37.1: *Invited Paper:* Development of Field-Emission Display

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Abstract

Mono-color Spindt-type Field Emission Displays(FEDs) have been supplied to the market and color FEDs have been started for the preparation of mass production. FEDs have the potential not only to realize superior expression for video picture image, but also to get low power consumption. The present status of FEDs is described in this paper.

1. Introduction

FEDs are one of the most attractive flat panel displays that realize high-level motion picture and low power consumption. Mono-color Spindt-type FEDs has been supplied to the market since seven years ago,[1] and preparation of mass production of color FEDs had started last year. The carbon nanotube(CNT) FED panel for information board was developed [2]. This large size display panel realizes a lightweight, wide viewing angle and low power consumption. We introduce the status of our development of FEDs with Spindt-type emitters and CNT-FEDs.

2. Three Elemental Technology of FEDs

Fundamentally, FEDs are constructed by three elemental technologies, micro or nano-fabrication technology of emitters, opt electronic semiconductor technology of anode patterns and vacuum packaging technology. Each three elemental technology is essential to realize FEDs with interrelationship. The concept is show in Fig.1.

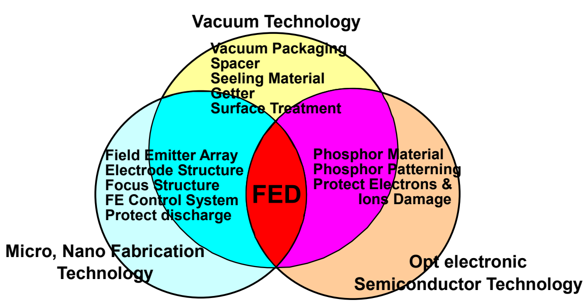

Fig.1 Three elemental technology of FEDs

For example, for stable and uniform field emission in small space of flat panels, stable anode and inner constructions, which have low gas desorptions and high resistance under high current density in packaging are essential besides fabrication of the each emitter with accurate micro or nano meter level. In case of high duty display device, for examples, character or small dots displays, the low voltage phosphors are used and Low-voltage FEDs showed sufficient practical life time [1].

In case of the full-color FEDs, to get practical luminance and life properties, the gap of the panel was set wider to apply higher anode voltage, about 3 kV, and a focus electrode was fabricated to the cathode to prevent color cross talk. Further development, such as, design of cathode and focus electrode, anode and spacer are being proceeded to improve the picture quality.

3. Features of FEDs

The FED has excellent features; thin panel thickness (approx. 2mm), self-emissive, distortion free image, wide viewing angle (about 170 degree), and quick response. The FED is also expected as a low power consumption display device. Figure 2 shows a comparison of power consumption of TV sets between CRT, LCD, PDP and FED.

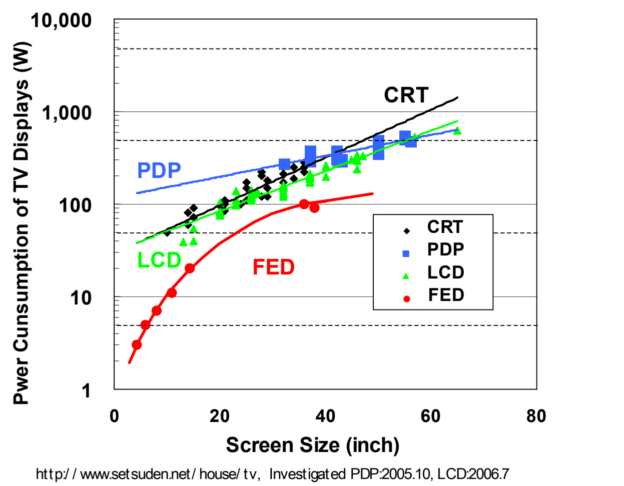

Fig.2 Comparison of power consumption of TV display sets.

These features show that FEDs have advantage of the application of TV images and high-speed moving pictures, which need relatively high brightness and wide dynamic range.

4. FED with Spindt-Type Emitter

The principle structure of the Spindt-type FED panel is shown in Fig.3.

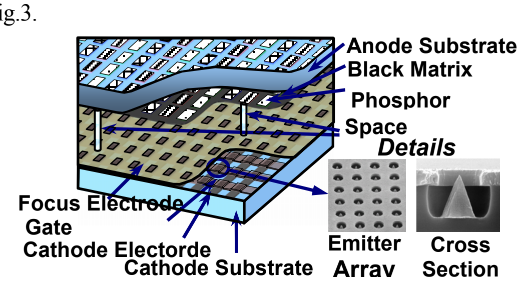

Fig.3 Structure of Spindt-type color FED

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Thickness of cathode and anode glass substrate is 1.1 mm each and the spacer length is 0.6mm, so the total thickness of panel is 2.8 mm. The cathode, gate and focus electrode is made of Nb, the emitter material is Mo and glass fibers are used for spacers. The anode voltage is 3 kV. On the cathode substrate, Spindt-type emitters are constructed at intersection of gate and cathode line and they are selected with X-Y matrix drive.

