Electron Beam Focusing in High Voltage Field Emission Displays

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INTRODUCTION

More attention has been attracted by high voltage operated field emission displays (HVFEDs) due to their high brightness comparable to that of cathode ray tubes (CRTs) than by low voltage operated FEDs (LVFEDs)[1]. For the high voltage operation of FEDs, a large spacing between a cathode and an anode is required to withstand the electrical breakdown and arcing problems, which frequently occur in a narrow vacuum gap due to high voltages applied to the anode. The maintenance of such a large cathode-to-anode gap results in several problems to be solved for the development of HVFEDs[2], which may not be serious in LVFEDs. With a larger gap, first of all for HVFEDs, an emitted electron beam diverges more over a desired color dot, although the application of high voltages to the anode improves beam collimation. Such an electron beam spreading leads to cross talks between pixels or color dots on the anode. To eliminate the cross talks, the focusing electrodes have usually been engaged in the Spindt-type field emitter arrays (FEAs). There have been two typical types of FEAs with focusing electrodes : in-plane focusing[3] and vertically double-gated focusing[4]. Both structures seem to have several limitations in the practical applications to real FED devices. The former focusing scheme has problems such as the limited number of microtips fabricated in a pixel, an involvement of a fine gate patterning process, and highly probable electric leakage between the inner and outer gates. The other focusing scheme is impractical due to the complexity of fabrication processes and the highly probable electric leakage between the upper and lower gates. Taking into consideration the easiness and yield of fabrication processes, thus, this study develops a new type of FEA structure with a focus electrode. Second, spacers to withstand a pressure of at least an atmosphere must be fabricated to keep a high aspect ratio and must be easily laid up inside the panel. Third, the presence of high voltages across spacers may increase the probability of vacuum arcs and electrical breakdown.

This study describes some issues relevant to the development of our HVFED devices. To solve the beam spreading problem in the 1.1mm gap, focus electrodes are engaged to collimate the electron beams on a color dot basis. The beam focusing is fairly satisfied to be secured experimentally, and also confirmed by a simulation. Ceramic spacers with a high aspect ratio are successfully fabricated and laid out in our panel, which is supported by a calculation with a good agreement. Since vacuum arcs are most likely related to outgassing, the panel is recommended to be treated with a carrier gas during sealing for minimizing a residual gas as well as for aging microtips and phosphor surfaces simultaneously. We enhance the panel performance by applying a mixture of Ar and H_2 as a carrier gas. Our packaged 5.2" HVFED device presents color images.

EXPERIMENTAL

A 5.2" diagonal full color FED with a resolution of 192×160×3 lines, close to a QVGA class, was developed based on Spindt type Mo microtip cathodes. The cathode electrodes were deposited up to the 1,500Å thickness. A resistive layer of amorphous silicon was grown to be 2500Å thick and then the insulating SiO_2 layer with the thickness of 1μm were deposited. A 3500Å thick layer of chromium was used as the gate metal. The second SiO_2 layer and the Cr focus electrode were 1μm and 4000Å thick, respectively. The 1.1μm holes were patterned by total internal reflection holographic lithography. Following the deposition of an Al sacrificial layer, Mo microtips were deposited in a cone shape inside the 1.1μm holes with an e-beam evaporation. A focus electrode surrounded each dot consisting of a number of microtips. In an anode, each color dot was designed to be 340μm×145μm in size. The anode with the RGB colors was screened with Y_2O_2S:Eu, ZnS:Cu, Al, and ZnS:Ag, Cl phosphors, respectively, using a slurry process[5]. Eight spacers, 1.1mm high, 130μm wide, and 1mm long, were periodically placed in a row of spacers. During sealing, a mixture of Ar and H_2 was introduced inside a panel to flow outgassed molecules out. After exhausting, a panel pressure in a low 10^{-6} Torr range was routinely achieved with non-evaporable getters activated. Our FED device was video-run for full colors in a PWM mode with a current controlled circuit.

Beam spreading was simulated by calculating electron beam trajectories and a resultant electron density distribution over a color dot on the anode in a given electric field, using a finite differential method. Electron emission from each individual microtip was assumed to occur with an angular Gaussian distribution, which was considered to be governed by the Fowler-Nordheim equation as well as the electrostatic fields around the microtip. The electrons were supposed to be launched from a microtip from -50° to 50°. The beam trajectories were calculated with an interval of 5°. The light emitted by phosphor is clearly visible when the amount of electrons incident on the phosphor is beyond a certain limit. This limit was decided from a comparison of the electron density distribution curve and experimental data. Then this limit was applied to other electron density distribution curves for various experimental conditions with different anode voltages and focusing electrode voltages to decide the bright spot widths. In this study, the bright spot width was defined as the spreading width of an electron beam on the anode.

