Simulation of a Pull-In-Enhanced Self-Aligned Buried-Gate MEMS Field-Emission Triode

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Key Results

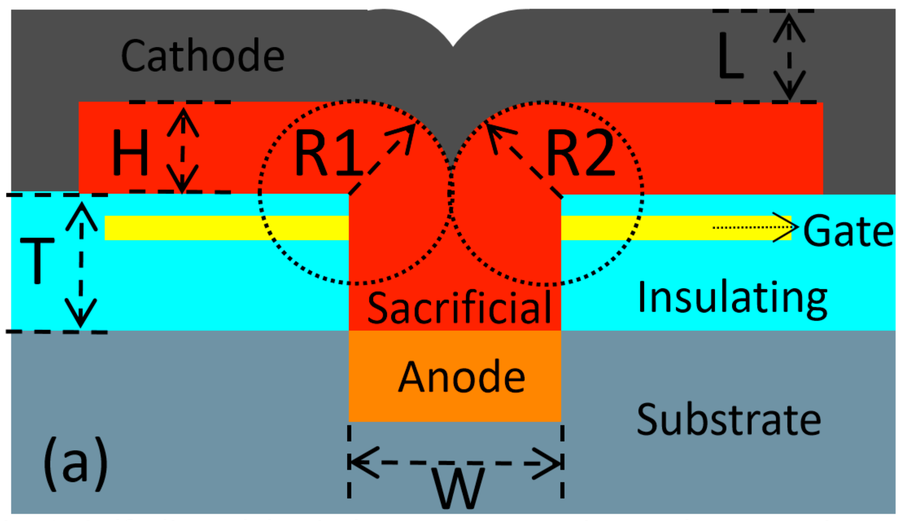
- **Self-aligned emitter from sacrificial-film deposition**
- **Pull-in: 10.16 V. Release: approximately 4.4 V**
- **Vacuum gap reduces from about 55 to 10 nm**
- **Emission current increases more than 10x**
- **Geometry tunes actuation and hysteresis**

1. Background & Motivation

- Vacuum channels support electron transport without semiconductor lattice scattering.
- Field-emission performance depends on tip sharpness, spacing and local electric field.
- Repeated alignment steps complicate conventional emitter fabrication.
- This work uses MEMS pull-in to actively tune the emission gap.

Goal: combine self-aligned emitter formation with electrical gap modulation.

2. Device Structure & Self-Aligned Emitter Concept



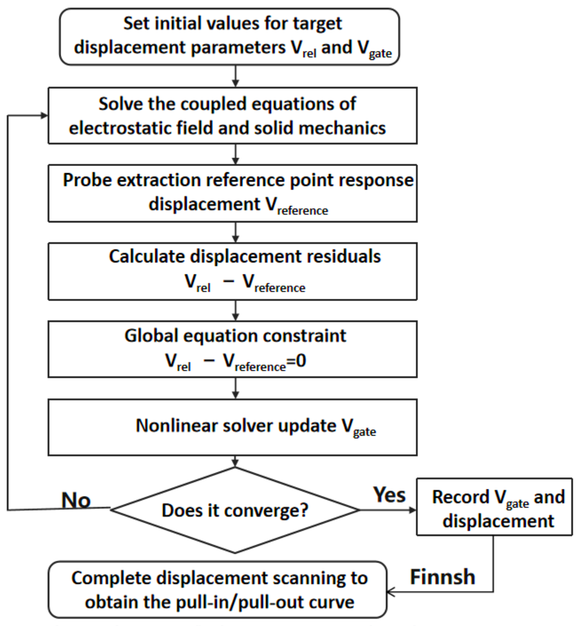
- Suspended cathode, buried gate, anode and an insulating stop layer.
- Trench-edge sacrificial deposition defines the emitter without additional cathode–gate alignment.
- Critical closure near 2H ≈ W produces the sharpest deposition-defined profile.
- Under-closure leaves an opening. Over-closure rounds the tip.

Emitter shape follows trench width W and sacrificial thickness H.

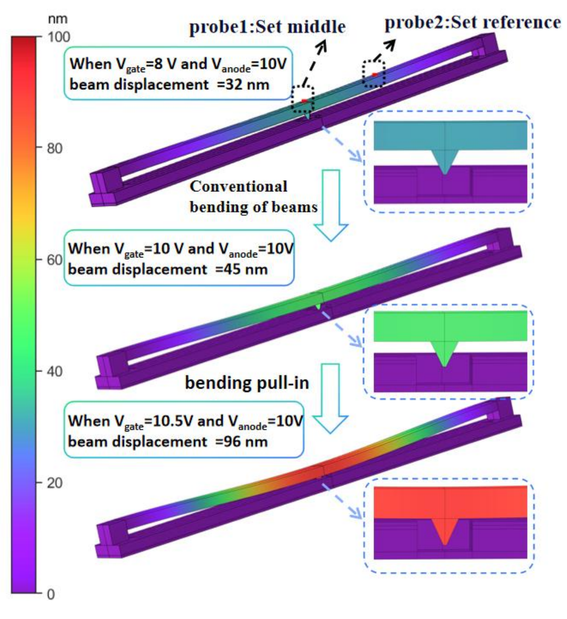
•Fig. 1. Self-aligned buried-gate cross section and geometric parameters