Figure 4 shows the cross section drawing of the cathode substrate [2].

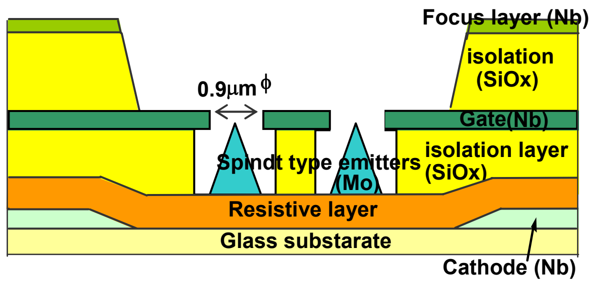

Fig.4 Cross section of the cathode

The cathode has a focus layer on the top of the gate to prevent the color crosstalk. The focus electric field is formed on the emitter array by the potential difference between the focus and gate electrode.

The anode substrate consists of Al anode electrode, color phosphors, and spacers. The SEM image of anode substrate is show in Fig.5.

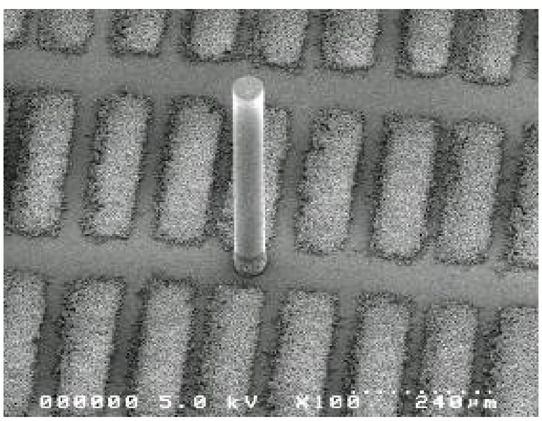

Fig.5 SEM image of anode substrate

We had developed a unique spacer structure and placement method, so that spacers should be invisible even placed in the screen area. The spacers are made of 50 µm diameter glass-fiber, which are cut at 0.6 mm length same as the distance of anode and cathode. The anode voltage of our FED is 3 kV, so the FED has no metal-back layer. It realizes the simple anode substrate structure. Y_2O_3:Eu is used as red phosphor, Y_2SiO_5:Tb is green and Y_2SiO_5:Ce is blue. The14.4-inch SVGA color FED that is developed for moving picture is shown in Fig.6.

Fig.6 Spindt-type 14.4-inch SVGA color FED.

(Va:3 kV, Brightness:400cd/m^2)

A 3-inch color FED that is produced for automobile engine monitor is in the market. The same type color FED is shown in Fig7. The screen size is 30 x 70 mm, pixel size is 184 (H) x 80 (V) x RGB, brightness is 600 cd/m^2 and the power consumption is 4 W.

Fig.7 Spindt-type 3-inch color FED

5. Development of FED Elemental Technology

5.1 Improvement of Spindt-Type emitter

At the first stage of our development, the life of field emission was unstable and extremely short. The Spindt-type Mo emitter was tested in a vacuum chamber to measure the influence of several gases on field emission by pulse drive. Fig.8 is that if field conversion factor β remains unchanged before and after inducing gas test, the transition of Work Function ϕ and Emission Surface Area s are estimated by the change of the slope and intercept of the Fowler-Nordheim Plot of the field emission characteristic.

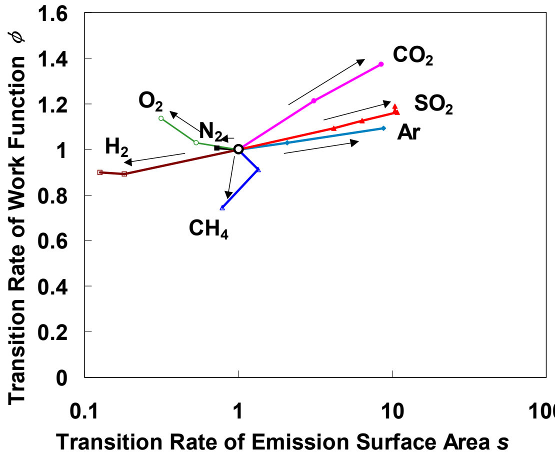

Fig.8 The influence of gases on the field emission property

In Fig.8, different influence were observed by the gases on field emission, and especially O_2 significantly deteriorate the emission. Considering above, we had mainly developed the materials and process for FEDs at the first stage of development.