RESULTS AND DISCUSSION

For HVFEDs with a large gap between cathode and anode plates, an emitted electron beam focusing is one of the main issues to be solved. In a normal type of an HVFED device without a focus electrode, we has experienced that the electron beam spreads to the extent that cross talks between pixels can not be avoided even quite a high anode voltage of 5,000V. The beam may be focused on at much higher biases, but it will give rise to more frequent vacuum arcs, shorter lifetimes, and lower yields. It is thus desirable that the focusing is achieved at lower anode voltages as long as the brightness is satisfactory. This has led us to design an HVFED device with a focus electrode. In our device, it was observed experimentally that the beam was collimated fairly well on an optimized condition, which was compared with simulation results. The simulation was programmed to calculate an electron beam trajectory in a given electric field and subsequent summations of the number of electrons as a function of locations yield an electron density distribution across a color dot on an anode. For the cathode structure with a focus electrode shown in Fig. 1, the simulation was performed to calculate an electron beam trajectory from a single microtip in given voltages of gate, focus electrode, and anode. Subsequent summations of the number of electrons from the microtips in a dot as a function of locations yielded an electron density distribution across a phosphor dot on the anode. Figure 2 shows the beam trajectory and the simulated electron density distribution over a dot in a given panel structure at a gate, a focus electrode, and an anode biased to 80, 0, and 4,500V, respectively. The electron density distributions along a color dot for different anode voltages is given in Fig. 3, normalized for each integrated electron density to maintain the same value. An indicated density, 1.4×10^5, is defined to be the minimum electron density with which a phosphor dot can emit a light as bright as discernible by naked eyes. A full width of a curve at 1.4×10^5 corresponds to the effective beam spread. The value of 1.4×10^5 is obtained by comparing the calculated density distributions with the measured beam spreads. Surprisingly, the same value is also applicable even in a calculation with focus electrode voltages. By measuring the full widths at 1.4×10^5, the simulated beam spreads at different anode and focus electrode biases are represented in Fig. 4(a) and (b), respectively, together with the experimental beam spread results.

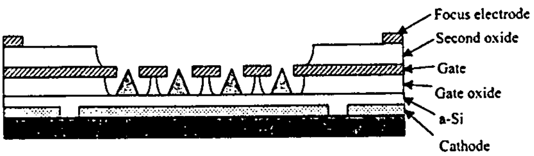


Fig. 1. Schematic of a cathode structure with a focus electrode.

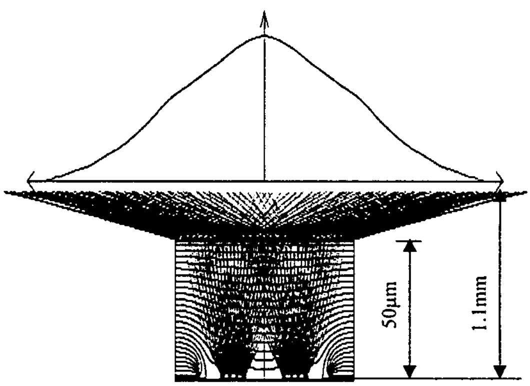


Fig. 2. Simulated beam spread across a color dot at a gate, a focus electrode, and an anode biased to 80, 0, and 4,500V, respectively, for a given panel structure.

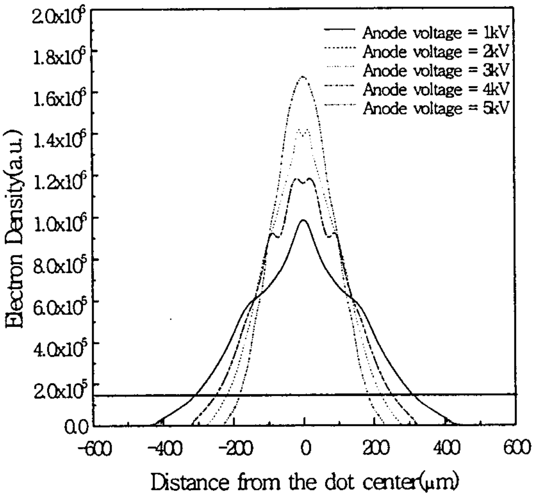


Fig. 3. Electron density distributions across a color dot for different anode voltages at a gate and a focus electrode voltages of 80 and 0V, respectively.

