

Abstract

Low-Voltage Tri-Electrode Electrostatic Actuator Using Solid Gap-Spacing Materials [†]

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Abstract: Employing a tri-electrode electrostatic actuator revealed a significant improvement in reducing the controlling voltage. However, the primary electrode fixed voltage can be a few times higher than the conventional topology. In this work, materials with relative permittivity of $\epsilon_r = 4.2$, 6.2 and 10 were explored as the spacing material to reduce the primary voltage, and the results are compared with using air. Simulations showed that the controlling voltage can be reduced more than two times (at $\epsilon_r = 4.2$) compared to the conventional topology while the primary electrode voltage required is lower than for air spacing and not more than two times larger than the conventional.

Keywords: MEMS; FEM; electrostatic actuator; pull-in effect; snap-down voltage

1. Introduction

The pull-in effect has always been one of the main design challenges of MEMS electrostatic actuators. In the conventional parallel plate topology, the actuator's travel range is limited to one-third of the gap spacing between the MEMS moving electrode and the stationary electrodes (D_1). The primary solution to the issue is to increase the gap spacing, which results in a higher required controlling voltage. There have been various approaches to reducing the controlling voltage besides increasing the range of motion [1]. Tri-electrode topology is another solution for reducing the controlling voltage, having two stationary controlling voltages. Figure 1 shows the conventional actuator configuration vs. the proposed tri-electrode topology. The tri-electrode consists of one perforated intermediate electrode with VI varying voltage and a solid electrode with fixed VP voltage. Simulation studies alongside experimental studies were carried out to show the performance of the actuator [2]. It was also shown that using a thicker gap-spacing material ($\epsilon_r > 1$) between the stationary electrodes (compared to filling with air/vacuum, $\epsilon_r = 1$) helps to simplify the fabrication while preserving the higher actuator's performance compared to the conventional topology. In this work, the impact of using different materials on the actuator's performance is investigated.



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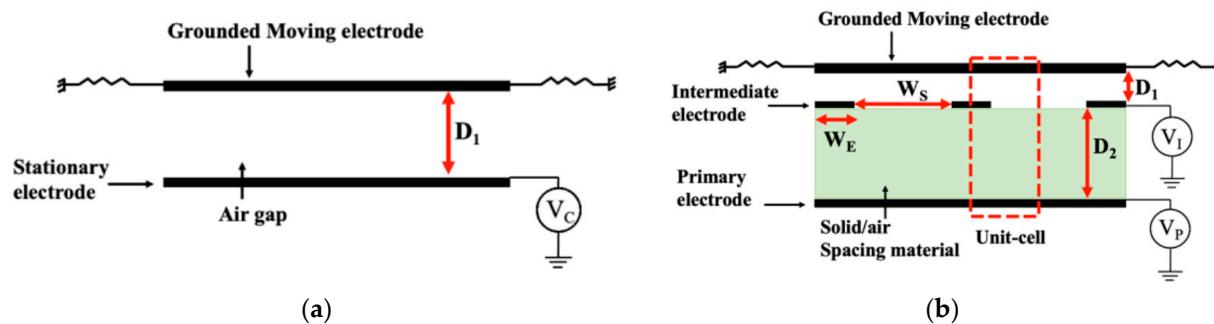


Figure 1. (a) Conventional parallel plate electrostatic actuator topology with V_C varying controlling voltage and (b) tri-electrode electrostatic actuator topology with fixed V_P and varying V_I controlling voltage.

2. Methods and Studies

Restoring spring force method and the FEM method were employed to extract the displacement vs. controlling voltage (V_I) response curves [3]. Each response curve is characterized by the snap-down voltage (V_S for conventional) and the displacement range (D_S for conventional) before snap-down. The figure of merit (FOM) is defined as the actuator displacement per controlling unit voltage (V_C or V_I). The tri-electrode simulations are normalized to the conventional topology's characteristics ($D_S = 1/3 D_1$ and $FOM_S = D_S/V_S$) to represent the improvements. The tri-electrode topology was studied in three modes of unipolar (FOM_u), bipolar (FOM_b) and maximum displacement. Materials with relative permittivity of $\epsilon_r = 1, 4.2, 6.2$ and 10 were explored as the spacing material between the stationary electrodes. The simulations were repeated for two different intermediate electrode gap spacings ($W_S = 3W_E$ and $18W_E$) illustrated in Figure 2, and the results are summarized in Table 1.

