# High-luminance and High-resolution YAG Projection Display Tube*

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**Abstract** In this paper, a 7.6 cm high-densely packed phosphor screen with a multi-layer interference filter is introduced by depositing phosphor on YAG faceplate using centrifugal sedimentation method. Its envelope is made of a kind of glass whose expansion coefficient is well matched with that of YAG. The electron gun consisting of an optimally designed pre-focusing lens and main focusing lens is improved for HDTV display application. The measurement results show that the green, red and blue tubes have the luminance of $1.4\times10^5$, $6.2\times10^4$ and $8\times10^3$cd/m$^2$ at a cathode current of 1.0 mA and an anode voltage of 29 kV, respectively, with a half-intensity line-width of 85 μm. An experimental 122 cm rear and 183 cm front projection TV set using YAG projection tubes achieves more than 1 000 TV lines horizontal resolution and 624 cd/m$^2$ and 890 cd/m$^2$ luminance, respectively, with an age of 5 000 hours.

**Key words** cathode ray tubes; yttrium aluminum garnet; HDTV display; projection tube

We have reported a new (5.0 ~7.6 cm diagonal) YAG phosphor screen for HDTV[1~4]. The substrate material (i.e. CRT faceplate) YAG, replacing conventional glass, has very high thermal conductivity and optical clearness. The phosphor screen is prepared by depositing phosphor on YAG using improved sedimentation and centrifugal sedimentation screening techniques. Since then, we have continued to develop high luminance, high resolution and long life YAG projection CRTs and projection TVs and improved their performances further.

In this paper, we describe the specifications and performances of a new 7.6 cm YAG projection CRTs, including the densely packed YAG phosphor screen having multi-layer interference filter, the glass envelope matched with YAG screen, and the pre-focusing lens and main focusing lens. The characteristics of experimental rear-projection TV set incorporating the new YAG projection CRTs are also presented.

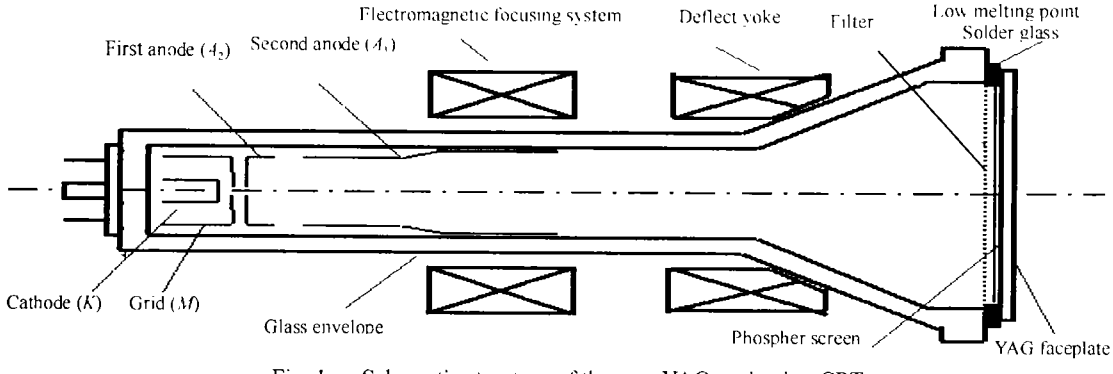


Fig. 1 Schematic structure of the new YAG projection CRT

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# 1 Specifications and Performances of the New YAG Projection CRTs

The schematic structure of the new YAG projection CRT is shown in Fig.1. The tube mainly consists of glass envelope, YAG phosphor screen with multi-layer interference filter, electron gun (quart-electrode emitting lens and focusing lens) and deflection yoke.

The glass envelope is sealed to YAG faceplate using low melting point solder glass. Table 1 summarizes the characteristics of the YAG projection CRTs.

**Table 1 Specifications of the new YAG projection CRT**

| Item | Specification |
|---|---|
| Bulb | 7.6 cm, 50° deflection, 29.1 mm diameter neck, plane phosphor screen featuring YAG faceplate with 2mm thickness, glass envelope |
| Useful screen/mm | 54.4×40.8(4:3) |
| Overall length/mm | 225 |
| Electron gun | Electrostatic and electromagnetic focusing |
| Phosphor screen | Densely packed screen with interference filter |
| Red | $Y_2O_3$: Eu |
| Phosphor Green | 0.95P53*(Ga)+0.05P1** |
| Blue | ZnS:Ag.Al |
| Cooling system | Liquid optical coupling |
| Life/h | More than 5 000 |

Notes: P53*(Ga). $Y_3(Al,Ga)_5O_{12}$:Tb; P1**: $Zn_2SiO_4$:Mn

## 1.1 Electron Gun

To improve the focusing characteristics of YAG projection tube, an optimally designed electrostatic and electromagnetic focusing electron gun was developed. As shown in Fig.1, cathode $K$, grid $M$ and the first anode $A_1$ form cathode lens producing crossover, and the first anode $A_1$ and the second anode $A_2$ compose the pre-focusing lens. As it is generally known, oxide cathode is cheaper and more easily available than impregnated cathode, so we used oxide cathode in the YAG projection tube. However oxide cathode has small maximum-current-density (about 1.5 A/cm$^2$) compared with impregnated cathode (4～10 A/cm$^2$). Therefore we increase the concentration of emitting current distribution by the method of increasing the potential of the first anode $A_1$ to 1.5 kV (0.5 kV for conventional electron gun). Meanwhile, high voltage of 1.5 kV for electrode $A_1$ decreases the crossover radius.

