

# Simulation of Cantilever Based Sensors for Smart Textile Applications

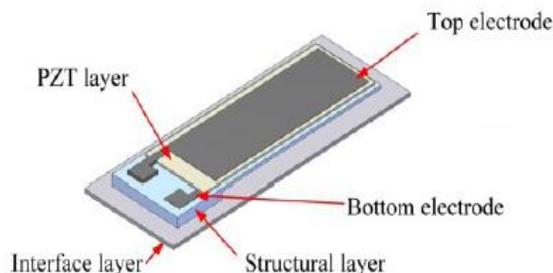
Jaisree Meena Priya K N J<sup>1</sup>, Sowmya S<sup>\*1</sup>, and Steffie Mano<sup>1</sup> Chandra Devi K<sup>1</sup>, Meenakshi Sundaram N<sup>1</sup>  
1: PSG College of Technology, Coimbatore- 641 004  
\*nandhusks@gmail.com

**Abstract:** Smart fabrics enable the integration of electronics into fabric. They can serve as a suitable sensor, providing around the clock assistance for the real time monitoring of health parameters. In this work, we aim to develop a free standing piezoelectric cantilever sensor integrated over the conventional fabric to improve their functionality. These smart sensors facilitate the conversion of physiological parameters or movement into electrical signals that can be further processed and evaluated. Here, a basic design of such a sensor is simulated using COMSOL Multiphysics 4.3b.

**Keywords:** Piezoelectric, Smart textile.

## 1. Introduction

“Intelligent or smart textiles” are emerging as a new area of exploration by the healthcare industry. These wearable textiles that integrate electronics, aim to keep health conditions on check. As doctors cannot have a close track of their patient’s health other than the clinical hours, the understanding of the medical condition interaction with the patient’s routine lifestyle and activities is greatly impeded. Hence the need to continuously observe the various physiological parameters has led to the advent of textile fabrics incorporating the appropriate sensors to monitor the vital health signs [1]. With the demand for deeper knowledge about the disease pathogenesis, smart textiles act as promising solution to develop patient-centric devices that will aid the physicians in diagnosis and thereby provide on - time medication.



**Figure 1:** 3D view of the proposed cantilever sensor model

Heart rate, respiratory rate, blood pressure, blood oxygen saturation and muscle activity are the physiological parameters of interest in rehabilitation [2, 3]. The continuous measurement of systemic blood pressure is an indicator of hypertension and end - organ damage [4]. The Smart Shirt technology with its architecture, advantages and applications has been reviewed by Sungmee Park *et al* [5]. Considering the above, we make an attempt to simulate smart textile sensors that monitor the various physiological measures namely, the body temperature, blood pressure and heart rate which are the sensitive indicators of chronic illness in critical conditioned patients.

The proposed sensor design constitutes of a cantilever made of piezoelectric material, anchored over a textile fabric as shown in figure 1. The optimization of the cantilever material and its dimensions has been performed to give better sensitivity.

## 2. Theory

Cantilevers with one of its free end are effective sensors at the nano and micrometer regime, exhibiting a bending effect. These structures show superior competence with other sensing platforms on the basis of its simple design and tunable sensitivity. The cantilever sensors are designed to have lower force constant to measure stress with enhanced sensitivity [6].

A further improvement to the sensor performance is attributed to the material that builds up the cantilever. The employment of a piezoelectric sensing material that is capable of producing an equivalent electrical signal in correspondence to a deformation (stress) makes the subsequent processing in the sensor easier. Moreover, the feasibility to screen print the piezoelectric over wearable textiles [7, 8] establishes its potentiality as suitable textile - compatible sensors.

