MEMS cantilever with electrostatically-controlled tip contact

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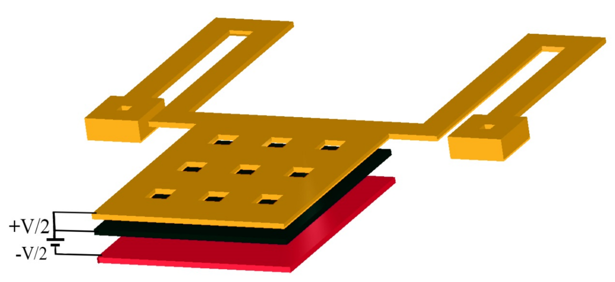
Introduction

A MEMS cantilever IR detector that lifts from the surface by electrostatic force is described. The design is comprised of three parallel square conductors. The lower two are fixed and are held at opposite potential, the upper moveable cantilever is biased the same as the middle plate. Here we provide analytical- and numerical- analysis and experimental proof of the electrostatic force. Size and position dependence of force is investigated to optimize device geometry. This design has application to MEMS micromirrors, switches and sensors.

Theory

The schematic below presents the considered device. A buried plate is held at –V/2 potential while a surface plate is held at +V/2, which is the bias as applied to a moveable cantilever above the surface.



The energy of a system of conductors at fixed potentials is

$$U = \frac{1}{2}\sum_{a,b} C_{ab}\phi_a\phi_b$$

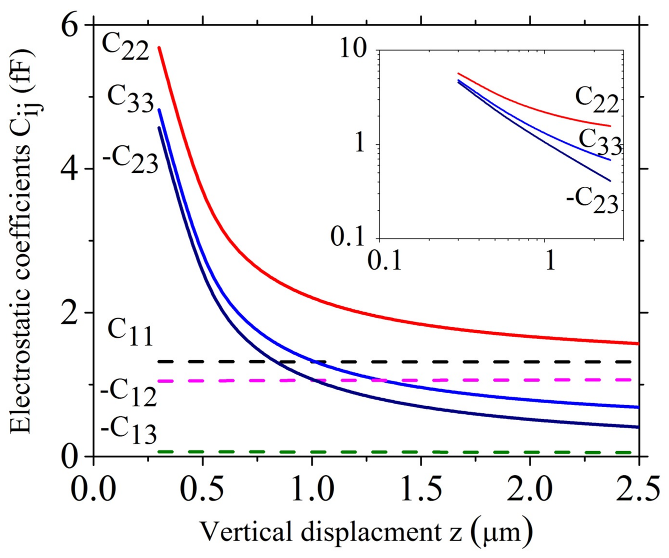
Where the coefficients of capacitance and electrostatic induction C_{ab} depend on shape, size and relative positions of the conductors. For our design

$$U = \frac{V^2}{8}\left[-2C_{12} - 2C_{13} + 2C_{23} + C_{11} + C_{22} + C_{33}\right]$$

Properly including energy of the voltage supplies needed to maintain potentials, we obtain

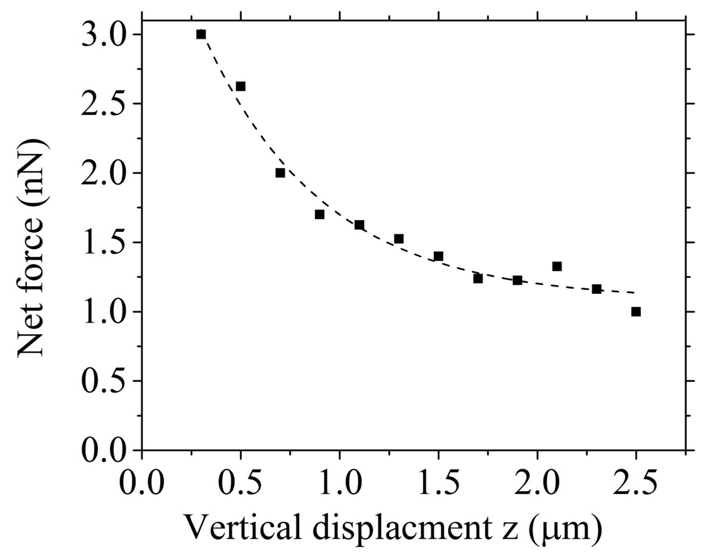
$$F = \frac{V^2}{8}\left[-2\frac{\partial C_{12}}{\partial z} - 2\frac{\partial C_{13}}{\partial z} + 2\frac{\partial C_{23}}{\partial z} + \frac{\partial C_{11}}{\partial z} + \frac{\partial C_{22}}{\partial z} + \frac{\partial C_{33}}{\partial z}\right]$$

