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DESIGN OF CAPACITIVE HUMIDITY SENSOR IN COMSOL MULTIPHYSICS

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ABSTRACT

This paper proposes the study and design of acapacitive humidity sensor in MEMS Technology using COMSOL Multiphysics. The main motivation behind this work is the need in automotive industry for a reliable humidity (r.h), new low-cost sensor which would be suitable for placement in cars. In medical applications, they are used to enhance the comfort level of patient by sensing and coupling with microcontrollers. Capacitive humidity sensor is a parallel plate capacitor with a sensitive layer sandwiched between the plates which work under a capacitive operating principle. The design includes a sensing material called membrane which is sensitive to the pressure (Physical quantity) like graphene, which enhance the deposition and even distribution of water molecules in the dielectric medium, this in turn results in better sensitivity.

Keywords: relative humidity, humidity sensor, MEMS, COMSOL multiphysics, simulation.

INTRODUCTION

A sensor is a device that converts one form of energy into other and delivers the user with a usable energy output in response to the precise measurable input (Madou, 1997). A MEMS design of sensor is constructed in order to achieve a certain engineering functions by electromechanical or electrochemical means; they are also known as micro sensors. Any kind of physical quantity can be measured with the help of a micro sensor. For example pressure, temperature, Humidity etc.

Micro scale humidity sensors are found in several applications where they are very useful in medical applications by enhancing the comfort level of patients with the help of sensing humidity and also when coupled with microcontrollers, they are more efficient.

Measurement of Humidity is one of the most substantial issues in abundant areas of applications such as instrumentation, agriculture, automated systems, GIS and climatology. Humidity is defined as the amount of moisture content in an atmosphere of air or other gases. Units of Humidity are based on the measurement techniques used. The most commonly used terms are Parts Per Million (PPM) by weight or by volume, Dew/Frost Point (D/F PT) an Relative Humidity (RH), where the two latter are subclasses of Absolute Humidity (AB).

Humidity is broadly classified into three types. They are,

- Relative Humidity
- Specific Humidity
- Absolute Humidity

RELATIVE HUMIDITY

Relative Humidity (also known and abbreviated asRH) is defined as ratio of the amount of water vapour in the air to the maximum (saturated) moisture content that the air can hold at a same given pressure and temperature of the gas. Relative Humidity is a temperature dependent magnitude, so it is a relative measurement.

The RH measurement is stated in percentage and given by the expression:

$$RH\% = \frac{P_v}{P_s} \times 100 \qquad (1)$$

Where P_v is the partial pressure of vapour
And P_s is the saturated vapour pressure

Relative Humidity is also expressed in terms of pressure where it is the ratio of pressure of water vapour in the gas to saturation pressure of water vapour at the temperature of the gas. It is given by

$$RH = \frac{\text{Pressure of water vapour in gas}}{\text{Saturated pressure of water vapour at the temperature of the gas}}$$

According to the sensing material used relative Humidity sensors are classified into three types, they are Semiconductor, Ceramic and Organic polymers. Also according to the operating principle they are classified into Electrical, Thermal conductivity and Mechanical type. Further Electrical type humidity sensor is classified into impedance and capacitance types.

PRINCIPLE AND STUDY

Capacitive humidity sensor

It detects humidity by measuring the change in the electrostatic capacity of an element corresponding to ambient humidity [1]. The sensor that detects the humidity based on a change of capacitance between two electrodes provided on a semiconductor substrate.

Humidity measurement in the hygrometer is measured by either electrical impedance or capacitance of the sensing matters that is which proportional to the variation in some organic and inorganic synthetic body physics. The basis of sensing moisture is the chemical and physical adsorption of water molecules.

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Study

When moist air is deposited on the surface, the water molecules are absorbed by the sensing material [2] these molecules will then diffuse into the dielectric resulting in a change of permittivity, this relation is given by the equation:

$$C = \varepsilon_0 . \varepsilon_r . \frac{A}{d} \tag{2}$$

Where A is area of the upper frame
ε_0 is the permittivity of air
ε_r is the permittivity of dielectric
d is distance between two armatures

The relative permittivity is calculated by the expression of Clausius-Mossoti [3]

$$\frac{N_A \alpha}{3\varepsilon_0} = \left(\frac{\varepsilon_{r(RH)}-1}{\varepsilon_{r(RH)}+2}\right) - \left(\frac{\varepsilon_{r(0)}-1}{\varepsilon_{r(0)}+2}\right) \tag{3}$$

Where ε_0 is the permittivity of the vacuum
α is molecular Polarisability depending on the material used in (cm^2/v)
V is the volume of detection layer
N_A is Avogadro's number is equal to #
$6.023 \times 10^{22} mol^{-1}$

SENSOR DESIGN IN COMSOL MULTIPHYSICS

COMSOL Multiphysics

Capacitive humidity sensors can be virtually designed using a powerful 3D modelling software, COMSOL. [7]

It provides user the flexibility to model the sensor also using a simple 2D user interface that can be easily converted into a 3D model. With the help of this software, the sensor can be modelled for any type of application like water sensing, touch sensing and pressure sensing.

