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Design of Electrostatic Comb Actuators Based on Finite Element Method

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Electrostatic comb actuators are commonly used to provide displacement-invariant force in micro electro-mechanical system (MEMS). Major application can be found in resonator, inertial sensor, accelerometer, and gyroscope. The size of the comb may be a few microns to millimeters. Principally, the electrostatic force is produced in the comb structure due to potential difference between the electrodes, which is used to actuate the system attached to it [1]. The higher forces are very often desirable for high sensitivity and performance. However to meet this demand, micro-scaled structures are very often fabricated on trial-error basis because of lack of well-established fabrication method. In this situation, designing on a computer prior to the actual fabrication would be very helpful. Moreover, in a virtual device, parameters can be changed much more quickly than trial-and-error fabrication reducing the time to market and also the cost to develop a commercial device considerably [2].

The aim of this paper is to present finite element modeling and analysis to design comb structure, and its limitation for realistic design. Design objective is to achieve higher actuation force. Since a computational model for design analysis at micro-scale based on FEM is never obsolete, this work will be useful for those who seek designing MEMS components in FEM as well as facilitate the MEMS industry to economically obtain feasible design parameters for micro-scaled devices [3, 4].

Theoretically, the available force principally depends on the number of the electrode fingers and the aspect ratio of the comb structure. Fig. 1 shows FE models of comb structure with different aspect ratios. The structure is made of polysilicon. Dielectric constant for polysilicon was assumed as 10000. The additional part was created between the two electrodes to define the presence of air as a medium. The surface of this medium contacting with that of movable electrode fingers was used as force generator to compute electrostatic force on the electrode. Actuation voltage was applied at the nodes of the top and bottom surfaces. Electrostatic field strength and voltage analysis was then performed.

Fig. 2 shows the voltage and force computed for model 3. The additional simulations were done with varying applied voltage in order to verify the FE models. Fig. 3 compares electrostatic force induced in different comb structures for varying applied voltages. This prediction is in very good agreement with the report by [5] where the effective structure for higher force was found to be combination effect of more fingers and high aspect ratio. However, aspect ratio has to be compromised with fabrication limitation at micro-scale. There are numerous sources of errors attributed to the computational results. Source of error mostly comes from inadequate assumptions such as detailed dimension of the comb drive and mathematical foundation compounded by element formulation applied in FE model. The dimensions including the gap used in these FE models were the authors' guess based on the information of 1 mm^2 actuator size. Consequently, it is hard to confidently say and comment on the accuracy of numerical figure.

In summary, finite element models have been successfully developed to analyze the electrostatic force produced in electrostatic comb actuator. With reference to the simulation results, it is fair to say that FEM can be applied to design MEMS components prior to actual fabrication to improve design, and also save time and fabrication cost. Current results show that the comb structure with more fingers and high aspect ratio produce higher actuation force. In future, the geometry of FE model used for verification should be created exactly the same as the one in real world. The findings in this work also lead to the conclusion that the mathematical foundation needs to be reevaluated. Stress induced in the components due to actuation force should be addressed.

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