## 3. Numerical Model

The suggested cantilever sensor is modeled to be highly sensitive for the detection of physical changes or movements over the human body surface. The

sensitivity of the static mode cantilever is best explained in terms of the spring constant as given by the following equation.

$$\text{Spring constant } k = \frac{E \cdot w \cdot t^3}{4 \cdot L^3} \quad (1)$$

where, E - Young's Modulus of the piezoelectric  
 w - Width of the cantilever  
 t - Thickness of the cantilever  
 L - Length of the cantilever

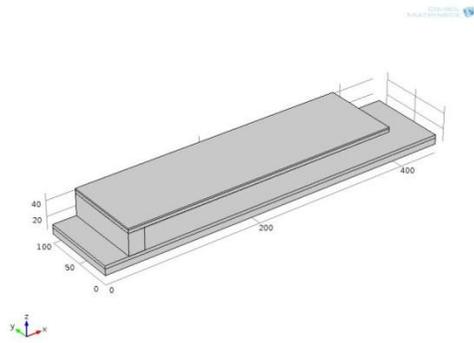
Stoney's equation relates the stress caused over the cantilever and the so produced deflection as below.

$$\Delta g = \frac{E \cdot \Delta h \cdot t^2}{(1-\nu) \cdot L^2} \quad (2)$$

where,  $\Delta g$  - Differential stress  
 $\Delta h$  - Deflection of the cantilever  
 $\nu$  - Poisson's ratio

### 3. Use of COMSOL Multiphysics

The simulation of the proposed MEMS based cantilever sensor (figure 2) for smart textile application was done using Structural mechanics module in COMSOL Multiphysics 4.3b



**Figure 2:** 3D model of MEMS based cantilever sensor

#### 3.1 Materials

The cantilever integrated over a nylon fabric is composed of an interface layer, structural layer and sensing layer.

**Table 1:** Materials used in various layers of the smart textile sensor with respect to the applications of interest

Layer	Material	Application
Interface layer	Silicon dioxide	Body temperature and Blood pressure monitoring
Structural layer	Polysilicon	Body temperature and Blood pressure monitoring
Sensing layer	Barium sodium niobate/ Bismuth germanate/ Lead zirconate titanate (PZT)	Blood pressure monitoring
	Gold/ Chromium/ Copper	Body temperature sensing

#### 3.2 Physics used

The physics of "Piezoelectric devices" is used for blood pressure monitoring, changes in the displacement and electric potential distribution were observed over the cantilever for a corresponding change in the blood pressure. This in turn accounts for the heart rate variations during normal and abnormal body conditions.

The body temperature sensing is carried out using the physics of "Thermal stress" and the stress developed on the cantilever with change in temperature is studied.

#### 4. Experimental Results

Blood pressure, also known as "arterial blood pressure" varies between a maximum (systolic) and a minimum (diastolic) during each heart beat. Hence the determination of the blood pressure can be considered as a direct measure of the heart beat.

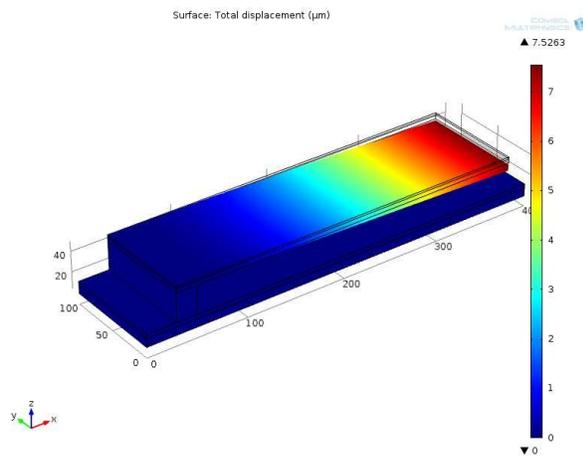
When a boundary load equivalent of the diastolic blood pressure (80 mmHg) was applied, displacement and electric potential of the cantilever was generated and the values increased for the systolic condition (120 mmHg). This verifies the linearity in displacement and electric potential with increasing blood pressure.

The performance of the cantilever varies for different sensing materials and dimensions which is tabulated below.

