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Design of Double Sided Cantilever Automation for Agriculture Field

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ABSTRACT

In order to change our agriculture to be simplified that reduces manpower in the agriculture field by means of digital technology is the basic idea of this paper. For this automation, the first step to design a sensor which detects both humidity and temperature. And this sensor is designed to work in both wired and wireless environment. This type of sensors is mainly designed for agriculture usage but user can also apply for different domain like boiler, chemical industry, oil refineries, medical, and etc. The sensor is simulated and derived in various levels of observation. Simulation is done with the help of Intellisuite software with finite element method for a sensor.

Keywords: Finite Element Method (FEM), Humidity Sensor, Temperature Sensor, MEMS, Double Sided Cantilever.

I. INTRODUCTION

The structure of double sided cantilever that detects both high and low values of temperature and humidity. To sense humidity level surface tensile technique is used and to sense temperature bimorph technique can be implemented [1].Array of MEMS sensors is equal to one normal conventional sensor efficient wise. To relax cantilever film stresses initially it uses thermal annealing process which changes the overall bimorph sensitivity. When compared with gold, Al/Ti metals show superior sensitivity [2]. This work is to analysethe deformation of bimorph material by means of varying temperature. If deformation occurs then the dimension varies, also it tends to thermal strain in the cantilever. This process of thermal induced deformation makes microstructure cantilever into thermal actuator [3]. If cantilever thickness is less that tends deflection to be more with very less input pressure (smaller than kilo-Pascal level) [4]. Every pressure sensor won't act as a differential sensor but differential sensor can act as pressure sensor [5].

Double sided cantilever structure gives two ideal measurement for both humidity and temperature with different material properties. To sense humidity, Platinum and Poly-silicon and to sense temperature gold and copper are used as sensing layer.

II. THEORITICAL ANALYSIS

A. Relative Humidity

The ratio of water vapour pressure to saturated water vapour pressure at gas temperature

Where,

$$RH = \frac{Pw}{Pws} \times 100\% \quad (1)$$

To have sufficient accuracy between 0 to 373 degrees Celsius of water vapour saturation pressure.

$$V = 1 - \frac{T}{Tc} \quad (2)$$

$$In\left(\frac{Pws}{Pc}\right) = \frac{Tc}{T}\left(c_1 v + c_2 v^{1.5} c_3 v^3 c_4 v^{3.5} c_5 v^4 c_6 v^{7.5}\right) \quad (3)$$

Temperature in K (T), saturation pressure hectopascal (HPa), the critical temperature as 647.096 (Tc), constant critical pressure of water vapors Pc=220 to 640 HPa and co-efficient (Ci).

From equation (1),

$$Pw = Pws \times \frac{RH}{100} \quad (4)$$

For example, take 50%RH

$$Pw = 4.24\ KPa \times \frac{50}{100} \quad (5)$$

Finally,

Pw=2.12KPa

Then the dew point temperature detection occurs that can be compared with regular time intervals,

$$Td = \frac{Tn}{\log 10 \frac{Pw}{A} - 1} \quad (6)$$

$$Td = 14°C$$

TABLE I

Dew Point Calculation		
Relative Humidity	**Dew Point (Rh)**	**(Pw) with Pws=30 (Degree Celcius)**
RH%	°C	As ambient temperature
10	32	0.424
20	24	0.848
30	20	1.272
40	16	1.696
50	14	2.12
60	12	2.544
70	10	2.968
80	08	3.392
90	06	3.816
100	05	4.24

$$A = C.\frac{Pw}{T} \quad (7)$$

$$A = 2.16679 \times \frac{0.424}{(273+30)} \quad (8)$$

$$A = 32 g/m^3$$

$$Pws = A.10^{\left(\frac{m.T}{T+Tn}\right)} \quad (9)$$

The saturation pressure level of water vapour over water A, m, Tn is constant.

