The Simulation of Gate-Aperture Effects on Brightness and Resolution of Field Emission Display with Double-Gate

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ABSTRACT

The brightness and resolution of Field Emission Display (FED) are two important characteristics. In this study, we have systematically developed a simulator of FED with double-gate. Major elements of this simulator include a Fowler-Nordheim field emission model, an electron trajectory simulation in vacuum space, and an electrical performance characteristic simulation. It was demonstrated that the smaller (1.2~1.8 μm) control gate aperture can enhance the anode current density, and the moderate focusing gate aperture can efficiently repress the divergence of electron beam form the emitter. The simulation results indicated that parameters of control gate aperture 0.8 μm and focusing gate aperture 1.2 μm definitely exhibited an optimal brightness and resolution of double-gated FED.

(KEY WORDS: FED; Double-Gate; Fowler-Nordheim; Electron Trajectory; Anode Current)
INTRODUCTION

Flat and thin replacements for the cathode ray tube (CRT) have been sought since the 1950’s [1]. Cathodoluminescent flat-panel displays represent one broad category of development, but have generally suffered from poor image quality or complex device structure. The field-emission display (FED) is a cathodoluminescent device that may overcome these limitations. In it, effective FED structures to improve the brightness and resolution on the screen are highly desired.

Traditional FED is developed with a single-gated structure [2]-[4]. A big disadvantage of such a single-gated FED is the evidently low display efficiency due to the poor focusing behavior on emitted electron trajectory [5]. Recently, FED with double-gated structure [6]-[8], providing an effectively focused electron beam, has been proposed to satisfy the requirement of high display efficiency. Unfortunately, to the best of our knowledge, the optimal and effective device parameter design of double-gated FED has not been established.

This article deals with design ideas of doubled-gated FED with optimal brightness and resolution performance, gives the simulation methods, and discuss the computation results.

Double-gated FED Structure and Simulation Methods

The simulated double-gated FED structure providing several relative fixed parameters is shown in Fig. 1. In this work, we tried to modify the control gate aperture ($A_{c8}$) to find the maximum anode current density, and the focusing gate aperture ($A_{f8}$) to obtain the best focusing effect, respectively.

A Fowler-Nordheim (F-N) emission module was developed to simulate electron field emission from the surface of emitter [9]-[10]. Emitted current density determined by the F-N equation is expressed as:

$$J(E) = \frac{1.27273 \times 10^{-6} e^{9.88614/\sqrt{\phi}^2}}{\phi} E^2 \times \exp\left(-\frac{6.5265 \times 10^7 \phi^{3/2}}{E}\right) \quad \text{Eq (1)}$$
where,

\[ E \] electric field on the emitting surface [V/cm];

\[ J \] emitted current density [A/cm²];

\[ \phi \] material work function of the emitter [eV].

The F-N equation is based on the kinetic formulation of the field emission current [11]. We calculate the device current by integrating the current density and taking the variation of the electric field across the surface of the tip into account. Hence, the electric field of the emission is considered.

As is well-known, the anode voltage and anode current density are two important factors to influence the brightness of FED [12]-[13]. The relationship between brightness (\(B\)) and anode voltage (\(V_a\)) as well as anode current density (\(J_a\)) is given by [14]:

\[ B = A \cdot \eta(J_a, V_a) \cdot J_a \cdot f \]  

...Eq (2)

Where, \((J_a, V_a)\) is the conversion efficiency from electron beam energy to light energy, and \(A\) is the conversion factor from light energy to brightness [15].

**Simulation Results and Discussion**

Since the control gate aperture and the focusing gate aperture have mutual-influence effects on the current performance of double-gated FED, first, we simulated different control gate aperture parameters with a fixed 2.2 \(\mu\)m of focusing gate aperture to observe the variation of anode current density, which is shown in Fig. 2. As illustrated in Fig. 2, the smaller control gate aperture in the range of 0.6~1.6 \(\mu\)m, the higher anode current was obtained. It implies that a decreased control gate aperture significantly increases the electric field around the tip area of emitter (cathode) and thus, leads to a higher anode current. Interestingly, as the anode current became larger due to a reduced control gate aperture, a considerable current leak through the control gate (ie, control-gate current) was simultaneously observed especially when the control gate aperture is smaller than 1.2 \(\mu\)m. Such a result, in our suggestion, is due to a broader focusing gate aperture, resulting a poor focusing effect and yielding a larger electron beam.
incidence to the control gate. It is noted that in this simulated range of control gate aperture, there is no detectable focusing-gate current.

Subsequently, we varied the focusing gate aperture with a compromised fixed 0.8 \( \mu \)m of control gate aperture to simulate the focusing effect on the FED, which was displayed in Fig. 3. As is shown in Fig. 3, as long as the focusing gate aperture broader than 1.8 \( \mu \)m, an evident control-gate current was obtained. Such a result implies that too wide focusing gate aperture can’t effectively congregate the electron beam which emitted from the cathode. Interestingly, a detectable leakage current at control gate also occurred whenever the focusing gate aperture was smaller than 1.2 \( \mu \)m. Such a result, in our suggestion, is due to the fact that the focusing gate voltage is not big enough, resulting in a diverged electron beam emitted from the cathode. Therefore, an optimal focusing gate aperture between 1.2~1.8 \( \mu \)m performing the best focusing effect was suggested. In Fig. 4, the simulated electron trajectory emitted form cathode to anode with a control gate aperture 0.8 \( \mu \)m, and a focusing gate aperture 1.2 \( \mu \)m strongly revealed that an effectively focused electron beam converged to a \( 3 \times 10^{-6} \) cm of electron spreading area can be definitely identified.

All the above simulated results illustrated that the optimal parameters of control gate aperture 0.8 \( \mu \)m and focusing gate aperture 1.2 \( \mu \)m were suggested to adopt to design an effective double-gated FED with a high brightness and high resolution performance.

CONCLUSION

The physical parameter effects on the electrical performance of double-gated FED have been systematically simulated and analyzed. The simulation results definitely indicated that a smaller control gate aperture can significantly increase the electric field around the tip area of emitter and results in a increased anode current and thus, a brighter display panel. On the other hand, evidence showed that adequate focus gate aperture (1.2~1.8 \( \mu \)m) not only can repress the occurrence of control-gate current, but also effectively converge the emitted electron beam from cathode, leading to a high resolution performance. Finally, a control gate aperture 0.8 \( \mu \)m and a focus gate aperture 1.2 \( \mu \)m was demonstrated to provide an optimal brightness and resolution for the double-gated FED application.
Acknowledgments

Two of the authors (Ching-Wu Wang, and Chih-Liang Chen) gratefully acknowledge the financial assistance from the National Science Council (NSC) in Taiwan under contract number: NSC89-2215-E-214-022.

References


Fig. 1. Schematic diagram of a double-gated FED structure.
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![Graph showing current as a function of control gate aperture.]

Fig. 2. The simulation results of different current characteristics as a function of control gate aperture.
Fig. 3. The simulation results of different current characteristics as a function of focusing gate aperture with a compromised fixed 0.8 $\mu$m of control gate aperture.
Fig. 4. The simulated electron trajectory with control gate aperture 0.8 μm and the