Design and Fabrication of a Solid-State pH Sensor Module

Considering Its Possible Applications

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***Abstract*— We developed a solid pH sensor, which can implement a real-time monitoring of pH value with low power consumption and high accuracy. The prototype of the pH sensor was fabricated and packaged well and can keep a linear output proportional to the changes in the pH value and has a high-sensitivity of >14 µA/pH. The developed pH sensor is believed to be significantly important for both the industrial and the civilian sectors for improving the efficiency of environment monitoring.**

Keywords- pH value test; solid state; MEMS sensor; Indium Tin Oxide

I. Introduction

Measurements of pH are important in many fields [1][2], such as chemical engineering, agriculture, medicine, environmental science, water treatment and purification, and many other applications. However, conventionally, the pH sensor has a reference electrode with a large size because of high concentration of electrolyte solution in it. The shortcoming of big size and large power consumption seriously restrict the application of traditional pH sensors, especially in the coming "Internet of Things" age where maintenance-free and wireless communications are essential for arbitrary distributing of the sensor node.

State-of-the-art microelectromechanical systems (MEMS) and complementary MOS (CMOS) techniques have undergone many advances [3]. As MEMS researchers, we need to contribute to the industrial revolution and improve the pH measurement technology. We have engaged in developing a solid-type pH sensor for real-time pH measurement recently. Figure 1 shows a typical pH sensor prototype including the package, measurement electrodes, and testing and transmission boards. MEMS fabrication technology was used in this work to realize the sensing electrode with high dimensional and performance homogeneity. The developed pH sensor offers the advantages of field effect transistor (FET) and indium tin oxide (ITO) sensing techniques. The sensor system can be fabricated with a compact size by eliminating the reference solution. The solid-state sensor structure is fit for long-term pH measurement, and the separate ITO sensing electrode can be patterned with a suitable capture structure for various test environments. In Sections 2 and 3, sensor system setup and preliminary results will be presented.

II. Electrode fabrication and Sensor system setup

A. Sensor electrodes fabrication

The fabrication procedure of the pH sensor electrodes has been introduced comprehensively in our previous works [4] [5]. By the MEMS technique, 47 die chip sensor electrodes can be fabricated on a 4-inch silicon wafer. The flat area of every single electrode can be controlled at <120 mm^2. The die chip of sensor electrodes was fabricated with a compact size can induce the packaged sensor system enjoying a high flexible application potential in feature works.

B. Sensor system setup

The given typical pH sensor prototype combines the functional components of sensor electrodes, testing and transmission boards, see upper left insert of Figure 1. An ITO-sensing electrode connects the gate terminal of a MOSFET, the specific FET was loaded on the testing board was used to measure the pH value of target solutions. Transmission board has a CPU, a wireless module, a chip temperature unit and an IR temperature sensor to coding and transmitting the tested date, recording the environment and board temperature, respectively.

III. Preliminary measurement results

A. Sensor sensitivity and output linearity

The output function of given solid pH was evaluated first. The lower right insert of Figure 1 shows the coded data of the output current versus pH characteristics, considering that the pH sensor is immersed in a solution with varying pH values. The coded data of the output current decreased as the pH value increased from 5 to 7, accordingly. Moreover, the output data was linearly proportional to the changes in the pH value, i.e., the output data can be represented by a first-

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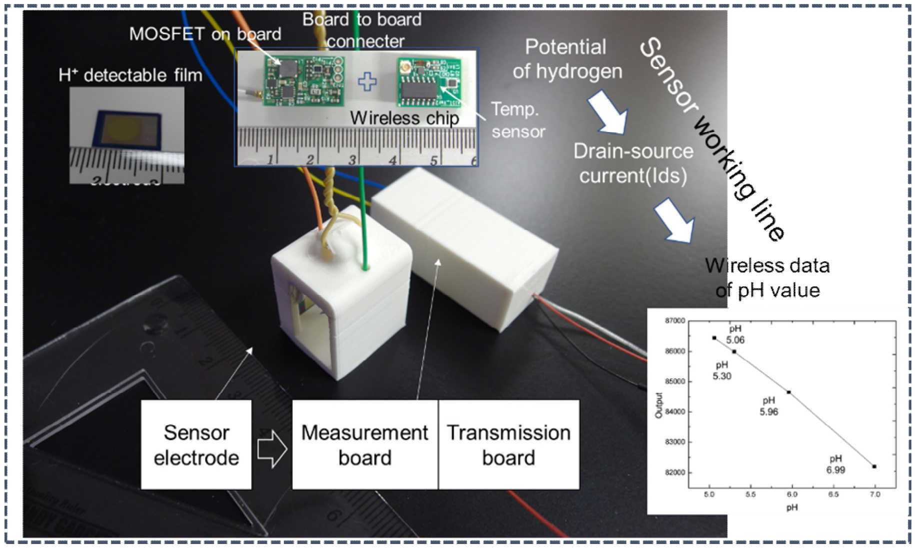

