A Novel Scheme of Mesh Generation from an Arbitrary Topography for MEMS Analysis

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ABSTRACT

This paper reports on the modeling and simulation methodology by using a scheme of mesh generation from an arbitrary topography for electrostatically driven microelectromechanical systems (MEMS). Using process recipe with mask layout generates a MEMS device, followed by the mesh generation. And then, a finite element method (FEM) is employed for calculating electric potential and capacitances. The modeling and simulation methodology is demonstrated using the combdrive of the size 452 μm _ 156 μm _ 8 μm as a representative example. The result is compared with the commercial tool to the electrostatic simulation, which is demonstrated with good accuracy. In addition, the simulation for a variation of capacitances as the effect of manufacturing tolerances is presented.

Keywords: MEMS, FEM, NURBS, topography, mesh generation.

1 INTRODUCTION

The exact calculation of electric capacitances of electrostatically driven microelectromechanical systems (MEMS) has become a crucial part of design and performance prediction. There have been repeatedly reported a variety of numerical methods and algorithms for the computation of electrostatic field problems and the subsequent calculation of capacitances of 2D and 3D geometries [1, 2]. However, the simulation for a variation of capacitances as the effect of manufacturing tolerances is rarely possible. Besides, approximating a complex structure makes it difficult to calculate exactly.

In this paper, we report a scheme of mesh generation from an arbitrary topography for MEMS analysis. This approach makes possible to analysis MEMS by representing excellently the surface without approximating a complex structure. And then, using process recipe with mask layout generates a finite element model of micro-combdrive, follow by simulating the effect of manufacturing tolerances.

2 SIMULATION METHOD

A 3D complex structure is generated by the topography simulator by using cell method based on the user-defined process recipe generated by layout and run-sheet editor [3]. It is difficult to simulate directly from the complex 3D structure that was generated by the topography simulator. To translate from the planar/non-planar resulting structure into mesh structure, a novel approach is proposed. We perform the critical step such as following steps: a) Extract polyhedrons formed by cell-faces only, which the material index of cells is same. b) Separate each polyhedron into polygons. The exposed direction of cell of the each polygon is same, or the angle between normal vectors of each cell is within critical angle. c) Extract nodes from a polygon edge, and sort them by counter clockwise. If there are inner polygons, inner nodes are split off. d) Find common polygons between polyhedrons. Finally, e) Write in a text file involving nodes, polygons, polyhedrons, and overall nodes on the each polygon for the data format of mesh generation. A mesh generation is performed by using AFM (Advancing Front Method) with Non-uniform rational B-spline (NURBS) generated with scattered data for each polygonal surface [4].

The data structure to perform the above steps is shown Fig. 1. Referring to Fig. 1, each polyhedron and polygon can has inner polyhedron and polygon, respectively. Fig. 2(a) is a schematic view illustrating the method defining a surface normal vector of 3D polygon composed of the cell-faces. The surface normal of a given polygon is calculated by summing up the normal vectors of surface cells within a certain vicinity to that surface point. The nodes are extracted along a polygon edge as shown in Fig. 2(b) and the above step 'c)'.

Fig. 3 shows a schematic diagram illustrating the micro-combdrive comprised of two electrodes, four anchor, folded beam, and comb finger as a representative example. The dimples are not included in the model. As a voltage is applied onto movable electrode or stationary electrode, the electrical charges are induced on the surface of the electrode. And then, the capacitance and electrostatic force are induced between electrodes. The electric potential, ϕ is calculated by solving Laplace's equation, Eq. (1). And then, the electric field, E is calculated by using Eq. (2). We employed a finite element method (FEM) for electrostatic analysis.

$$\varepsilon_0 \nabla(\varepsilon_r \nabla \phi(\vec{r})) = 0 \quad (1)$$

$$E = -\nabla \phi(\vec{r}) \quad (2)$$

where ε is the dielectric constant of the medium in which the plate id placed. For calculating the capacitance, we employ the principle of energy conservation using the electric field energy stored in the volume as shown in the Eq. (3). The relation of Eq. (4) is used to calculating capacitance.

$$W = \frac{1}{2}\varepsilon_0 \iiint_v \varepsilon_r [\nabla \phi(\vec{r})]^2 dV \quad (3)$$

$$W = \frac{1}{2} C U^2 \quad (4)$$

where U is the voltage differences.

