Journal of Nano- and Electronic Physics
Vol. **11** No 2, 02015(4pp) (2019)

Журнал нано- та електронної фізики
Том **11** № 2, 02015(4cc) (2019)

DC, AC, and Transient Simulation Study of MEMS Cantilever

S.S. Khot[1], A.A. Patil[1], V.N. Mokashi[2], P.P. Waifalkar[3], K.V. More[4], R.K. Kamat[2], T.D. Dongale[1,*]

[1] *Computational Electronics and Nanoscience Research Laboratory, School of Nanoscience and Biotechnology, Shivaji University, Kolhapur-416004, India*
[2] *Department of Electronics, Shivaji University, Kolhapur-416004, India*
[3] *Department of Physics, Shivaji University, Kolhapur-416004, India*
[4] *Department of Chemistry, Shivaji University, Kolhapur-416004, India*

(Received 17 October 2018; revised manuscript received 03 April 2019; published online 15 April 2019)

The present reports deals with the DC, AC, and transient simulation study of MEMS cantilever. The open-ended rectangular system is simulated in the present investigation. In the present case, we have varied the length of MEMS cantilever (platinum electrode) and studied its effect on the following cases: i) the effect of voltage on the capacitance and beam position (DC analysis), ii) time domain beam position, capacitance, and voltage (AC analysis), and iii) time domain beam position, capacitance, and voltage (transient analysis). The results suggested that the length of an active electrode of MEMS cantilever significantly affects the MEMS performance. In addition, the voltage of MEMS cantilever linearly increases with respect to time and it was found to be independent of the electrode length and dielectric materials, which were used in the considered system.

Keywords: Micro-electro-mechanical system, Simulation, Cantilever.

DOI: 10.21272/jnep.11(2).02015 PACS numbers: 85.85. + j, 07.05.Tp

1. INTRODUCTION

In recent years, micro-electro-mechanical systems (MEMS) have attracted significant attention due to their wide applicability in the many applications domains. They served as a basic building block for many applications such as sensors, biomedical devices, process control, automotive industries and defense [1-2]. However, they are different from the molecular technology or molecular electronics. MEMS's entire design is based on the synergetic integration of mechanical and electronic subcomponent. Due to current technological achievements, we can scale down such systems in micrometer scale or even nanometer scale (NEMS) and produce beautiful complex structures and systems for a variety of applications [3-4].

The size of indusial components of MEMS is in the range of 1 and 100 μm and entire MEMS devices or system come in the size of 20 μm to 1 mm [3]. The size and dimension of the MEMS decide the various figures of merits. For example, as we reduced the size and control on environmental effects, we can achieve high-speed operation, low noise, better stability in the operation, large operational voltage range, small footprint, low power consumption and low power dissipation [5-6].

In the present investigation, we have varied the length of active electrode of MEMS cantilever and studied its effect on various parameters, such as effect of voltage on the capacitance and beam position (DC analysis), time domain beam position, capacitance, and voltage (AC analysis), and time domain beam position, capacitance, and voltage (transient analysis). Furthermore, we have also studied the effect of the voltage on the capacitance in the transient analysis case.

2. DETAILS OF SIMULATION

MEMS actuating element is a thin parallel plate capacitor like the system in which electrodes are separated by air and a dielectric medium. In the present investigation, we have used platinum as an active electrode. In addition to this, we have selected four different dielectric materials, such as Aluminum Oxide (Al_2O_3), Hafnium Oxide (HfO_2), Silicon Nitride (Si_3N_4), and Silicon Dioxide (SiO_2) and studied the DC, AC and transient behavior for each case. The details of the simulation parameters are summarized in Table 1 and Table 2.