Figure 1. pH sensor system

degree polynomial equation. Thus, the pH sensor can be easily used to measure the pH of target solutions by fitting the output current to the pH value.

B. Temperature calibration for long-term measurement

Normally, in a commercial pH sensor, several temperature sensors are placed into the sensor system to calibrate the output from the effect of temperature. As previously mentioned, for our sensor, two types of temperature sensors (chip sensor and IR temperature device unit) were loaded on the transmission board to calibrate the given pH sensor. Figure 2 shows the results of pH sensor output versus on-board temperature at the same time. A pH=7.3@25 solution was simultaneously tested by the given pH sensor and temperature sensor. The comparison results can be used to eliminate the temperature effect of the given pH sensor system for the next long-term field measurement.

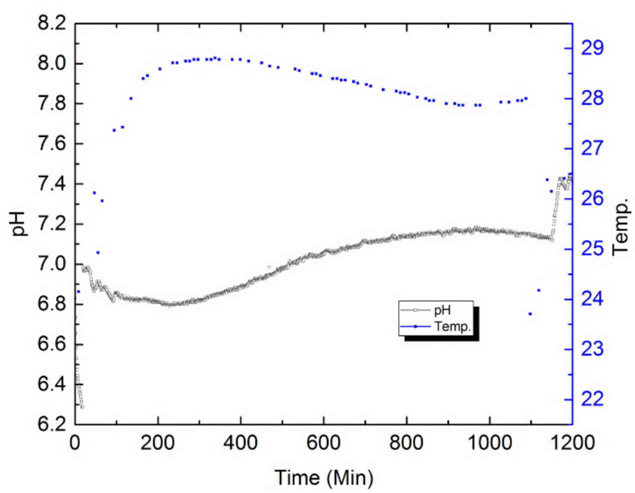

Figure 2. Temperature and pH test feature of the given sensor.

IV. Conclusion

We developed a solid-state pH sensor for real time pH monitoring. The given sensor was packaged and preliminary tested. As the results show, the developed pH sensor has a good stability and linear output performance. After the temperature calibration process, a long-term field measurement for industrial application is going on, and the tested data can provide very important database information for the management system to realize of smart manufactory. Moreover, in order to realize a commercial pH sensor with a long time stable performance, the fabrication method of sensor electrodes, cost of testing and transmission boards and package approach are also considered to be improved.

References

[1] P. Batista, “An embedded measurement system for the electrical characterization of EGFET as a pH sensor,” Sci. Technol, vol. 25, pp. 027001-1-6, 2014.

[2] J. Bausells, J. Carrabina, A. Errachid, and A. Merlos, “Ion-sensitive field-effect transistors fabricated in a commercial CMOS technology,” Sens. Actuators B, vol. 57, pp. 56-62, 1999.

[3] A. Richter et al. “Review on hydrogel-based pH sensors and microsensors,” Sensors, vol. 8, pp. 561-581, 2008.

[4] L. Zhang, J. Lu, H. Okada, H. Nogami, and T. Itoh, “Development of ITO- and FET-based cow rumen sensor for long-term pH value monitoring,” Symposium on Design, Test, Integration and Packaging of MEMS/MOEMS (DTIP), vol. 2016, pp.92-96, May 2016.

[5] L. Zhang et al. “Low-Power Highly Sensitive pH sensor with μ-dots protective structures for monitoring rumen in cows in real-time,” IEEE Sens. J. vol. 17, pp. 7281 - 7289, 2017.