Generally displacement co-efficient Δz is to calculate the maximum deflection of the cantilever beam.

$$\Delta z = \frac{3(1-v)\ \delta s\ (\frac{l}{2})}{E} \quad (10)$$

Where δs implies applied input pressure towards the cantilever beam with E and V as the material properties of cantilever beam using young's modulus and Poisson ratio's. Then the aspect ratio of cantilevers bending moment is,

$$(M) = WL \quad (11)$$

Where the deflection of the cantilever at load will be,

$$(L) = \frac{1}{3}\frac{W(L+r_n)^3}{E} + \frac{W(L+r_n)}{\frac{5}{6}AG} \quad (12)$$

Where W= leaver arm distance and length (L)

The force acting on opposite direction with applied input pressure at the cantilever beam will produce maximum deflection. The aspect ratio of the beam decides the dimension and maximum deflection of cantilever beam.

$$R_A = P + WL - R_B \tag{13}$$

$$R_A = P + WL - \left(\frac{(P_1+WL)}{2} + \frac{M}{L}\right) \tag{14}$$

$$R_A = \frac{(P_1+WL)}{2} - \frac{M_1}{L} \tag{15}$$

With different input value, reaction force changes when the aspect ratio and deflection of the cantilever is changed.

B. Thermal Expansion

By two different material with dissimilar coefficients of thermal expansion where connected together to vary temperature that causes change in structure of cantilever to deform in desired way.

Radius of a curvature with deformed structure expressed as,

$$\frac{1}{r} = \frac{6w_1w_2E_1E_2t_1t_2(t_1t_2)(a_1-a_2)\Delta T}{(W_1E_1t_1^2)^2+(W_2E_2t_2^2)^2+2W_1W_2E_1E_2t_1t_2(2t_1^2+3t_1t_2+2t_2^2)} \tag{16}$$

$$\delta = r - r\cos\theta \cong \frac{1}{2}r\theta^2 \tag{17}$$

$$\theta = \frac{arc\ length\ (L)}{radius\ (r)} \tag{18}$$

The angle of ‘θ’ is calculated for micro-cantilever at maximum deflection from the point of right angle triangle, considering as arc-angleθ.

$$d = r - r\cos\theta \tag{19}$$

If overall bending angle is small then the magnitude of vertical displacement can be estimated by replacing$\cos\theta$with above equation.

$$d = r - r(1 - \frac{1}{2}\theta^2 + O(\theta^4)) \tag{20}$$

$$d = \frac{1}{2}r\theta^2 \tag{21}$$

Vertically free cantilever displacement is derived from the above equation (17).

C. Thermal resistance

The electrical resistivity can be calculated with significant change in the temperature sensitivity.

$$R_T = R_o(1 + a_R(T - T_o)) \tag{22}$$

R_TWill be electrical resistance with temperature T and $R_o$same as$R_T$but$R_o$is based on$T_o$temperature co-efficient of resistance (TCR)a_R.

$$\sigma_x = E\varepsilon_x \tag{23}$$

$$\sigma_x = -EKY \tag{24}$$

Where,

$$K = \frac{1}{\rho} = 8.33 \times 10^{-3} m^{-1} \tag{25}$$

$$\delta = \rho(1 - \cos\theta) \tag{26}$$

$$\rho = \frac{\delta}{(1-\cos\theta)} \tag{27}$$

Due to bending σ_x leads to compression or tension and subjected by longitudinal line of the cantilever beam, if material is linear elastic.

III. DESIGN PROCEDURE WITH ASSIGNING BOUNDARY CONDITION

The cantilever beam is designed by the 3D builder and by using theoretical dimensional values. With respect to the application, cantilever dimensions and shape is designed. Materials are selected with respect to properties like elasticity, young’s modulus, Poisson ratio and density. Each layer have different material characteristic because layer1 is substrate, layer2 is dielectric and top layer will be sensing layer. To increase sensitivity two (or) more materials combined together.

And next step is finite element method (FEM) of thermo-electro mechanical system. For application purpose the parameter changes for sensing temperature and humidity. The displacement, stress misses, stress in Z-axis and reaction force are common. The ultimate aim of finite element method is to subdivide a larger components into smaller and simple parts.

