Active control of the emission current of field emitter arrays

Kuniyoshi Yokoo, Manabu Arai, Masahiro Mori, Jongsuck Bae, and Shoichi Ono
Research Institute of Electrical Communication, Tohoku University, Katahira Sendai 980-77, Japan

(Received 7 July 1994; accepted 22 November 1994)

The current control and the stabilization in field emission of gated field emitter arrays (FEAs) are the highest demand for applications to a flat panel display and other beam devices. The concept of the field-effect-controlled field emission cathode is very useful for these purposes. We carried out preliminary experiments of the idea and showed that the controllability and the stability of emission current of FEA were significantly improved by an actively controlled FEA. Additionally, we discussed beam focusing of FEA for a flat panel display application.

I. INTRODUCTION

Matrix-addressed field emitter display (FED) is the most attractive application of field emitter array (FEA), because the display promises high speed, large viewing angle, full color capability with high resolution and high brightness, and low-power consumption. The LETI demonstrated 6 in. monochrome and full color FEDs as television displays and as computer monitors.[1] However, the specific difficulty in the development of FEDs is that the emission current from FEA must be uniform and stable over the whole size of the display in large dimensions. The resistive layer is deposited under the emitter tips in the LETI displays and a multidiameter array structure is examined in the FED developed in Fujitsu Laboratory to improve emission uniformity.[2] In addition, the matrix emitters should be driven by sufficiently low voltage in order to reduce the power consumption and to allow the use of low-voltage complementary metal–oxide–semiconductor (CMOS) circuit for addressing pixels. Emitter protection for a short circuit between emitter tips and gates is very important in a display application because any short circuit due to processing problems of FEA in large dimensions or a tip failure during operation results in a full row or column error in a display. Reduction of cross talk in emitted electrons from FEA is another requirement in a high-resolution display. Although a triode structure has been examined for beam focusing,[3] highly reliable fabrication process is necessary and it seems to be difficult to satisfy this requirement by the fabrication process, especially in large dimensions of display. The field-effect-controlled (FEC) field emission cathode reported by Ting *et al.* of the Naval Research Laboratory satisfies most of the above requirements for a display application.[4] Because the FEC field emission cathode constructed monolithically with a FEA and an active device, such as a field-effect transistor (FET) and a thin-film transistor (TFT), has intrinsic advantages for the display application as they pointed out.

(1) Emission current for each pixel is controlled and stabilized by applying a few volts on the gate of FET or TFT. Then, a well-developed low-voltage integrated circuit is available for addressing the pixels due to sufficiently low addressing voltage.
(2) Fluctuation in brightness between pixels in the display is compensated by feeding back the fluctuation signals to respective pixels through memory devices.
(3) Since the current of an individual emitter or a block of emitters is limited by an active device, a short circuit between emitter and gate does not result in a fatal display fault.

We examined the controllability and the stability of the emission current from 10×10 Si-FEA by using a commercially available FET, as a first step of the investigation of the idea. The emission was well controlled at current above several tenths of nA by changing a gate voltage of the FET and the stability of emission current was significantly improved even at pressure of 10^{-6} Torr compared with the resistive layer stabilization.

Regarding the cross talks between pixels in a display, we examined a FEA structure with guard rings as focusing electrodes, which surrounded an individual emitter or a block of emitter arrays on the same plane of the gate electrode of FEA. Simulation results showed that the beam focusing in the FEA was sufficient for FED application. This FEA structure significantly simplifies the fabrication process compared with that of a triode structure of FEA and enables the fabrication to be reliable and the FEA in large dimensions to be uniform.

II. STRUCTURE OF FEC FIELD EMISSION CATHODE

Figure 1 shows the basic concept of the FEC field emission cathode and its equivalent circuit. The FEA is fabricated monolithically with FET or TFT. The emission current from an individual emitter tip or a block of emitter arrays is controlled and stabilized by the constant current characteristic of FET in the case of Fig. 1. The emission current is only fixed by the gate voltage of the FET and the series resistance connected to the source electrode of the FET and disparity in the emission current between emitters is eliminated by adjusting the gate voltages of FETs for respective emitters, though the driving voltage of FEA increases slightly.

For a display application, the addressing voltages are applied on the gate and source lines of FETs matrix and are sufficiently low compared with that of usual gate or anode addressings, which results in use of well-developed low-voltage CMOS integrated circuits for addressing the pixels.

