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ABSTRACT

A humidity sensor having linear relationship in relative humidity (RH) versus electrical capacitance (C) characteristics is fabricated. As the humidity-sensing part of the sensor, the double layered film by polyphenylene ether sulfone (PES) and cellulose acetate butyrate (CAB) is used. Prior to the fabrication, RH-C characteristics are simulated by using RH-C characteristic for PES and CAB. The "linearity" of RH-C characteristic of the sensor fabricated is as small as ±0.8%RH in the humidity range from 0%RH to 95%RH at the operating frequency of 400kHz. This characteristic shows good agreement with the simulated one. The width of the hysteresis in RH-C characteristic is 1.5%RH at maximum. The temperature coefficient of RH-C characteristic is as small as ~0.04%RH/℃ at maximum in the temperature range from 30℃ to 60℃. The sensors can measure RH in ±3%RH accuracy after kept in 60℃, 90%RH or -24℃, ~100%RH for 200days.

INTRODUCTION

The precise control of humidity is required in a variety of fields, such as the agriculture and the manufacturing industry. Some type of the dew point meters [1] and the psychrometers [2] permit a relatively accurate measurement of humidity. Though, they are too delicate to be mastered and are relatively expensive. Therefore, the development of convenient and accurate hygrometers is desired. The electrical capacitive humidity sensors [3-5] using cellulose acetate butyrate containing 38% of butyryl group (CAB) or using polyphenylene ether sulfone (PES) as a humidity-sensing part are the candidates owing to their small hysteresis width, fast response and fine long term stability [6]. However, relative humidity (RH) versus electrical capacitance (C) characteristics of the sensor using CAB or PES are non-linear, and it lowers the accuracy of output signal of the hygrometer.

In this paper, the fabrication process and the characterization of the humidity sensor with linear relationship in RH-C characteristics by using CAB and PES are described.

DESIGN OF THE HUMIDITY SENSOR WITH LINEAR RELATIONSHIP IN RH-C CHARACTERISTICS

RH-C characteristics of CAB and PES are shown in Fig.1. The capacitance of sensors is normalized by the capacitance at 0%RH. The capacitance in the curves is the average value in increasing and in decreasing humidity. The C change is

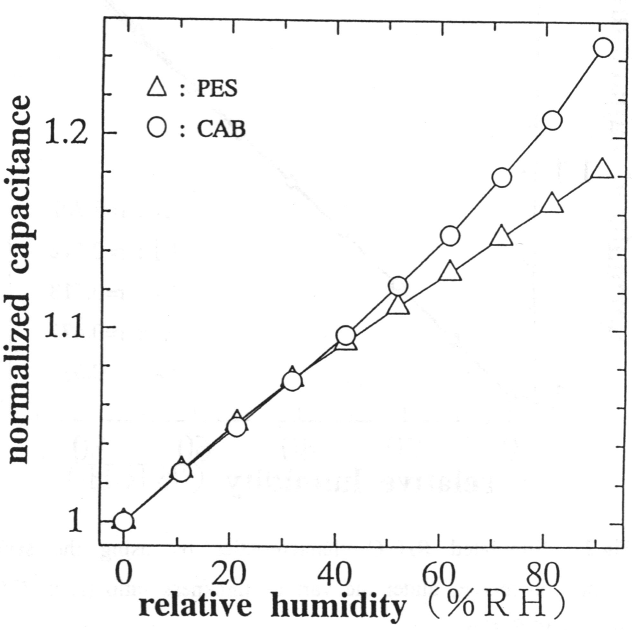

Fig.1 RH-C characteristics of PES and CAB at 30℃ for the operating frequency of 400kHz.

sensitive in the higher humidity region for CAB, and sensitive in the lower humidity region for PES. The RH-C characteristics are not affected by the variety of their shape. A combination of CAB and PES, therefore, will make possible to design a humidity sensor with linear relationship in RH-C characteristics.