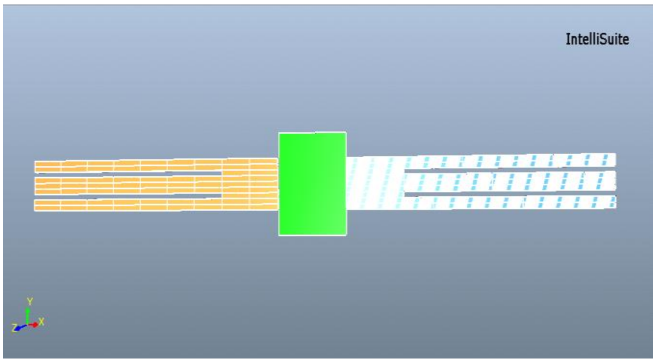

Figure 1. Double Sided Cantilever

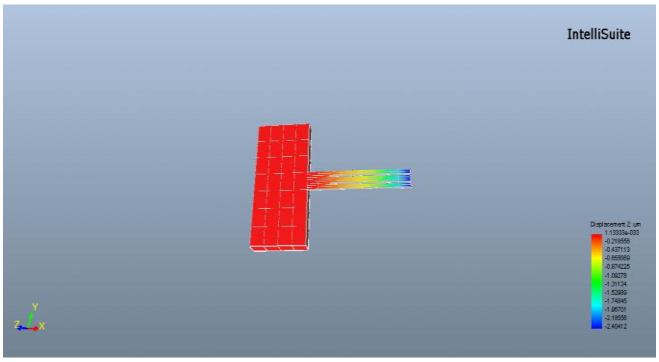

Figure 2. Simulated Result of Pressure Sensor with 10 Kpa Input

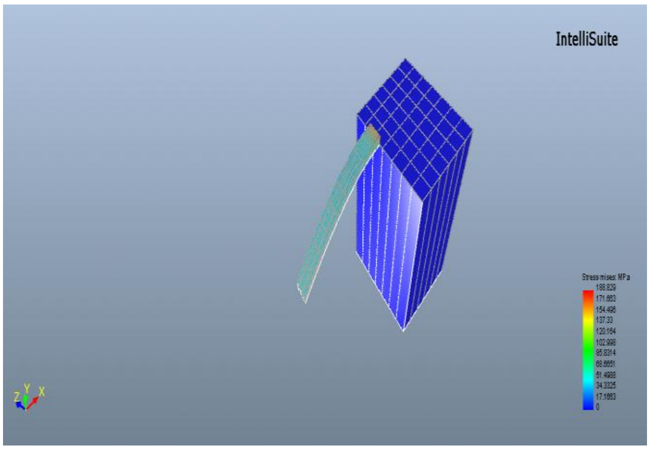

Figure 3. Simulated Result of Temperature Sensor with 10 Degree Celsius Input

IV. RESULTS AND DISCUSSION

When compared with analytical and simulation results are close to each other. By changing the main input temperature and humidity on top of the sensing layer of the sensor we can get different values. With mechanical mesh in micro-meter is given before to the input feeding to partition the sensor into micro-meter range. The applied input values are directly proportional to the deflection coefficient of the cantilever beam.

