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A simulation study on vertical focusing in micro-tip FED

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Abstract – Electron beam trajectory simulation results on the high voltage FED with cone-type field emitters predict that the cross-talk phenomena would be seen due to the divergence of the electron beam. In this study, computer simulations with design of experiment technique and the SNU-FEAT program were carried out for five input parameters of the aperture focusing structure. The results tell that the focusing voltage is a dominant factor. And, the beam divergence index could be reduced to 10.7 μm with the aperture focusing structure, however, the operating voltage of the field emitter is predicted to increase by 40% maximum.

Key words: field emitter, beam divergence, aperture focusing

I. Introduction

Recently, the high voltage FED (HV-FED) has been actively developed for high luminance [1, 2]. Because the anode-to-cathode gap is normally larger than 1mm in the HV-FED structure, the electron beam divergence is more severe than in the low-voltage FED (LV-FED), and should be properly controlled for high resolution and good color purity. While using electrostatic lens to focus the electron beam has been widely used in the electron source applications for many years, implementing this concept in the display based on the micro-fabricated field emitter array seems to be a quite challenge in the process and device aspects.

In this study, some simulation results on the beam divergence in cone-type emitter structure are presented, and optimized conditions on the five parameters in the aperture focusing design are described.

II. Beam Divergence Without Focusing Electrode

The beam trajectory in the cone-type emitter structure depends on the anode voltage, the gate-to-anode distance, and the gate voltage. Fig. 1 shows the beam divergence (Δr) as a function of the gate-to-anode electric field for three gate-to-anode distance. Δr means the lateral distance from the tip to the location on the anode plate where the electron strikes, assuming the maximum half emission angle of 30° [3]. The SNU-FEAT program [4] was used for the trajectory and field calculation.

As expected, the beam divergence increases with lower gate-to-anode electric field and larger gap distance. In case of the conventional LV- FED with the anode voltage of 400 V and the gap distance of 200 μm, Δr is expected to be 50 μm. Because this value corresponds to the B/M (black matrix) width in the anode screen with the fill factor of 40%, as shown in Table 1, the degradation of color purity due to the beam divergence could not occur. Conclusively, the external focusing means is not necessary in the 10.4" diagonal LV-FED with VGA resolution. However, Δr is expected to be 85 μm in the HV-FED with the anode voltage of 5 kV and the gap distance of 1 mm,

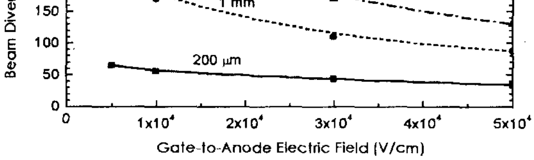

Fig. 1. The beam divergence as a function of the electric field between the gate and the anode for the gate-to-cathode distance of 200 μm, 1 mm, and 2 mm.

Table 1. The black matrix width of a 10.4" VGA display for the fill factor of 69% and 40%

Fill Factor (%)	Pixel Pitch (μm)	Phosphor size (μm)	B/M size (μm)
69	325	H : 88, V : 275	H : 20, V : 50
40	325	H : 51, V : 275	H : 57, V : 50

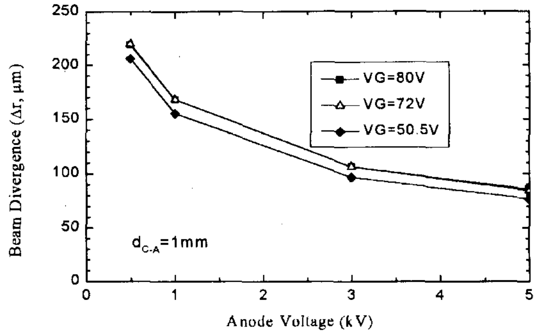

Fig. 2. Beam divergence as a function of the anode voltage for the gate voltage of 50.5 V, 72 V, and 80 V. The distance between the gate and the anode is 1 mm.

resulting in the degradation of color purity.

Fig. 2 shows the beam divergence as a function of the anode voltage for three gate voltages. The gate voltages of 80 V, 72 V, and 50.5 V correspond to the gate hole diameters of 1.5 μm, 1.0 μm, 0.55 μm, respectively [5] for the same emission current. It can be seen that the gate voltage has a minor effect on the beam divergence compared to the anode voltage and the gap distance. It means that even though reducing the gate hole diameter can help reducing the operating voltage, it does not appear to affect the beam divergence significantly.