The experimental and calculated results agree very well, although some deviation is shown at the focus electrode voltages of -20 and -40V. As expected, the higher the anode voltage, the more focused the electron beam. Even at the anode voltage of 5,000V, the gate voltage of 80V, and with the focus electrode grounded, however, the electron beam diverges up to 320㎛ in the experiment. For our phosphor dot 145㎛ wide with black matrixes 45㎛ wide in its both sides, the beam 320㎛ wide intrudes into 1/3 of both neighboring dots. With the variation of focus electrode voltages for the 4500V anode, as presented in Fig. 4(b), the beam spreading is little affected in the range of 0 up to 80V, but the beam is focused on more and more at -10V and -20V. At -20V, the beam spreads up to 270㎛. For our pixel design, the 270㎛ spread beam is almost confined to only its counterpart dot 145㎛ wide, because the beam hitting the black matrixes beside the dot does not make any contribution to luminescence. Figure 5 represents an image of the beam focused almost on the color dot. By adopting the focus electrode to the HVFED panel, we successfully separate the RGB colors to achieve satisfactory color purity in running moving pictures in our device.

Most importantly for an FED device, spac-

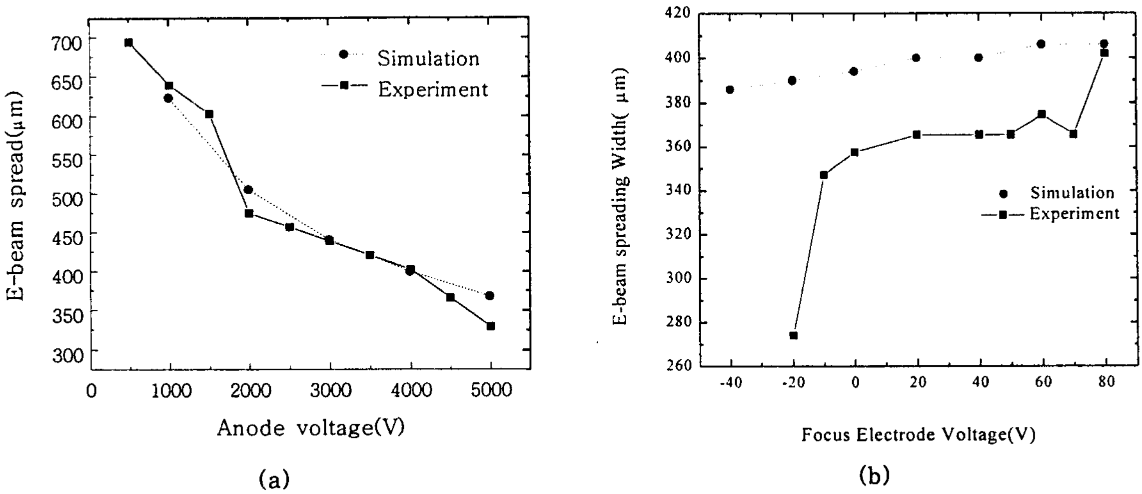


Fig. 4. Experimental and simulated beam spreads (a) at different anode and (b) focus electrode biases. In (a), the focus electrode voltage is 0V and in (b), the anode voltage is 4,500V, both at the fixed gate bias of 80V.

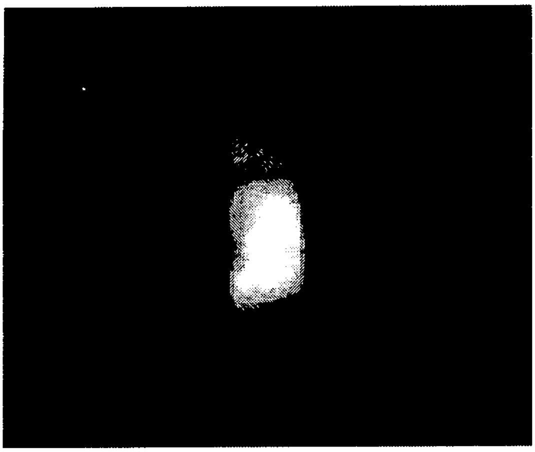


Fig. 5. Focused beam image on a color dot at 80, -20, and 4,500V for a gate, a focus electrode and an anode, respectively.