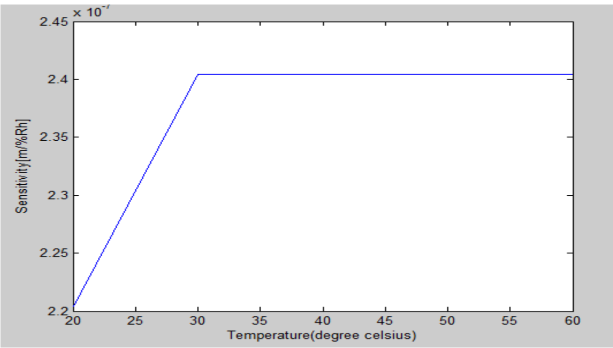

Figure 4. Temperature vs Sensitivity

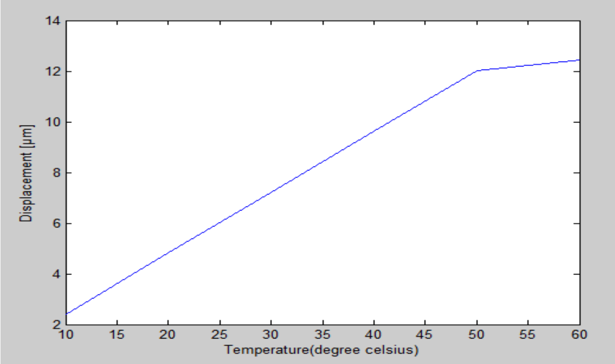

Figure 5. Temperature vs displacement

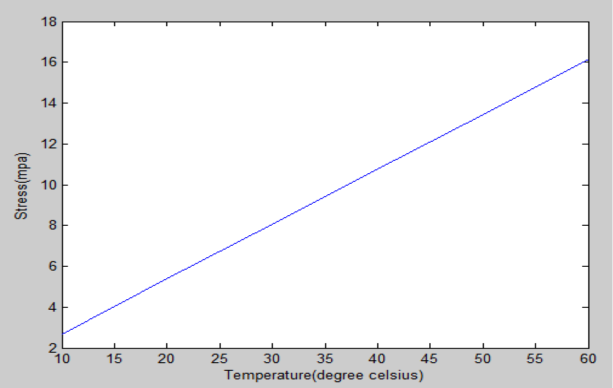

Figure 6. Temperature vs stress

From figure (4) there is a gradual increase of sensitivity and temperature but after reaching 2.4, the sensitivity level and displacement will be maintained constant because of material property. When temperature increases, stress on the layer also increases because both are depend with each other. Here for temperature both the stress and displacement will be proportional. Also sensitivity is derived from displacement of the sensor. Layers aspect ratio will vary whenever the thickness of the cantilever is changed.

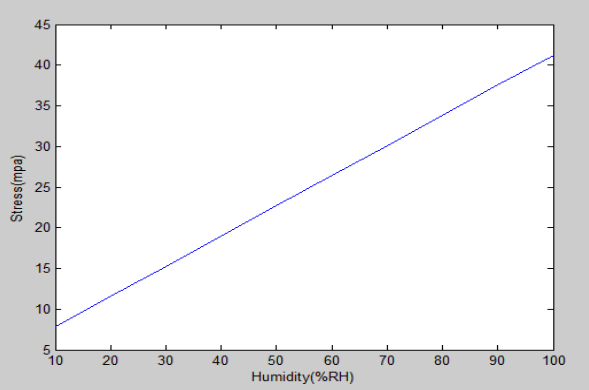

Figure 7. Humidity vs Stress

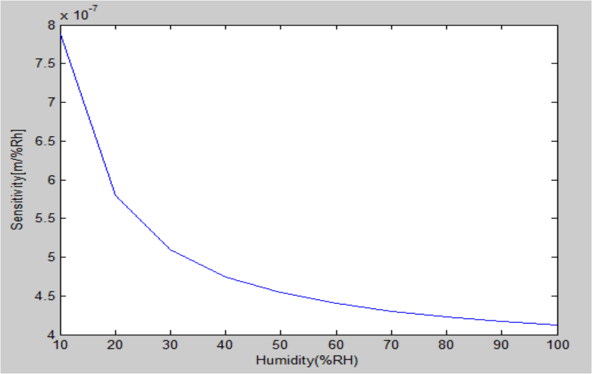

Figure 8. Humidity vs Sensitivity

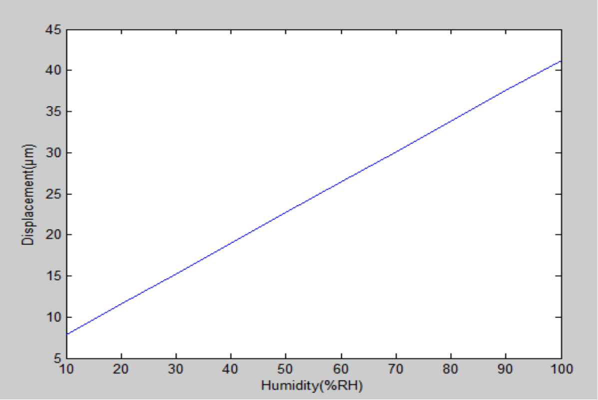

Figure 9. Humidity vs Displacement

A. For Humidity Sensing

TABLE III

Layers	**Dimensions And Thickness Of Layers**		
	Layer Name	**Dimension**	**Thickness (um)**
0	Substrate (Silicon)	20x40	25
1	Dielectric (Sio2)	150x20	0.4 0.2 0.3
2	Sensing (Platinum)	150x20	0.4 0.2 0.25
3	Sensing (Poly-silicon)	150x20	0.2 0.15 0.1

Where silicon has young's modulus value of 170 (Gpa), Poisson ratio of 0.26 and density of 2.32 (gm/cc) as material properties. Every layer has their individual material property (young's modulus, Poisson ratio, density) to give produce its own characteristics. The substrate of sensor is to give physical strength.