Capacitance and induction coefficients were found numerically by FastCap,



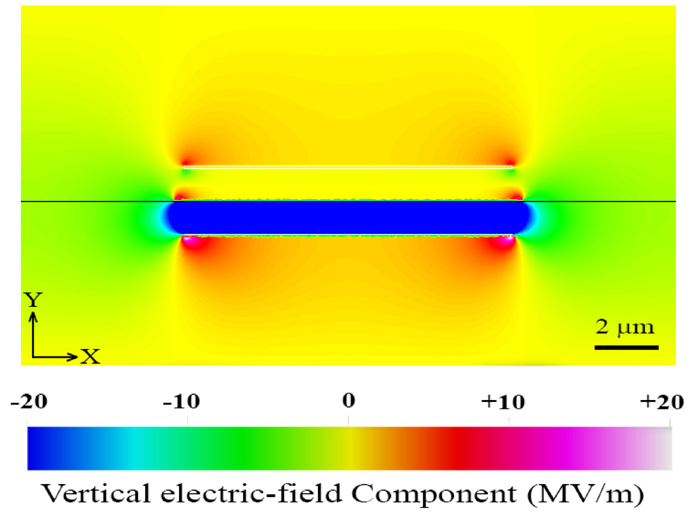
giving

$$F \cong \frac{V^2}{8}\left[2\frac{\partial C_{23}}{\partial z} + \frac{\partial C_{22}}{\partial z} + \frac{\partial C_{33}}{\partial z}\right]$$

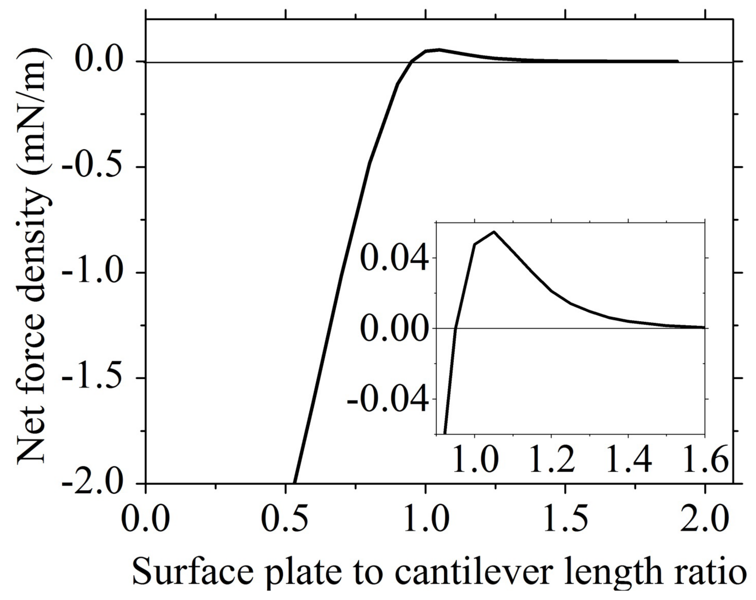


Numerical calculations

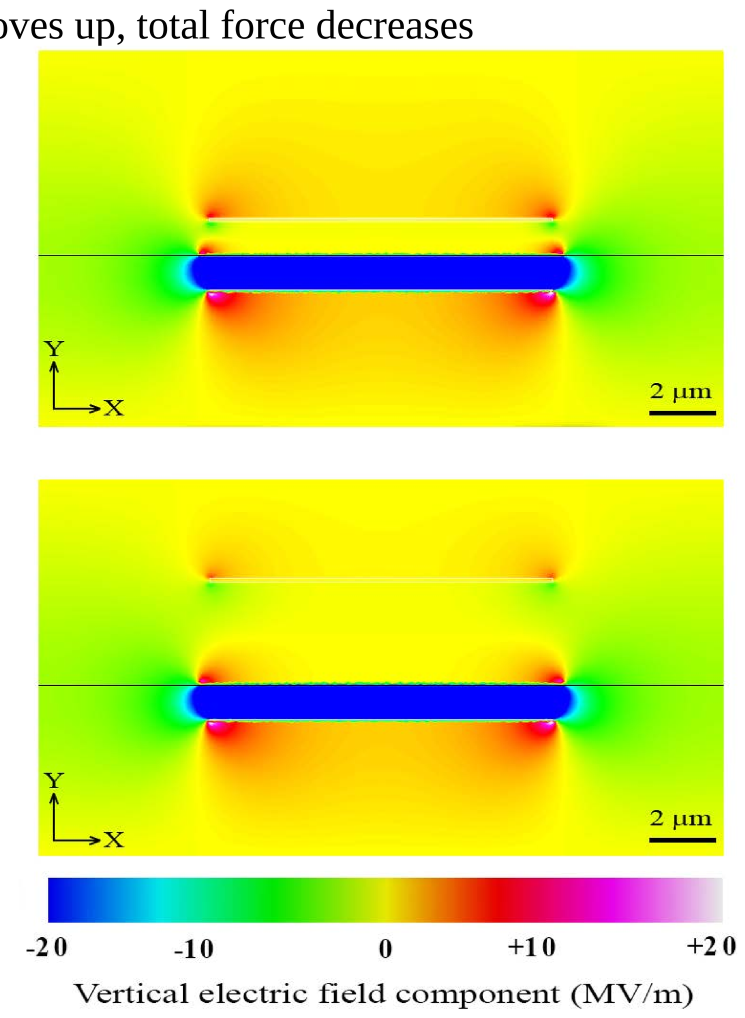
A 2D finite element calculations determine the net electric field from the local negative electrostatic pressure $\varepsilon_0 E^2/2$