Table 1 – Dielectric materials used in the simulations

Sr. No.	Material	Dielectric constant
1	Aluminium Oxide	11
2	Hafnium Oxide	25
3	Silicon Nitride	7.5
4	Silicon Dioxide	3.9

Table 2 – Details of the simulation parameters of MEMS cantilever system

Sr. No.	Material	Size
1	Width	100 μm
2	Thickness	2 μm
3	Air Gap	3 μm
4	Dielectric Thickness	250 nm
5	No. of Grids	40

For the present investigation, we have used MEMS Lab simulation tool [7]. The platinum is used as an active electrode material for the present study. The various parameters of the platinum electrode are as follows: Young's modulus 168 GPa, Poisson's ratio 0.38, and density of the material 21450 Kg/m^3. In the present case, we have varied the length of active electrode of MEMS cantilever and studied its effect on various parameters, such as effect of voltage on the capacitance and beam position (DC analysis), time domain beam position, capacitance, and voltage (AC

* tdd.snst@unishivaji.ac.in

analysis), and time domain beam position, capacitance, and voltage (transient analysis). Furthermore, we have also studied the effect of the voltage on the capacitance in the transient analysis case. Other MEMS cantilever parameters, such as width and thickness of electrodes, air gap, dielectric thickness and numbers of grids are kept constant for all simulation cases. In order to study the behavior of beam position, capacitance and voltage with respect to time, we have varied the length of active electrodes, such as 300 μm, 400 μm, 500 μm and 600 μm, respectively.

3. RESULTS AND DISCUSSION

In the case of the MEMS cantilever, when the top electrode is attracted towards the bottom electrode, the top platinum electrode undergoes in pull in the state with respect to the bottom electrode. This results in either analog mode of operation or digital mode of the operation of the MEMS cantilever. In the analog mode, the position of the MEMS cantilever varies smoothly whereas, an abrupt transition is observed in the digital mode of operation. Both types of operation modes are useful in the various kinds of applications. For example, micro-mirrors used in the projectors or reflective diffraction grating used in the spectrometer use analog mode [8] whereas RF-MEMS capacitive or Ohmic switch use digital mode [9]. The DC simulation results of the present case are shown in Fig. 1.

The effect of length of the platinum electrode on DC capacitance-voltage (C-V) characteristics of MEMS cantilever with four different dielectric materials are shown in Fig. 1a-d, respectively. The general operational modes of the MEMS cantilever are divided into four sections viz. below pull-in state ($0 \le V < V_{PI}$), pull-in voltage ($V = V_{PI}$), post-pull-in state ($V > V_{PO}$), and pull out voltage ($V = V_{PO}$). It is observed that the pull-in voltage for all dielectric materials and electrode lengths remains the same, however dramatic change in the pull out voltage is observed for the various dielectric materials and electrode lengths. Furthermore, the capacitance of the MEMS cantilever also varies as a function of dielectric constant and electrode length. The results suggested that the Al_2O_3 based system possess lower capacitance and HfO_2 based system shows higher capacitance with respect to other dielectric materials and electrode lengths. The effect of length of the platinum electrode on beam position-voltage characteristics of MEMS cantilever with four different dielectric materials was simulated. The results suggested that both pull in voltage and pull out voltage change with respect to beam position scenario.

The AC analysis is important to investigate the effect of well behaving AC signal on the MEMS cantilever. The effect of electrode length on the time domain beam position characteristics of MEMS cantilever for different dielectric materials is shown in Fig. 2a-d, respectively. The results suggested that the stable beam position is achieved at the higher electrode length. In the present case, it is 600 μm. In addition to this, all dielectric materials show the same behavior. This suggested that the time domain beam position characteristic of the MEMS cantilever is independent of the dielectric materials. It is interesting to note that the time domain beam position fluctuated as the length of the active electrode increased. Furthermore, the effect of electrode length on