Respect to mono-color FEDs we have already supplied for the monitors of professional audio-visual equipments and we think that they have proved the good reliability and performance. Their reliability level can be insured more than 10,000 hours of luminance lifetime. Figure 9 shows the comparison of the results of AES micro-analysis on the emitter tips in FED before and after more than 23,000h life test.

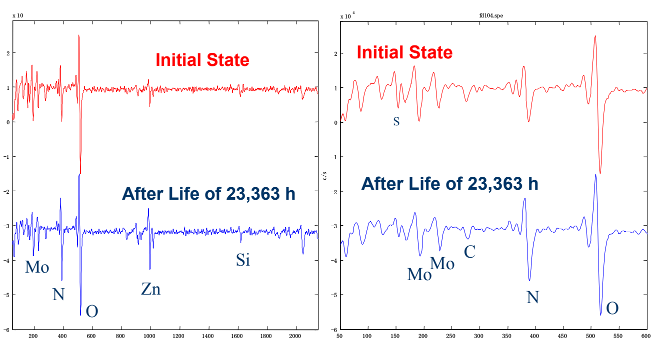

Fig.9 AES micro-analysis on the emitter tip in FED.

In Fig.9, there is little difference between the surface of tip at initial state and at after life of more than 23 thousand hours, except Zn element. This Zn element is assumed that the composition of phosphor of ZnO, so this means that it is the result of decomposition of the phosphor for long life. This result shows that the tip of Mo emitter is very stable and tuff in FEDs.

The characteristic of Spindt-type emitter is shown in Fig.10. The gate hole diameter is smaller and the gate hole density is higher, the threshold voltage of extract electron is lower and extract electron density is higher. We are trying to fabricate the optimum design emitter to cope with the development of emitter process.

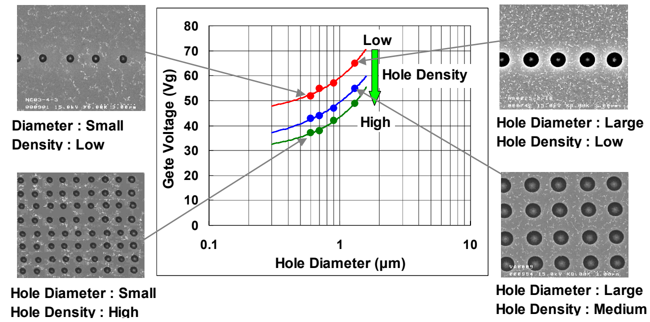

Fig.10 The characteristic of Spindt-type emitter

It is often said that the process cost of the emitters which are made of CNTs or DLC is lower than that of Spindt-type emitters. It may be true since Spindt-type emitters require costly special facilities, especially for large size displays. However, regarding the uniformity and resolution which are very important characters of high quality display, Spindt-type emitters have superior properties than those of CNTs or DLC emitters. Therefore Spindt-type emitters will be able to become the most practical emission source for medium to small size FEDs.

5.2 Transition of FED Panel Structure

The transition of FED panel structure is shown in Fig.11. Within the three elemental technologies mentiond in section 2, the vacuum packaging technology is especially important for FEDs. We realized the thin flat vacuum panel without evacuating tube using fiber spacers and printed non-evaporated getter on anode[3].

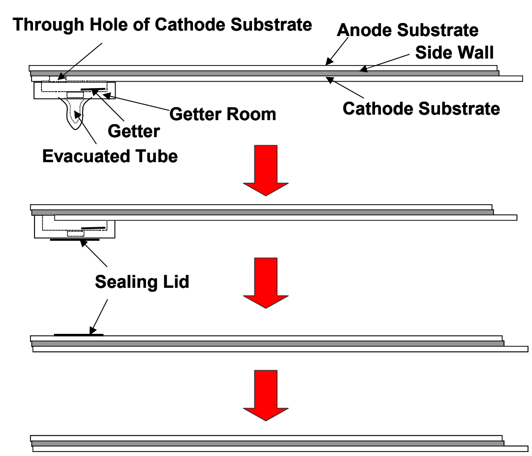

Fig.11 Transition of FED panel structure.

5.3 Development of New Phosphors

We are developing and improving FED phosphors to improve the luminescent color purity and reliability of luminance. The CIE color coordinates of developing new blue phosphor AlN:Eu is shown in Fig.12 and the phosphor aging curve of the relative efficiency of the new blue phosphor to Y_2SiO_5:Ce is shown in Fig.13. This new blue Nitride phosphor is co-developed with the National Institute for Materials Science.

