Research on the Performance of Solid-State pH Sensor Affected by the Sensing Materials

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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. In this work, three kinds of different metal oxide materials are used to fabricate the sensing electrode layers. Mechanical and functional properties comparisons are of material coatings on the sensor electrodes are comprehensively evaluated. As the results show, the given pH sensor based on SnO_2 can keep a linear output proportional to the changes in the pH value and has a higher sensitivity of >530 μV/pH.**

Keywords- pH value test; solid state; MEMS process; Metal Oxide

I. INTRODUCTION AND ELECTRODE FABRICATION

Measurements of pH are important in many fields, such as chemical engineering, medicine, environmental science, agriculture, and many other applications. Recently, Micro-electromechanical systems (MEMS) technology has undergone many advances, such as super compact size, high sensitivity and high uniformity of working functions. As part of the MEMS researchers, we would like to contribute to the industrial revolution and improve the pH measurement technology.

Recently, a solid-type pH sensor has been developed for real-time pH measurement. The given solid pH sensor offers the advantages of field effect transistor and metal oxide sensing techniques. The sensor system can be fabricated in a compact size by eliminating the reference solution. The solid-state sensor structure is fit for long-term pH measurement, and the separate sensing electrode can be patterned with a suitable capture structure for various test environments. In previous research works, the given indium tin oxide (ITO)-based solid-type pH sensor was used to test the pH value of Japanese cows' stomach for monitoring the health condition of them. The ITO-sensor can keep a good linear output in the testing range from pH 4.5-8.0. The given sensor can test the pH value in cows' stomach well [1].

However, for realizing a trillion-sensor society, i.e., arbitrary distributing of the sensor node in diverse testing environment, the solid-state pH sensor needs a larger working range, higher sensitivity and longer durability. Thus, in this work, different sensing materials are used to fabricate the sensor electrode. Mechanical and functional properties comparisons are of material coatings on the electrodes are comprehensively evaluated.

Figure 1 shows the schematic view of our proposed pH sensor measurement system with potential application fields. MEMS fabrication technology was used in this work to realize the sensing electrode with high dimensional and performance homogeneity. The given typical pH sensor prototype combines the functional components of sensor electrodes, measurement units and transmission boards. A metal-oxide-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 and a chip thermometer unit to coding and transmitting the tested date, recording the environment temperature for calibration, respectively.

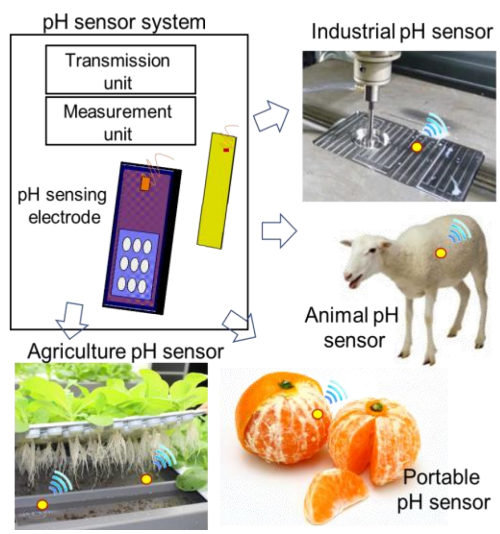

Figure 1. Schematic view of our proposed pH sensor measurement system with potential application fields.

The fabrication procedure of the pH sensor electrodes has been introduced comprehensively in our previous works [2]. 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.

II. PRELIMINARY MEASUREMENT RESULTS

A. Mechanical properties comparisons are of sensing materials coatings

Figure 2 shows the measured surface roughness of different sensing materials with arithmetical average value (Ra). The insets are AFM scanning images on the sensing electrode local area. The AFM images showed the surface topographies of fabricated Ta_2O_5, SnO_2 and ITO with the arithmetical average roughness value of 2.5 nm, 1.2 nm and 1.1 nm, respectively. As the AFM image shows, the sensing films on the electrode retained a smooth surface with less morphological defects after the MEMS etching processes. The sensing electrode enjoys uniform surface and is very suitable for use in the development of an electronic device, because, in some cases, the sensing film has a rough grain surface, which can completely obscure the material intrinsic charge transport properties.

