

Anodic aluminum oxide-based capacitive humidity sensor integrated with micro-heater

Y. D. Kim^{*}, B. B. Jung^{**}, H. K. Lee^{***}, K. H. Lee^{****} and H. C. Park^{*****}

^{*} Pohang University of Science and Technology, San31, Hyoja-Dong, Nam-Gu, Pohang, Gyeongbuk, 790-784, Korea (south), ydk@postech.ac.kr

^{**} Pohang University of Science and Technology, Korea (south), bbjung@postech.ac.kr

^{***} Pohang University of Science and Technology, Korea (south), qq9481@postech.ac.kr

^{****} Pohang University of Science and Technology, Korea (south), ce20047@postech.ac.kr

^{*****} Pohang University of Science and Technology, Korea (south), hcpark@postech.ac.kr

ABSTRACT

AAO(Anodic Aluminum Oxide) film is fabricated as a sensing material for capacitive humidity sensors. Since AAO films have a lot of nano-size pores, many water vapors can be absorbed. As a porous layer thickness increases, sensor increases sensitivity as well as hysteresis. Rectangular spiral-shaped and interdigitated type are designed and fabricated as electrode types. Performance of the rectangular spiral-shaped type are compared with that of the interdigitated type. A micro heater is also integrated to evaporate condensed water vapors and contaminants. Linearity and reliability are improved by the heater and amount of hysteresis is reduced.

Keywords: AAO, pore, capacitive, humidity sensor, heater

1 INTRODUCTION

Humidity sensors are very useful to many industrial and agricultural fields. Those are getting smaller, cheaper, lighter and better in recent years.

Humidity sensors based on alumina were investigated and the characteristics of the sensors have been demonstrated by Le Hoang Mai et al. [1]. A capacitive humidity sensor integrated with micro heater and ring oscillator circuit is fabricated and investigated by C. Dai [2]. R.K. Nahar investigated an understanding of performance degradation of the capacitive humidity sensor with anodized aluminum oxide thin-film at high humidity [3]. Among various humidity sensor types, capacitive-type and resistive-type are popular. Capacitive humidity sensors have several advantages over the other humidity sensor types. They exhibit a linear response to humidity and can be operated over wide range of relative humidity and wide temperature ranges[4]. Because AAO (Anodic Aluminum Oxide) structures have a lot of nano-size pores, capacitive humidity sensor with good performance is expected using the AAO.

2 DESIGN AND FABRICATION OF SENSOR

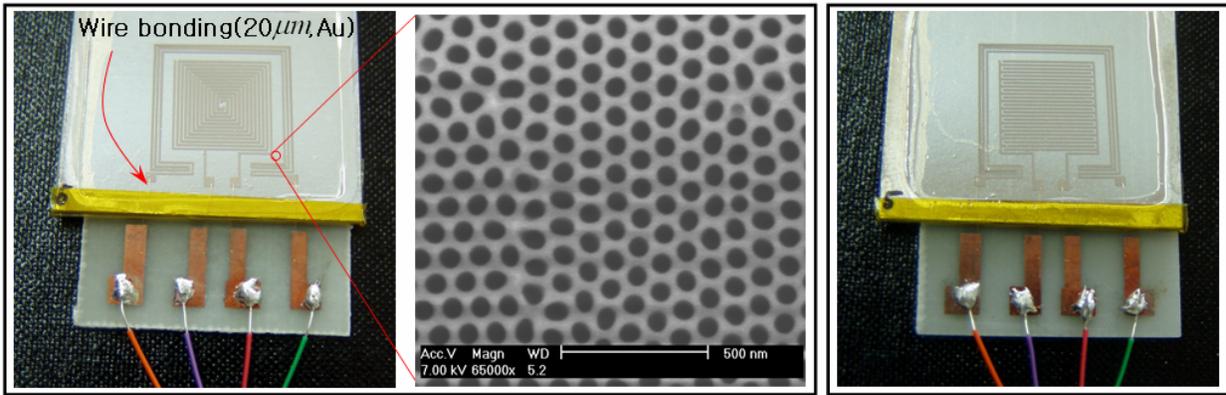
Among various AAO(Anodic Aluminum Oxide) fabrication methods, AAO films were fabricated by oxalic acid. The SEM image of fig.1 shows micrograph of the AAO, where black circle-shapes are nano-sized pores. Because AAO films have a lot of nano-size pores, many water vapor can be absorbed into these pores. So the AAO film is fabricated as a sensing material of sensors.

In designing a humidity sensor, important considerations and requirements are a good sensitivity, a accuracy over wide ranges of both humidity and temperature, a short response time, a resistance against contaminants, a negligible temperature dependence, cost effectiveness and a stability[5]. These performances of a humidity sensor are determined by important design factors. They are pore size, thickness of porous layer, electrode type and heater type.

Sensitivity, response time and linearity are a function of electrode type and size. Disadvantages of the parallel plate type are relatively long response time and difficulty to deposit a sandwich layer of sensing films. After first electrode and sensing layer are deposited, second electrode should be added on top of the sensing layer. The interdigitated type show a good sensitivity and a easy fabrication compared to the parallel plate type. The rectangular spiral-shaped type has a little more capacitance than the interdigitated type.