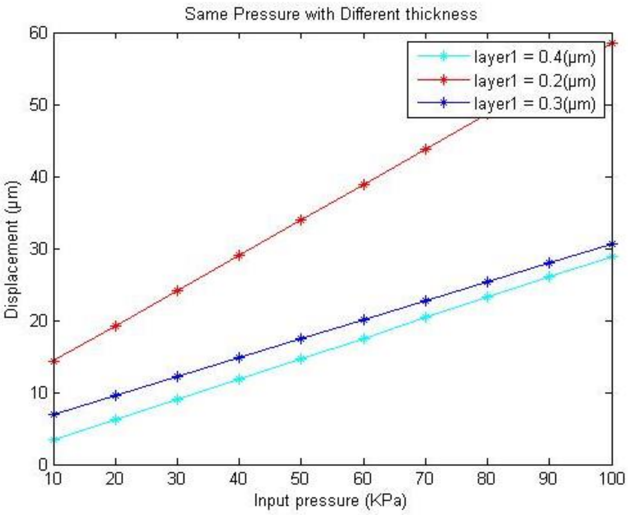

Figure 10. By Changing Various Thicknesses for Layer 1

The dielectric layer has material property as young's modulus of 61 (GPA), Poisson ratio 0.24 and density 2.1 (gm/cc). With same input thickness of the layer 2 and layer 3 is constant, layer 1 varies with minimum, maximum and moderate deflection. Layer 2 is to be sensing layer that has more sensing properties compare with other layers because this layer will be directly contacted with atmosphere. Two sensing layers are used because to increase the sensitivity and deflection one has more deflection property and other give more elasticity.

With same input thickness of the layer 1 and layer 3 is constant, layer 2 varies with minimum, maximum and moderate deflection.

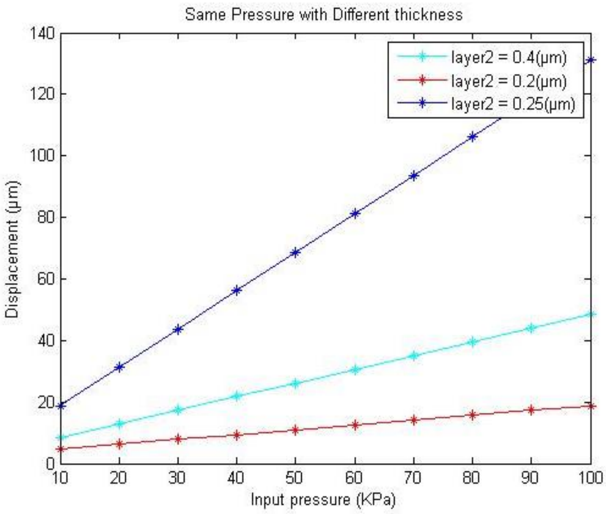

Figure 11. By Changing Various Thicknesses for Layer 2

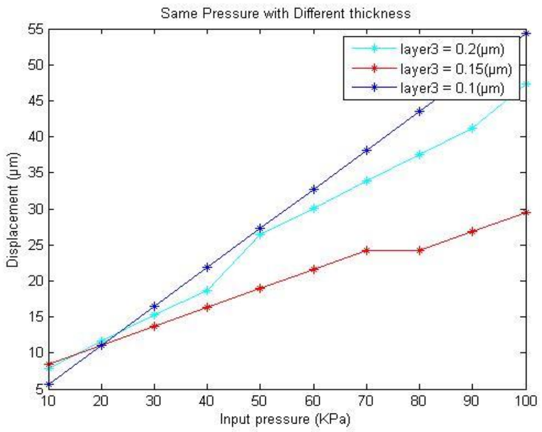

Figure 12. By Changing Various Thicknesses for Layer 3

Platinum has high Poisson ratio and density gives more elasticity. Poly-silicon gives more deflection because young's modulus is 160 (Gpa).

