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MODELING AND SIMULATION OF MEMS CHARACTERISTICS: A NUMERICAL INTEGRATION APPROACH

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ABSTRACT

The advent of precision three-dimensional micro machining technologies in the last couple of decades has seen the birth of an exciting and potentially revolutionary field called Microelectromechanical Systems (MEMS). The complexity of Microsystems is steadily increasing due to the scaling of microelectronic devices.

Looking at the MEMS devices, the moment the moving elements touch the static part of the system will have a major influence on the overall performance of the device. Hence one definitely needs to consider the touchdown effect in the system behavior .This paper gives a numerical integration approach of capacitive MEMS characteristics modeling.

Keywords: *pressure sensor, touch-down, behavioral model, optimization*

1. INTRODUCTION

Absolute pressure sensors are required in many applications including industrial process control, Environmental monitoring and biomedical systems. Capacitive pressure sensors provide very high pressure sensitivity, low noise, and low temperature sensitivity and are preferred in many high performance emerging applications.

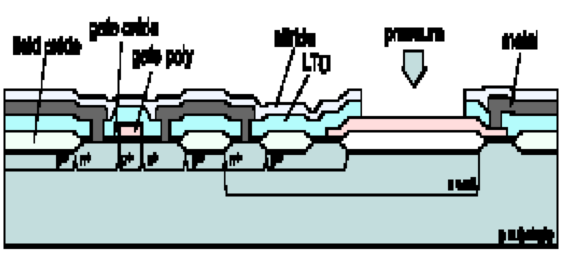

Fig. 1: Schematic cross section of the sensor chip

Fig. 1 shows a schematic cross section of a capacitive pressure sensor including an integrated NMOS-Transistor. Using this technology, the NMOS layers are used for manufacturing the sensor system. The structure of the pressure sensor (Fig.1) is composed of a movable electrode (the sensors membrane), the implanted n-well as back plate electrode and the pressure chamber between them.

There is a thin oxide layer on top of the counter electrode which results from the etching of the chamber.

2. TOUCH DOWN EFFECT

One of the most difficult objectives in modeling micro electromechanical devices depending on the movement of membrane structures is the consideration of the touch-down effect. It appears, whenever the movable electrode touches the oxide at the counter electrode. In the touch-mode the counter electrode is isolated from the movable electrode by the thin oxide layer. This will play an important role in the behavior model. So far no analytical solution including the touch-down effect has been found. The difficulty is that one would have to solve a partial differential equation with changing border conditions. There have been solutions using finite

Fig.2 Dividing membrane & electrode into partial areas of 100X100

element formulation [5] or 3D coupled simulations between electrostatic and mechanical elements [4], but none of these solutions is practical for system simulations and especially not for model based system characterization

50	.	3	2	**50**	2	3	.	50	Y0
				.					.Y1
				2					Y2
				1					.Y3
50	**.**	**2**	**1**	**1**	**1**	**2**	**.**	**50**	**Y4**
				1					Y5
				2	.			.	Y6
				.					.
				50					Y 100
X 0	X 1	X 2	.	.					X10 0

3. ADDING THE TOUCH-DOWN IN A BEHAVIORAL MODEL

The calculation of the membranes deflection is based on the theory of large excursions for quadratic plates with clamped edges [1]. In [2] it is supposed to calculate the membranes excursion

$$\omega(x,y)=\omega_0\left[1+c_1\frac{x^2+y^2}{(a/2)^2}+c_2\frac{x^2y^2}{(a/2)^4}\right]\cos\left[\frac{\pi x}{a}\right]\cos\left[\frac{\pi y}{a}\right] \qquad (1)$$

Where ωo excursion of the middle point of the membrane, *a*: length of membrane edge, *x*, *y*: geometric coordinates

The excursion of the middle point ωo of the plate results from the pressure that acts on the membrane. The expression (1) is valid until the membrane touches the counter electrode. Afterwards the shape of the bending line deviates extremely from (1), which results in an error in the used to make conclusions about the extern pressure, errors will occur in the developed system, for the design is partially based on wrong calculations. In order to be able to include the touch-down effect into a behavioral model, the membrane as well as the lower electrode has to be divided into s × s partial areas (Fig. 2) and hence form s × s partial capacitors. This way it is possible to detect the touchdown of each partial plate by evaluating the deflection *ωm (xi, yi)* at its mid point.