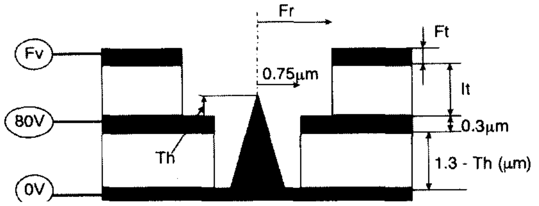

Fig. 3. The field emitter structure with a focusing electrode used for simulations. A voltage of 5kV is applied to the anode, which is 1 mm apart from the gate.

III. Simulations on Aperture Focusing Structure

In order to optimize the parameters such as radius of the focusing electrode (Fr), thickness of the focusing electrode (Ft), thickness of the insulator (It), focusing voltage (Fv), and tip protrusion from the top of the gate (Th), simulation studies on the beam trajectory were performed with design of experiment technique. In the model emitter structure, it was assumed that the gate voltage was 80 V, the gate hole diameter was 1.5 μm, the aspect ratio of the tip was 1.3:1, the gap distance was 1mm, and the anode voltage was 5 kV, as shown in Fig. 3. Table 2 shows the levels of five parameters which are reasonable for the actual fabrication processes. Based on the design of experiment technique, an orthogonal table of L18 for the five parameters with three levels was used.

Fig. 4 shows the beam divergence and the maximum field on the tip depending on the five parameters. It can be seen that the voltage level of the focusing electrode significantly affects the beam divergence and the beam divergence is reduced with the lowering of the voltage level. However, the low-

Table 2. Control factors and their levels

Parameters	Level 1	Level 2	Level 3	Unit
Focusing Voltage (Fv)	0	10	20	V
Focusing Gate Radius (Fr)	0.75	1.0	1.25	μm
Focusing Gate Thickness (Ft)	0.2	0.3	0.4	μm
Insulator Thickness (It)	0.5	0.75	1.0	μm
Tip Height (Th)	0.0	0.2	0.4	μm

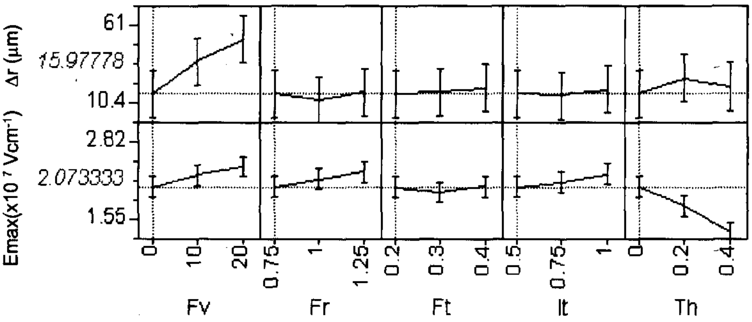

Fig. 4. Output of analysis with JMP program (Ver. 3.2). Δr and Emax as a function of parameters of Fv, Fr, Ft, It, Th.

Table 3. Comparison of performance for three parameter condition sets. The condition set #3 corresponds to the emitter structure without focusing gate

Condition set #	Fv (V)	Fr (μm)	Ft (μm)	It (μm)	Th (μm)	Δr (μm)	Emax ($\times 10^7$ V/cm)	V_G (V) @50 nA/tip
1	0	1.0	0.2	0.75	0	10.7	2.29	115
2	20	1.25	0.4	1.0	0	58.3	2.88	91
3	–	–	–	–	0	85.0	3.29	80

ering of the focusing voltage causes the reduction of the field intensity on the tip. When the tip locates at the same level as the top of the gate, the beam divergence can be minimized and the field intensity maximized. Even though the other parameters are thought to have a minor effect on the beam divergence, their effect on the field intensity on the tip cannot be neglected.

Table 3 shows the optimized conditions and the corresponding beam divergence and field intensity for the minimum beam divergence (set #1), maximum field intensity (set #2), and for no focusing electrode (set #3). As shown in the table, Δr can be reduced to 10.7 μm for the field emitter with the aperture focusing electrode, whereas the gate voltage is predicted to increase by 35 V, compared to the field emitter with no focusing electrode.

IV. Conclusion

Optimization of five major parameters in the aperture focusing structure was carried out using the design of experiment technique. The beam divergence index could be decreased to 10.7 μm under the optimized condition. However, the operating voltage is expected to increase by about 40%. The aperture focusing design can help controlling the beam divergence effectively, but it seems to be quite challengeable to implement the aperture focusing structure.

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