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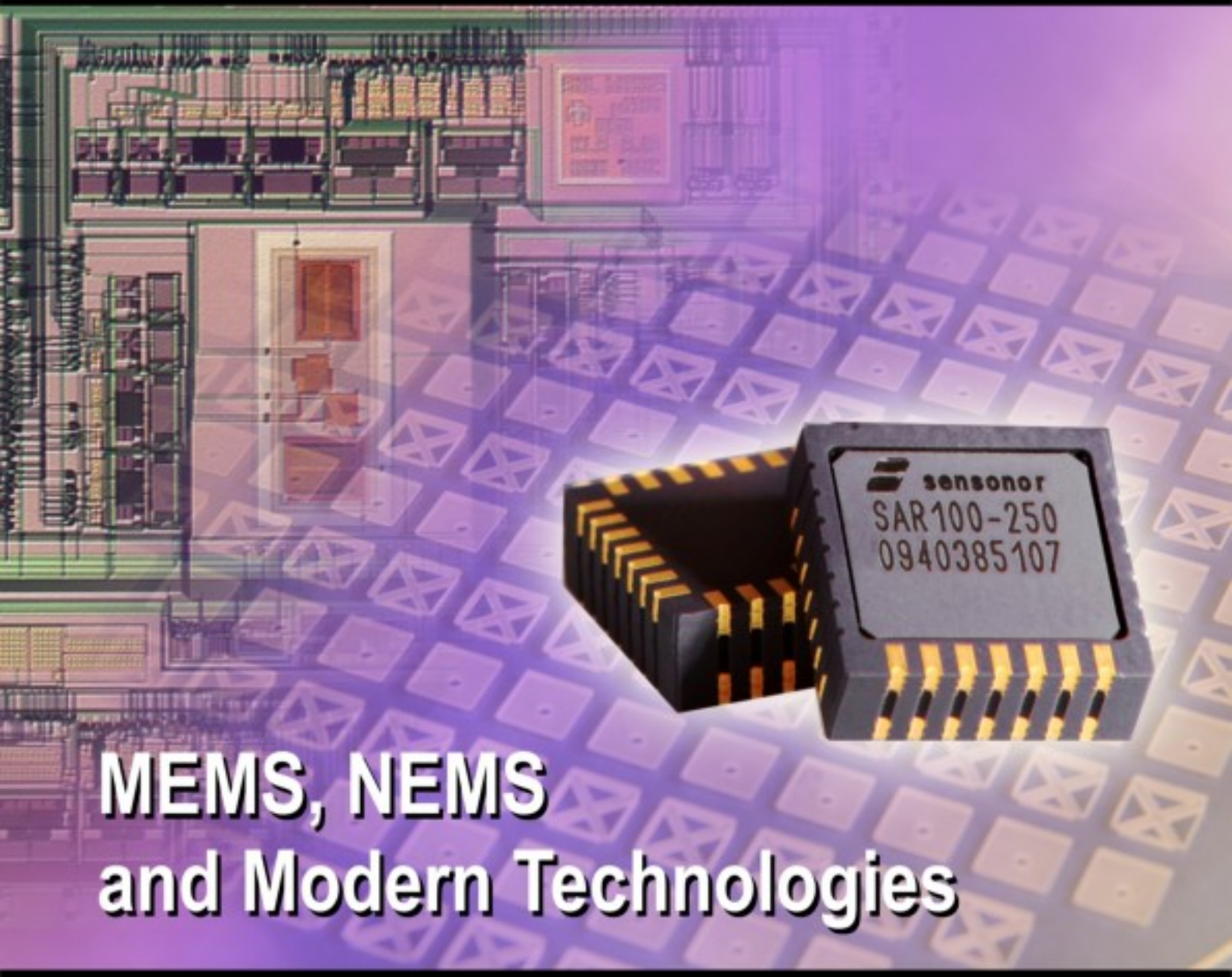

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Optimization of Contact Force and Pull-in Voltage for Series based MEMS Switch

