CHARACTERIZATION OF SCREEN PRINTED $BaTiO_3$ THICK FILM HUMIDITY SENSOR

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ABSTRACT

In this paper the humidity-sensitive electrical properties of $BaTiO_3$ thick-films were studied. Thick films were screen printed onto the ceramic substrates by using the conventional thick film screen printing machine. An interdigitated electrode pattern was printed underneath the humidity sensing material layer to maximize the electrical properties between two conducting structures. The characterization of the thick film humidity sensor was measured at 1kHz, $1V_{pp}$. The experimental results show that the sensor resistance decreases and the capacitance increases with Relative Humidity of 20 to 95%RH range. A resistance-humidity sensor characteristic shows a good linearity with a small hysteresis observed. The sensor response time and recovery time is about 7s and 15s respectively. The influence of temperature on the sensor characteristic had also been investigated. As a conclusion, screen printing of $BaTiO_3$ thick films show a good promising material as a resistive-type humidity sensor.

Keywords: *humidity sensor, thick film technology, interdigitated electrode.*

INTRODUCTION

Nowadays, the measurement of humidity has received great attention due to the recognized importance of water partial pressure in various industries such as the production of electronic devices, precisions instruments, textile and foodstuffs. Among the different types of sensor, those based on electrical properties such as impedance, resistance or capacitances are best suited to modern automatic control system. Some porous perovskite-type have possibility to be used as humidity sensing material which operate both at low temperatures (<100 ºC) as ionic sensors and at higher temperatures (>400 ºC) as semiconductors [1]. In this respect, $BaTiO_3$ material showed a good response to humidity level at room temperature [2]. It was reported that the $BaTiO_3$ bulk sample with low density and high resistivity shows large and nearly linear sensitivity to the charged of humidity. He also reported that the microstructure of the sintered body plays a major role in humidity detection [3]. Generally, a film has microstructure properties similar to those of sintered bodies and has several advantages over bulk materials. On humidity detection, the response time in film material is much shorter than in bulk form since water molecules can directly reach the sensing ceramic surface. Besides, miniaturization sensor can be achieved through integrating the thick film sensor and signal conditioning circuit in a single substrate. One of the methods to produce thick film sensor is based on thick film screen printing technology. Compared with the other methods, the thick-film screen printing is a relatively simple and shows several appreciable capabilities, such as flexibility in choice of materials and design, low cost in automation and mass production and good reproducibility [4 - 6].

In this paper, the preparation and fabrication of $BaTiO_3$ as a humidity sensor based on the screen printing technique is described. The electrical characterizations of the thick film humidity sensor are investigated and the experimental results are presented.

EXPERIMENTAL WORKS

The Barium Titanate powders were produced by solid state reaction based on raw material of $BaCO_3$ and TiO_2. Equimolar amounts of the raw material were weighed based on chemical reaction which is given as follow [7]:

$$BaCO_3 + TiO_2 \longrightarrow BaTiO_3 + CO_2$$

The powders were mixed with acetone and ball milled for one day, then dried in oven at 110°C. Next, the mixing powder were grinded intermediately before calcined at ramp rate of 3°C/minute to 850°C and held for 12 hours, followed by cooling at rate of 3°C/minute. After these procedures, the mixing powder was grinded to obtain fine grain particle size using pestle and mortal. The powder was then sintered at 1000°C for 8 hours, grinded and sieved through 20µm siever.

The thick film paste was prepared by mixing the organic vehicles with the Barium Titanate powder, in ratio of 30:70 [8]. The organic vehicles were prepared by mixing the α-Terpineol solvent with ethyl cellulose resins. A small percentage of Bi2O3 (5% wt.) powder was added to the mixture as a bonding agent and to improve the adhesion of the film to the substrate [9]. To form a homogenously paste, the mixture was stirred using magnetic stirrer which was maintained at the speed of 110 rpm and 40ºC for 15 minutes.

The paste was screen printed onto a ceramic glass substrate with an interdigitated electrode pattern as shown in Figure 1 by using the DEK J1202 screen printing machine. The silver paint was used as a conductor for the interdigitated pattern, with 8 interdigits on each contact, giving a total of 16 interdigits. The total area occupied by interdigits is 6mm x 8mm with space between interdigits of 0.2mm respectively. The thick film humidity sensor was characterized after the sample was sintered at 850°C for 10 minutes.