Basically, there are two ways to linearize the characteristics. The one is to connect the capacitors by CAB and by PES in series, and the other is to connect them in parallel. In this study, the series connection is chosen from a sense of miniaturization of the sensor chip. The synthesized capacitance of the sensor, which composed of the capacitors by CAB and PES connected in series, is formulated simply as follows.

$$C_S=C_{CAB}\cdot C_{PES}/(C_{CAB}+C_{PES}) \cdots\cdots (1)$$

where C_S : synthesized capacitance
C_{CAB} : capacitance by CAB film
C_{PES} : capacitance by PES film

SIMULATION OF RH-C CHARACTERISTICS

Prior to the fabrication of the humidity sensor, the dependence of RH-C characteristics by the changing of thickness

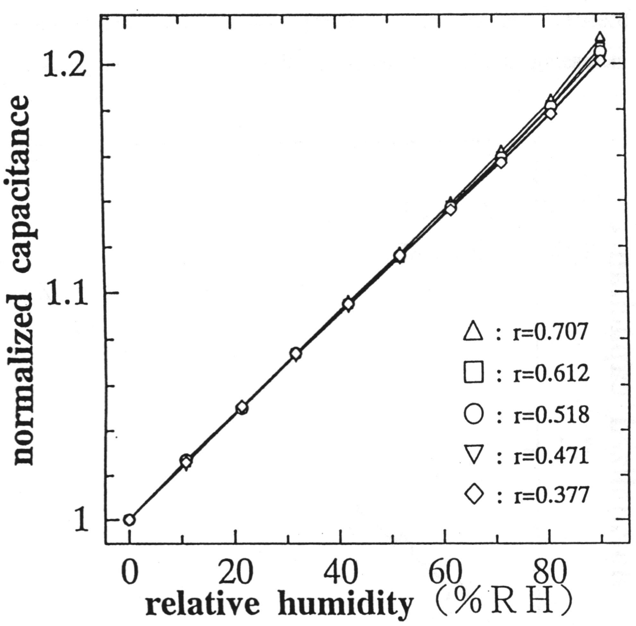

Fig.2 Simulated RH-C characteristics by using the series connection model, under the various thickness ratio (r) of CAB film to PES film.

ratio of CAB film to PES film is simulated. Simulated RH-C characteristics are shown in Fig.2. In this figure, r means the thickness ratio of CAB film to PES film. It is found that the linearity of each RH-C characteristics is improved compared with that of CAB or PES. Here, to characteristic the linearity quantitatively, we define the "linearity" as to be the "maximum error width of RH" between the RH-C curve and the closely resembled straight line in the humidity range from 0%RH to 95%RH as shown in Fig.3. In the case of intersecting point number is two (case A), the closely resembled straight line is drawn under the condition written in the formula (2).

$$\triangle RH_1=\triangle RH_2=\triangle RH_3 \cdots\cdots (2)$$

On the other hand, in the case of the intersecting point number is three (case B), the straight line is drawn under the conditions written in the formulae (3) and (4).

$$\triangle RH_1'=\triangle RH_2' \cdots\cdots (3)$$
$$\triangle RH_3'=\triangle RH_4' \cdots\cdots (4)$$

The linearities of simulated RH-C characteristics are listed in Table 1 with that for PES and CAB. It is found that the linearity takes a minimum value of ±0.7%RH at r is equal to 0.518.

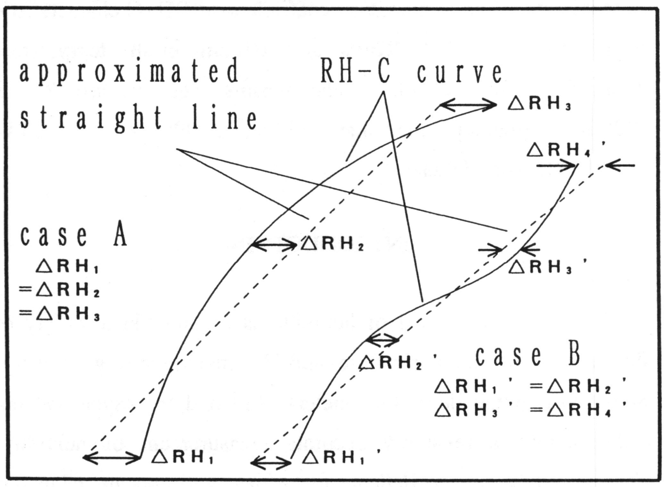

Fig.3 Determination of linearity of RH-C characteristic. In the case A, the linearity means $\triangle RH_1$. In the case B, when $\triangle RH_1'>\triangle RH_3'$, the linearity means $\triangle RH_1'$, and if $\triangle RH_1'<\triangle RH_3'$, the linearity means $\triangle RH_3'$.