Rectangular spiral-shaped and interdigitated type are designed and fabricated as shown in fig. 1[6]. Electrode width is 200 μm . And size of gap between electrodes is also 200 μm .

The rectangular heater wraps the electrode. Sizes of width and gap are the same as the electrode. Electrode and heater are fabricated on the AAO films by aluminum of 500 nm thickness.



(a) Rectangular spiral-shaped type

(b) Interdigitated type

Figure 1: Humidity sensor devices.

3 PERFORMANCE EXPERIMENT OF HUMIDITY SENSOR

Fig. 2 shows the schematics of the experimental set up. Humidity sensor device is stored in a control chamber, to control humidity and temperature. Humidity is increased from 30% to 95% and decreased from 95% to 30%. Temperature is fixed at 30 °C. Capacitance is measured by the LCR meter. Electric power is supplied to the heater.

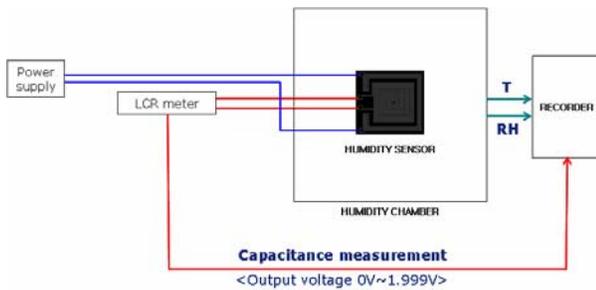


Figure 2 : Experimental set up.

3.1 Effect of design factors

Sensitivity of capacitive humidity sensor can be defined as the following eq.(1) in general.

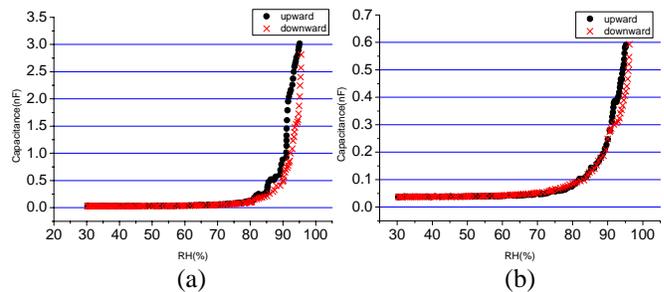
$$S_1 = \left(\frac{C_u}{C_l} - 1 \right) \cdot 100\% \quad (1)$$

But it can be expressed in eq.(2) also in case of linear sensor responses. Subscripts u and l represent the values at the upper and lower limit of the operating range, respectively[7].

$$S_2 = \frac{C_u - C_l}{RH_u - RH_l} \quad (2)$$

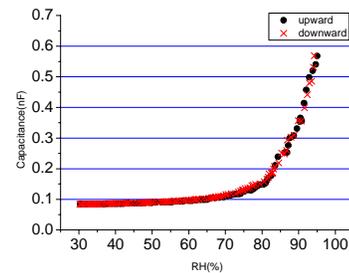
Hysteresis is the difference in output signal when measured for a up-trace and down-trace of the input signal.

Fig. 3 shows the capacitance characteristics with different porous layer thickness, where electrode types are the same rectangular spiral-shaped type. It shows big hysteresis from 80% RH in case of 50 μm porous layer thickness. It also does hysteresis from 90%RH in case of 30 μm porous layer thickness. But there is no hysteresis in case of 10 μm porous layer thickness. As porous layer thickness increases, a sensitivity become higher, which means thick porous layer can absorb more water vapor.



(a)

(b)



(c)

Figure 3: Capacitance characteristic of rectangular spiral-shaped type : with 50 μm porous layer thickness (a); with 30 μm porous layer thickness (b); and with 10 μm porous layer thickness (c).

Fig. 4 shows the capacitance characteristics with different electrode types. It shows big hysteresis from 80%RH in case of both rectangular spiral-shaped type and interdigitated type. Thus, it can be said that hysteresis is independent of the electrode type. But sensitivity of rectangular spiral-shaped type is higher than that of interdigitated type.

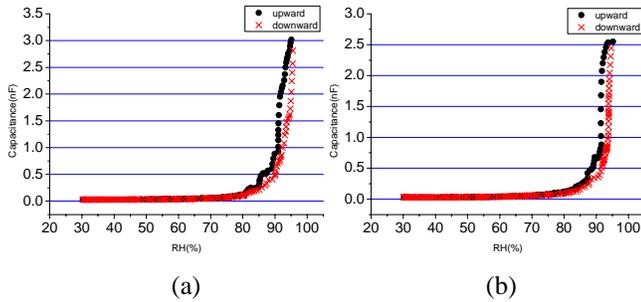


Figure 4: Capacitance characteristic : of rectangular spiral-shaped type(a); of interdigitated type(b) with 50 μm porous layer thickness.

Fig. 5 shows capacitance characteristics of the interdigitated type with different pore size. They have the same 30 μm porous layer thickness. There is no hysteresis in cases 80 nm and 60 nm pore sizes. But there is small hysteresis from about 85% RH in case of 40 nm pore size. As pore size decreases, sensitivity also decreases because smaller pores have smaller areas to absorb water vapor.