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Abstract: Cantilever based metal-to-metal contact type MEMS series switch has many applications namely in RF MEMS, Power MEMS etc. A typical MEMS switch consists of a cantilever as actuating element to make the contact between the two metal terminals of the switch. The cantilever is pulled down by applying a pull-in voltage to the control electrode that is located below the middle portion of the cantilever while only the tip portion of the cantilever makes contact between the two terminals. Detailed analysis of bending of the cantilever for different pull-in voltages reveals some interesting facts. At low pull-in voltage the cantilever tip barely touches the two terminals, thus resulting in very less contact area. To increase contact area a very high pull-in voltage is applied, but it lifts the tip from the free end due to concave curving of the cantilever in the middle region of the cantilever where the electrode is located. Again it results in less contact area. Furthermore, the high pull-in voltage produces large stress at the base of the cantilever close to the anchor. Therefore, an optimum, pull-in voltage must exist at which the concave curving is eliminated and contact area is maximum. In this paper authors report the finding of optimum contact force and pull-in voltage. *Copyright © 2010 IFSA.*

Keywords: MEMS, Cantilever, Coventorware

1. Introduction

Micromachining is a technology that enables the batch fabrication of miniature mechanical structures, devices and systems [1]. MEMS technology is now rapidly emerging as an enabling technology to yield a new generation of high-performance sensors, actuators, resonators etc [2, 3]. MEMS switches are widely used in RF-microwave area, as RF switches, varactors, inductors, high Q-resonators, filters

and antennas [4, 5]. Further high power MEMS switches are also emerging as a new potential field. A standard MEMS switch considered for study is as shown in Fig. 1.

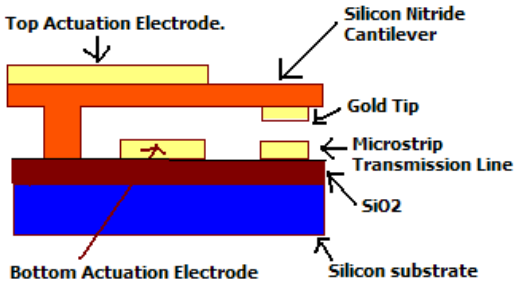


Fig. 1. Cross-section view of standard MEMS switch.

Fig. 1 highlights the selected configuration for current design. It is decided that the switch movement will be in vertical direction with electrostatic actuation mechanism. In electrical configuration the contact type will be of metal – to – metal direct contact (DC) and the circuit configuration will be of series type i.e. the switch contact will be placed in series with the transmission line. This type of switch configuration is called DC- Contact MEMS Series Switch and can be used for both RF and power applications. For RF MEMS Switch application the switch should have the signal lines and tip to be designed at desired RF-microwave frequency to be switch on/off. On the other hand for Power MEMS switch application the signal lines and tip should be of sufficient thickness to carry the required current. Further these switches can be arranged in series or parallel depending on high voltage or high current application.

