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MICRO SYSTEM WITH MEMS SENSOR FOR DETECTING SLEEP APNEA

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ABSTRACT

Current solutions for Sleep Apnea needs the patient to undergo overnight sleep studies in a sleep laboratory lasting for at least eight hours. This is very costly and sometimes inconvenient for the patients. The use of Micro sensors reduces the cost as well as the size of the entire system for sleep Apnea detection considerably. With the help of a powerful Apnea screening algorithm and the proposed MEMS sensor sleep Apnea can be effectively scored even in home environment. The respiratory rhythm of the patient can be recorded using the proposed sensor and can be conditioned using signal conditioning IC's in association with an effective Apnea screening algorithm.

Keywords: micro electrical mechanical system (MEMS), MEMS capcitive pressure sensor, COMSOL, sleep apnea, breathing rhythm, simulation.

1. INTRODUCTION

Sleep Apnea is a common sleep disorder with pauses in the normal breath of a person. If the breathing amplitude reduces from the normal value of a human being and if the reduction in amplitude lasts for a period of 10sec an Apnea event is registered. This sleep disorder might lead to chronic conditions like Cardiac arrest, Heart attack and even heart failure. Sleep Apnea causes the Hypoxemia, which will even affect the quality sleep of the person [1]. Untreated sleep Apnea will even increase the chances of diseases like Stroke [2], Hypertension [3], and Depression [4].

The current standard for diagnosing sleep Apnea is Poly SomnoGraphy PSG) which is a room sized equipment having a large number of sensors connected to the body of the patient being diagnosed. This is the main reason why about 80 % of the people who suffer from sleep Apnea are being untreated [1]. PSG is a comprehensive study by recording different bio physiological parameters like electro encephalogram (EEG), electro oculogram (EOG), electro cardiogram (ECG) etc [1]. It needs to place a number of sensors on the body of the person who is being diagnosed. The sensors will monitor different body activities of the person through monitoring the thoracic and abdominal movements using different belts. The data obtained from different sensors need to be manually screened by a specialist. All this set up is quiet difficult for a patient and is quiet expensive.

Oxygen plays a vital role in the body of a human being and so it is very important to monitor the Oxygen saturation level in the blood. There are different techniques to monitor the respiratory system and the respiratory parameters. The monitoring of respiratory activity can be done by recording the sound that comes because of the nasal flow [5]. Microphone based techniques were also developed that will sense the sound waves related to the respiratory system [6]. A real-time auto adjustable smart pillow system was developed which included Pulseoximeter, Smart phone based central controller and an adjustable Smart pillow [7].

All the above mentioned techniques require much complicated signal processing algorithm which in turn increases the complexity of the entire system. In order to compensate for the above said limitation a Home Sleep Apnea Scoring device was proposed that uses a miniaturized sensor for measuring the nasal air flow [1]. MEMS sensor senses the air flow of the patient, which is the most reliable parameter to be monitored in the case of sleep Apnea [8]. A time domain signal processing algorithm is proposed and implemented in a miniaturized IC. The sensor used in that study is a MEMS piezo resistive pressure sensor which outputs an electrical signal in accordance with the pressure of the nasal air flow. The entire prototype device was consisting of a MEMS Piezoresistive sensor, a signal processing chip and a wireless system for communication [1].

But the problem with the MEMS Piezo resistive sensor is its nonlinear dependence of the output on temperature. Also it is having large initial offset, drift of offset with temperature and also the output voltage decreases considerably with increase in the operating temperature. Since the parameter to be measured is the nasal air flow and which is having temperature dependency, there is a chance of erroneous reading at the sensor output.

So the use of another sensor for the entire system can be an alternative thought for performing the same function of the system described above. Here we propose an idea of using a MEMS Capacitive Pressure Sensor for detecting the nasal air flow and thus registering the sleep Apnea event using an algorithm that works on time domain. The objective of this study is to design and simulate the characteristics of the senor module which is the crucial element of the entire system.

2. APNEA SCORING SYSTEM WITH MEMS SENSOR

Basically there are two types of sleep Apnea, Obstructive Apnea and Central Apnea. When the breathing rhythm of a person is disturbed and if the amplitude level of the breath is reduced by 20% which

ARPN Journal of Engineering and Applied Sciences

extends for some 10 seconds, then it is characterized as an Apnea event [1]. Another such event is named as Hypopnea where there is a reduction of around 70% of the normal breathing amplitude together with a reduction in the oxygen saturation level of the patient. The entire events together identified using an Apnea Hypopnea Index (AHI). Here we describe the different parts of the entire system.