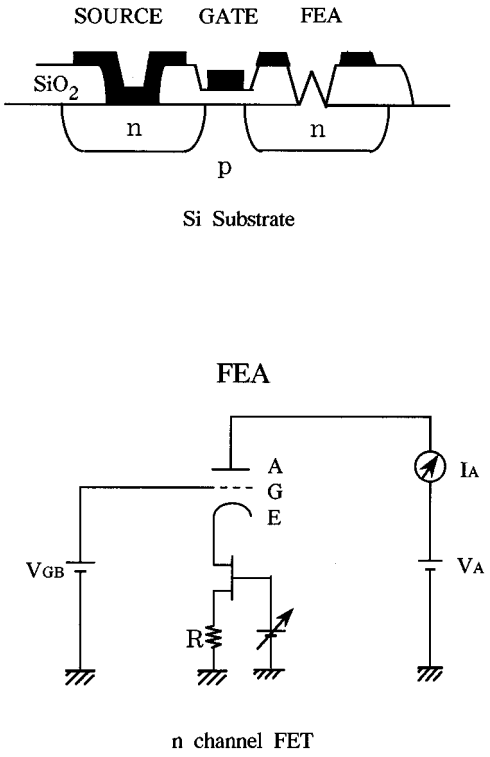

FIG. 1. Basic concept of the FEC field emission cathode (Ref. 4) and its equivalent circuit.

Emission current of each pixel can be measured and compared with a desired current by addressing the pixels and then a compensation signal for each pixel can be calculated and stored into memory devices. Therefore, when fluctuation in brightness between the pixels are occurred, the compensation signals can be fed back to the gate of FETs of the respective pixels through the memory devices.

In addition, a short circuit between emitter tip and gate due to processing problems of FEA in large dimensions or a tip failure during operation does not result in a fatal display fault, since the total current of an individual emitter or a block of emitters is governed by the constant current characteristic of the FET.

These advantages of the FEC field emission cathode will overcome most of the difficulties in the development of high-definition high-quality FEDs.

III. PRELIMINARY EXPERIMENTS

Figure 2 shows scanning electron microscope (SEM) micrograph of the gated Si-FEA fabricated by reactive ion etching and thermal oxidation technique.[5]

10×10 tips gated Si-FEA with gate aperture of 2 μm has been used for preliminary experiments, and a commercially available FET is connected to the FEA as shown by the equivalent circuit in Fig. 1. Figure 3(a) shows a typical current–voltage characteristic of used FEA. The emission current is generated near the gated voltage of 100 V. Figure 3(b) shows emission current driven by the gate voltage of

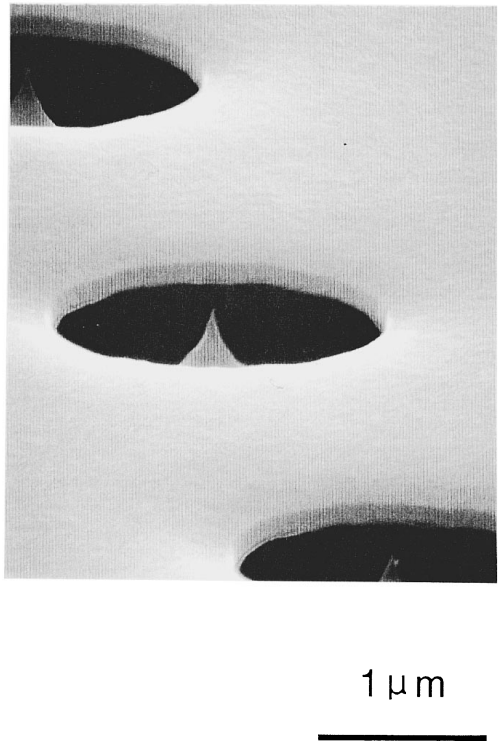

FIG. 2. SEM micrograph of gated Si-FEA.

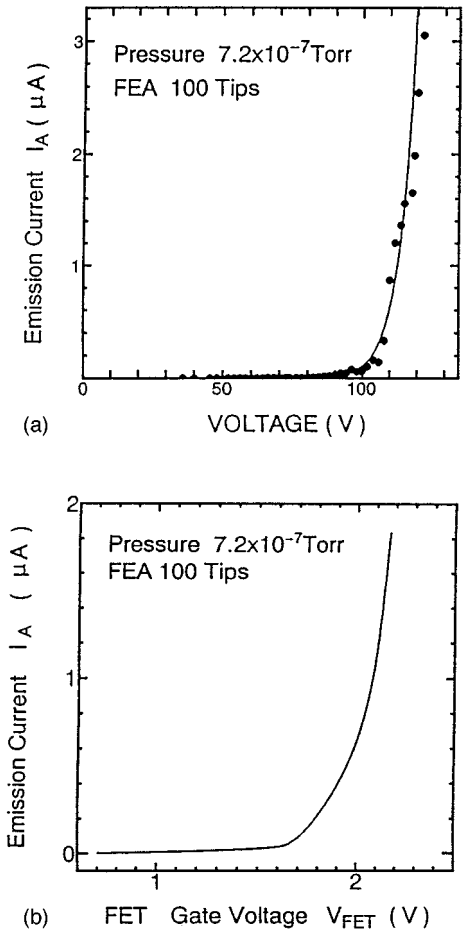

FIG. 3. Current–voltage characteristic of 10×10 tips gated Si-FEA (a), a typical emission characteristic controlled by the gate voltage of FET (b).