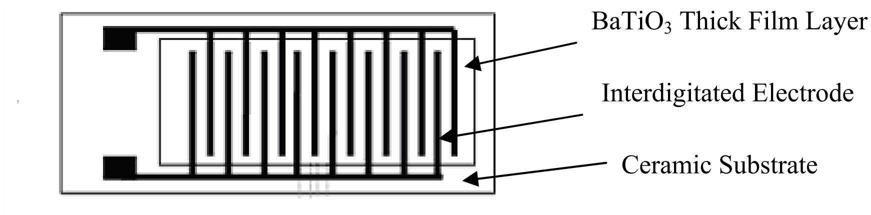

Figure 1: Layout of the $BaTiO_3$ Thick Film Structure

The properties of the humidity sensor were characterized in climatic chamber where the humidity and temperature can be separately adjusted and kept at constant level. The a.c resistance and capacitance as a function of relative humidity (RH) were measured at 1 KHz, 1 V_{pp} using an LCR meter. The humidity was ramped from 20 to 95%RH in steps of 10%RH, at a constant temperature.

RESULTS AND DISCUSSION

Resistance-Humidity Characteristics

The curve of Resistance against Relative Humidity of the $BaTiO_3$ thick-film sensor is given in Figure 2. The sensor is characterized by varying the Relative Humidity at a temperature of 25ºC. The solid line in the figure is measured from low RH to high RH for adsorption process, and the dotted line is for desorption process which is measured in the opposite direction.

From the graph, it can be seen that the resistance changes from 10^7 to $10^4\Omega$ and a good linearity. A decrease in resistance with the increase of humidity was observed. This is due to the adsorption and capillary condensation of water which leads to increase in the charge carrier, protons in the sensor system. Meanwhile, the hysteresis of the sensor is determined from different paths of resistance when the humidity is increased and decreased. From Figure 2, the maximum humidity hysteresis of the sensor is about 3%RH. Ideally, the sensor should follow the same resistance path when it is cycled back from high RH to low RH.

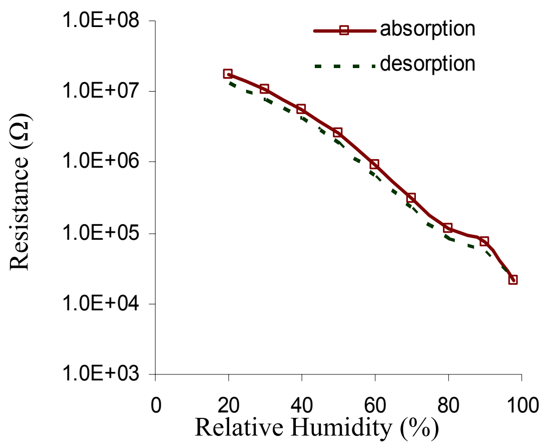

Figure 2: Resistance against Relative Humidity of the humidity sensor

Capacitance Characteristic

The capacitance-humidity characteristics of the sensor was also measured at the same conditions of resistance characteristic and the curve is given in Figure 3.

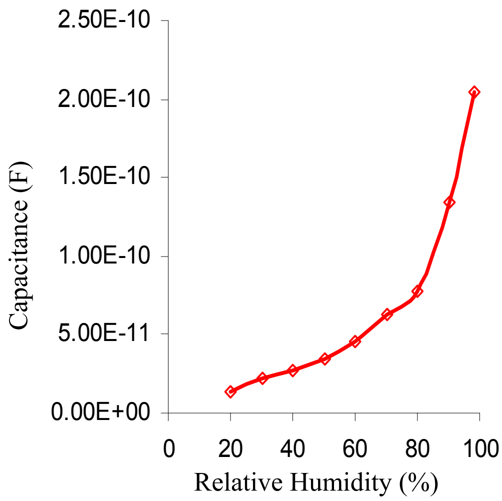

Figure 3: Curves of Capacitance versus Relative Humidity

The results show that the capacitance is exponentially increases with relative humidity from low RH to high RH. The small changes in capacitance at low RH are due to the weak polarization appearing because only few water molecules are adsorbed. At high RH, adsorbed molecules gathered so much resulting in strong polarization appearing as confirmed by ref. [2]. This consequently increases the dielectric constant that also represents an increase in capacitance value.

