STABILITY ANALYSES OF ELECTROSTATIC TORSIONAL RF MEMS SWITCH

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Summary The stability analyses of the electrostatic torsional RF MEMS (radio frequency micro-electro-mechanical-systems) Switch are presented in the paper with the consideration of van der Waals (vdW) force. The critical applied voltage and tilting angle are calculated by static equilibrium equations. Furthermore, the dynamic behavior of RF MEMS switch is studied by the qualitative analysis of nonlinear equation of motion.

INTRODUCTION

Pull-in phenomenon is an important characteristic in the RF MEMS or NEMS switches. The actuating forces inducing pull-in include electrostatic force, vdW force, Casimir force and other surface forces. The analyses of pull-in phenomenon on torsional microactuators have been reported in some literatures [2-5], and the analytical models have been derived for the calculation of the pull-in voltage and tilting angle. The torsional NEMS actuator driven by Casimir force in experiments is introduced [1]. However, those researches did not consider vdW force. VdW force can be approximately neglected in MEMS, but play important roles in NEMS. Lin and Zhao [6] studied the dynamics behavior of nanoscale electrostatic parallel-plate RF switches, considering vdW force.

The SEM (Scanning Electron Microscope) image and 1 Degree of Freedom schematic of the torsional RF Switch [4] are shown in Fig.1. The angle of torsion φ is the only degree of freedom. When a voltage between one of the actuator electrodes and the movable plate is applied, the electrostatic force between them will produce an electrostatic torsion $M_{electr.}$ [4], simultaneously, vdW force between two parallel plates will produce vdW torsion M_{vdW}. When the plate rotates, the torsional beam will produce the mechanical restoring torque $M_{restoring}$ [4]. In addition, due to inertia and damping, there exists damping and inertia torque $M_{damping}$ and $M_{inertia}$ [4].

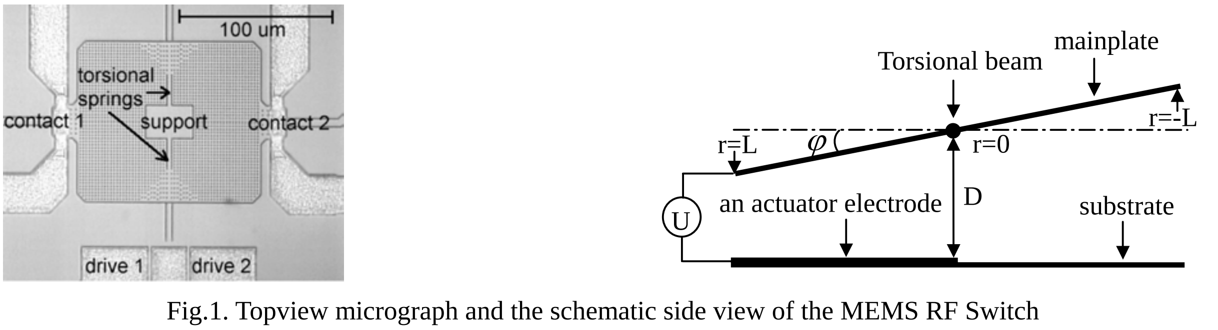

Fig.1. Topview micrograph and the schematic side view of the MEMS RF Switch

THEORICAL ANALYSIS OF STABILITY

Static equilibrium

In the static equilibrium, the equation with vdW torsion can be derived by

$$M_{electr.} + M_{vdW} = M_{restoring} \tag{1}$$

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The relation of applied voltage and tilting angle can be obtained by Eq.(1), furthermore, the critical voltage and tilting angle can be calculated. The critical tilting angle is not independent on the sizes of structures as shown in [4], but varies with the scales of structures, especially in nano-scale. Simultaneously, the error of critical voltage is large for the cases with and without the consideration of vdW torsion. It is because that vdW force plays an important role when the scale of device is sufficient small. When the gap between two plates gets further small and reaches critical value, the pull-in occurs even without the applied voltage.