3. Multiphysics Model & Pull-In Mechanism

Process-defined emitter geometry → **Electrostatic–mechanical coupling** → **Displacement control & continuation** → **Local field & emission calculation**

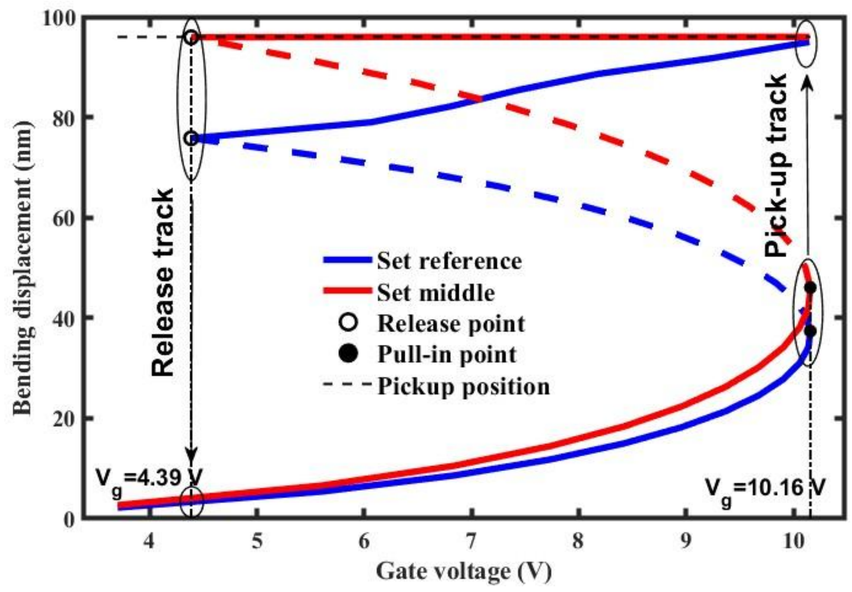


•Fig. 2. Flowchart of the inverse displacement controlled solution method.



•Fig. 3. Calculation results of displacement of cantilever beam under different voltages

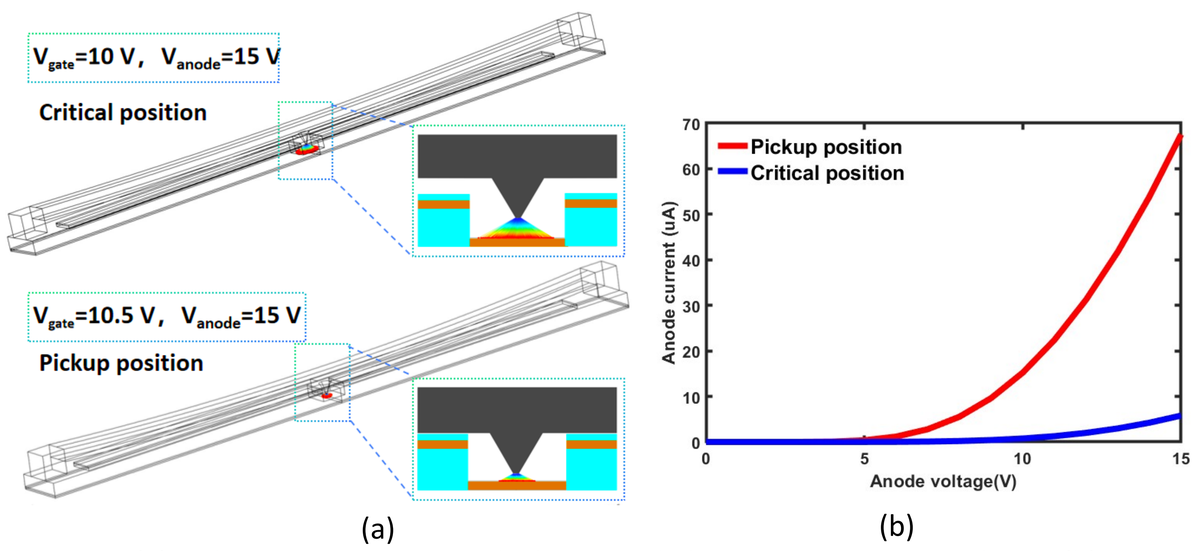
4. Pull-In / Release Characteristics



•Fig. 4. Simulated pull-in and release characteristics of the nominal suspended source.

