A Highly Sensitive Humidity Sensor Using a Modified Polyimide Film

Yong-Ho Kim, Joon-Young Lee, Yong-Jun Kim, and Jung-Hyun Kim*

Abstract—**This paper presents the design, fabrication sequence and measurement results of a highly sensitive capacitive-type humidity sensor using a polyimide film without hydrophobic elements. The structure of the humidity sensor is MIM (metal-insulator-metal). For a high sensitivity, a modified aromatic polyimides as a moisture absorbing layer has been synthesized instead of using general polyimides containing hydrophobic elements. The polyimide film was obtained by synthesizing and thermally polymerizing polyamic acid composed of m-pyromellitic dianhydride, phenelenediamine and dimethylacetamide. Characteristics of fabricated sensors which include sensitivity, hysteresis and stability have been measured. The measurement result shows the percent normalized capacitance change of 0.37/%RH over a range from 10 to 90%RH, hysteresis of 0.77% over the same %RH range and maximum drift of 0.25% at 50%RH. The result shows that the developed humidity sensor can be applied to evaluate a hermeticity of various sensors and actuator systems as well as micro packages.**

Keywords—**Capacitive humidity sensor, modified aromatic polyimide films, hydrophobic**

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I. INTRODUCTION

As the demand for a successful packaging increases, a tool to evaluate hermeticity of micro packaging has become important. As failures are mainly due to contaminants such as moisture, a highly sensitive and stable humidity sensor has got much attention [1].

In a capacitive type humidity sensor, there are three parameters to determine the performance which is an effective area of electrodes, thickness and dielectric constant change of moisture absorbing layer. Although a larger area of electrodes and thinner absorbing layer are necessary for lager capacitance, there are constraints that are overall sensor size and uniformity of moisture absorbing layer. Furthermore, the important characteristics in a capacitive humidity sensor, especially for the sensitivity, is not a absolute amount of a capacitance change over a specific range of relative humidity but a normalized capacitance change over it. The normalized percent capacitance change is defined as Equation (1).

$$NPCC = \frac{C_f - C_i}{C_i} \times \frac{1}{\Delta RH} \times 100 \qquad (1)$$

where *NPCC : Normalized percent capacitance change*

C_i *: Capacitance at an initial relative humidity*

C_f *: Capacitance at a final relative humidity*

ΔRH *: Relative humidity change*

The large change of a dielectric constant of moisture absorbing layer over a range of relative humidity is a crucial factor for a large normalized percent capacitance change.

Generally, most of commercial polyimides for electronic application include fluorine elements which make a dielectric constant stable to moisture and to be kept low value to prevent cross-talking [2, 3]. Therefore, It can be an alternative to use a modified polyimide film as a moisture absorbing layer than to use commercially available one [4-6]. In this research, a capacitive humidity sensor has been fabricated with a polyimide that is synthesized with PMDA (pyromellitic dianhydride) and m-PDA (m-phenylenediamine) and its performance including sensitivity, hysteresis and stability has been tested.

II. Moisture Sensing Layer Preparation

Polyimide is a polymer material which can be obtained by thermal or chemical polymerization of polyamic acid (PAA) composed of two monomers, diamine and dianhydride, and aprotic solvent. Polyimide has been widely used for interlayer dielectrics in electronic industry where a low dielectric constant and insensitivity to moisture are imperative. Therefore 17 group element, for example fluorine or chlorine, has been included in diamine or dianhydride. As these kinds of polyimide films are not suitable for high sensitivity humidity sensor, the polyamic acid (PAA) has been synthesized from the reaction of diamine, m-PDA (m-phenylenediamine) without any fluorine elements, with dianhydride PMDA (pyromellitic dianhydride) in aprotic solvent. Polyimide film has been obtained by thermal polymerization of the polyamic acid.

The superior sensitivity of the polyimide film composed of m-PDA and PMDA to moisture had been approved by chemical engineers [7]. Furthermore, the excellent properties such as thermal stability (glass transition temperature>450℃) and chemical resistance make it fully compatible to general micro fabrication processes. The synthesis procedure and chemical structure of the polyimide film is shown at <Figure 1>.