An electromagnetic focusing system was used as main lens. We developed large width (more than 50 mm) magnetic focusing coil around the tube's glass neck. The optimum magnetic field distribution of electromagnetic focusing lens was achieved according to the expanding field principle. As a result, the electron gun realized 50% electron beam spot diameters of 65 μm and 70 μm at cathode currents of 0.5 mA and 1.0 mA, respectively.

## 1.2 YAG Phosphor Screen

As shown in Fig.1, YAG phosphor screen features YAG faceplate. The YAG faceplate has higher thermal conductivity ($\lambda$=0.12 W·cm$^{-1}$·K$^{-1}$ at room temperature) than conventional glass faceplate ($\lambda$=0.01 W·cm$^{-1}$·K$^{-1}$). Moreover, the YAG has high mechanical strength and excellent insulation characteristics, and the YAG faceplate is much thinner ($D$=2 mm) than glass ($D$=10 mm or so). According

to thermodynamics, when phosphor screen is in thermal equilibrium, the conducted thermal energy on per unit area of phosphor screen faceplate in per unit time is

$$Q = \lambda \frac{\Delta T}{D} \tag{1}$$

where $\lambda$ is the thermal conductivity of faceplate; $\Delta T$ is the temperature difference of inside and outside faceplate; $D$ is the thickness of faceplate. By Eq.(1), for the same electron excitation power density, the temperature difference of YAG phosphor screen is only one sixtieth of glass phosphor screen. By means of calculation and experiment, the temperature difference between the inside and outside of YAG phosphor screen is only 1.8℃ (vs. 110℃ for glass phosphor screen) at 1 W/cm$^2$ electron excitation power density. With the help of liquid cooling, the YAG phosphor screen, to a great extent, avoids the phosphor's thermal quenching and "burning out" caused by high density electron bombardment existing seriously in conventional glass projection phosphor screen. Therefore the YAG phosphor screen can obtain higher luminance and longer life than glass phosphor screen.

In order to further improve the luminance chromaticity and resolution on the projection screen of the YAG projection TV, we applied multi-layer interference filter between the phosphor layer and the YAG faceplate, comprising a number of layers which are alternately high refractive index and low refractive index. The filter has the transmission characteristics of short-wave pass for normal incidence and small-angle pass for the central wavelength of light emitted by the phosphor. Therefore large angle light is reflected by the filter to the phosphor and is scattered with an angular redistribution, resulting in part of the light being re-emitted at small angles, which changes the angle distribution of the emitted light from Lambertian cosine distribution to a more peaked emission in the forward direction with a gain at the smaller angles. So we achieves a significantly improved collection of light by the lens, which increases the luminance on the projection screen. Meanwhile being the filter's characteristics of short-wave pass mentioned above, it changes the spectral distribution of the emitted light, and there is an attenuation of unwanted long-wave components, which improves the chromaticity and reduces chromatic aberration.

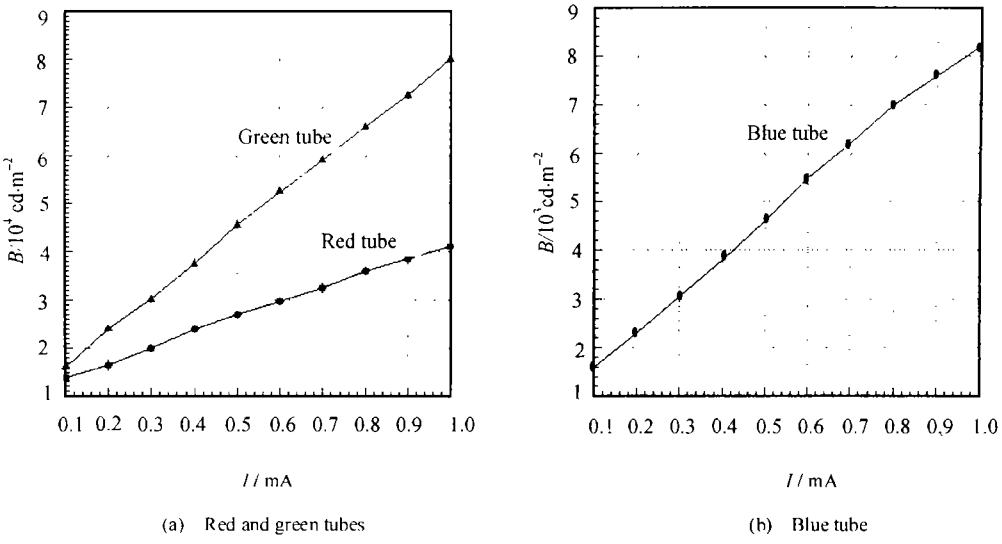
We have adopted centrifugal sedimentation technique to fabricate high-densely packed YAG phosphor screen. The bulbs of YAG projection tubes are set in buckets of centrifugal apparatus after mixing the sedimentation solution and phosphor particles. The motor rotates to produce a centrifugal acceleration of about $2\times10^3$ m/s$^2$. Thus the phosphors are firmly deposited on YAG substrate without pinholes.