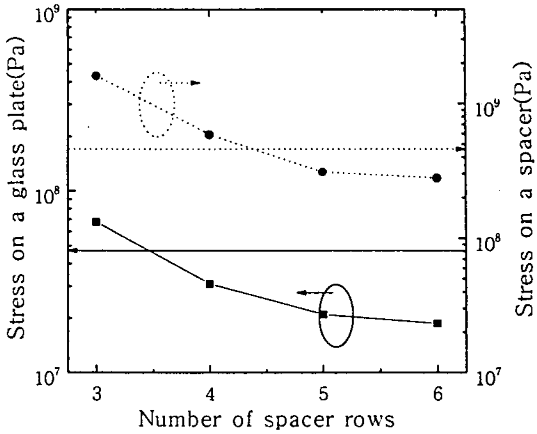
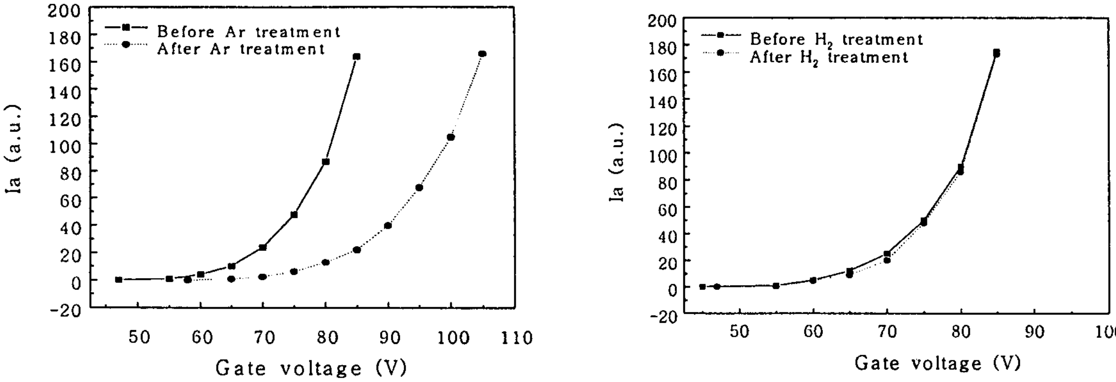


Fig. 6. Maximum stresses on a glass plate and spacers with the number of spacer rows. The shear fracture stresses of a glass plate and a spacer, 3.64×10^7 and 3.63×10^8 Pa, are indicated.

ers must be mechanically strong to prevent collapse, although many specifications are asked in terms of electrical, physical, and chemical properties. This study optimizes the number of spacer rows by an experiment as well as by simulating a stress distribution across a glass plate and spacers. As shown in Fig. 6, the maximum stresses on the glass plate and the spacers, which occurs just on their contact points, decrease with increasing the rows of spacers. Based on the shear fracture stresses of a glass plate and a spacer, 3.6×10^7 and 3.6×10^8 Pa indicated, respectively, at least 5 rows of spacers are needed to inhibit both of them from being broken. One has to also take account of a bending deflection of the glass plate between spacer rows, because glass bending wrecks the display's optical uniformity. The defection up to 20㎛ is allowable to us. In our panel, the optimal number of spacer rows is determined to be 7, for which the maximum deflection is measured be 18㎛ at the center between adjacent rows of spacers.

In our previous report[6], carrier gas mixtures of Ar and H_2 were investigated in terms of their effect on the luminance of RGB phosphors, but this study extends to a panel level characterization. Figure 7 represents the emission characteristics of FED panels with the pure Ar gas and a mixture of Ar and 1.5% H_2 flowed during sealing. I-V curves are compared for the very FEA before and after packaging. For the pure Ar gas, emission currents decrease drastically after sealing, most probably due to oxidation of microtips. When treated with the mixture of Ar and 1.5% H_2, on the other hand, an FEA keeps almost the identical emission performance. A small addition of a reducing gas, H_2 in our case, seems to be so effective in protecting microtips from being deteriorated.

Although a specific composition of a carrier gas is so good to FEAs, it would be of no use if it degrades the luminance characteristics of phosphors. For the pure Ar gas as well as the mixture of Ar and H_2, their effect on the color chromaticity of RGB phosphors is summarized in Table 1. Compared with the NTSC standard, the Ar+1.5% H_2 is the best for the red phosphor, but the green phosphor is independent of the H_2 addition.



(a) (b)

Fig. 7. I-V curves before and after sealing with (a) the pure Ar gas and (b) a mixture of Ar and 1.5% H_2 flowed.

For the blue phosphor, the addition of 1.5 and 3% H_2 is good. In measuring with an electron gun at a fixed accelerated voltage, the gas flows of 1.5% and 3% H_2 reduce the phosphor brightness by more than 10% and 30%, respectively, compared with the Ar gas flow[6]. For the 1.5% H_2 gas, however, the panel brightness seems to enhance more by the increase of emission currents. Considering all effect on the panel performance, the mixture of Ar and 1.5% H_2 is concluded to be optimal and then has been successfully used for our packaging process.