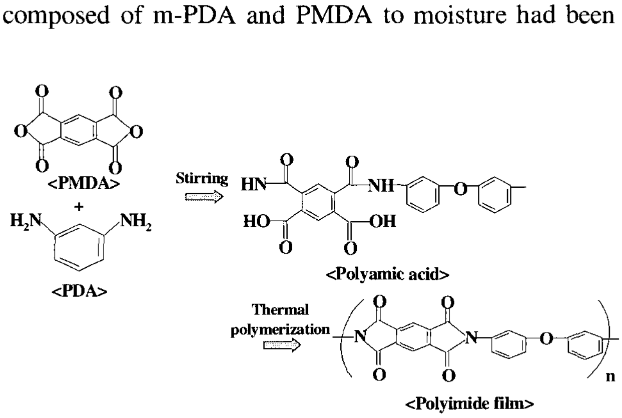
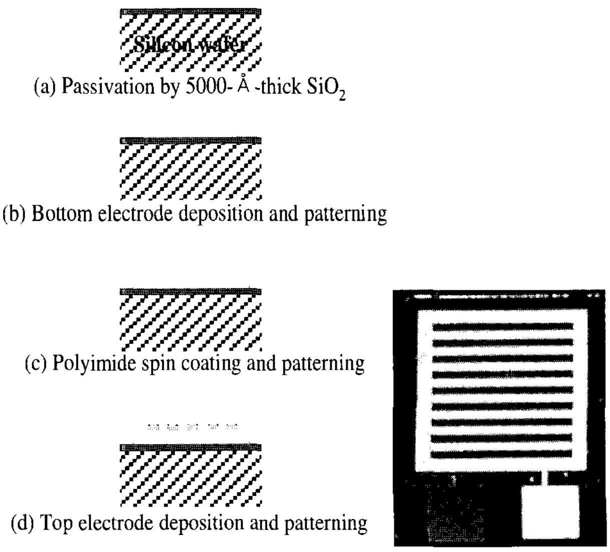


Fig. 1. The synthesis sequence and chemical structure of the modified polyimide film

III. Fabrication

The capacitive humidity sensors with the size of 0.96x0.96~9.6x9.6 mm^2 have been fabricated by 'polymer/metal multilayer processing [8, 9]' based on micro fabrication technology. It begins with a silicon wafer passivated with 5000Å silicon dioxide. Afterward, a conventional surface micromachining technology with a photoresist is used for 3000Å Au bottom electrode formation on a adhesion layer of 200Å Cr. The moisture sensing layer, polyamic acid in this case, is spincoated and cured with three steps which are 4 hours at 50℃ in a vacuum oven for rapid solvent removal, 1 hour at 200℃ and finally 1 hour at 300℃ for gradual and perfect polymerization. The 1.0~1.2 ㎛-thick polyimide film is patterned by O_2 RIE with the condition of pressure of 100mTorr, power of 100W for 15min. The last fabrication step is performed with the upper electrode deposition of



(a) Passivation by 5000-Å-thick SiO_2
(b) Bottom electrode deposition and patterning
(c) Polyimide spin coating and patterning
(d) Top electrode deposition and patterning

A. Simplified fabrication sequences B. Fabricated humidity sensor

Fig. 2. Fabrication sequences and optical photograph of the humidity sensor

1um-thick Al and patterned to get 50%, 60% and 70% effective area by standard photolithography processes. <Figure 2> shows the simplified fabrication sequence and optical photograph.

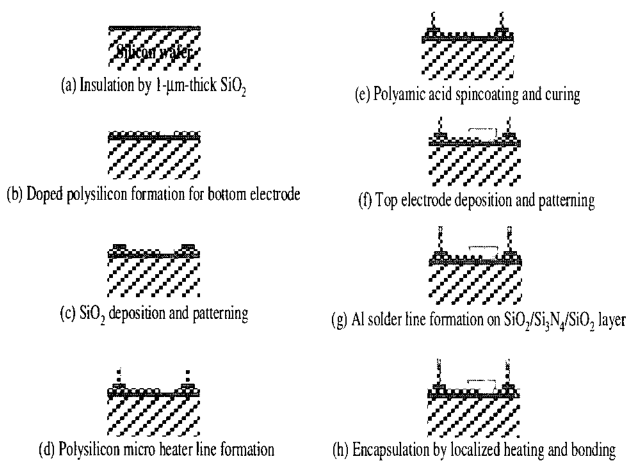


Fig. 3. Integration sequence of the humidity sensor with a micro package

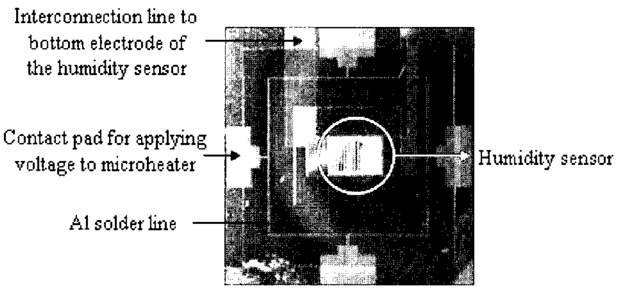


Fig. 4. Optical picture of the integrated humidity sensor in a micro package

A micro package using localized bonding with a polysilicon heater has been also fabricated to verify that the humidity sensor can be integrated in a micro package. It started with a silicon wafer passivated with 5000Å silicon dioxide followed by polysilicon deposition and patterning which layer is for a bottom electrode of the humidity sensor and interconnection line. Silicon dioxide was deposited and patterned for insulation of a polysilicon heater line and configuration of a micro heater, polysilicon, was defined. A moisture absorbing layer on a polysilicon bottom electrode and Al top electrode was formed. For a localized heating and bonding, Al solder was patterned and pyrex glass was used to encapsulate the micro package. Detail Integration sequence are presented at <Figure 3> and <Figure 4> shows optical picture of the fabrication result.

