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Research paper

Mems based integrated temperature and humidity sensor for agricultural monitoring

B. Priyadarisshini [1] *, D. Sindhaniselvi [1], T. Shanmuganatham [1]

[1] Department of Electronics and Instrumentation Engineering, Pondicherry Engineering college, Pondicherry 605 014.Pondicherry, India

**Corresponding author E-mail: shanmugananthamster@gmail.com*

Abstract

Temperature and Humidity are interrelated parameters in the agricultural field to monitor the growth of the crop. This paper is proposed to design the MEMS based integrated temperature and humidity sensor for the cardinal temperature range of 35°F to 105°F and the relative humidity range of 60 % to 100% which is suitable for cultivating crops range in our country. These interrelated parameters are to be maintained for the better quality and high yield of the crop in the agricultural field. The integrated sensor is designed using simple cantilever and its analyzed. Further, sensitivity is enhanced with perforation in the sensing layer and dielectric layer and ribs in the dielectric layer.

Keywords: *Micro Cantilever; Temperature; Humidity; Displacement; Pressure.*

1. Introduction

MEMS sensor is a popular miniaturized technique with electro mechanical elements, which is used to monitor and control several parameters in different application to achieve automation. One such application is automatic monitoring of agricultural parameters in the field. Now – a – days, agricultural activities such as ploughing, farming, planting and harvesting are automated which reduces the cost and time is given in [1]-[5]. Similarly, the agricultural parameters are automatically monitored to yield better quality of crop and human intervention [6]-[7]. The most important agricultural parameter are temperature, humidity, soil moisture, soil nutrients and soil pH. If these sensors are integrated by using MEMS technology in single chip, it will be affordable to farmers. This paper is proposed as an initiative to design and integrate temperature and humidity sensor by using simple microcantilever is given [8]-[9]. As Temperature and humidity are the influential key factors which have sensitive impact in the growth and yield of the crop. For cultivating the crop, it is essential to regulate the temperature by providing a light source, but humidity becomes unnoticed in [10]-[12]. Microcantilever plays a vital role to achieve deflection with respect temperature and humidity in terms of pressure for the temperature range of 35°F to 105°F and Relative Humidity range of 60 % to 100 % in the temperature range of 25°C to 45°C as this is recommended agricultural temperature range of our country. The sensor is designed using microcantilever and integrated and its performance is analyzed with respect to deflection. The deflection sensitivity is maximized by sculpting as a perforation and ribs, the vertical beam to the integrated sensor is also presented.

2. Design of micro cantilever

2.1. Structure of integrated sensor

Microcantilever is integrated on a square silicon substrate with dimension of 600 µm x 600 µm x 0.5 µm. The mask has been applied on the substrate to etch the substrate for the dimension of 500 µm x 500 µm x 0.5 µm. This act as a supporting beam to fix the integrated temperature sensor and humidity sensor. Silicon is best semiconductor for integrating discrete devices, as it is cheaper in cost and available in ample. The microcatilever based temperature sensor is of two layers such as silicon dioxide, Aluminium (Al) with the dimension of 200µm x 100µm x 0.5µm. Aluminum is optimal temperature sensing layer, Henceforth it has well in thermal expansion and good sensitivity [4]. Microcantilever based humidity sensor is of three layers such as dielectric layer with Silicon dioxide (SiO_2) and two sensing layer such as the sensing layer 2 with Polysilicon (PolySi) and sensing layer 1 with Platinum beneath the sensing layer 2 . Humidity sensor is constructed with the similar dimension of 200µm x 100µm x0.5µm for simplicity. The integrated sensor is shown in Fig. 1.

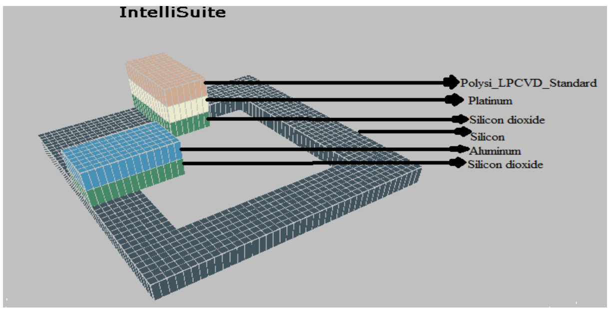

Fig. 1: Integrated Temperature and Humidity Sensor.