With a FED panel fully packaged, the brightness is measured in a white color at different anode voltages while keeping the gate voltage of 80V, as given in Fig. 8. The 300 cd/㎡, a meaningful milestone of FED development approaching the CRT like quality in brightness, is achieved at the anode voltage of 4,000V, and furthermore beyond the 400 cd/㎡ at 5,000V. Figure 9 demon-

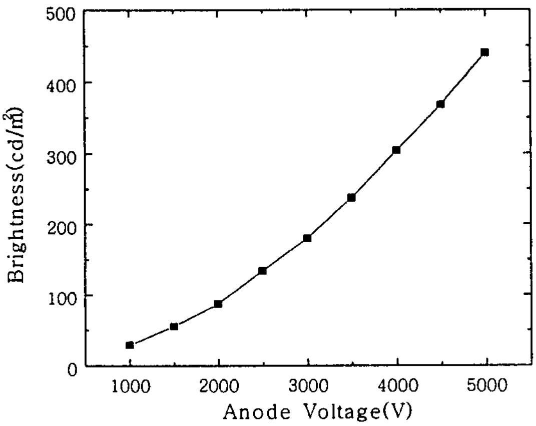


Fig. 8. Brightness in a white color measured in a panel at different anode voltages and the fixed gate bias of 80V.

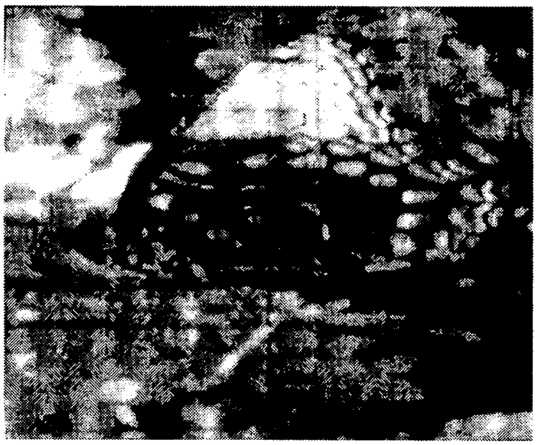


Fig. 9. A 5.2" full color FED image at 80V for a gate and 4,000V for an anode.

strates a color image of our 5.2" FED at a gate bias of 80V and an anode bias of 4,000V.

CONCLUSION

We have successfully developed a high voltage operated 5.2" full color FED device with a focus electrode engaged. The electron beam spreading is characterized experimentally as well as by simulations. A fairly good agreement is shown between experimental and calculated results. The optimum beam focusing is experimentally achieved at the anode voltage of 4,500V and the focus electrode bias of -20V. Full packaging experiments and stress analyses determine the optimal number of spacer rows. Ceramic spacers with high aspect ratio has been successfully fabricated and placed in panels. A sealing process using our own unique carrier gas of Ar and 1.5% H_2, is developed such that a device is effectively protected from deterioration of performance. Our FED device yields the brightness in excess of 400 cd/㎡ in the white color at the anode voltage of 5,000V. A full color image is demonstrated approximately in a QVGA mode.

REFERENCES

[1] M. Anandan, G. Jones, and A. P. Ghosh, Asia Display '98, Workshop Dig., Seoul, Korea(1998), p. 131.

[2] B. B. Chalamala, Y. Wei, and B. E. Gnade, IEEE Spectrum, April(1998), p. 42.

[3] C.-M. Tang, T. A. Swyden, A. C. Ting, X. F. Liu, L. Yadon, C. T. Sune, and G. W. Jones, IEDM Tech. Dig. 761(1993).

[4] A. Hosona, S. Kawabuchi, S. Horibata, and S. Okuda, J. Vac. Sci. Technol. B 17, 575(1999).

[5] L. Ozawa, "Application of Cathode Luminescence to Display Devices", Kodansha, Tokyo, Japan(1994), p. 32.

[6] J. M. Kim, N. S. Lee, J. E. Jung, Y. W. Jin, W. K. Yi, J. H. Lee, and H. W, Proc. of the 18th International Display Research Conference, Seoul, Korea(1998), p. 65.

[7] Z. F. Ren, Z. P. Huang, J. W. Xu, J. H. Wang, P. Bush, M. P. Siegal, and P. N. Provencio, Science **282**, 1105(1998).