A. MEMS Sensor

The emergence of MEMS technology made large enhancements in the biomedical field for the past years. The main concern for any MEMS sensor or device for biomedical applications is that it should be biocompatible. Also the MEMS sensor helps the users in many ways since it is having small size and reduced cost. MEMS sensors can be integrated using the well-established CMOS technology which again improves the feasibility of the sensor to use for biomedical applications.

MEMS Capacitive Pressure sensor works on the principle that whenever a differential pressure is applied on the movable plate of the capacitor there occur a change in the thickness of the dielectric medium between the fixed plate and the movable plate. This thickness change produces a change in capacitance at the output of the sensor which is a direct measurement of the pressure of the nasal airflow. So the flow rate of the nasal air flow is measured in terms of a change in differential pressure.

B. Algorithm for detecting sleep Apnea

A time domain Apnea detection algorithm is proposed which uses a comparator that compares the difference between the breathing signal obtained from the sensor and a predefined threshold value. The threshold value can be set as 10 seconds which directly indicates the existence of an Apnea event.

C. Apnea scoring device

The sensor proposed here captures the nasal air flow from the exhaled air pressure. This pressure signal is converted into a corresponding electrical signal by the transducer and is given to an IC for signal processing. The IC performs the functions of amplifier, hysteresis comparator and breathing rhythm detector.

3. DESIGN OF THE MEMS SENSOR

Here we propose to use micro-electro-mechanical system (MEMS) technology for designing the sensor module of the Apnea scoring system. The MEMS capacitive pressure sensor structure is modelled using COMSOL software. The sensor part consists of one fixed plate, i.e, the substrate and a movable plate. The dielectric medium is sandwiched in between the two plates of the parallel plate capacitor.

A. Modelling

The geometry of the structure is made in micrometer dimensions. And the physics applied for the study is Electro mechanics. The entire structure is modelled in 3D volume.

The pressure of the nasal air flow is applied on top of the movable plate and the variation of the capacitance and displacement of the diaphragm is monitored. Differential pressure is assumed to be the input variable in our stationary study.

The modelled structure of the MEMS Capacitive Pressure sensor is as shown below in Figure-1.

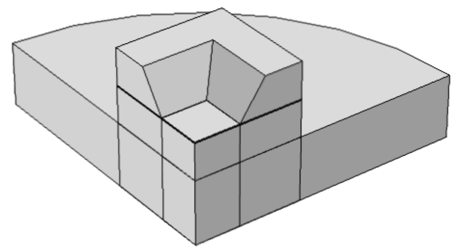

Figure-1. MEMS Capacitive Pressure Sensor structure using COMSOL.

We used Steel AISI 4340 as the base substrate material which is considered to be the fixed plate of the sensor module. Silicon is used as the movable plate of the diaphragm on top of which the nasal air flow is applied. Vacuum is considered as the dielectric medium in between the two parallel plates. Young's modulus and Poisson's ratio of the steel material are considered.

Different parameters are defined globally for the simulation purpose. The parameters include Differential Pressure, Operating Temperature and the Die Bonding Temperature.

Differential pressure is the pressure corresponding to the exhale pressure of the nasal air flow. That we considered as the input parameter. The air flow pressure is applied as shown below in Figure-2.

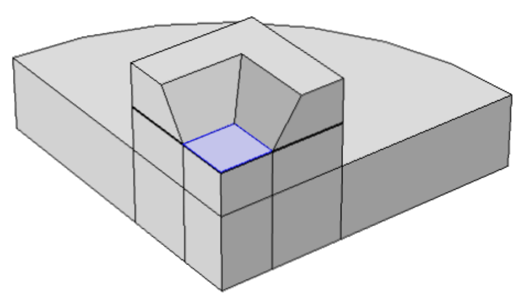

Figure-2. Applying the nasal air pressure corresponding to exhale activity of the patient.

The major equation that supports the study is the one given below.

$$C = \varepsilon A/d \quad \text{(i)}$$

ARPN Journal of Engineering and Applied Sciences

where

ε = the dielectric constant of the medium under consideration

A = area of cross section of the parallel plates of the capacitor

d = distance between the parallel plates

C = the capacitance of the capacitor

B. Working

As given in the equation (i) the capacitance of the parallel plate capacitor is inversely proportional to the thickness of the dielectric medium. Since the dielectric is defined as a linear elastic dielectric medium, whenever there occur a pressure change on the movable plate of the diaphragm the thickness of the dielectric medium or the distance between the parallel plates will get changed and accordingly the capacitance of the sensor gets changed. So in this case the thickness of the dielectric medium is the varying parameter.