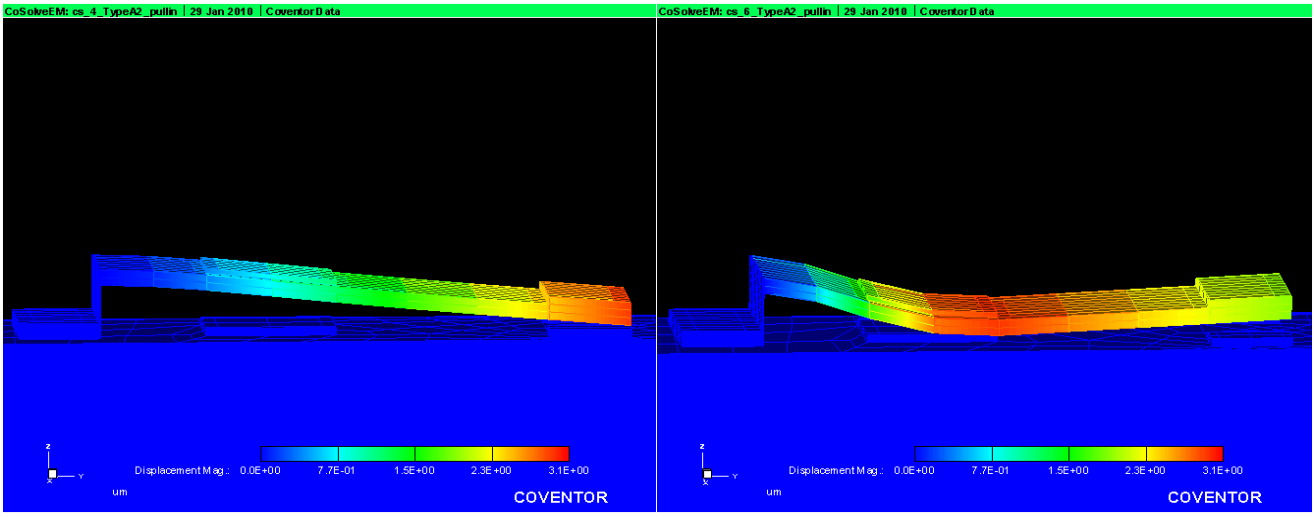
The MEMS switch performance parameters can be stated as follows, pull-in voltage, hold-on voltage, switching frequency, contact force and contact area. Clearly the MEMS switch should have lowest possible pull-in and hold-on voltage; and higher switching frequency, contact force and area. Pull-in voltage is defined as the voltage required to snap off the gap between the electrodes. But this voltage may not give the maximum contact force and area, which is required for better contact between the tip and the signal line.

Detailed analysis of the bending of the cantilever for different pull-in voltages reveals some interesting facts as shown in Fig. 2. At low pull-in voltage the cantilever tip barely touch the two terminals (see Fig. 2a.); thus resulting in very less contact area. To increase contact area a very high pull-in voltage is applied, but it lifts the tip from the free end (see Fig. 2b.) due to concave curving of the cantilever in the middle region of the cantilever where the electrode is located. Again result is less contact area. Furthermore, the high pull-in voltage produces large stress at the base of the cantilever close to the anchor. Therefore, an optimum, low pull-in voltage must exist at which the concave curving is eliminated and contact area is maximum. Initial simulation results, using Coventorware [6], are given at the two ends of applied voltage – low voltage and high voltage, to show evidence that the optimization problem exists.

In this paper authors report the finding of low optimum voltage that can give maximum contact force across the two terminals. The dimensions of the cantilevers were varied as follows.

- Cantilever Length: 325 um and 375 um.
- Cantilever width: 75 um, 100 um, and 125 um.
- Electrode position from anchor: 10%, 20%, 30%, and 40%.

The thickness of cantilever 1um was kept constant the materials used Silicon nitride for structural layer and gold for electrodes and tip was kept constant.



(a) (b)

Fig. 2. (a) Switch position at on-set of pull-in voltage, (b) Switch position when voltage is increased beyond pull-in.

2. Experiments and Result

Using the above variable parameters six set were made for optimization (see Table 1) by keeping one set of dimension fixed and varying the electrode position from 10% to 40% from anchor. The parameters were used to make models in Coventorware software, which were further simulated. The contact force and pull-in voltage was extracted from the simulated data.

Graphs were plotted from the data to find the lowest pull-in voltage, high contact force and high contact area.

From above plot in Fig. 3 it is clear that as the electrode positions moves away from anchor the pull-in voltage decreases, which is accepted as applied electrostatic force will decrease towards the free end of cantilever. The length of the cantilever has considerable effect on the pull-in voltage and width of cantilever has very less effect on pull-in voltage. Thus form all the sets above the least pull-in voltage is achieved by Set E i.e. cantilever length = 375 um; width = 100 um and with electrode position 40% (150 um) away from the anchor end which is 12 V.