Table 1 The linearity of simulated RH-C characteristics and of measured for PES and CAB.

r	0.707	0.612	0.518	0.471	0.377	CAB	PES
linearity (±%RH)	2.0	1.5	0.7	1.3	1.8	5.7	4.3

FABRICATION OF THE HUMIDITY SENSOR

The structure of the sensor is shown in Fig.4 schematically. The lower electrode made of chromium 400nm in thickness is mounted on the substrate of alkali free glass. Humidity-sensing films of PES and CAB are coated by spinner on the substrate, on which the lower electrode is deposited. The upper electrode, which is permeable to the water vapor also made of chromium is deposited on CAB film. Both electrodes are formed by a conventional vacuum deposition method.

The film thickness ratio of CAB to PES, which gives the best linearity of RH-C characteristics, is obtained experimentally by controlling of spin coating parameter for CAB. PES dissolved in dimethyl sulfoxide (DMSO) is dropped on the substrate, on which the lower electrode is deposited, and spread uniformly by spinning. The mean thickness of PES film is 4190nm. CAB film is also obtained by spin coating method on PES film under a various speed of revolution. CAB is dissolved in cyclohexanone 10wt% in concentration. Thickness changing of CAB film due to the variation of speed of revolution is shown in Fig.5. Where the ambient temperature is 25℃, and the duration time of main spinning is 10seconds. It is found from the figure that the desired thickness of 2170nm (r=0.518) is obtained at the revolution speed of about 2650rpm.

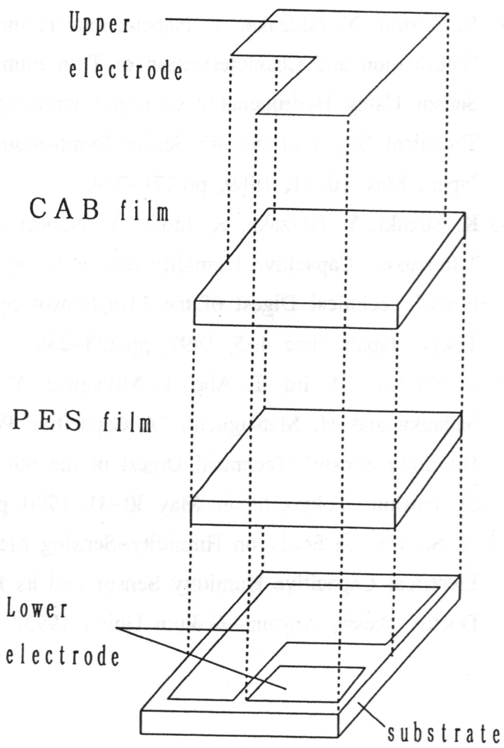

Fig.4 Structure of the capacitive humidity sensor by the double layered humidity-sensing film.

RH-C CHARACTERISTIC OF THE HUMIDITY SENSOR FABRICATED

RH-C characteristic of the sensor fabricated is shown in Fig.6 with the simulated characteristic. The linearity of the measured characteristic is ±0.8%RH. The measured characteristic agrees considerably with the simulated characteristic in the humidity range from 0%RH to 95%RH.

Temperature dependence of the characteristic is shown in Fig.7 with the humidity hysteresis characteristic. The capacitance of the sensor is normalized by the capacitance at 0%RH for 30℃. The temperature coefficient is ~0.04%RH/℃ at maximum for about 95%RH. This small value has its origin in the small temperature coefficients for PES and CAB. Hysteresis width at maximum is 1.5%RH, and this is a