IV. MEASUREMENT

All devices are dried for 36 hours at 50℃ prior to measurement to remove moisture that is absorbed in the polyimide film during fabrication processes. The sensor performances such as sensitivity, hysteresis and stability, have been measured inside a environmental chamber (WEISS WK1[340]) of which resolution is ±1% relative humidity and ±0.5℃ temperature with a aid of RCL meter(HP4274A) at 100kHz. The device used for sensitivity and hysteresis measurement has the size of 2.8x2.8 mm^2 with 71.3% effective electrode area and 1㎛-thick polyimide film. Stability has been measured with the size of 4.8x4.8 mm^2 with 71.3% effective electrode area and 1um-thick absorption layer. All the measurement results show that the humidity sensor developed has good sensitivity, hysteresis and stability, especially for hysteresis and stability, compared to those of other research groups [4-6].

4.1 Sensitivity

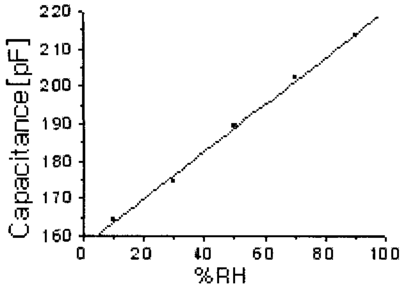
The measurement has been performed from 10% to 90% with 20% increments at 40℃. At specific relative humidity level, the capacitance has been recorded for 30min after 30min %RH stabilization step. The sensitivity should be defined as the amount of the capacitance change over the reference capacitance with respect to specific relative humidity range(10~90%) as defined in Eq. (1) because the absolute value of capacitance change can be simply increased with a device size and thickness of a moisture absorption layer. The normalized capacitance change is 0.37/%RH and the deviation form linear fitted line is 0.46% as shown in Fig. 5(a).

4.2 Hysteresis

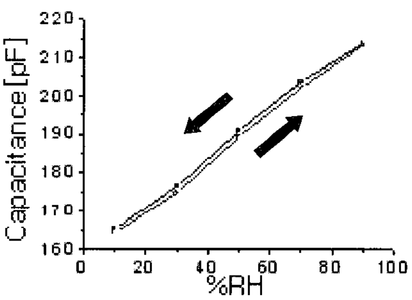
It is important to have a small deviation from the first measured capacitance over repetitive use of humidity sensors. Thus, the test has been performed by changing %RH from 10% to 90% and from 90% to 10% consecutively with increments 20%RH at 40℃. The result shows the measured hysteresis of 0.77% which is represented at Fig. 5 (b).

4.3 Stability

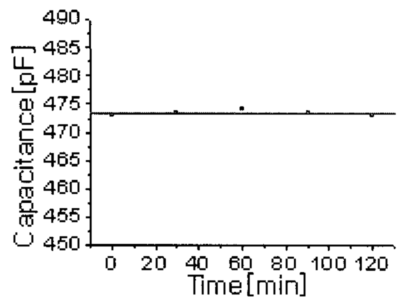
The characteristic has been measured at 50%RH for 120min every 30min of which result is shown at Fig. 5 (c). Average drift from the average value is 0.08% and the maximum drift is approximately 0.25%.



(a) Sensitivity



(b) Hysteresis



(c) Stability at 50%RH

Fig. 5. Measurement results for the fabricated humidity sensor

V. CONCLUSION

As the demand to evaluate a hermeticity of micro packages increases, a relative humidity sensor with good characteristics such as sensitivity, hysteresis and stability has been realized with the modified polyimide film without any fluorine elements prepared by m-PDA and PMDA using 'polymer/metal multilayer processing' based upon micro fabrication technology. At the same time, it has been verified that the humidity sensor can be integrated with a micro package which has been fabricated by localized heating and bonding technique with a polysilicon micro heater.

The measurement was performed using an environmental chamber and RLC meter. The result shows the normalized capacitance of 37.45/%RH, hysteresis of 0.77%.and stability less than 1% has been achieved mainly due to polyimide film with no hydrophobic element and high glass transition temperature. According to these results, it is expected that the developed humidity sensor can be applied to evaluate a hermeticity of a sensor and actuator systems as well as micro packages.

ACKNOWLEDGEMENT

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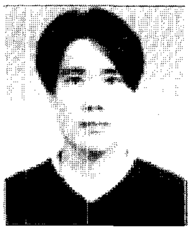

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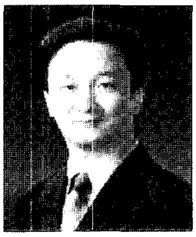

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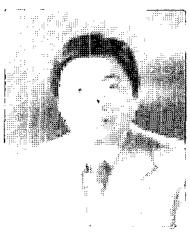

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