4. RESULTS AND DISCUSSIONS

Simulated the MEMS capacitive pressure sensor using COMSOL and obtained different results. The sensor is simulated for a variety of pressure range. A terminal voltage of 1Volt is applied to the sensor.

The simulation results are shown below in Figure-3 through Figure-10.

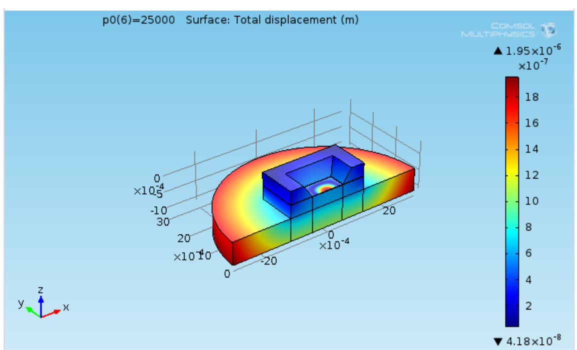

Figure-3. Displacement in µm.

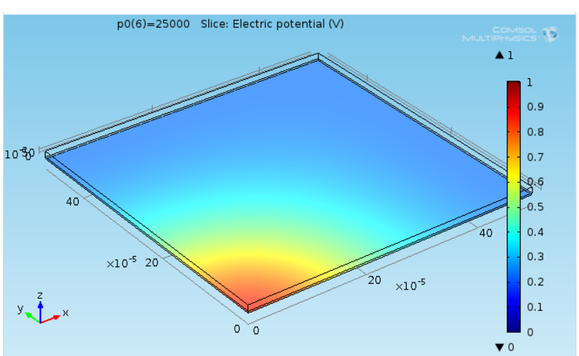

Figure-4. Electric potential in V.

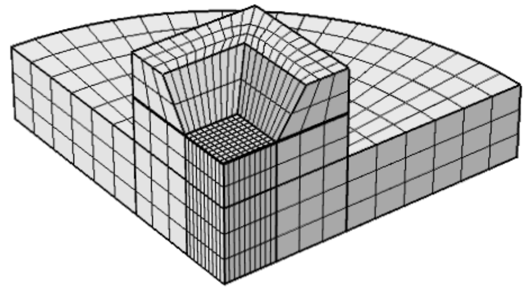

Figure-5. Meshing done for the MEMS sensor structure.

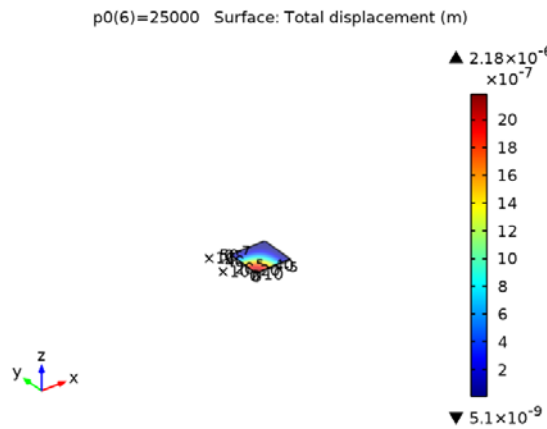

Figure-6. Total displacement in m.

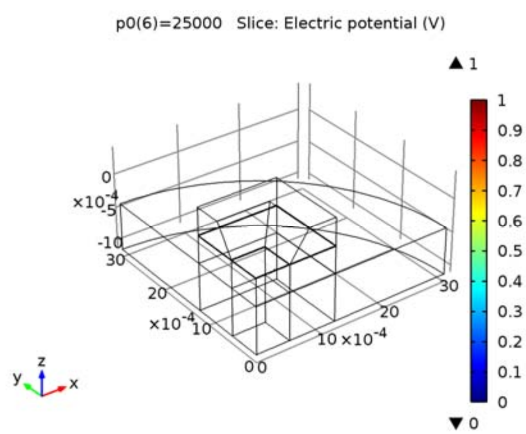

Figure-7. Slice electric potential (V).