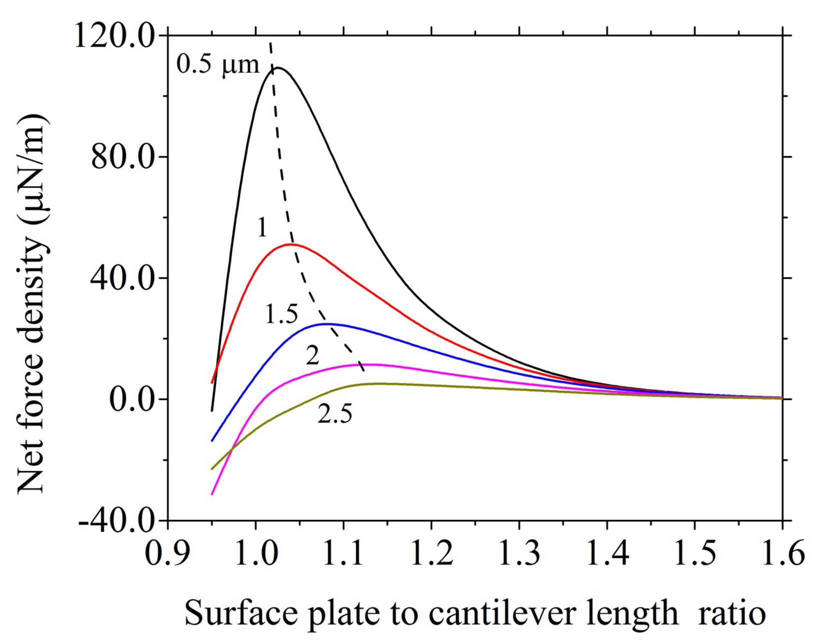
In the limit of no surface plate, the force on the cantilever is downward. In the limit of infinite surface plate, there is no net force on cantilever. due to perfect screening. The maximum upward force occurs at an intermediate surface plate dimension, slightly larger than the other plates, which we determine from numerical calulations.



As cantilever moves up, total force decreases

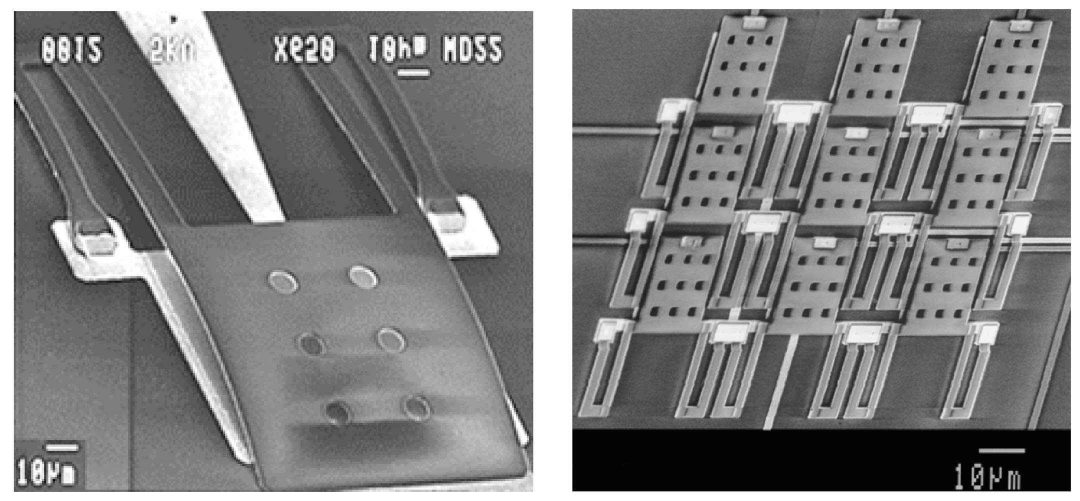


For larger separations z, the optimum size ratio increases. The maximum achievable net force is a decreasing function of z.



