTC, SVGA etc. The video circuit has the characteristics of a wide bandwidth and high-output. The digital convergence system obtained a precision convergence. A dynamic focusing circuit is applied in M projection display system to realize optimal focusing.

As a result, the 50-in. rear-projection TV set achieves a resolution of more than 1600 TV lines, mean white luminance of 1800 lm, respectively, and an age of 10000 hour.

5. Conclusion

The 5-in. $MgAl_2O_4$ projections CRTs have the characteristics of high luminance, high resolution, and long life. A 50-in. rear projection TV incorporating the new CRTs shows an output luminance of 1800 lm, resolution more than 1600TV lines and a lifetime longer than 10000 hours. A low cost projection HDTV is foreseeable in the near future.

6. Acknowledgements

The authors would like to thank Prof. Shin-Tson Wu from University of Central Florida for his helpful advice. We would like to acknowledge many colleagues and partners at University of Electronic Science and Technology of China.

7. References

[1] Q. H. Wang, J. B. Cheng, Z. L. Lin. "A new YAG phosphor screen for projection CRT", Electronics Letters, 34, 1420 (1998).

[2] 2. Q. H. Wang, J. Cheng, Z. L. Lin, G. Yang. "High-luminance and high resolution CRTs for projection HDTV display", J. SID, 7,183 (1999).

[3] 3. H. Yamamoto and H. Matsukiyo, "Problems and progress in cathode-ray phosphors for high-definition displays", J. Luminescence 43, 43 (1991).

[4] 4. T. Asano, K. Hirota, K. Oku, Y. Tanaka, K. Nakayama, and M. Ohsawa, "A 6.9-in. high-resolution projection CRT for HDTV display", J. SID, 3, 113(1994).

[5] 5. R.L.Mecher. "Projection Television", Proceedings of 19th International Display Research Conference, Berlin, Germany, 81 (1999).