Micromachining and Modeling of Self-Focused Field Emission Electron Sources

Personnel

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Sponsorship

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The Field Emission Display (FED) is most efficient when the phosphor screen is biased at a high voltage (>5kV) because of increased electron penetration depth and reduced non-radiative recombination at the surface. High screen bias requires greater screen-cathode separation to prevent breakdown of the dielectric spacers. However, the resolution of the display decreases with screen-cathode separation because of the ±20° inherent spread in the electron beam. In order to have high resolution, most FEDs are proximity focused and use low voltage screens leading to lower luminous efficiency (1 lm/watt compared to 10 lm/watt for high voltage screens) and shorter lifetime. The electron beam diverges because of the lateral component of electron velocity produced by the radial field near the tip and horizontal pull of the gate electrode. The objective of this work is to improve the resolution of the FEAs with high voltage screens by introducing an additional electrode to collimate the electrons.

This project deals with design, modeling, fabrication, and characterization of field emitter arrays with integrated focus (IFE-FEA). An original analytical model of device electrostatics is developed and used to extract an expression for the emission current as a function of voltage and device geometry. The model also permits calculation of electron trajectories and was used to demonstrate the collimation effect. Next, we developed a novel CMP-based fabrication process that produced an IFE-FEA with dimensions approximately two times smaller than any previously reported [Figures 29 and 30] The remainder of the work deals with characterizing this device. Electrical characteristics were found to be in fair agreement with the model. Detailed measurements of the focusing performance show that under optimal conditions the spot size is reduced almost down to the original array size.

To measure the spatial divergence of the beam, a phosphor screen was employed as the anode. A quantitative microscopy camera was used to observe light emission from the screen and obtain a measure of the spatial spread of the electrons. By using a quantitative camera, and an array with an almost constant current with focus voltage, it is possible to ensure that changes in the apparent spot size are caused by a change in the divergence of the beam and not by other causes (such as brightness changes, which might be observed if the beam current fluctuated). These measurements, taken in UHV through a viewport, show a clear focusing effect with an optimal focus at V_F=12V. Micrographs are shown Figure 31. At higher focusing fields the beam begins to increase in size, which is caused by over focusing (i.e. electrons cross the optical axis).

An estimate of the spot size is also listed in Figure 3. The ratio of the focus voltage and the gate voltage at the optimum focus point is 0.24. This value is consistent with earlier theoretical work by Yang, which predicted that the optimum focus would occur at V_F/V_G=0.34. Yang's simulations were for a slightly different geometry than ultimately fabricated which leads to some disagreement. Modeling indicates that optimal collimation will be maintained by a fixed voltage ratio between the focus and extraction gate for a large range of gate voltages.

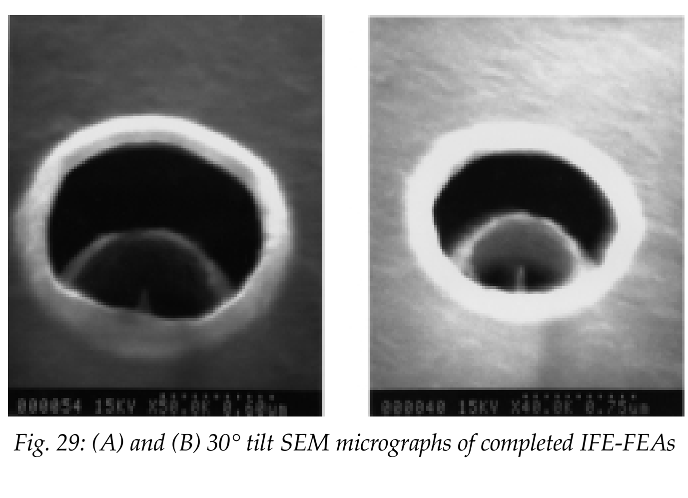


Fig. 29: (A) and (B) 30° tilt SEM micrographs of completed IFE-FEAs

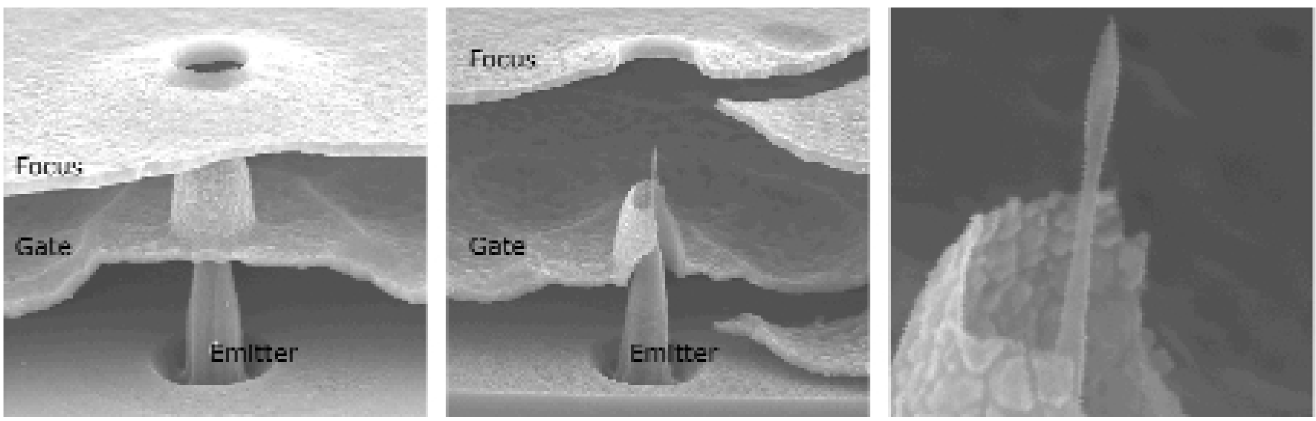
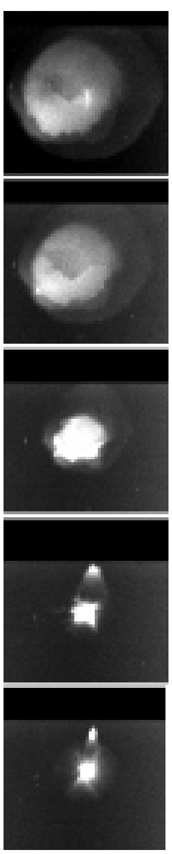


Fig. 30: Micrographs of cross-sections of completed devices.



V_f=50V — *Size ≈ 420 microns*

V_f=35V — *Size ≈ 345 microns*

V_f=21V — *Size ≈ 240 microns*

V_f=12V — *Size ≈ 25 microns*

V_f=10V — *Size ≈ 35 microns*

Fig. 31: At the optimal value of focus bias (V_F=12V), spot size is minimized, which implies collimation of the electron beam. At lower values of the bias, there is evidence of spot size increase.