Using a layout editor and run-sheet editor, and graphic user interface provided in this work creates the solid model [5]. The layout and the solid model after process simulation under investigation are shown in the Fig. 4. The solid model is converted the mesh structure for finite element analysis (FEA). Fig. 5 is the FE model of the size 452 μm _ 156 μm _ 8 μm constructed by extruding a vacuum volume. The resultant meshed model has 37,380 tetrahedron elements and 9,720 nodes. These numbers doesn't change with geometric tolerances.

3 RESULTS AND DISCUSSION

Fig. 6 shows an electric potential and electric field distribution. The applied voltage onto movable electrode is 25 [v]. The capacitance calculated by using results of electric potential and electric field distribution was 2.211 [fF]. The result was compared with the commercial tool to the electrostatic simulation [6]. The dimension is equal to our FE model. The result of the commercial tool is 2.136 [fF], which is the difference of 3.39 %.

We investigated a variation of capacitances as the effect of geometric tolerances that may produce during the manufacturing. In Fig. 7, The geometric tolerance is the range of –10 % ~ + 10 %. As a result, the resultant capacitances is the range of 2.191~2.227 [fF]. The sensitivity (the range of capacitance / the range geometric tolerance) defined in this work is 0.000398 [fF/μm].

4 CONCLUSIONS

We have generated the mesh from an arbitrary topography. And then, we have calculated capacitances of electrostatically driven micro-combdrive by employing the principle of energy conservation. The result has compared with the commercial tool to the electrostatic simulation, which has demonstrated with good accuracy within 3.39%. In addition, the sensitivity defined in this work is 0.000398 [fF/μm]. As a result, we have confirmed that the simulation of sensitivity with geometric tolerance can be investigated to quantify the reliability of MEMS devices.

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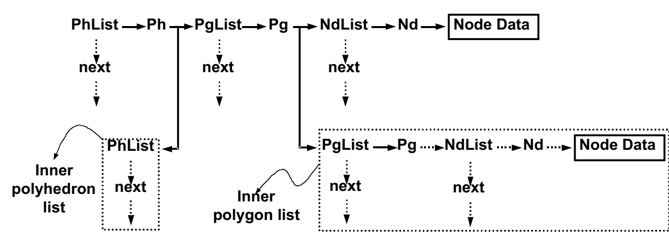
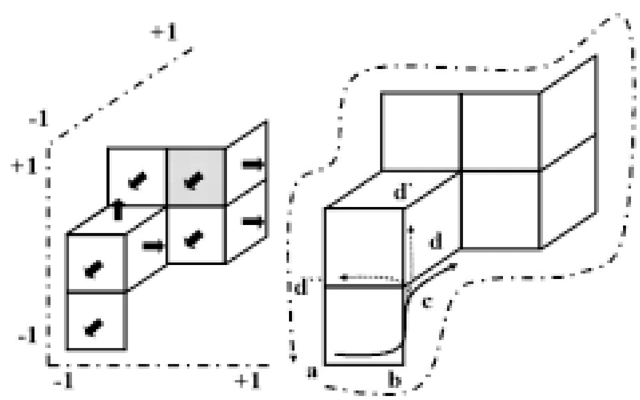


Figure 1: Schematic view illustrating a data structure for translating 3D cellular topography into the mesh structure.



(a) (b)

Figure 2: Schematic views illustrating (a) a surface normal of 3D polygon and (b) an edge of 3D polygon composed of the cell-faces.