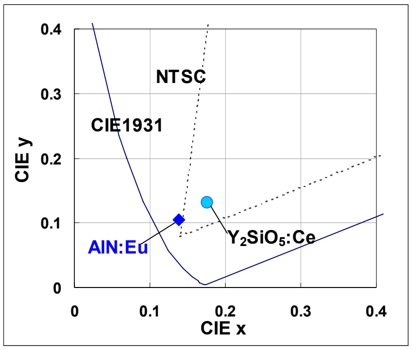

Fig.12 The CIE color coordinates of new blue phosphor

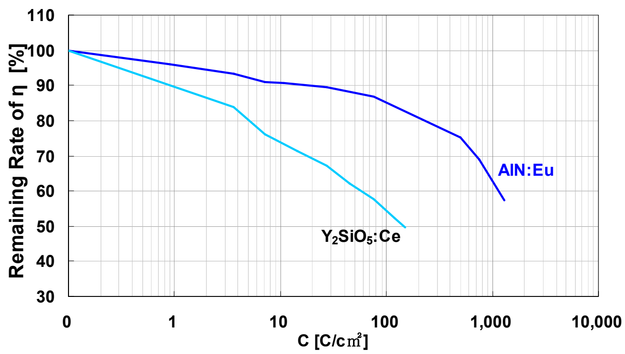

Fig.13 The phosphor aging curve of the relative efficiency of the new blue phosphor to Y_2SiO_5:Ce

In Figs. 12 and 13 this new blue phosphor shows better cathodoluminescent properties than those of conventional Y_2SiO_5:Ce. The measurement condition is that anode voltage is 3 kV, duty is 1/240 and pulse width is 60 μs. As the irradiation condition of FED is under anode voltage of less than 10 kV, the anode current density is higher than CRT for similar luminance. This means FED phosphor irradiation region is more sallow than CRTs and the rejoin needs more tuff and stable to electron bombardment.

6. FED with Carbon Nanotube Emmiter

CNT is a attractive material in the hope of improving the field emission characteristic by utilizing its extremely sharp needle and reducing the manufacturing cost of large area cathode. On the other hand, there are problems of uniformity and efficient emission depends on that the accurate location of the emission site of CNTs and the effective gate edge. We developed the diode type CNT-FED, CNT fabricated cathode electrodes and phosphor coated anode electrode are located parallel in a vacuum panel [4].

As the anode electrode works as extract electrode and anode electrode, the lower the extract voltage, the lower the excitation voltage of phosphor. Therefore, unless there are low voltage excitation phosphors that have high efficiency, diode type CNT-FED cannot be realized. Besides, the diode type CNT-FED has merit of simple structure, the extract electron is almost 100% into anode pattern as anode electrode plane which is extract electric electrode plane is parallel against the emission sites. Figure 14 shows the carbon nanotube (CNT) FED panels. A unit panel size is 96×96 mm^2, anode voltage is 120 V, spot brightness is more than 1,800 cd/m^2.

Right side of Fig.14 shows the transparent like CNT-FED panel.

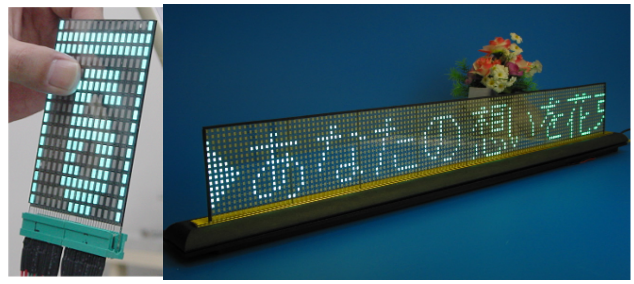

Fig.14 CNT-FED Panel and the transparent like CNT-FED.

In the case of the transparent like CNT-FED the display screen size is 768 (H) x 96 (V) mm and 128 (H) x 16 (V) dots and the power consumption is 7 W in scrolling. As the features of these FED panels are thin, lightweight and low power consumption, they will be suited for scroll type large sign board system.

These panels use the multi walled CNTs (MWCNTs) which were made by arc-discharged method. The MWCNT emitter layer is treated to raise the extract efficiency of emission by removing the surface layer after deposited by screen-printing method. To accomplish thin CNT-FED as much as the thickness of 2 glass plates, the development of non-evaporated getter which can be screen printing in the gap of anode and cathode substrates is indispensable.

7. Summary

FED has potential to realize a self-illuminated, high quality and low power consumption display device. The Spindt-type mono-color FEDs are already being supplied to the market and they have been proved the good reliability and performance. The color FEDs have been started for the preparation of mass production. Besides the electron source, the advancement of the anode technology, vacuum packaging technology and other basic technologies are indispensable for the realization of products of FEDs.

The development of FEDs has not yet over, but the development of FEDs in 2^{nd} stage has just started now.

8. Acknowledgements

The authors would like to thank to Dr.N.Hirosaki's group in the National Institute for Materials Science for the co-development of phosphors.

9. References

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