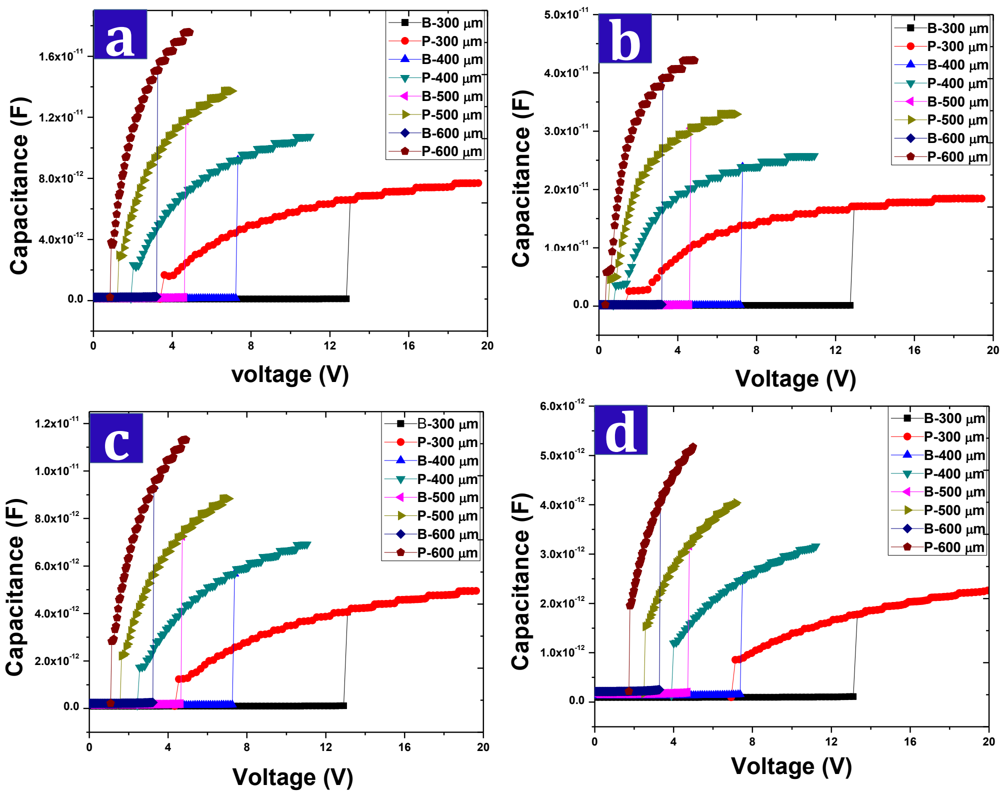

Fig. 1 – Capacitance-Voltage (C-V) characteristics of MEMS cantilever with four different dielectric materials: (a) Al2O3; (b) HfO_2; (c) Si_3N_4 and (d) SiO_2 and different lengths of the platinum electrode

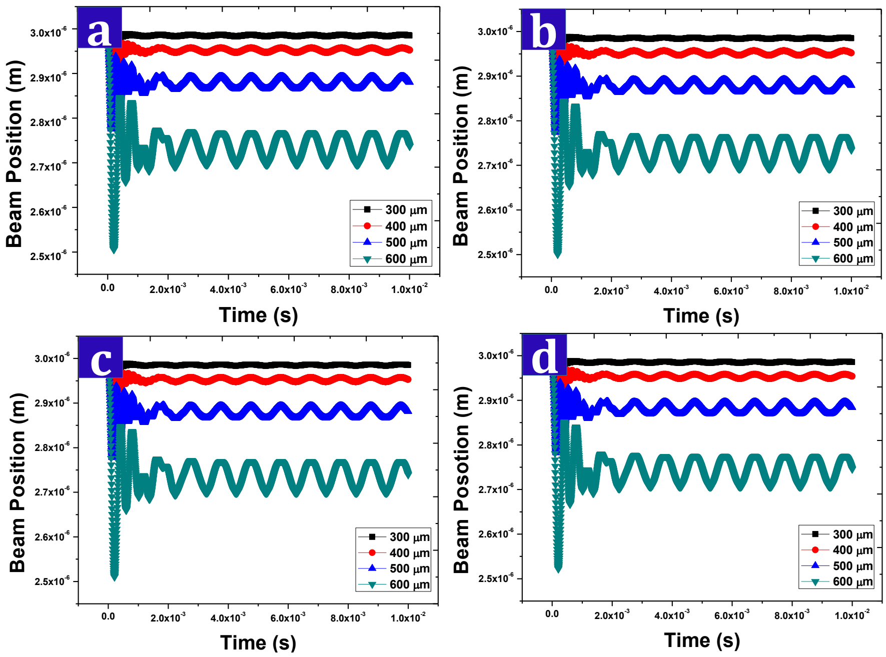

Fig. 2 – Effect of electrode length on the time domain beam position characteristics of MEMS cantilever for (a) Al_2O3; (b) HfO_2; (c) Si_3N_4 and (d) SiO_2 dielectric materials

the time domain capacitance characteristics of MEMS cantilever for different dielectric materials was simulated. It is observed that the magnitude of the capacitance tends to increase as the electrode length increases. It is interesting to note that the magnitude of the capacitance increases stepwise for a stepwise increase in the electrode length from 300 μm to 600 μm. The effect of electrode length on the time domain voltage characteristics of MEMS cantilever for different dielectric materials was simulated. The sinusoidal function like characteristics is observed for all cases. In addition to this, the amplitude of the voltage signal of MEMS cantilever for different dielectric materials is found to be constant for all cases. This suggested that the time domain voltage characteristics of MEMS cantilever are independent of the dialectic materials and electrode length.