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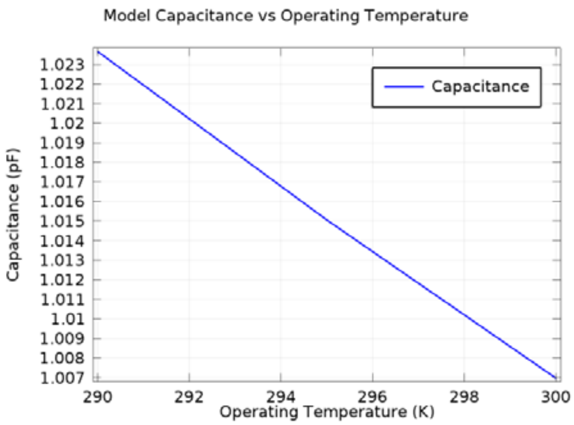

Figure-8. Model capacitance Vs Operating temperature.

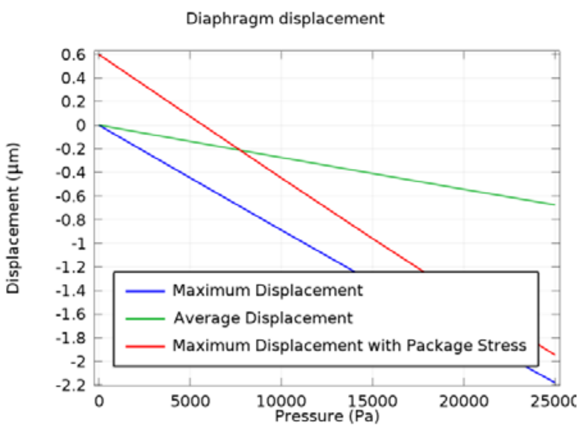

Figure-9. Diaphragm displacement Vs Differential pressure.

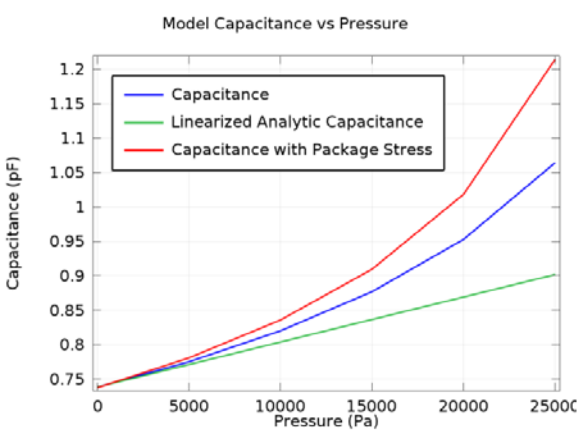

Figure-10. Model capacitance Vs Differential pressure.

From Figure-8, it is understood that the sensor produces a linear response with varying operating temperature values. The output capacitance of the sensor varies linearly with temperature of the exhale air flow. This is the major advantage of using MEMS Capacitive Pressure Sensor rather than MEMS Piezoresistive Sensor.

The derived values of Sensor Output Capacitance are given below.

Table-1. Capacitance output of the sensor.

p0	Capacitance (F)
0	7.37852e-13
5000	7.74676e-13
10000	8.19692e-13
15000	8.76663e-13
20000	9.5272e-13
25000	1.06405e-12

5. CONCLUSIONS

This study is based on the fact that the currently existing diagnosing techniques for detecting Sleep Apnea is having individual drawbacks as discussed above in the Introduction section. As told above the MEMS piezo resistive sensor is having the drawback of so called temperature dependence and nonlinear response at the output. That is the importance of this sensor design explained in this study.

The simulation results show that the MEMS Capacitive Pressure sensor gives an output capacitance which is a linear response with respect to the differential pressure input. The flow rate of the exhale nasal flow is measured in terms of the differential pressure applied on the sensor. The sensor can be connected through a cable to the signal processing chip and which could be used to implement the time domain Apnea scoring algorithm. The entire system could be an excellent diagnosing technique for sleep Apnea detection which can be done in home atmosphere itself.

The simulation studies showed that the sensor produces a maximum displacement of $1.95\times10^{(-7)}$ µm and a maximum capacitance of 1.06405e-12F with respect to the differential pressure applied on the sensor.
The sensor output results are briefed below.

Table-2. Output results of the sensor.

Parameter	Value
Maximum Output Displacement	$1.95\times10^{(-7)}$ µm
Maximum Output Capacitance	1.06405e-12 F
Minimum Output Capacitance	7.37852e-13 F

From the results it can be concluded that the designed MEMS Capacitive Pressure Sensor provides a very good linear result as compared to that of the MEMS Piezoresistive Sensor. So the MEMS Capacitive Pressure Sensor can be effectively used as a sensing module for detecting Sleep Apnea Event.

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