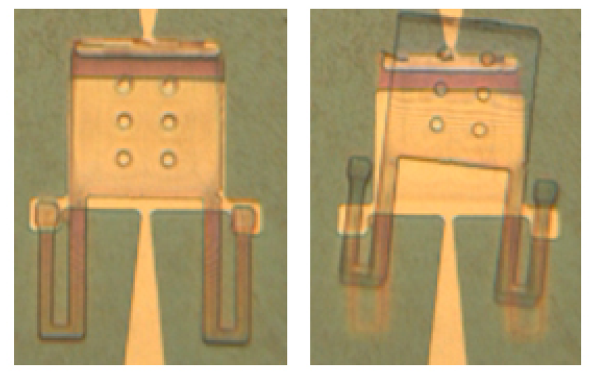
Fabrication and Testing

Single 100 µm elements and and 3x3 array of 20 µm elements were fabricated in the UCF Physics department cleanroom.

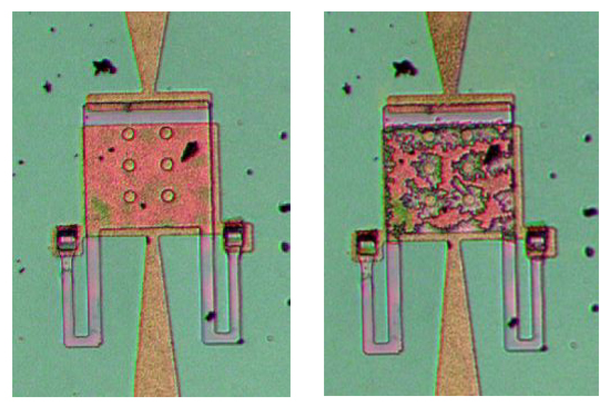


Upward motion of the biased cantilever was observed by video microscopy:

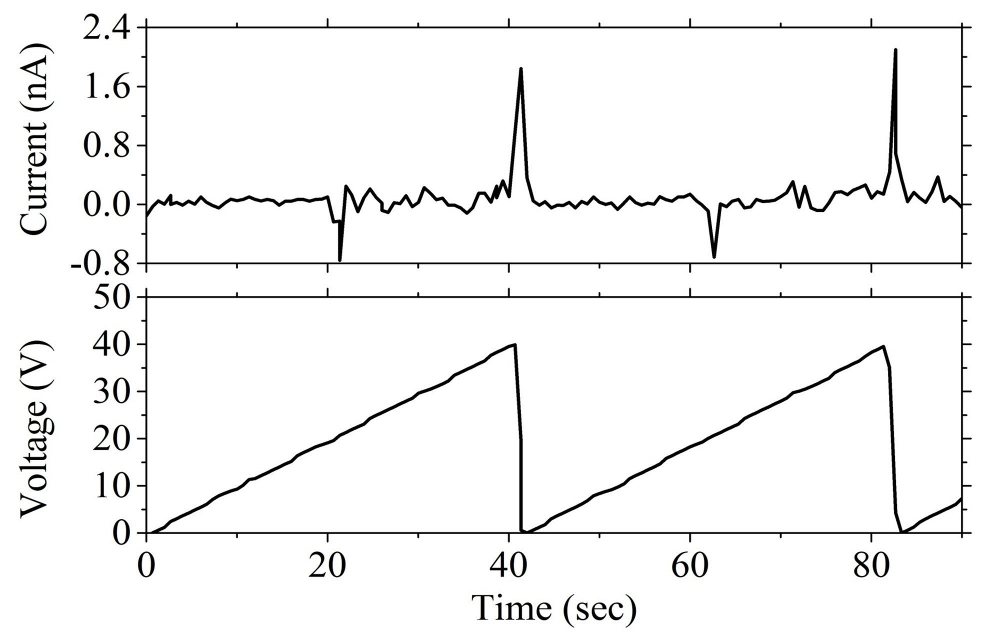
Moments before and after reaching 40 V applied bias, where the electrostatic force has become sufficient to rip the cantilever off of its anchors, causing it to be displaced.



Electrostatic force slowly lifts the cantilever from sticky residue of the polyimide sacrificial layer, causing air bubbles to push into the space under the semi-transparent cantilever from the edges and release holes.



Vertical displacement was also observed electrically by applying a saw tooth bias and measuring induction current through the tip contact. The sign and magnitude of the current transients are understood.



Conclusion

An electrostatic force that lifts a MEMS cantilever from the surface, for a design comprised of three parallel conducting plates, has been calculated theoretically, numerically, and demonstrated experimentally. Optimum surface plate to cantilever size ratio has been calculated and the effect of cantilever position on maximum force has been determined. This design can achieve high fill factor by burying extra components to achieve vertical motion. It may find wide application in MEMS devices to overcome sticking forces such as the Casimir force. It is also applicable for accurate position controlling of MEMS devices such as micromirrors, switches, and sensors.

Acknowledgments

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