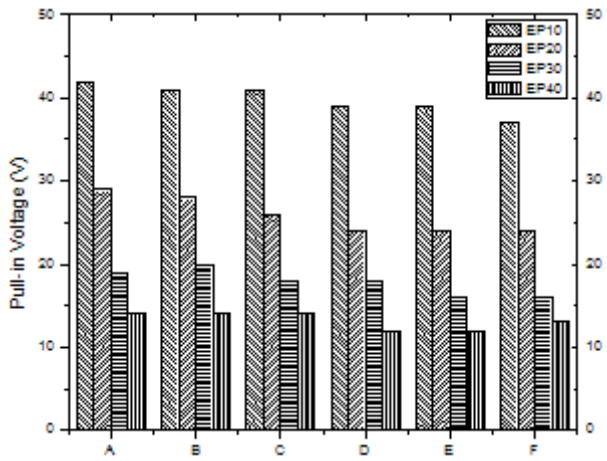


Fig. 3. Plot of Pull-in voltage v/s each sets with varying electrode position.

Table 1. Simulation Data.

Set Name	Model Name	Position (um) (Electrode position)	Pull-in Voltage (V)	Contact Force X 10^{-2} N
A L= 325um W=75um	A1	32.5 (10%)	44.25	1.063
	A2	65 (20%)	26.5	7.09
	A3	97.5 (30%)	18.2	2.037
	A4	130 (40%)	13.5	4.955
B L= 325um W=100um	B1	32.5 (10%)	41	2.33
	B2	65 (20%)	27	9.934
	B3	97.5 (30%)	17.75	2.544
	B4	130 (40%)	13	12.62
C L= 325um W=125um	C1	32.5 (10%)	42	6.47
	C2	65 (20%)	25.25	1.858
	C3	97.5 (30%)	18	3.323
	C4	130 (40%)	14	20.067
D L= 375um W=75um	D1	37.5 (10%)	39	3.624
	D2	75 (20%)	24	2.210
	D3	112.5 (30%)	18	9.657
	D4	150 (40%)	12	3.30
E L= 375um W=100um	E1	37.5 (10%)	39	4.65
	E2	75 (20%)	25	5.65
	E3	112.5 (30%)	16	1.121
	E4	150 (40%)	12	5.725
F L= 375um W=125um	F1	37.5 (10%)	37	1.647
	F2	75 (20%)	24	4.614
	F3	112.5 (30%)	16	3.510
	F4	150 (40%)	13	22.76

Fig. 4 of Contact force v/s electrode position overall doesn't show any pattern, but the maximum contact force is achieved with Set F i.e. cantilever length = 375 um; width = 125 um and with electrode position 40% (150 um) which gives contact force 22.7 x 10^{-2} N. Logically it is acceptable because this set has 125um width, which implies the maximum contact area. Similarly the other set C with cantilever length as 325 um and width 125 um with 40% electrode position shows contact force of 20.067 x 10^{-2} N, whose value is close to the maximum.

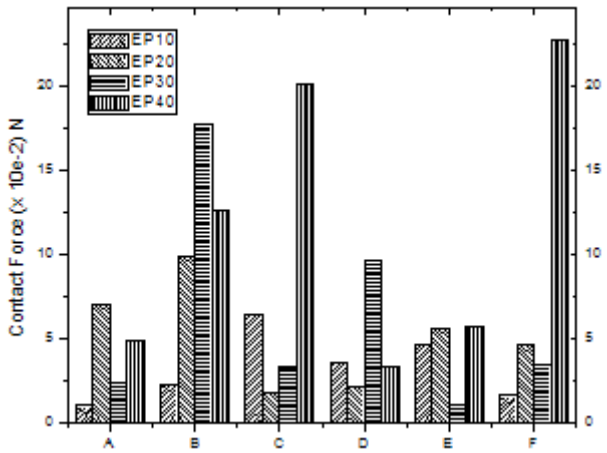


Fig. 4. Plot of Contact force v/s each sets with varying electrode position.

