A CMOS-MEMS Humidity Sensor

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Abstract. This paper presents an integrated humidity sensor which is comprised of a humidity sensing element and a readout circuitry. The sensor is realized in TSMC 0.35 \( \mu \)m CMOS process with subsequent micromachining technology. The presented humidity sensor can achieve good linearity over the relative humidity range from 20% to 80%. The total power dissipation of readout circuit is 37.1 mW and the chip size is 1220\( \times \)1042 \( \mu \)m². The designed humidity sensor has the advantages of high integration, small size, high sensitivity and high reproducibility. Its feasibility has been demonstrated by experimental results.

Keywords: humidity sensor, capacitive sensor, CMOS-MEMS process

1. Introduction

Humidity sensor is widely used in different application areas, especially in the industry requires the environment of humidity control, such as the semiconductor and LCD fabrication industries. High-humidity environment also enhance the growth speed of bacteria and fungus. It may harm the human’s health and damage the stored materials. Therefore, proper sensing and control of humidity is very important.

The common existing humidity sensing element can be classified into the following four types: capacitive [1-2], resistive [3-4], oscillatory [5] and piezoelectric [6]. The capacitive and resistive sensing elements are easier to realize with semiconductor process. For these two sensing types, the resistive one is more susceptible to temperature thus larger error will be induced. The capacitive-type of humidity sensing elements are less sensitive to temperature and have lower power consumption.

The sensing film material used in capacitive humidity sensor often possesses the features of high resistivity and low relative permittivity (about 3 to 7), and has functional groups for the adsorbing of water molecules. Ether (-O-) is one of the functional groups and is the composition of polyvinyl alcohol (P.V.A.). It is known that the relative permittivity of water is about 80, which is much higher than the sensing film. After the water molecules have been adsorbed by sensing film, the overall relative permittivity is increased. It results in the increased values of capacitance. This is the main principle of the presented humidity sensing element in the article. Because of the availability and properties of good water absorption, water retention and adhesion of P.V.A., it has been adopted in our designed humidity sensing element.

The designed integrated sensor comprises sensing element and readout circuit. It is implemented in TSMC 0.35 \( \mu \)m CMOS process. The total power dissipation of readout circuit is 37.1 mW and the chip size of overall sensor is 1220\( \times \)1042 \( \mu \)m². The measured result confirms the feasibility of our design.

2. Humidity Sensing Element Design

The schematic of the humidity sensor structure is shown in Fig. 1. It comprises comb electrodes, sensing film, heater, readout circuit, and silicon substrate.
The structure of the comb electrodes is shown in Fig. 2, and it is consisted of metal (Al) and via (W) layers. The gap between two comb electrodes is formed by removing the oxide layer with dry etching technology. The designed electrode width is 5μm with 4μm spacing. The total area of sensing element is 1000×1022 μm². After etching process, we coated 10 wt% of P.V.A. in the gap of comb electrodes as the sensing film. Thus the relative permittivity will be changed after adsorbing water molecules, and hence the capacitance between comb electrodes is changed. In addition, the readout circuit senses the change of capacitance and converts the signal to frequency form. Furthermore, the polysilicon layer is used as a heater which locates under the comb electrodes in order to achieve the reset function. It speeds up the release of water molecules for present measurement. The cross-section view of the humidity sensor is shown in Fig. 3.

3. Readout Circuit Design

The capacitive sensing circuit with outputted voltage signal is common adopted for signal processing. It is conductive to real-time measurement of voltage signal. The capacitance variations in the sensing element result in various outputted voltage level. However, if the sensor outputs a weak voltage signal, it will be hard to distinguish the measured signal from noise interference. So the resolution of sensor is limited. Therefore, we monitor the variations of outputted frequency of circuit for detecting capacitance variation. A self-oscillated oscillator is used to sense the capacitance variation of the sensing element. The different capacitance of the sensing element leads to different outputted frequency of the sensing circuit.

3.1. CMOS Oscillator Principle

The basic CMOS oscillator composed of two inverters, a resistor, and a capacitor, is shown in Fig. 4(a) [7]. The period depends on the charge and discharge time of node A, and is proportional to the product of $RC_s$. Fig 4(b) shows the voltage waveforms of the nodes in the circuit of Fig 4(a). The voltage of node A are given by
\[ v_j(T_1) = V_{DD} \left( 1 - e^{-\frac{t}{\tau}} \right) \Rightarrow T_1 = \tau \ln \frac{V_{DD}}{V_{DD} - V_{th}} \]  

(1)

\[ v_j(T_2) = V_{DD} e^{-\frac{t}{\tau}} \Rightarrow T_2 = \tau \ln \frac{V_{DD}}{V_{th}} \]  

(2)

The time constant \( \tau \) is defined by

\[ \tau = RC \]  

(3)

The period \( T \) of this CMOS oscillator can be described as

\[ T = T_1 + T_2 = RC \ln \left( \frac{V_{DD}}{V_{DD} - V_{th}} \right) \]  

(4)

3.2. The Realization of CMOS Oscillator

For the practical application of circuit in Fig. 4(a), the output waveform of node B will not be a square wave if the voltage of node A can not approach logic threshold \( V_{th} \). For the deriving of better square waveform and correct operation of the oscillator circuit, the Buffer 1 is added to faster charge the capacitor \( C_S \), as shown in Fig. 5. Thus the voltage of node A will be larger than \( V_{th} \). In addition, a large buffer (Buffer 2) is used to drive the external off-chip load. The \( C_S \) in Fig. 5 is realized by the sensing element in Section 2.

4. Measurement Results

As shown in Fig. 6, the designed humidity sensor is tested in a humidity-controllable environment. We inject the nitrogen into a filter bottle to generate water vapour. So we can change the humidity in measurement environment by adjusting the inputted quantity of nitrogen. The sensor chip is tested by the measurement of outputted oscillation frequency with a DC supply voltage of 3.3V.
The experimental result shows that the humidity sensor operates correctly for the RH of 20% to 60%, as shown in Fig. 7. To improve the operating range of the humidity sensing element, the property of the sensing film has been modified by oxygen plasma reaction and immersion with 0.1 wt% NaCl solution, respectively. After these processing procedures, the humidity sensor is tested in the same measurement environment. In Fig. 7, it shows that the designed sensor with the process of oxygen plasma reaction can work validly for the RH of 20% to 80%. Besides, the designed sensor with the process of immersion with 0.1 wt% NaCl solution can also work validly for the RH of 20% to 80%. Also, in Fig. 7, it can be observed that the linearity of the sensing element is improved for our modifications of sensing film.

In addition, we can compute the capacitance in different environment of humidity. Fig. 8 shows the measured equivalent capacitance in various environment of humidity. Since the reproducibility is an important parameter of sensing element, the sensor is tested for many times. The reproducibility of the designed sensor is verified by various testing of the designed sensor with the process of oxygen plasma reaction. Fig. 9 shows the tested results of different experimental measurement. The photograph of fabricated sensor chip is shown in Fig 10.

![Fig. 6: Structure of the measurement environment.](image)

![Fig. 7: Measurement results of the humidity sensor.](image)

![Fig. 8: Equivalent measured capacitance in various environment of humidity.](image)
5. Conclusions

In this article, a CMOS-MEMS humidity sensor has been presented. The sensor system integrates humidity sensing element with its readout circuit. The humidity sensor has the advantages of high integration, small size, high sensitivity and high reproducibility. This humidity sensor may have potential for many applications, such as industrial automation and environmental monitoring.

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7. References