Qualitative analysis of equations of motion

The dimensionless nonlinear equation of motion including vdW torsion can be obtained by

$$M_{electr.} + M_{vdW} = M_{restoring} + M_{damping} + M_{inertia} \tag{2}$$

The qualitative analysis of autonomous system of Eq.(2) shows that there are two equilibrium points when applied voltage exists, and three equilibrium points when applied voltage doesn't exist. For the first case, two equilibrium points are respectively a stable center point or focus point, and an unstable saddle point. The phase portraits connecting two equilibrium points on the phase plane show periodic, heteroclinic and homoclinic orbits (as shown Fig.2a and 2b). It can be concluded that the movable plate makes periodic oscillation or convergent oscillation near the stable equilibrium point and snaps down the substrate beyond the saddle point. For the second case, three equilibrium points are respectively a stable center point or focus point, and two unstable saddle points. The phase portraits connecting three equilibrium points on the phase plane show periodic, heteroclinic and homoclinic orbits (as shown Fig.2c and 2d).

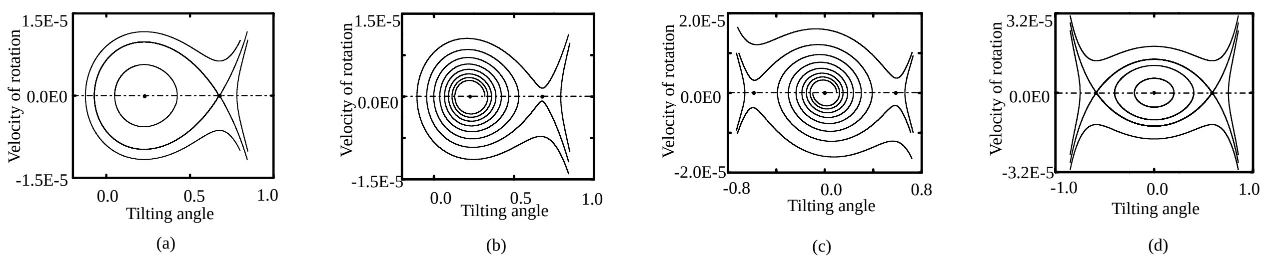

Fig.2 The phase portraits of the torsional RF MEMS switch with vdW torsion: (a) with voltage and without damping; (b) with voltage and damping; (c) without voltage and with damping; (d) without voltage and damping.

CONCLUSION

When the scales of structures are sufficient small, vdW force should be considered at the design of MEMS/NEMS actuator. Analysis shows that the inherent instability of the RF switch is dependent on the scales of structures. The critical tilting angle varies with the sizes of devices. The critical pull-in voltage has large relative error for sufficiently small scale if vdW torsion is neglected. Moreover, the pull-in can still happen without the driving voltage when the critical gap is reached. Furthermore, the qualitative analysis of the equation of motion shows that the equilibrium points of the corresponding autonomous system include stable focus point and center point, as well as unstable saddle point. The phase portraits show the periodic, heteroclinic and homoclinic orbits.

References

[1] H.B. Chan, V.A. Aksyuk, R.N. Kleiman, D.J. Bishop, F. Capasso: *Science*, vol. 291: 194-197, Mar. 2001.

[2] Y. Nemirovsky, O. Degani: *J. Microelectromech. Syst.*, vol. 10: 601-615, 2001.

[3] O. Degani, Y. Nemirovsky: *J. Microelectromech. Syst.*, vol. 11: 20-26, 2002.

[4] R. Satter, F. Plötz, G. Fattinger, G. Wachutka: *Sens. Actuators A*, vol. 97-98: 337-346, 2002.

[5] F. Plötz, S. Michaelis, R. Aigner, H.-J. Timme, J. Binder, R. Noé: *Sens. Actuators A*, vol. 92, no. 1-3: 312-317, 2001.

[6] W.H. Lin, Y.P. Zhao: *Chinese Physics Letters*, vol. 20, no.11: 2070-2073, 2003.