**Table 2:** Displacement values for different piezoelectric materials at diastolic condition.

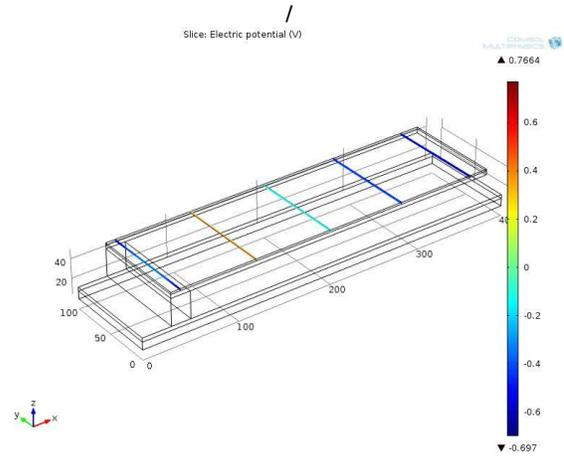
**Cantilever dimensions:** Length: 350 $\mu\text{m}$ , Width: 100 $\mu\text{m}$ , Thickness: 8 $\mu\text{m}$

MATERIAL	MAXIMUM DISPLACEMENT FOR 80 mmHg ( $\mu\text{m}$ )	MAXIMUM VOLTAGE FOR 80 mmHg (V)
Barium sodium niobate	4.8275	0.2231
Bismuth germanate	6.5014	0.3476
Lead zirconium Titanate	7.5263	0.7664

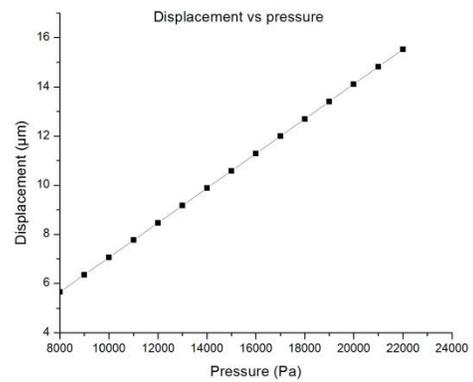


**Figure 3:** Simulated displacement of PZT based cantilever for 80mmHg

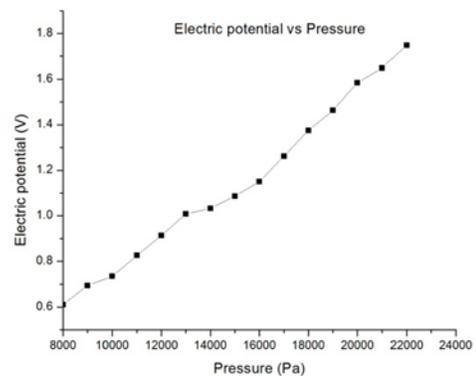
Among the materials used as sensing layer, Lead Zirconate Titanate shows the highest displacement for 80 mmHg pressure. As the input pressure increases, the displacement and electrical potential value also increases for PZT material.



**Figure 4:** Simulated electric potential slice of PZT based cantilever for 80mmHg

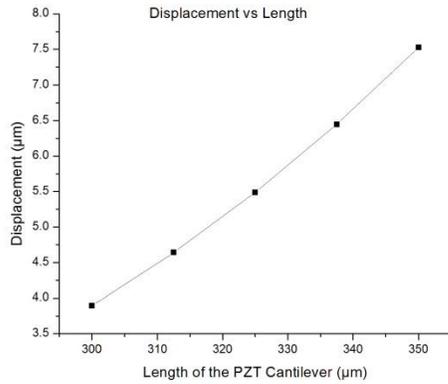


**Graph 1:** Displacement vs Pressure response of PZT based cantilever



**Graph 2:** Electrical potential vs Pressure response of PZT based cantilever

Length of the PZT based cantilever was varied and the corresponding displacement changes at diastolic blood condition were observed.