3. Conclusion

Optimization experiments were designed and simulation was done using Coventor ware software based on finite elemental method. The optimization was planned to achieve lowest pull-in voltage and maximum contact force which was achieved. The Set F with cantilever length of 375 um, width of 125 um and electrode position of 40% (150 um) which gave pull-in voltage of 13 V and contact force of 22.76 N. Thus for each structure/switch has an optimum pull-in voltage which will give maximum contact force, in this work it was Set F.

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Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually. *Sensors & Transducers Journal* is indexed and abstracted very quickly by Chemical Abstracts, IndexCopernicus Journals Master List, Open J-Gate, Google Scholar, etc.

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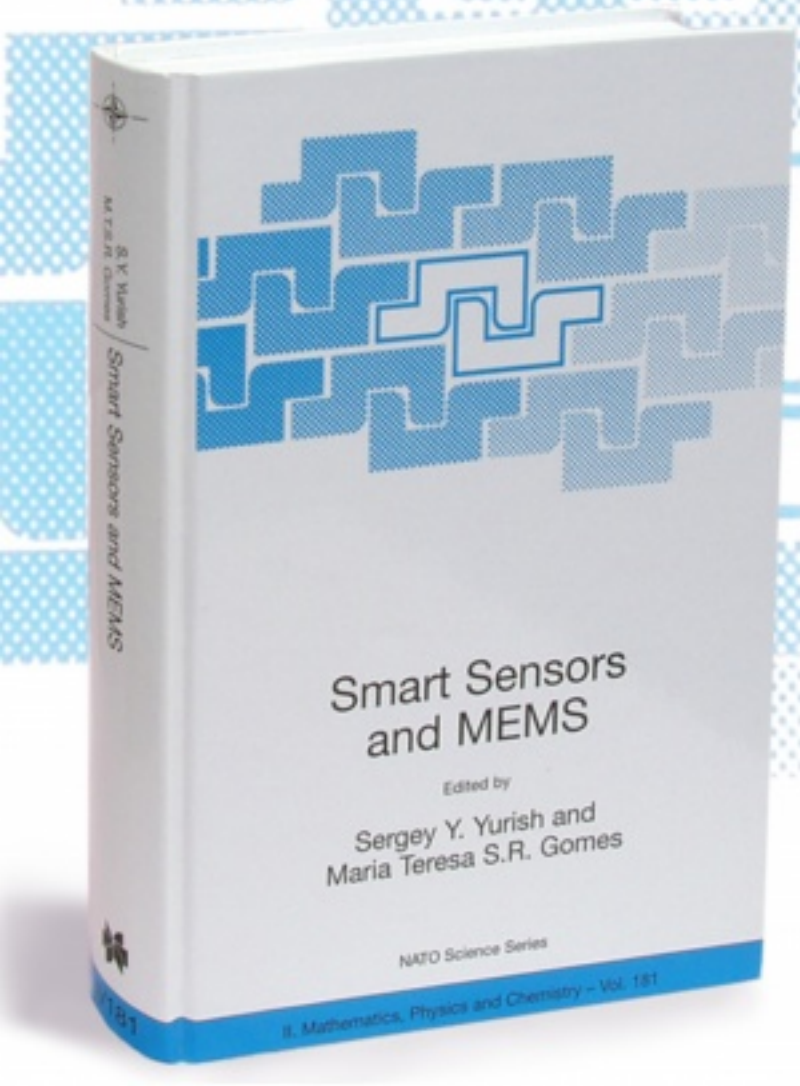

Smart Sensors and MEMS

Edited by

Sergey Y. Yurish and
Maria Teresa S.R. Gomes

The book provides an unique collection of contributions on latest achievements in sensors area and technologies that have made by eleven internationally recognized leading experts ...and gives an excellent opportunity to provide a systematic, in-depth treatment of the new and rapidly developing field of smart sensors and MEMS.

The volume is an excellent guide for practicing engineers, researchers and students interested in this crucial aspect of actual smart sensor design.

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