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Model Reduction for Pull-in Voltage Analysis of SOI MEMS based Capacitive Accelerometer

Neha Tiwari
Electrical Engineering
RCET,Bhilai

Sunil R. Gupta
Electronics and Telecommunication
RCET,Bhilai

ABSTRACT

In general, MEMS accelerometers fabrication relies more on trial and error than on clear design principles. Since the trial and error basis fabrication and testing of a MEMS are extremely costly, comprehensive modeling and simulation can be valuable tool to evaluate different designs and perform parametric studies each MEMS design before actual fabrication. This paper presents work done for SOI Mumps based capacitive accelerometer for health monitoring system and its reduction for the finite element simulation purpose in Coventorware. Reduction of structure for pull in voltage analysis by reducing the structure has been done. System level simulation is efficient in time but finite element method is needed for accuracy. Here the reduction of model needed as the structure is of thousand microns and its parts are of few microns, simulation of which is costly in computation time and resource needed.

KEYWORDS

Accelerometer, Capacitive, Coventorware Comb type, FEM, MEMS, SOI , Pull in Voltage

1. INTRODUCTION

In recent years, high resolution MEMS (Micro Electro Mechanical System) capacitive accelerometer is highly needed due to its enormous demand in various field [1]. The present work deals with the design and performance analysis of SOI (Silicon on Insulator) Mumps (Multi User Multi Processing) based Capacitive Accelerometer provided by MEMSCAP which gives 25 µm uniform thickness of structure and only provides one structural layer. SOI MUMPS is four mask level SOI patterning and etching process. This
process starts with SOI wafer whose substrate is 400µm thick, oxide
layer is 2µm thick and silicon (structural layer) is 25µm thick. It provides only one structural layer of silicon so the thickness of the device is of 25 µm all over [2]. A Finite Element (FE) simulation of these devices using the different software available is costly in terms of time as convergence problem. In general, MEMS fabrication relies more on trial and error than on clear design principles. The trial and error basis fabrication and after that testing of a device are extremely costly. Therefore, comprehensive modeling and simulation is highly needed before actual fabrication [3]. When it comes to FE simulation for pull in voltage analysis it's task of highly computation time. Pull in phenomenon is very common in comb type accelerometer, analysis of which is very important for successful operation of device [4]. Comb type capacitive accelerometer consist of two types of fingers fixed and moving combs. The movable fingers are attached to a proof mass and proof mass is suspended by beam or, spring which is anchored in frame. The proof mass and moving or sensing combs moves with applied acceleration. The proof mass and movable fingers move along the direction of body force. This movement changes the gap between combs and capacitance between them changes accordingly. Comb type capacitive accelerometer has four different parts proof mass, Beam or Spring, Moving combs or sensing combs and fixed combs. Here, we are designing the comb type accelerometer which is having the following dimensions as given in Table 1.

Table 1 Dimensions of Structure

Structural Parts	**Dimensions**
Proof mass (µm)	4022 x 1200 x 25
Structural layer thickness (µm)	25
Overlapping length of sense combs (µm)	500
No of Sense Comb	112
No of actuation combs	5
Gap between fixed and moving fingers	2
Spring or Beam (µm)	330 x 6
Calculated Mass (Kg)	3.0165 E-07
Spring constant (N/m)	107.60

For FE simulation of this models partition is needed as the different parts have different dimensions (figure 1). While performing static analysis capacitance can be calculated by taking each part of the structure i.e. (moving comb, sensing comb, proof mass, beam and frame) and all should be partitioned for efficient meshing as all are having different dimensions. This process takes lot of time and resources and gives memory related issues. And when the simulation has been carried out it took very high computation time.

2. PULL- IN VOLTAGE

Actuation fingers has been provided in the structure for self test purpose of the device. When voltage is applied in this combs, electrostatic force generated between them. This force will work to reduce the gap between them. At small voltages, this force countered by spring force but as voltage increases the combs will eventually snap together. As long as spring force (restoring force) is greater than electrostatic force the system will work properly but the point comes when electrostatic force will overcome restoring force and combs (fixed and moving comb) will stuck with each other. This phenomenon of accelerometer is called pull in effect. And, the voltage at which Electrostatic force equals to restoring force is called Pull in Voltage (V_P) .There are various methods available for calculating it [4]. The simplest expression is given by equation (1).

$$V_p = \sqrt{\frac{8Kd^3}{\in A_{el}}} \quad \dots (1)$$

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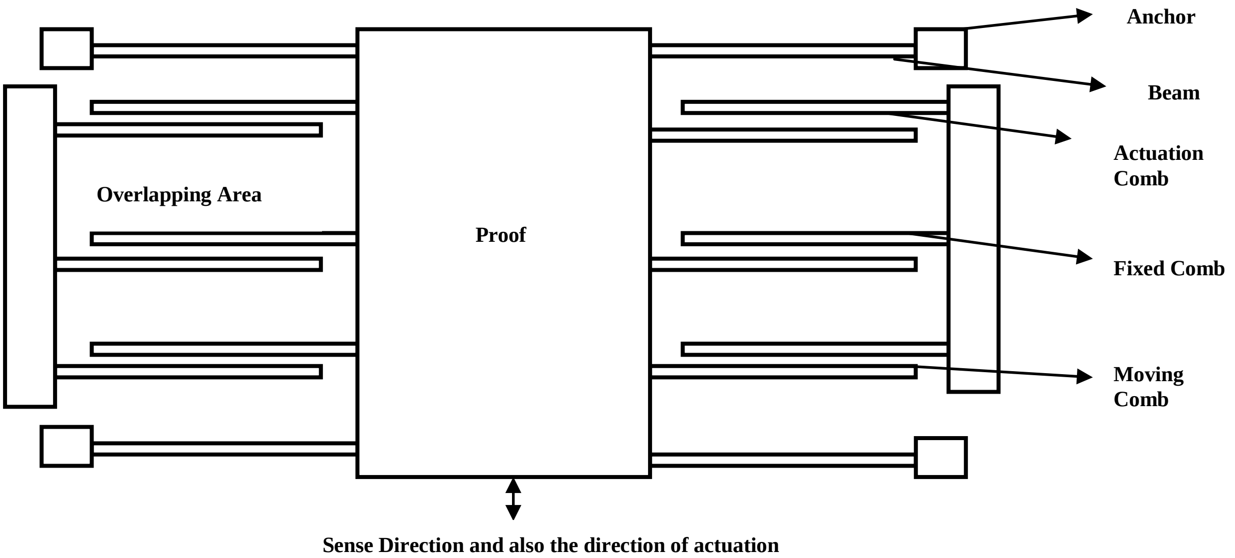