The transient analysis is important to investigate the effect of signal on the MEMS cantilever. The transient analysis results of the MEMS cantilever with four different dielectric materials and different electrode lengths are summarized in this section. We particularly studied the following cases for transient simulation: time domain beam position with different electrode length with different dielectric materials, beam position vs. voltage with different electrode length with different dielectric materials, time domain capacitance with different electrode length with different dielectric materials, capacitance vs. voltage with different electrode length with different dielectric materials, time domain voltage characteristics with different electrode length with different dielectric materials. The effect of electrode length on the transient time-domain beam position characteristics of MEMS cantilever for different dielectric materials is shown in Fig. 3a, d, respectively. It is observed that the beam position characteristic of MEMS cantilever is dependent on the electrode length for the transient case. In addition to this, very small fluctuations are observed for the beam having lower length and larger fluctuations are observed for the beam having higher length. It is interesting to note that the HfO_2 dielectric based system shows the larger fluctuations than other dielectric based systems. This may be due to the high dielectric constant of HfO_2. Similar results are also observed in the case of voltage-dependent beam position characteristics of MEMS cantilever. The effect of electrode length on the transient time domain capacitance characteristics of MEMS cantilever for different dielectric materials was simulated. Similar to the AC case, the magnitude of the capacitance was found to increase as the electrode length increased in the transient case scenario. However, the HfO_2 dielectric based system shows a decrease in the capacitance at higher electrode length. This suggested that the study of the transient behavior is important to investigate the dynamic behavior of the system. Similar results are also observed in the case of the voltage-dependent capacitance characteristics of the MEMS cantilever. The time domain voltage characteristics suggested that the voltage of MEMS cantilever linearly increases with respect to time. Furthermore, it is independent of the electrode length and dielectric materials used in the system.

4. CONCLUSIONS

The results suggested that the length of an active electrode of MEMS cantilever significantly affects the MEMS performance. The DC analysis results suggested that the pull-in voltage for all dielectric materials and electrode lengths remains the same; however, a dramatic change in the pull out voltage is observed for the various dielectric materials and electrode lengths. Furthermore, the capacitance of MEMS cantilever also varies as a function of dielectric constant and electrode length. The AC analysis results suggested that the stable beam position is achieved at the higher electrode length. The time domain beam position characteristics of MEMS cantilever