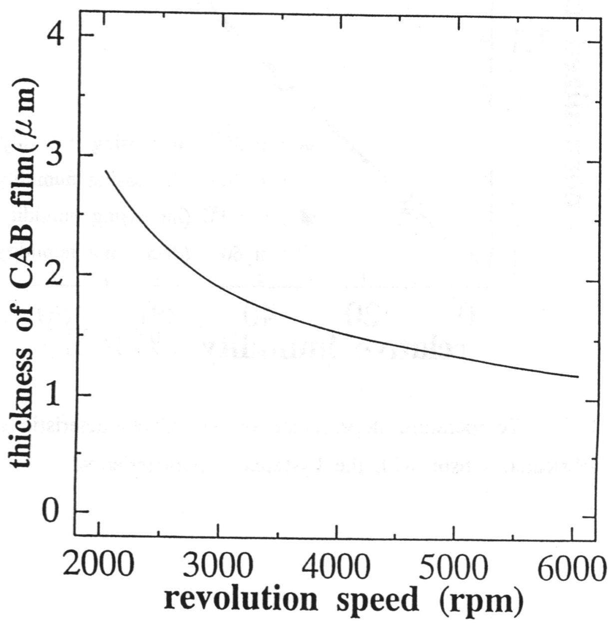

Fig.5 Thickness change of CAB film due to variation of the speed of revolution.

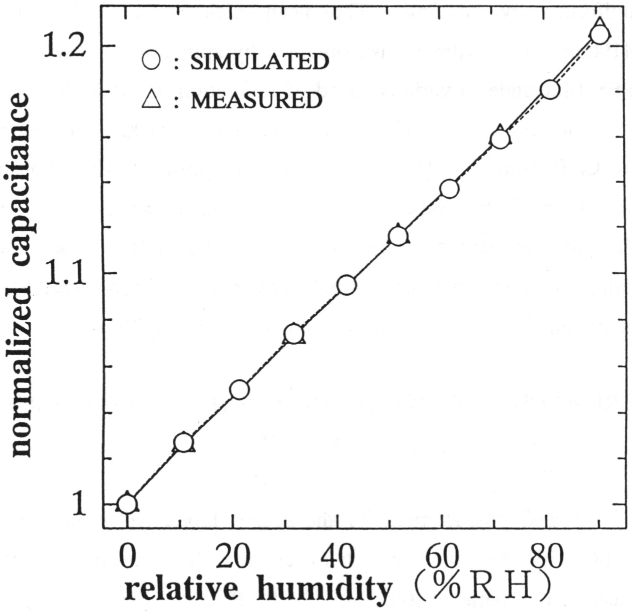

Fig.6 Simulated and measured RH–C characteristics of the humidity sensor at 30℃.

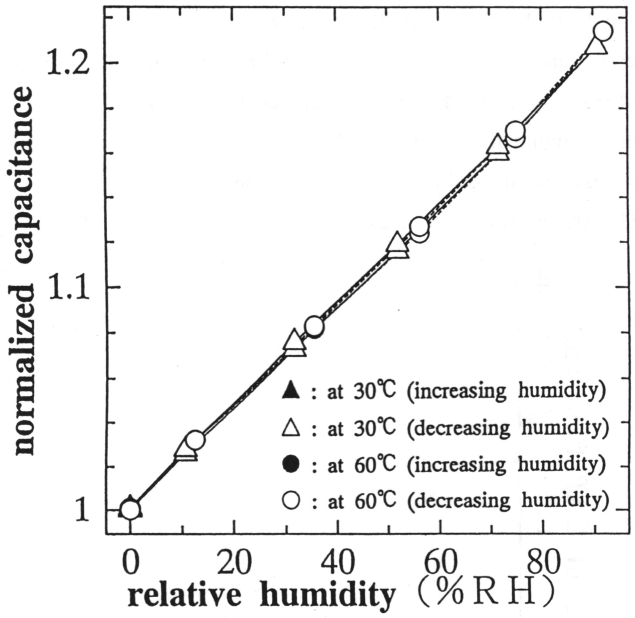

Fig.7 Temperature dependence of RH–C characteristic of the fabricated sensor with the hysteresis characteristics.

intermediate value between 1.0%RH for PES and 3.0%RH for CAB.

The durability of the sensor fabricated is almost same to that of the sensor by CAB. For instance, the sensor works stably with ±3%RH in accuracy after kept in 60℃, 90%RH or -24℃, ~100%RH atmosphere for 200days, though the characteristic changes irreversibly under the condition of 80℃, 90%RH or 150℃, ~0%RH.

CONCLUSION

The humidity sensor with linear relationship of ±0.8%RH in RH–C characteristic in the humidity range from 0%RH to 95%RH was fabricated by using the double layered humidity-sensing film by PES and CAB.

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