Effects of Anode Distance on Field Emitter Array Performance in Simulation

Youngjin Shin, Kenneth Chap, Ellie Bultena, Akintunde I. Akinwande
Department of Electrical Engineering and Computer Science, MIT, Cambridge, MA 02139
Corresponding author: ys18@mit.edu

We present our exploration into channel electric field redistributions of field emitter arrays (FEAs) by simulating the electrostatics at various anode-to-emitter distances, L_{AE}. Silicon FEAs are cold cathode electron sources that have shown promise for high-power applications such as power switches. One of the limiting factors of FEAs as a power switch is its relatively low efficiency at lower voltages. Some of the factors that contribute to an FEA's efficiency are the on-voltage (V_{ON}=25V-30V), operating anode-to-emitter voltage (V_{AE}), and the gate leakage current. Typically, to achieve a higher efficiency (>99%), FEAs are utilized in high-voltage applications that require >10kV bias on the anode to maximize the ratio between V_{AE} and V_{ON} [1]. However, there are challenges in operating FEAs at high-voltages due to large amounts of leakage current when driving higher current densities. In prior works, it has been implied that electrons emitted at a non-vertical emission angle are collected by the gate electrode, increasing the leakage current [2]. L_{AE} has mainly been studied for its effects on space charge but have not yet discussed its impact on reducing the gate leakage current when the device is in saturation, improving the output power efficiency. In this study, we conduct electrostatic simulations in COMSOL to demonstrate how decreasing L_{AE} influences channel field redistribution to reduce leakage current at the gate aperture with flat and cusp anode geometries.

Our simulations show that changes in L_{AE} result in distinct local electric field distribution patterns along the gate aperture; at smaller L_{AE}, the electric field is mostly vertical, whereas at large L_{AE}, the non-uniform field has higher horizontal electric field components away from the center of the gate aperture. Fig.1 and Fig.2 show the electric field distributions across the gate apertures for a 3x3 FEA at V_{AE}=200V, V_{GE}=40V, and L_{AE}=2μm, 5μm, and 30μm for a flat and cusp anode, respectively. The field distribution at 30μm indicates that it is likely that a smaller proportion of electrons from the emitter are collected at the anode compared to the 2μm and 5μm configuration due to the electric field being almost entirely vertical across the entire gate aperture. The cusp anode shows the most dramatic difference between 2μm and 5μm, likely owing to its focused tip shape. Our results indicate that reducing L_{AE} increases the vertical electric field, encouraging the emitted electrons have a vertical trajectory towards the anode, preventing its collection at the gate. Future work will focus on experimental validation of these findings and analyzing how to prevent breakdown at L_{AE}<5μm.

Keywords- Field Emitter Array (FEA), field redistribution, anode-to-emitter distance (L_{AE}).

References

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[2] Y. Shin, N. Karaulac, W. Chern, and A. I. Akinwande, "Compact Modeling Approach of Field Emitter Arrays", in 2024 37th International Vacuum Nanoelectronics Conference (IVNC), Jul. 2024, pp. 1–2.