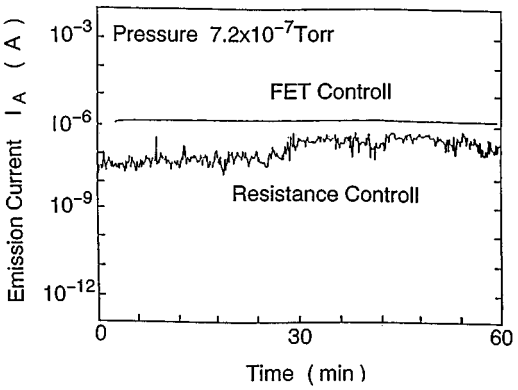

FIG. 4. Current fluctuation of the FET-controlled and the resistance-controlled FEAs.

FET at a constant gate voltage of FEA. The emission current was well controlled at the currents above several tenths of nA by the gate voltage of the FET ranging from 1 to 2 V, as shown in Fig. 3(b).

Current stabilization was examined by applying a constant voltage on the gate of FET. Figure 4 shows the current fluctuation of a FET-controlled FEA measured at the pressure of 7×10^{-7} Torr. A current fluctuation of 1 M Ω resistance-controlled FEA is plotted in the figure for the comparison in improvement of current fluctuation. The emission current of the resistance-controlled FEA increases gradually with the time by a forming process, as reported by many researchers, and the high current fluctuation continue afterwards. On the other hand, the emission current of the FET-controlled FEA was nearly constant from the beginning to the end of the measurements and the improvement in the current stabilization was significant as shown in Fig. 4. These characteristics are inherent in the FEC field emission cathode and are especially important for FED applications as described before.

IV. BEAM FOCUSING

Electrons are emitted from FEA with a relatively wide angle of 20° or 30°. Then, some focusing technique of electron beam is necessary for a high-resolution display to reduce cross talk between pixels. Figure 5 shows a schematic drawing of a FEA structure with a guard ring for beam focusing. The guard ring surrounds an individual emitter or a

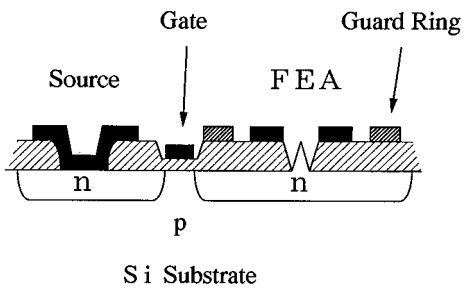

FIG. 5. A schematic drawing of the FEA structure with guard ring for beam focusing.

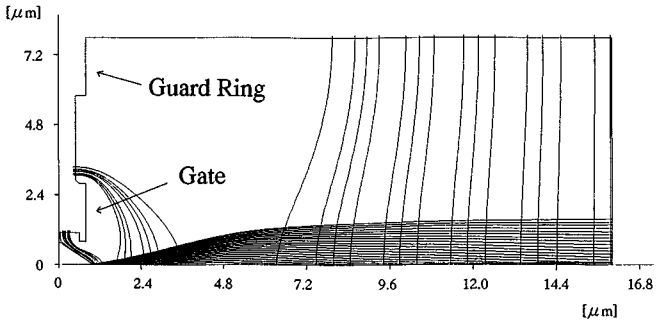

FIG. 6. A simulation result of electron trajectories emitted from a single emitter with guard ring.

block of emitter arrays and is fabricated on the same plane of the gate of FEA. Figure 6 shows one of simulation results of electron trajectories emitted from a single emitter with a guard ring. When an opposite polarity of voltage close to the gate potential is applied on the guard ring, the electron trajectories become almost parallel to the beam axis and the focusing of electron beam is sufficient to overcome cross talks between pixels in a FED, as shown in Fig. 6. The fabrication process of the structure is simple and reliable compared with that of a triode structure for beam focusing.

The monolithic FEA structure with an active device and a guard ring, as shown in Fig. 5, might be definitely a suitable structure of FEA in FED applications.

V. CONCLUSION

We have carried out preliminary experiments of the FEC field emission cathode proposed by the group of the Naval Research Laboratory and verified that the proposed structure could significantly improve the controllability and the stability of emission current from FEA which were essential for a display application. In addition, we examined a FEA structure with a guard ring for beam focusing by the simulation and showed that the beam focusing was sufficient to reduce cross talks between pixels in a FED. We are intending to fabricate the monolithic FEA structure with FET and guard ring.

ACKNOWLEDGMENTS

A part of this work was carried out in the superclean room of the Laboratory for Microelectronics, Tohoku University. The authors would like to acknowledge Professor J. Murota, Tohoku University, for fabrication of FEA and stimulating discussions. This work was supported by a Grant-in-Aid for Scientific Research from the ministry of Education, Science and Culture of Japan and the Fund of Broadcasting.

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