Ion-Sensitive Field-Effect Transistor as a pH sensor

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***Abstract* — The paper presents process design and fabrication of an ion-sensitive field-effect transistor (ISFET). The fabricated ISFET structure is an N-channel, depletion-mode device. The standard self-aligned process is adopted and silicon dioxide was used as the sensing film for pH sensing application. The sensitivity of SiO_2-ISFET is found to be ~ 33 mV/pH.**

***Index Terms* —** ISFET, Silicon dioxide, pH sensor.

I. INTRODUCTION

Water quality monitoring is becoming important for human beings due to water contamination. World Health Organization has set standards for water quality monitoring and treatment [1]. Testing of water quality is broadly divided into three categories, namely physical, chemical and bacteriological tests. Bureau of Indian Standards (BIS) has also set the Indian Standards for drinking water quality and the tolerance limits of different parameters for water [2]. For potable water, pH monitoring is one of the most important parameter and their acceptable limit is from pH range 6.5-8.5. Apart from conventional techniques, pH measurements are performed by potentiometric and spectrophotometric measurement techniques. Ion selective techniques have limited life and due to the presence of glass electrodes, there are challenges such as drift and electrode calibration, whereas the spectrophotometric pH measurement technique require indicator dyes, which require more instrumentation and relatively higher power requirements for *in-situ* measurements [3]. Ion-sensitive field-effect transistor (ISFET) is an alternative technique for the measurement of pH. ISFET has gained interest after the pioneering work of Bergveld et al. [4]. It is equivalent to Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET), except the top metal electrode over the conduction channel is replaced by the electrolyte (analyte solution) and a reference electrode. The gate oxide is covered with thin layer of amphoteric insulating materials such as silicon nitride (Si_3N_4), aluminum oxide (Al_2O_3), aluminium nitride (AlN), tantalum pentoxide (Ta_2O_5), etc [5].

ISFET is used to measure the H^+ ion concentration in the analyte solution in contact with the gate oxide. Ions present in the solution interact with the gate oxide due to protonation and de-protonation of surface functional groups which modifies the interfacial potential, which in turn modifies the channel conductance leading to change in drain current. A site-binding model is used to connect interfacial potential to the concentration of hydrogen ions present in the solution interacting with the gate oxide [6]. ISFET is a potential device for point-of-care (POC) applications as a chemical or biological sensing platform. By suitable immobilizing / functionalization with enzyme [7], antibody [8], it can detect the concentration of ions in a solution [9]. ISFET has inherent advantages relative to ion sensors (glass electrodes) due to its high input impedance, which does not allow current to flow through the measured object which is indispensible need for a health monitoring system [9].

II. ISFET STRUCTURE AND OPERATION

As discussed, ISFET structure is similar to that of metal-oxide-semiconductor field-effect transistor (MOSFET), and is depicted in Fig. 1.

In the present study SiO_2 is used as sensing membrane. SOI based ISFET device was fabricated by using self-aligned process technology, the device is an n-channel and it is a depletion mode ISFET device. The channel length (L) and width (W) are taken as 20 µm and 400 µm, respectively.

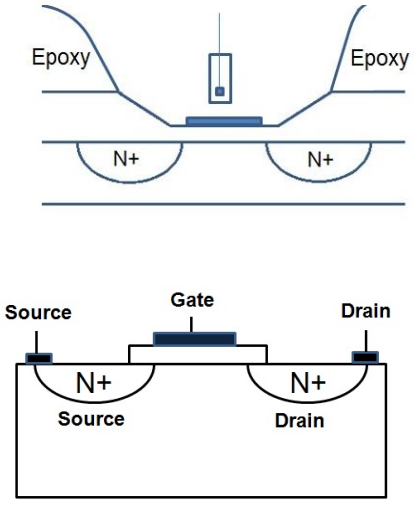

Figure-1: Schematic diagram of ISFET and MOSFET.

III. RESULTS AND DISCUSSION

Electrical characterization of SiO_2 ISFET was performed by dipping it in different pH solutions (Merck make), the gate voltage applied between the electrolyte and the Ag/AgCl electrode controls the current between drain and source contact. Transfer characteristics of the SiO_2 ISFET were obtained for different pH solutions ranging from pH 4, 7 and pH 10, and the sensitivity is found out to be ~ 33 mV/pH.

IV. CONCLUSIONS

ISFET is an attractive alternative to pH measurement technique due to its high input impedance and solid state nature, which is compatible with CMOS fabrication processes. In this work, SiO_2-ISFET was successfully fabricated and tested as a pH sensor and the sensitivity was found to be close to the theoretical limits for silicon dioxide based ISFET.

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REFERENCES

[1] Edition, Third. "Guidelines for Drinking-water Quality.", World Health Organization (2008).

[2] Draft Indian Standard, " Drinking Water – Specification", Bureau of Indian Standards.

[3] S. Aßmann, C. Frank, and A. Körtzinger. "Spectrophotometric high-precision seawater pH determination for use in underway measuring systems." *Ocean Science* 7.5 (2011): 597.

[4] P. Bergveld, "Thirty years of ISFETOLOGY: What happened in the past 30 years and what may happen in the next 30 years," *Sensors and Actuators B,* vol. 88, pp. 1-20, 2003.

[5] S. Sinha, R. Rathore , S.K. Sinha , R. Sharma , R. Mukhiya , V. K. Khanna, "Modeling and Simulation of ISFET Microsensor for Different Sensing Films." In *ISSS*

International Conference on Smart Materials, Structures and Systems. 2014.

[6] D. E. Yates, S. Levine, T. W. Healy, "Site-binding model of the electrical double layer at the oxide/water interface," *J. Chem. Soc. Faraday Trans.*, vol. 70, no. 1, pp. 1807-1818, 1974.

[7] C-S Lee, S. K. Kim, M. Kim, "Ion-Sensitive Field-Effect Transistor for Biological Sensing," *Sensors*, Vol. 9, 7111–7131, 2009.

[8] S. Hideshima, R. Sato, S. Kuroiwa, T. Osaka, "Fabrication of stable antibody-modified field effect transistors using electrical activation of Schiff base cross-linkages for tumor marker detection," *Biosensors and Bioelectronics*, vol. 26, pp 2419-2425, 2011.

[9] K. Ohashi and T. Osaka, "Industrialization Trial of a Biosensor Technology," *ECS Transactions*, Vol. 75 (39), PP 1-9, 2017.