Response Time

The sensor response-recovery time is determined as the sensor unit move very quickly from humidity level of 95%RH to a humidity level of 33%RH and from 95%RH to 33%RH respectively. The sensor is connected with an ac source signal of 1kHz at $2V_{pp}$ and a 150kΩ resistor in series. The response signal is recorded based on voltage output versus time response. The graph of voltage against time that represents response-recovery time of the sensor is shown in Figure 4.

From the graph, the response time of the adsorption process is about 7s and the recovery time of the desorption process is about 15s before the equilibrium state is achieved. The differences of the response-recovery time is due to the different energy levels for water molecules take place. Adsorption is an exothermic process, whereas desorption needs external energy for water molecules to depart from film surface [10]. Therefore, a relatively long time seems to be required to desorb the water vapour.

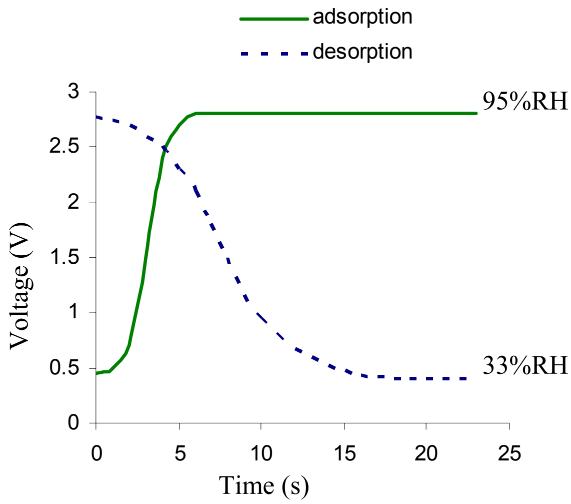

Figure 4: Response-recovery time of the sensor

Temperature Dependence

The resistance-humidity characteristic at two different temperatures of 25ºC and 40ºC is measured in order to determine whether the temperature influences the humidity sensor element. The humidity sensitivity of the sensor for both operating temperatures is shown in Figure 5. The plots of T40 and T25 represent the resistance-humidity characteristic measured at 40ºC and 25ºC respectively.

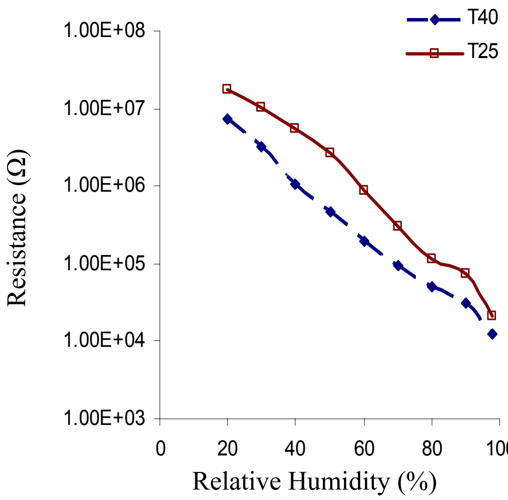

Figure 5: Temperature dependence of resistance-humidity characteristics

The result shows that the sensor resistance across the whole humidity range generally decreases with an increase in temperature. Besides the adsorption of water in ceramic layer, increases in temperature which enhances the conductivity of the material was due to the fast moving electron in the system, which leads to reduction in material resistance. However, the temperature effect is relatively low compared to the measured humidity value, indicating a potential for a temperature independence humidity sensor application. Beside, an electronic circuit with a thermistor may be used for temperature compensation in order to make the sensor as a temperature independent humidity sensor.

CONCLUSION

A $BaTiO_3$ thick film humidity sensor has been successfully fabricated by using the thick film screen printing machine. The results show that the sensor resistance decreases while the sensor capacitance increases with increasing humidity. The sensor resistance-humidity characteristics show a good linearity in the range 20-95% and the maximum hysteresis is about 3%RH. The sensor response and recovery time are acceptable, but it was observed that there is a temperature effect on the resistance-humidity characteristic. In conclusion, screen printed $BaTiO_3$ thick films shows a good promising material as a resistive-type humidity sensor.

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