- Pull-in voltage: 10.16 V. Release voltage: approximately 4.4 V.
- Forward and reverse sweeps show a pronounced hysteresis window.
- Dashed curves represent unstable equilibria obtained by continuation.

5. Field-Emission Enhancement



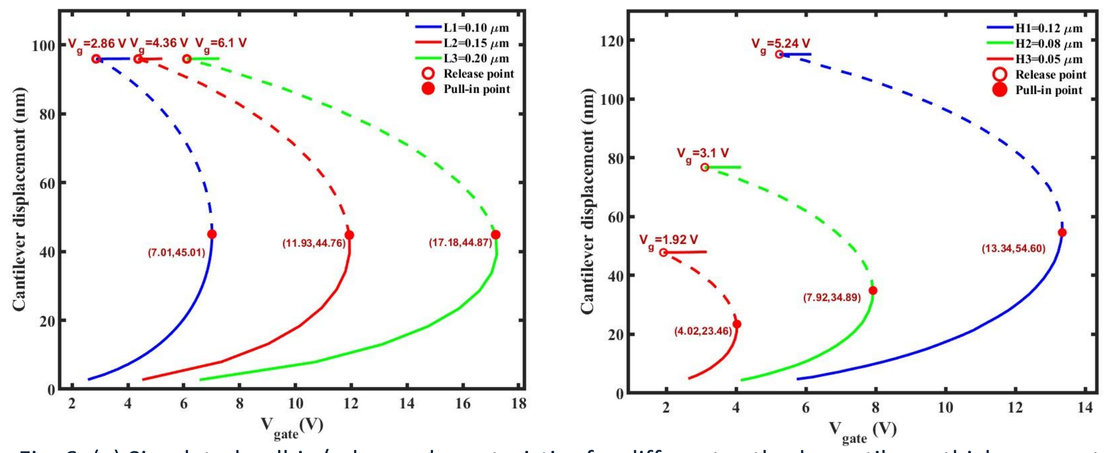
•Fig. 5.(a) Field emission current calculation and electron trajectory simulation (b) Current-Anode voltage (IA–VA) characteristics at the threshold and pull-in states.

- Before pull-in, the emitter–anode gap is larger and emission is weaker.
- After pull-in, the smaller gap strengthens the local electric field.
- At Va = 15 V, current rises from approximately 6 μA to 68 μA.
- Fowler–Nordheim tunneling explains the strong current sensitivity to field.

Electrostatic pull-in actively enhances field emission.

6. Parametric Study

A Cantilever thickness | **B Initial cathode–gate gap**

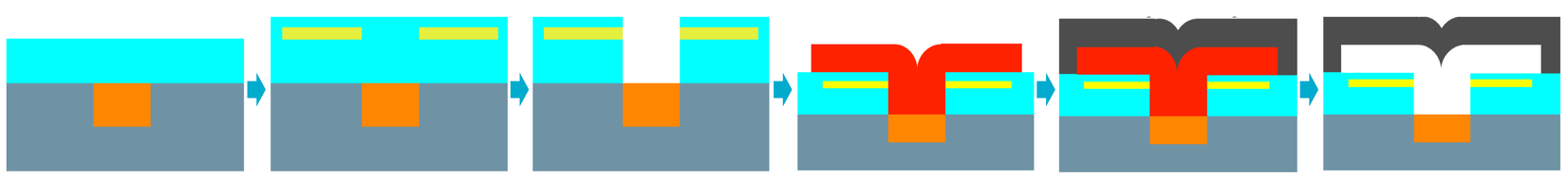


•Fig. 6. (a) Simulated pull-in/release characteristics for different cathode cantilever thicknesses at a fixed initial cathode-gate gap of 100nm.(b)Simulated pull-in/release characteristics for different initial cathode-gate gaps with a fixed cathode thickness of 0.14

- Thickness: 0.10 to 0.20 μm.
- Pull-in voltage: 7.01 to 17.18 V.
- Critical displacement stays near 45 nm.
- Initial gap: 50 to 120 nm.
- Pull-in voltage: 4.02 to 13.34 V.
- A larger gap requires higher actuation voltage.

Geometry tunes actuation thresholds and hysteresis.

7. Proposed Fabrication Process



Step 1 Buried anode and insulation

Step 2 Gate formation and insulation

Step 3 Channel / trench etching

Step 4 Conformal sacrificial film deposition

Step 5 Cathode deposition over the template

Step 6 Sacrificial release of the cantilever

8. Conclusion

- Self-aligned deposition and MEMS actuation enable electrical vacuum-gap regulation.
- Pull-in reduces the gap and substantially increases emission current.
- Cantilever thickness and spacing tune mechanical switching.

A simulated route toward tunable vacuum microelectronics.

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