Fig 1 Structure of Accelerometer

coming by FE simulation (Cosolve or, Elecro-mechanical Analysis) is 3.5V ± 2% . This 2% fluctuation in result is coming for different values of number of combs i.e. $3/4^{th}$,

Where K is the equivalent spring constant, d is the gap between the combs, Ɛ is the permittivity and A_{el} is the equivalent area between the combs.

3. Reduction of Structure

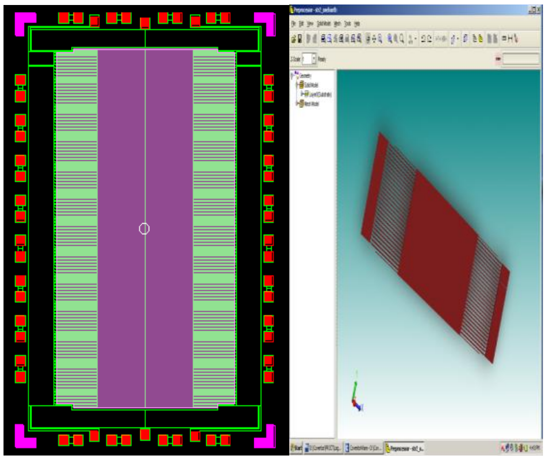
In this design the equivalent area is multiplication of number of comb sets to area of each comb set. The equivalent spring constant is equal to beam constant of one beam (Figure 1). For pull in voltage simulation all of the parts of structural layer should be considered which consist of moving as well as fixed combs. And, we need frame also for fixing the combs in a simpler way. After this for meshing we need to partition the structure having different dimension. For this process also the capacity of RAM and hard disk needed is quite high which is not possible in low grade CPUs. For reducing the computation time the structure size should be reduced so that the number of elements after meshing reduces. By equation (1) only equivalent area which is 2n times the overlapping area for each comb.

4. Simulation Results

The 2D layout of accelerometer shown in figure 2 (a) is showing the complexity of structure. So by reducing this to certain level the computation time and resource needed can be reduced. Figure 2 (b) shows the 3D of reduced modal. The simulation has been carried out in Coventorware by FE tool and Saber tool. The structure has been simulated for pull in voltage by taking one fourth, half and three fourth of the total model. And, the pull in voltage coming for each has been matched with each other in the variation of ±2% which is quite less. In saber simulation tool we don't have a provision of providing actuation combs. So, we have to take each comb as a sensing combs so that it will give some difference in the simulation results. The pull in voltage

half and $1/4^{th}$ of the total number of combs. And, by system level simulation pull in voltage is 3.63 V due to change in number of combs as we don't have a provision of actuation combs in saber simulation. This mismatch is of 3.71% between the two simulation methods. Fig 3 shows the simulation time reduces

with reducing the size of the structure. By calculating the pull in voltage for small multiple of structure one can calculate the value for the whole structure.



(a) (b)

Fig 2 (a) 2D layout of accelerometer (b) 3D modal of reduced structure

5. Conclusion

Finite Element method is widely used due to its accuracy. But it is costly in computation time as well as resource needed. And, also for simulation of MEMS comb type capacitive accelerometer of thousand microns size having a various different parts of few microns only is a very tedious task. This paper gives the reduction technique for FE simulation of static analysis i.e. for finding pull in voltage. By reduction of the structure we are getting accurate result within tolerance of 2% and reduced computation time. Many other methods are available for reduction of model in FE simulation but this is one of the simplest one.

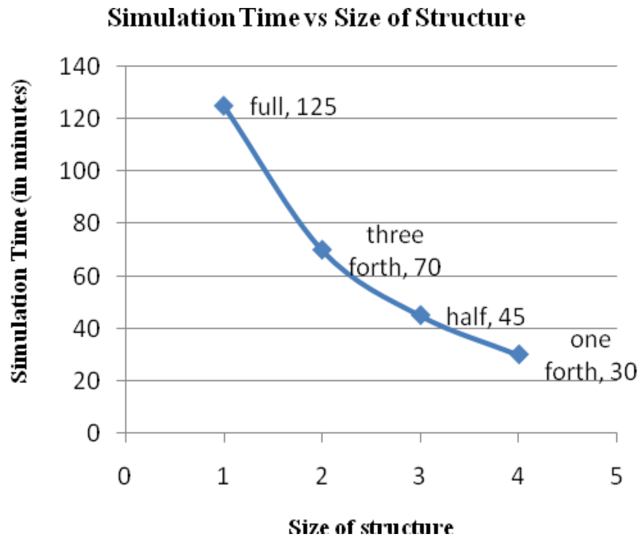


Fig 3 Simulation time vs Structure Size

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