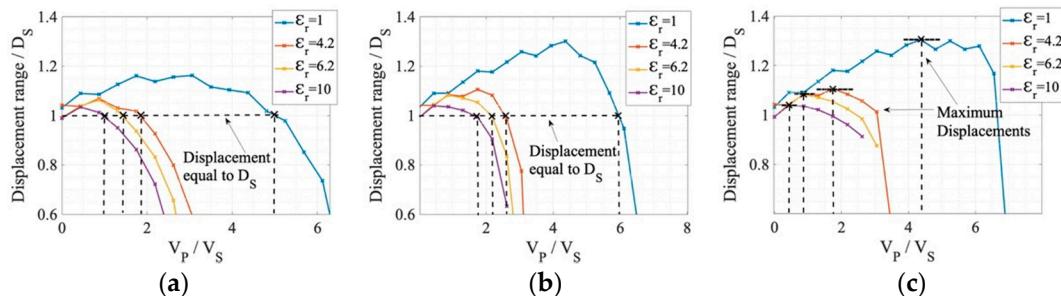


Figure 2. Displacement vs. V_P for (a) unipolar, (b) bipolar and (c) max displacement at $D_2 = 1.67D_1$ and $W_S = 3W_E$.

Table 1. FOM (unipolar and bipolar) and maximum displacement for $W_S = 3WE$ and $18WE$ for $\epsilon_r = 1, 4.2, 6.2$ and 10 .

ϵ	FOM _u /FOM _S		FOM _b /FOM _S		Max Displacement/D _S	
	$W_S = 3W_E$	$W_S = 18W_E$	$W_S = 3W_E$	$W_S = 18W_E$	$W_S = 3W_E$	$W_S = 18W_E$
1	1.50 ($V_P = 5.0V_S$)	1.34 ($V_P = 4.3V_S$)	3.10 ($V_P = 6.0V_S$)	2.70 ($V_P = 4.8V_S$)	1.30 ($V_P = 4.4V_S$)	1.62 ($V_P = 5.0V_S$)
4.2	1.09 ($V_P = 1.8V_S$)	0.74 ($V_P = 1.4V_S$)	2.12 ($V_P = 2.5V_S$)	1.59 ($V_P = 2.0V_S$)	1.11 ($V_P = 1.7V_S$)	1.20 ($V_P = 1.7V_S$)
6.2	1.00 ($V_P = 1.4V_S$)	0.70 ($V_P = 1.1V_S$)	1.60 ($V_P = 2.1V_S$)	1.25 ($V_P = 1.6V_S$)	1.08 ($V_P = 0.9V_S$)	1.13 ($V_P = 0.9V_S$)
10	0.85 ($V_P = 1.0V_S$)	0.64 ($V_P = 0.9V_S$)	1.20 ($V_P = 1.6V_S$)	1.12 ($V_P = 1.4V_S$)	1.04 ($V_P = 0.4V_S$)	1.08 ($V_P = 0.6V_S$)

3. Discussion and Conclusions

Simulations show that the higher the permittivity of the solid material, the smaller V_p at which the D_s displacement occurs. However, the maximum displacement possible before snap-down and FOM (unipolar and bipolar) are higher at a smaller ϵ_r . In all cases, the larger gap spacing ($W_s = 18W_e$) provides greater maximum displacement possible before snap-down, but a lower FOM. Comparing the cases of air ($\epsilon_r = 1$) and $\epsilon_r = 4.2$, and for the gap spacing $W_s = 3W_e$, we see that for bipolar operation, the controlling voltage is reduced by more than two times (2.12 FOM_S), needing a primary electrode voltage $V_p = 2.5V_s$, while the case of air requires a higher primary voltage for FOM improvement.

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