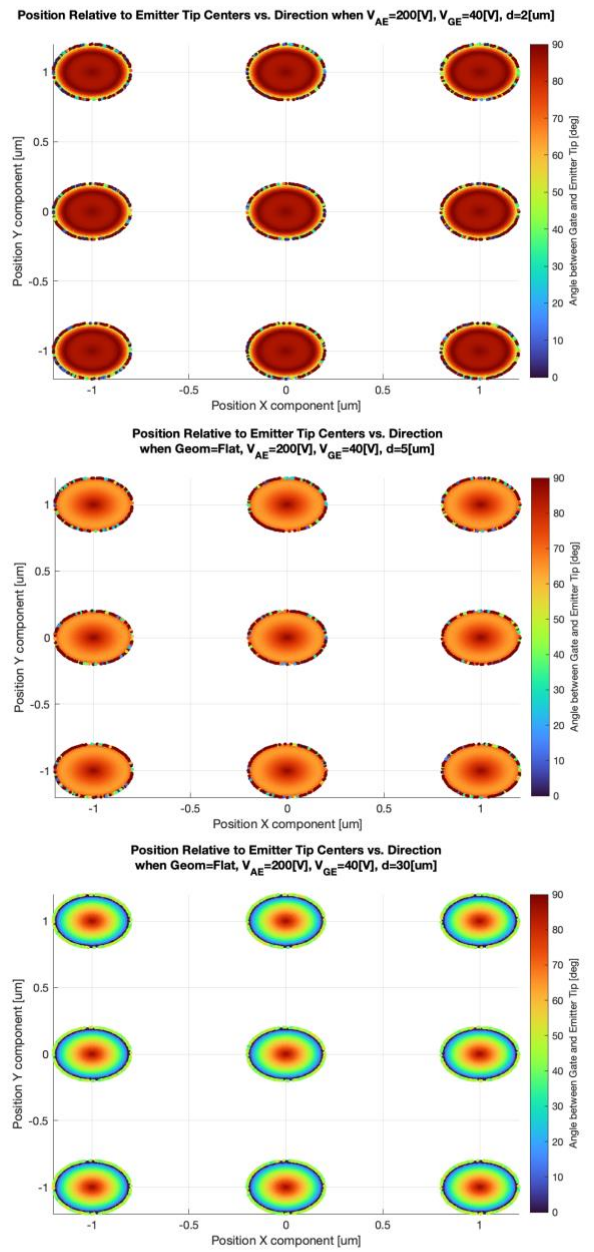

Fig1. Electric field distribution for a 3x3 FEA at 2μm (top), 5μm (middle), and 30μm (bottom) anode-to-emitter distance at V_{AE} = 200V, and V_{GE} = 40V with a flat anode. Color scale depicts the field direction.

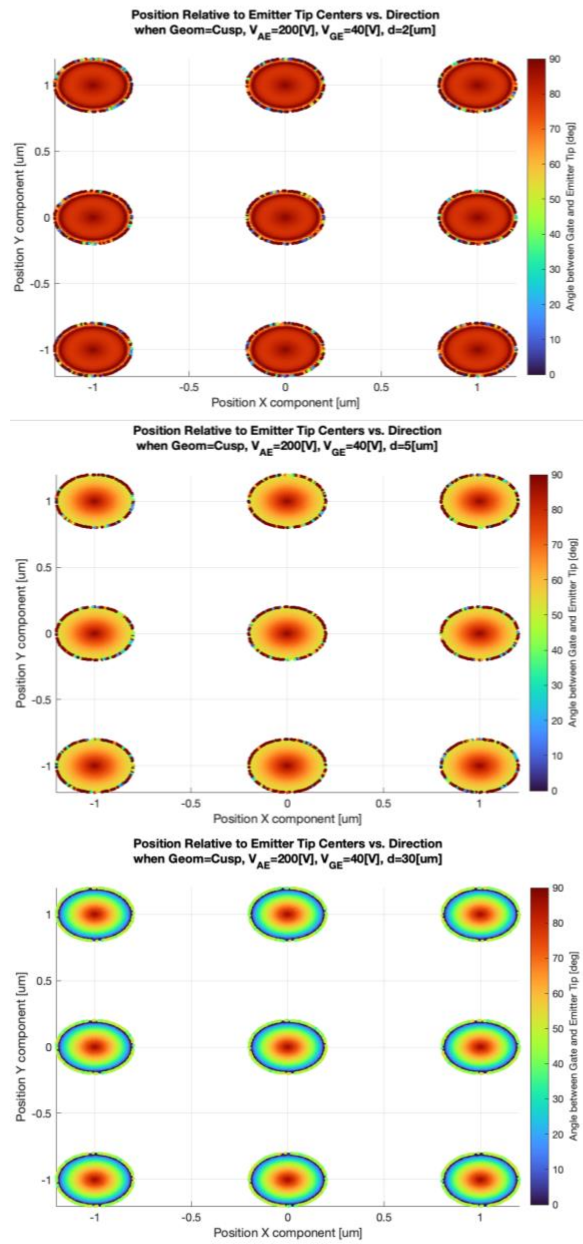

Fig2. Electric field distribution for a 3x3 FEA at 2μm (top), 5μm (middle), and 30μm (bottom) anode-to-emitter distance at V_{AE} = 200V, and V_{GE} = 40V with a cusp anode. Color scale depicts the field direction.