Design of sensor

The capacitive humidity sensor mainly consists of two metal armatures between which an insulating polymer is sandwiched layer acts as a dielectric.

The modelled sandwich structure of capacitive humidity sensor is shown in the Figure-1.

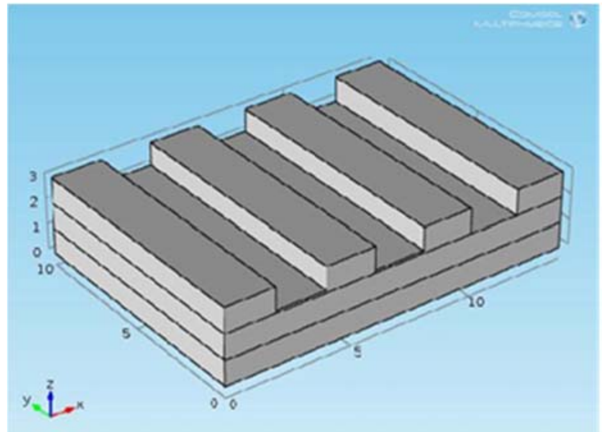

Figure-1. Schematic representation of the humidity sensor.

A Pressure sensing membrane is added between the two armatures to ensure the absorption and even distribution of water molecules by the dielectric material.

Selection of polymer

Choosing the best polymer is an important task which gives the best absorption and better response time. These two parameters depend on the nature of the polymer being used. A study was performed with several polymers. Table-1 summarizes the results [2]. It is found that the polymer Polyimide provides better absorption.

The comparison table of polymers is shown below.

Table-1. Comparison of two commonly used polymers.

Polymers	Diffusion $(\mu m^2/s)$	Concentration (mol/m^3)	Time (sec)
Polyimide	$2.81\,e^{-13}$	$2.0850\,e^{-16}$	0.03
Polyvinyl acetate	$1.10\,e^{-09}$	$1.8103\,e^{-15}$	0.03

Sensor dimensions

Sensor dimensions are given below,

Blocks: 14μm*10μm*1μm

Parallel blocks: 2μm*10μm*1μm (with spacing of 2 μm)

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RESULT AND OBSERVATION

The sensor simulation is shown in the forms of total displacement.

The simulated result of the designed (sandwich structure) capacitive humidity sensor is shown in the Figure-2 polymer sandwiched in between two metal

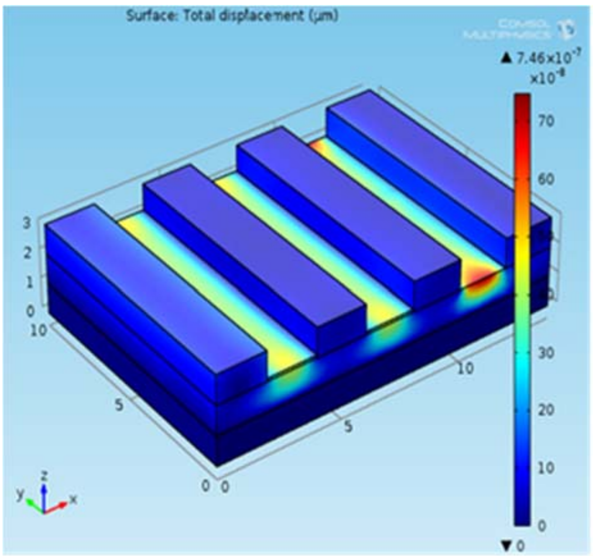

Figure-2. Simulation of capacitive humidity sensor.

CONCLUSIONS

A structure of humidity sensor is designed in COMSOL Multiphysics. This sensor is composed of polymer sandwiched in between two metal electrodes. It is studied that polyimide gives a better sensitivity. The formation of membrane is useful for diffusion and distribution of water molecules. Further, It can be developed into an Interdigital capacitive structure (comb structure) [9] where the recent polymer called Resorcinol-formaldehyde aerogels can be replaced to give the better sensitivity [8].

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