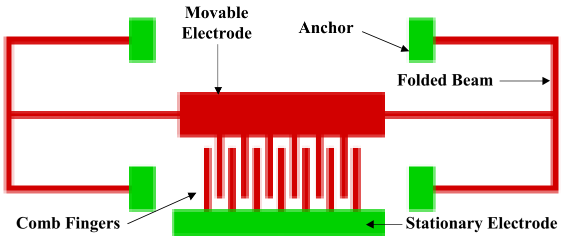
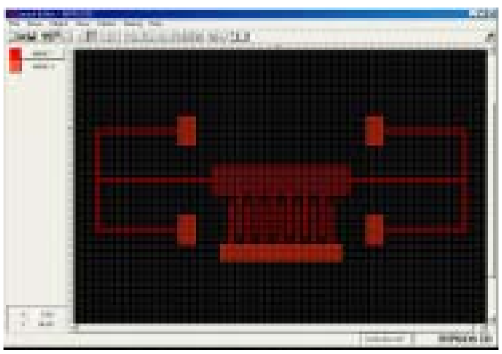
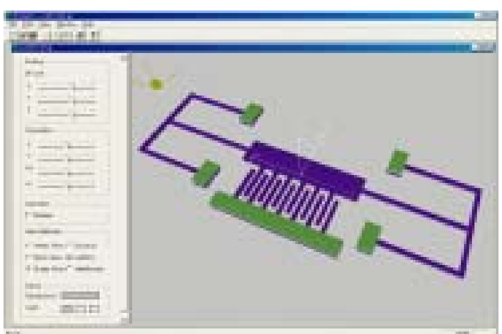


Figure 3: Schematic diagram illustrating the micro-combdrive.



(a)



(b)

Figure 4: Plots showing (a) a layout and (b) a solid model of the micro-combdrive.

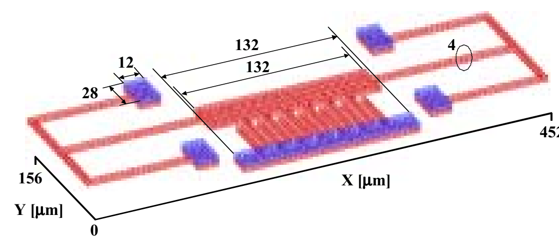
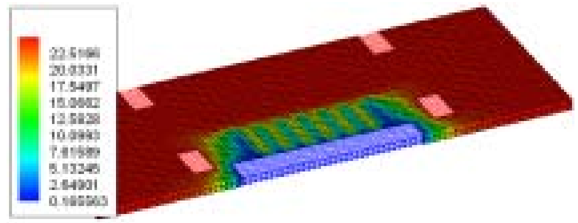
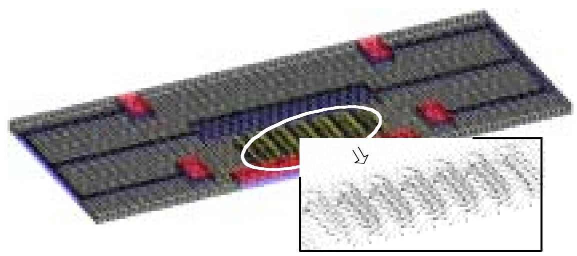


Figure 5: Plots showing a finite element (FE) model.



(a)



(b)

Figure 6: Plot showing (a) an electric potential distribution and (b) an electric field distribution.

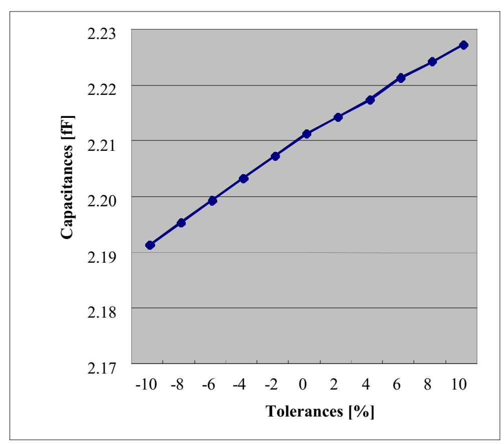


Figure 7: Plot showing a variation of capacitances as the effect of manufacturing tolerances.