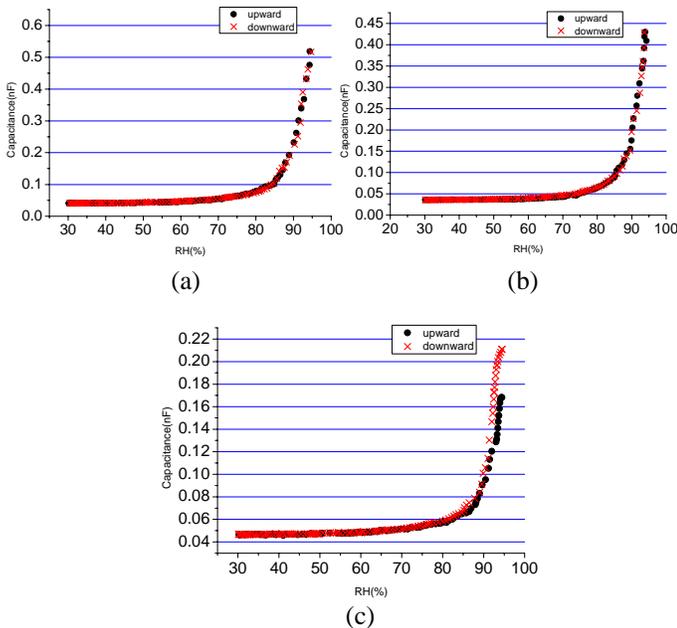


Figure 5: Capacitance characteristic of interdigitated type : with 80 nm pore size(a); with 60 nm pore size(b); with 40 nm pore size(c);

3.2 Effect of heating

Some of water molecules are not desorbed from pore wall especially in high humidity, because many of them are condensed and trapped on the pore wall. In high humidity, a humidity sensor does not show good linearity and shows bad stability.

In order to evaporate condensed water vapor and contaminants, micro heater is integrated by which linearity and reliability are improved and hysteresis is reduced[8].

Fig. 6 shows the capacitance characteristic of rectangular spiral-shaped type with 10 μm porous layer and 80 nm pore size with and without heating.

Without heating, measured capacitance range is from 84.1 pF to 569 pF as a humidity increases from 30% to 95%. With heating, measured capacitance range is from 62.4 pF to 81.9 pF, that indicates that sensitivity become lower when the heat is applied. But with heating, humidity sensor shows a good linearity with small hysteresis.

The response times of the sensor are 18 seconds for with-heating and 80 seconds for without-heating. The response time is the time required to reach 90% of the final (stable) output of the sensor after increase of chamber humidity

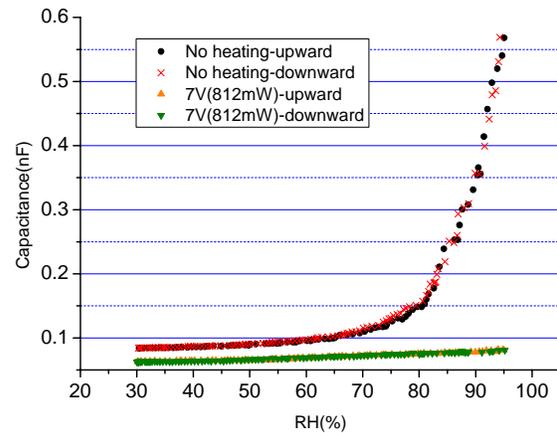


Figure 6: Capacitance characteristic of rectangular spiral-shaped type with 10 μm porous layer thickness and 80 nm pore size with and without heating.

4 SUMMARY

This research investigated the AAO-based capacitive humidity sensor. Because AAO films have a lot of nano-size pores, many water vapor can be absorbed.

As porous layer thickness increases, sensitivity becomes higher, which means thick porous layer can absorb more water vapor. In cases of 50 μm and 30 μm porous layers, there are hysteresis. Sensitivity of rectangular spiral-shaped type is higher than that of interdigitated type. But hysteresis is independent of the electrode type.

It shows a good linearity with no hysteresis for the relative humidity when the heater is integrated. The sensitivity is 0.3 pF/% and the response time is 18 second. Under the condition, we do not need a additional linear modification.

REFERENCES

- [1] L. H. Mai et al., Sensors and Actuators B 66, 63 (2000)
- [2] C. Dai, Sensors and Actuators B 122, 375 (2007)
- [3] R.K. Nahar, Sensors and Actuators B 63, 49(2000)
- [4] JON S. Wilson "Sensor Technology Handbook", Newnes, 271-273,2005
- [5] Z.M. Rittersma, Sensors and Actuators A 96, 196(2002)
- [6] J.S.Kim, Sensors and Actuators B 30, 159(1996)
- [7] Craig A. Grimes, Elizabeth C. Dickey and Michael V.Pishko, "Encyclopedia of Sensors", American Scientific Publishers, vol.4, 481-509,2006
- [8] P.Furjes, Sensors and Actuators B 95, 140(2003)