For the common PTV phosphors ($Y_2O_3$:Eu for red, $0.95Y_3(Al,Ga)_5O_{12}$:Tb+$0.05Zn_2SiO_4$:Mn for green and ZnS:Ag, Al for blue ), the red, green and blue YAG phosphor screens have excellent linear luminance-current characteristics as shown in Fig.2. At a cathode current of 1.0 mA, the red, green and blue YAG phosphor screens have the luminance of $6.2\times10^4$, $1.4\times10^5$ and $8.0\times10^3$ cd/m$^2$, respectively, and the 50% green screen spot diameter is 85 μm.

### 1.3 Glass Envelope

As we known, the YAG faceplate in YAG projection CRT has the expansion coefficient of $75\times10^{-7}$℃$^{-1}$ and a kind of electrovacuum glass with such expansion coefficient is not available. We developed a new kind of electrovacuum glass having perfect physical and chemical properties. The YAG tube envelope is made from the new glass because of the almost perfect match between its expansion coefficient and that of YAG. The glass has perfect X-ray absorption. We successfully realized the seal of

YAG faceplate to glass envelop using a kind of low melting point solder glass. The seal process includes the solder cream's concoction, coating and bake.




(a) Red and green tubes (b) Blue tube

Fig.2 Luminance of YAG projection CRTs vs. cathode current (at the condition of 29 kV anode voltage, 54.4 mm×40.8 mm raster size and best focusing)

### 1.4 Heat Radiator and Liquid Coolant

For projection CRT, the accumulation of heat produced by high-density electron bombardment is serious, therefore heat radiator and liquid coolant are necessary. As shown in Fig 1, the YAG projection tube's radiator is made of aluminum having a surface of densely thin stripes with black coating, and therefore it has a function of good heat radiation. At the same time, the radiator also acts as a combiner that combines the projection CRT to the projection lens. The liquid coolant in heat radiator has the function of conducting heat and coupling between projection CRT and projection lens. We developed a kind of polydimethyl siloxone fluid with excellent proprieties as coolant.

### 1.5 Aging of the YAG Projection Tube

The life of projection CRT is usually determined by cathode and phosphor screen. As it is generally known, the oxide cathode in YAG projection CRT has a life of 5 000~10 000 hours. Therefore the life of YAG projection CRT mainly rests with the YAG phosphor screen. From the above analysis we know that the YAG phosphor screen operates at relatively low temperature compared with conventional glass phosphor screen, and phosphor browning is not serious even after a long time operation, so YAG projection CRT has the characteristics of long life.

We have done the experiment and test about the age of YAG projection CRTs. The tube operated three and half an hours and then rested half an hour at the condition of 0.5 mA cathode current and 29 kV anode voltage. The tube's luminance is still 70% when the operation time amounts to 5 000 hours. It is estimated that the age of the tube reaches 10 000 hours.

## 2 Application of the YAG Projection Tube to 183 cm Rear-projection and 122 cm Front-projection TV Sets

An experimental 122 cm rear-projection and 183 cm front projection TV set incorporating the new YAG projection CRT shows good performances. It achieves a resolution of more than 1 000 TV lines, the

mean white luminance of 624 cd/m$^2$ and 890 cd/m$^2$, respectively, and the age of at least 5 000 hours, which satisfy HDTV display.

## 3 Conclusion

The 7.6 cm YAG projection display tube has the characteristics of high luminance high resolution and long life. It is a new developed projection CRT differing from conventional glass projection CRT and epitaxially grown YAG luminescent CRT.

The authors would like to express their appreciation to all the people who participated in this project.

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# 高亮度高分辨率YAG投影显示管*

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**【摘要】** 介绍了一种HDTV显示用的7.6 cmYAG(钇铝石榴石)投影阴极射线管(CRT)，采用离心沉屏法将荧光粉沉积在YAG面板上制作高密度荧光屏，该荧光屏上制作有多层干涉过滤膜。管壳采用能与YAG进行匹配封接的玻璃材料。经过优化设计的预聚焦透镜和主聚焦透镜满足显示HDTV图像的要求。测试结果表明，在阴极电流为1.0 mA和阳极电压为29 kV条件下，红、绿、蓝管的亮度分别可达1.4×10$^5$cd/m$^2$、6.2×10$^4$ cd/m$^2$和8×10$^3$ cd/m$^2$，绿色管子50%图像线宽为85 μm。采用该管的122 cm背投和183 cm前投电视机的水平分辨率为1 000电视线，平均白场亮度分别为624 cd/m$^2$和890 cd/m$^2$.

**关　键　词**　阴极射线管；　钇铝石榴石；　高清晰度显示；　投影管

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