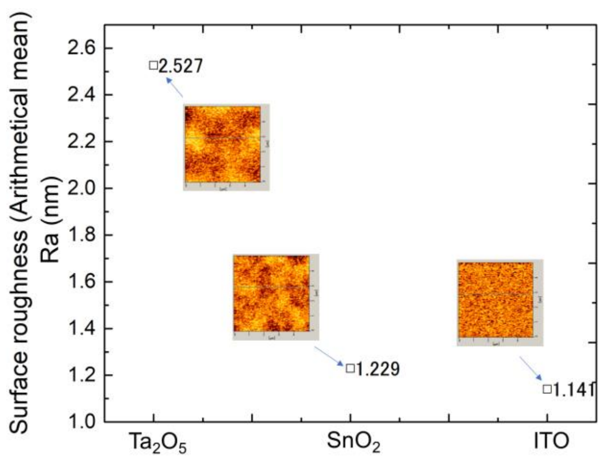

Figure 2. Measured arithmetical average surface roughness of different sensing materials. The insets are the AFM images of the sensing electrode local area.

TABLE I. THE COMPARISON OF SENSING MATERIALS

	Ta_2O_5	SnO_2	ITO
Fabrication	Etching	Etching	Lift-off or etching
pH range	2-11	3-10	4-9
Surface homogeneity	2.527 nm (Ra)	1.229 nm (Ra)	1.141 nm (Ra)
Drift	>pH0.1	pH0.05	±pH0.1

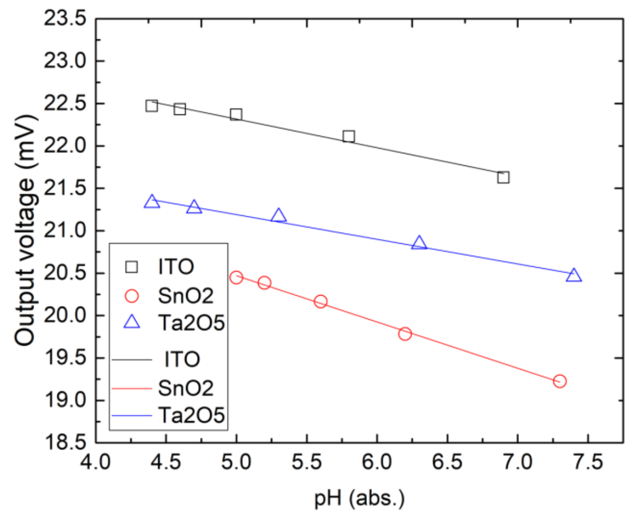

Figure 3. The output voltage of pH sensor with different sensing martials against the measured pH values.

B. Functional properties comparison of sensing metrials coatings

Figure 3 shows the output voltage of pH sensor with different sensing martials versus the measured pH values. As the results show, the ITO-based and Ta_2O_5-based pH sensors have the sensitivities of 340 µV/pH and 290 µV/pH, respectively. The given pH sensor based on SnO_2 can keep a linear output proportional to the changes in the pH value and has a higher sensitivity of 530 µV/pH. Table 1 shows the comparison between the sensing materials. We can understand the merits and demerits of given materials, reasonably. More detailed results and discussion will be presented at the conference.

III. DISCUSSIION AND CONCLUSION

We developed a solid-state pH sensor for real time pH monitoring. Different sensing materials are used to fabricated the sensor electrode. Mechanical and functional properties comparisons are of material coatings on the electrodes are comprehensively evaluated. The solid-state sensor can be packaged super compact size as a portable sensor device to test water, foods and fruits in our daily life. Moreover, in industrial field, many low-cost solid pH sensors can provide mass data of target solutions and water to help the company realizing an Internet of Things management system.

REFERENCES

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