The capacitance of the partial plates can be calculated by using the approximation of a plate capacitance. The distance between the plates of one partial capacitance is set to be the distance *h* - ω*m*(*xi*, *yi*) between the mid point of the membrane and the counter electrode at the point (*xi*, *yi*), where h is the height of the pressure chamber. Until the touch-down is reached, the calculation of ω*m*(*xi*, *yi*) is based on the known theory formulated in equation (1). In touch mode the deflection ω*m*(*xi*, *yi*) is constantly set to *h*, hence the distance is equal to zero.

$$\omega x(x_1-y_1)=\begin{cases} h-\omega(x_1-y_1) & for\,\omega(x_1,y_1)<h \\ h & for\,\omega(x_1,y_1)\geq h \end{cases} \qquad (2)$$

Fig:3 shows the plate diaphragm deformation before touchdown effect when h= ωo

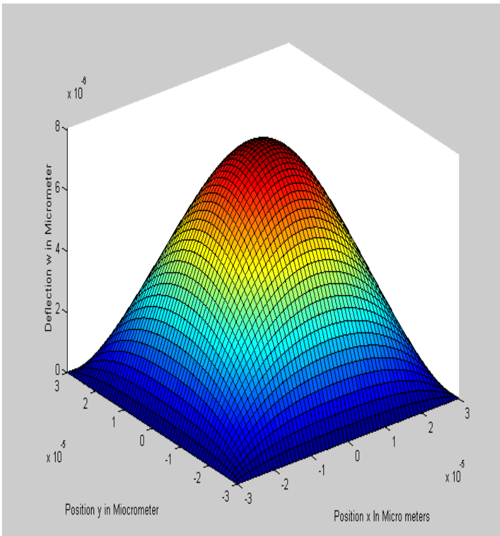

Fig:3 Diaphragm deformation before touch down effect

One can say from fig:3 that as long as h= ωo i.e. excursion is equal to the separation of the plates. The shape of the parabola remains unchanged. The moment touchdown occurs the bending line cutoff from the top as shown in fig:4

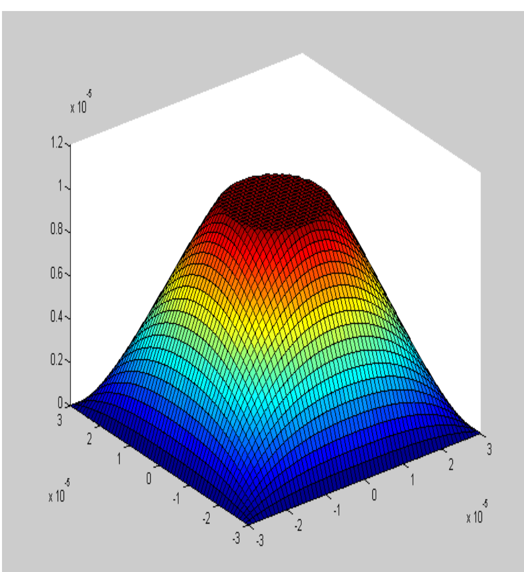

Fig:4 shows the touchdown effect

The total deflection capacitance is calculated by

$$C_{total} = \sum_{t=0}^{s-1} \sum_{f=0}^{s-1} \frac{C_{pox} C_p(x_1, y_1)}{C_{pox} + C_p(x_1, y_1)} \quad (3)$$

Where *Cpox* is the partial oxide capacitance and *Cp*(*xi*, *yj*) is the partial deflection capacitance that can be calculated by

$$C_p(x_1, y_1) = \varepsilon_0 \frac{(a/s)^2}{h - \omega_x(x_1, y_1)} \quad (4)$$

In order to reduce the error made due to the discretization a partitioning of 100 × 100 is used. Making use of the given symmetry of the bending line, the number of necessary calculations can be reduced immensely.

Although it is possible to detected the touch-down with the above proposed solution shown in fig: 5 ,If there is any discrepancies between measurement and model developed looking at the touch-mode itself. Therefore the calculation of the bending line had to be modified further.

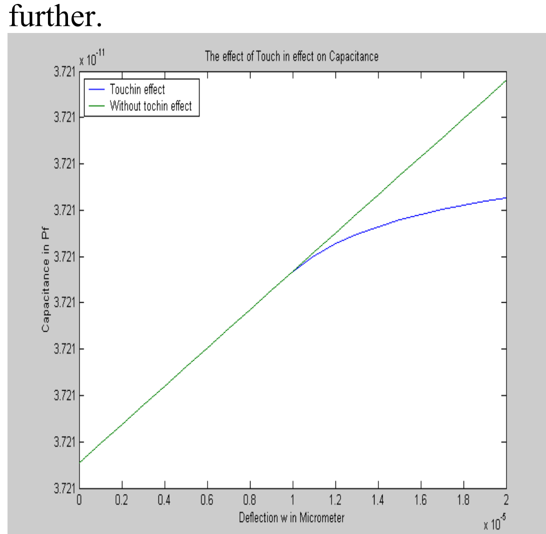

Fig:5 showing the touchdown effect

4. CONCLUSION

In this paper a model of a capacitive MEMS pressure sensor was presented, which includes the touchdown effect as well as the touch-mode. Good correspondence between measurement and theory may be achieved. Based on this model design optimizations can also be carried out using direct mathematical methods.

Hence the proposed modeling approach can be used as a reliable basis for design optimizations of capacitive pressure sensors. in further scope of this paper the experimental model can be tested against this mathematical model developed.

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