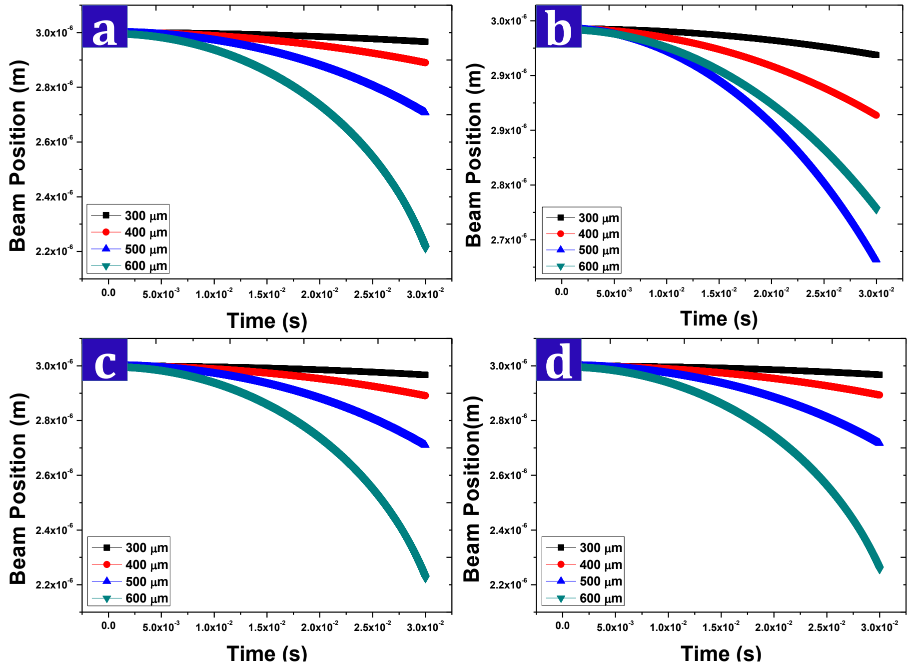

Fig. 3 – Effect of the electrode length on the time domain beam position characteristics of MEMS cantilever for (a) Al_2O3; (b) HfO_2; (c) Si_3N_4 and (d) SiO_2 dielectric materials

Is independent of the dielectric materials. Furthermore, the magnitude of the capacitance tends to increase as the electrode length increases. The transient simulation results suggested that the beam position characteristic of MEMS cantilever is dependent on the electrode length. Similar to the AC case, the magnitude of the capacitance tends to increase as the electrode length increases in the transient case scenario. Furthermore, the voltage of MEMS cantilever linearly increases with respect to time and it is found to be independent of the electrode length and dielectric materials used in the system.

REFERENCES

1. D. Yamane, T. Konishi, T. Matsushima, K. Machida, H. Toshiyoshi, K. Masu, *Appl. Phys. Lett.* **104**, 074102 (2014).
2. R. Jivani, G. Lakhtaria, D. Patadiya, L. Patel, N. Jivani, B. Jhala, *Saudi Pharm. J.* **24**, 1 (2016).
3. B. Du, J. Ma, X. Jiao, R. Zhang, H. Zhong, Y. Shi, *J. Nanosci. Nanotechnol.* **16**, 8061 (2016).
4. S. Palit, A. Jain, M.A. Alam, *J. Appl. Phys.* **113**, 144906 (2013).
5. A. Jain, S. Palit, M.A. Alam, *J. Microelectromech. Syst.* **21**, 420 (2012).
6. A. Jain, P.R. Nair, M.A. Alam, *Appl. Phys. Lett.* **98**, 234104 (2011).
7. O. Adeosun, S. Palit, A. Jain, M. Alam, X. Jin, MEMSLab (2014).
8. C. Winter, L. Fabre, F. Conte, L. Kilcher, F. Kechana, N. Abelé, M. Kayal, *Procedia Chem.* **1**, 1311 (2009).
9. S. Molaei & B. Ganji, *Microsyst. Technol.* **23**, 1907 (2017).

Дослідження моделювання постійного, змінного та перехідного струмів кантілівера MEMS

S.S. Khot[1], A.A. Patil[1], V.N. Mokashi[2], P.P. Waifalkar[3], K.V. More[4], R.K. Kamat[2], T.D. Dongale[1]

[1] *Computational Electronics and Nanoscience Research Laboratory, School of Nanoscience and Biotechnology, Shivaji University, Kolhapur-416004, India*
[2] *Department of Electronics, Shivaji University, Kolhapur-416004, India*
[3] *Department of Physics, Shivaji University, Kolhapur-416004, India*
[4] *Department of Chemistry, Shivaji University, Kolhapur-416004, India*

Робота присвячена дослідженню моделювання постійного, змінного та перехідного струмів кантілівера MEMS. У роботі моделюється прямокутна система відкритого типу. У даному випадку ми змінювали довжину кантілівера MEMS (платиновий електрод) і вивчали його вплив у наступних випадках: і) вплив напруги на ємність і положення променю (аналіз постійного струму), іі) положення променю у часовій області, ємність і напруга (аналіз змінного струму) та ііі) положення променю у часовій області, ємність і напруга (аналіз перехідних процесів). Результати показали, що довжина активного електрода кантілівера MEMS значно впливає на продуктивність MEMS. Крім того, напруга на кантілівері MEMS лінійно зростає з часом і виявилося, що вона не залежить від довжини електрода і діелектричних матеріалів, які використовувалися в розглянутій системі.

Ключові слова: Мікроелектромеханічна система, Моделювання, Кантілівер.