**Graph 3:** Displacement vs Length response of PZT based cantilever

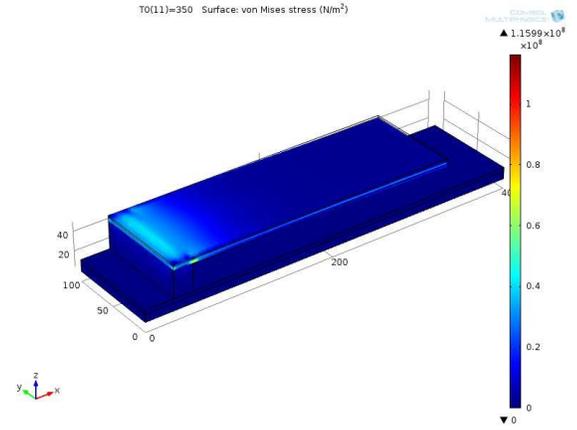
As the inception of a disease is first indicated by a rise in body temperature, the model thus designed is found to experience stress with changes in the temperature on the body surface.

**Table 3:** Stress values for different materials for normal body temperature

**Cantilever dimensions:** Length: 300µm, Width: 100µm, Thickness: 8µm

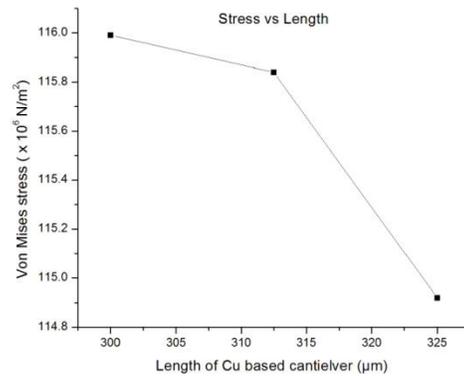
MATERIAL	MAXIMUM STRESS (N/m <sup>2</sup> )
Au	7.9601*10 <sup>7</sup>
Cr	4.884*10 <sup>7</sup>
Cu	1.1599*10 <sup>8</sup>

Among the materials used as sensing layer, copper showed increased stress response for normal body temperature.



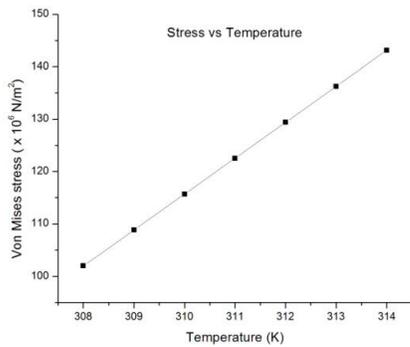
**Figure 5:** Simulated stress of Cu based cantilever for normal body temperature (37<sup>0</sup> C)

Length of the Cu based cantilever was varied and the corresponding changes in stress value was observed.



**Graph 4:** Stress vs Length response of Cu based cantilever

The stress developed on the surface of the cantilever was observed to increase with rise in temperature.



**Graph 5:** Stress vs Temperature response of Cu based cantilever

#### 4. Discussion

The results reveal that the proposed smart textile sensor design show a linear sensing behavior (Graphs 1, 2). The optimized experimental results indicate that Lead Zirconate Titanate (PZT) is relatively more sensitive to blood pressure variations showing a increased displacement and electric potential of  $3.8935\mu\text{m}$  and  $0.2753\text{V}$  respectively (Table 2). While Copper (Cu) was identified to be a better temperature sensing element as it showed a maximum stress of  $1.0112 \times 10^8 \text{ N/m}^2$  (Table 3). The sensitivity of the sensor improves for a longer cantilever showing greater deflection (Graph 3) due to the uniform distribution of stress throughout the cantilever surface. The response of the sensor to temperature, in terms of stress declines for increasing length of the cantilever (Graph 4). The performance of the sensor was observed for hypothermia and hyperthermia conditions and a linear increase in stress with rise in temperature occurred (Graph 5). These results are in accordance with Equations 1 and 2.

#### 5. Conclusions

A smart textile piezoelectric sensor for evaluating the blood pressure and body temperature was simulated using a simple structure with COMSOL Multiphysics 4.3b. The optimization of the sensor dimension for improved sensitivity was also performed.

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