2.2. Material properties

The properties of sensing material, dielectric material and substrate material used in temperature sensor and humidity sensor are given in Table I

Table 1: Material Properties for the Materials Used in the Simulation

Material	Density (ρ) (10-6 Ω ×cm)	Young Modulus (GPa)	Poisson Ratio	Dia-lect Cost	Thermal conductivity (At 300K (W/m K))	Thermal expansion (At 300K (10-6 Material / °C)
Si	0.22	170	0.26	-	156	2.616
SiO_2	2.2	73	0.17	3.9	1.4	0.4-0.55
Pt	21.45	146.9	0.38	-	71.6	8.8
Al	2.7	70	0.36		236	25
Polysilicon_LP CVD _Standard	2.32	169	0.22	4.2	-	-

2.3. Conversion of fahrenheit to celsius

The suitable temperature range for cultivating the crops are 35°F to 105°F is converted in terms of degree Celsius for the respective range by using the equation (1) and shown in Table II

$$T_c = \frac{5}{9} * (T_f - 32) \tag{1}$$

Where Tc - air temperature in degrees Celsius (°C),
Tf - air temperature in degrees Fahrenheit (°F).

Table 2: Equivalent Celsius for the Temperature Range of 35°F to 105°F

RH (%)	Deflection (µm)	
	T = 35ºC	T = 105°C
10	35	1.66667
20	40	4.44444
30	45	7.22222
40	50	10
50	55	12.7778
60	60	15.5556
70	65	18.3333
80	70	21.1111
90	75	23.8889
100	80	26.6667

2.4. Equivalent pressure

Humidity sensor is simulated with equivalent pressure of relative humidity 10% to 100% is given by the equations (2), (3) and (3) at 25°C and 40°C.

$$RH\ (\%) = \frac{E}{E_S} * 100 \tag{2}$$

$$E_S = 6.11 \times 10^{\left(\frac{7.5\,TC}{237.7+TC}\right)} \tag{3}$$

$$E = 6.11 * 10^{\,(7.5\,TC/\,(237.7+Tdc)}) \tag{4}$$

Where T_c - air temperature in degrees Celsius (°C), T_f - air temperature in degrees Fahrenheit (°F), E_s- saturated vapor pressure in Mega Pascal (MPa), E - absolute Vapor pressure in Kilo Pascal (KPa),T_{dc} - dew point temperature in degrees Celsius (°C), T_{df} - dew point temperature in degrees Fahrenheit (°F). In India the necessary temperature to yield a crop ranges from 25°C to 40°C and tolerance level is always maintained within the temperature range for cultivating. The Relative Humidity RH (%) is converted into equivalent pressure for the maximum and minimum temperature samples 25°C to 40°C is in given Table III.

Table 3: Equivalent Pressure at Temperature 25°C and 40°C

RH (%)	Deflection (µm)	
	T = 25°C	T = 40°C
10	$3.1e^{-04}$	$7.3\ e^{-04}$
20	$6.2e^{-04}$	$1.46\ e^{-03}$
30	$9.3e^{-04}$	$2.19\ e^{-03}$
40	$1.24e^{-03}$	$2.92\ e^{-03}$
50	$1.55e^{-03}$	$3.65\ e^{-03}$
60	$1.86e^{-03}$	$4.38\ e^{-03}$
70	$2.17e^{-03}$	$5.11\ e^{-03}$
80	$2.84e^{-03}$	$5.84\ e^{-03}$
90	$2.79\ e^{-03}$	$6.57\ e^{-03}$
100	$3.1\ e^{-03}$	$7.3\ e^{-03}$

3. Deflection analysis

3.1. Deflection output for integrated sensor

The deflection analysis of integrated sensor gives 19.2677 µm at 40.556°C and 27.6779 µm for 100 % relative humidity for temperature 25°C. The deflection analysis is carried in the Table IV.

Table 4: Deflection Analysis for Integrated Temperature and Humidity Sensor for Maximum Range

Parameter	Maximum Range	Deflection (µm)
Temperature (°C)	40.556	19.2677
Humidity (%) At 25°C	100	27.6799

3.2. Enhancement of deflection output for integrated sensor

The deflection is improved for Temperature and humidity sensor by the addition of ribs in the substrate and perforation on all the layer in the micro cantilever structure to enhance the deflection. The integrated sensor with perforation and ribs are added is shown in Fig. 2.

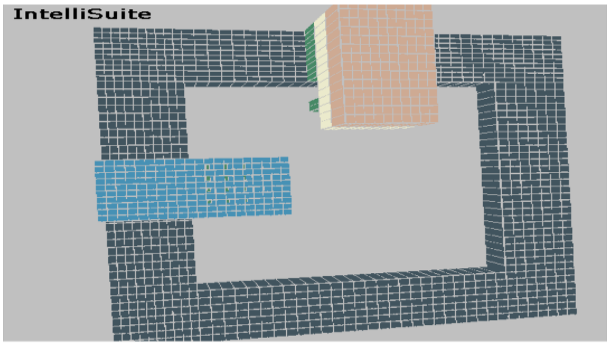

Fig. 1: Integrated Temperature and Humidity Sensor with Perforations and Ribs.