With same input thickness of the layer 1 and layer 2 is constant, layer 3 varies with minimum, maximum and moderate deflection. The sensing layer 2 and 3 has highest material property for humidity sensing. For each layer only the thickness is varied to detect moderate deflection because minimum has more deflection which leads to breakage of cantilever. If thickness is maximum then it leads to less deflection and would not sense lowest pressure in atmosphere.

B. For Temperature Sensing

TABLE IIIII

Layers	Dimensions And Thickness Of Layers		
	Layer name	**Dimension**	**Thickness (µm)**
0	Substrate (Silicon)	20x40	25
1	Dielectric (Platinum)	150x20	0.1 0.15 0.2
2	Sensing (Au)	150x20	0.15 0.1 0.05

3	Sensing (Cu)	150x20	0.2 0.15 0.1

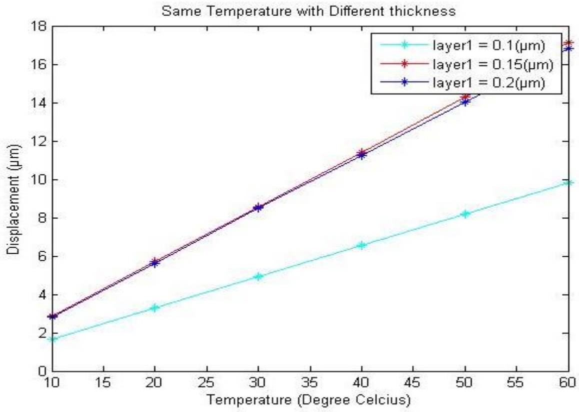

Figure 13. By changing various thicknesses for layer 1

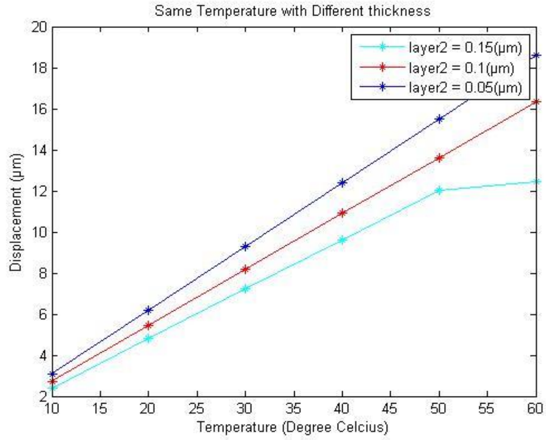

Figure 14. By Changing Various Thicknesses for Layer 2

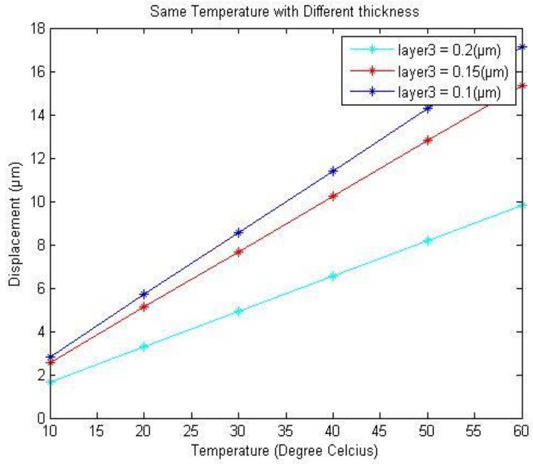

Figure 15. By Changing Various Thicknesses for Layer 3

V. CONCLUSION

This sensor is designed mainly for automation in agriculture and also to implement MEMS concept. The basic need for automation is to connect natural environment with digital environment as conversion of mechanical into digital or other. For this process we need sensors, basically for agriculture farmer to sense temperature, humidity, moisture, fertilizers and pesticides. If farmer knows temperature and humidity they can take safety precautions of their land in case of irregular environmental climate change cause negative impact on land and leads nutrition leach. To avoid this, designing a sensor is necessary which detects both temperature and humidity simultaneously.

VI. REFERENCES

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