3.3. Perforated temperature sensor

In the temperature sensor, the deflection has been improved by the sculpting multiple square perforation with the dimension of 10 µm length and 10µm width and thickness of 1µm in the dielectric layer and the sensing layer. Hence it is carried it out for the deflection analysis for the agricultural temperature range of 35°F to 105°F in the Table V.

Table 5: Deflection Analysis for Temperature Sensor with Perforations Font Specifications for A4 Papers

Temperature (°F)	Temperature (°C)	Deflection (µm)
35	1.66667	0.799415
40	4.44444	2.13176
45	7.22222	3.46412
50	10	4.79647
55	12.7778	6.12883
60	15.5556	7.46649

65	18.3333	8.79351
70	21.1111	10.1259
75	23.8889	11.4582
80	26.6667	12.7906
85	29.4444	14.1229
90	32.2222	15.4553
95	35	16.7876
100	37.7778	18.12
105	40.556	19.4526

From the above data, the deflection of temperature is revealed to be linear as shown in Fig. 3. It is further carried out for obtaining the electrical output.

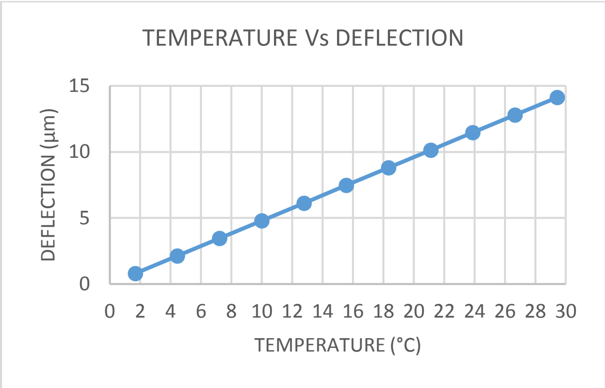

Fig. 3: Temperature vs Deflection.

Fig. 3. shows the deflection output of the temperature sensor is linear. Hence it is suitable for converting the deflection output into electrical output by using peizoresistive technique

3.4. Ribbed humidity sensor

The deflection analysis for the humidity sensor is enhanced by sculpting the dielectric layer as vertical beam called as rib with the dimension of 20µm x 100µm x 0.5µm and it is carried out for 10% to 100% relative humidity for the minimum temperature of 25°C to maximum temperature of 40°C is shown in the Table VI.

Table 6: Deflection Analysis for Humidity Sensor with Ribs

RH (%)	Deflection (µm)	
	T = 25ºC	T = 40ºC
10	30.27	31.37
20	31.08	33.28
30	31.89	35.19
40	32.71	37.10
50	33.52	39.01
60	34.33	40.92
70	35.14	42.83
80	35.95	44.75
90	36.76	46.66
100	37.57	48.57

From the above data, the deflection of humidity sensor is revealed to be linear for the maximum temperature 25°C to 40°C as shown in Fig. 4. It is further carried out for obtaining the electrical output.

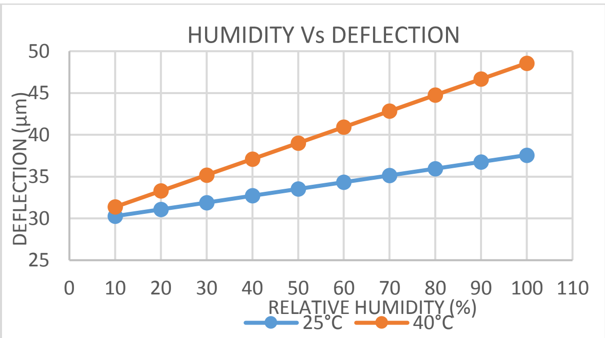

Fig. 4: Humidity vs Deflection.

Fig. 4. shows the deflection output of the humidity sensor is linear. Hence it is suitable for converting the deflection output into electrical output by using peizoresistive technique.

4. Conclusion

The simple cantilever is incorporated for integrating MEMS based temperature and humidity sensing for the agricultural application . By integrating the sensors, reduces the complexity and cost. The deflection is analyzed for the integrated sensor with respect to to temperature (°C) and relative humidity (%). When the temperature is given to the temperature sening layer on the multiple square perforated microcantilever, the deformation occurs by 19.4526 µm for 40.556°C and thus enhanced by 0.96% . When the pressure is exposed to humidity sensing layer by adding middle rib in the substrate material below the sensing layers, the deformation occurs by 37.57 µm for 100 % Relative Humidity at 40°C is enhanced by 35.73 %. From this study it is identified that the perforations and ribs in the microcantilever have a tendency to deflect more. This integrated low cost, compact MEMS device can be inexpensive to farmers and can avoid the consequence of water scarcity.

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