An Implementation of an Electronic Tongue System based on a Multi-Sensor Potentiometric Readout Circuit with Embedded Calibration and Temperature Compensation

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***Abstract*— We present an Electronic Tongue system composed of an analog front-end (AFE) with embedded calibration and temperature compensation for interfacing with an array of *ISFETs* (Ion-Sensitive FETs) or *EGFETs* (Extended Gate FETs). The *AFE* consists of a floating bridge type constant voltage constant current (CVCC) structure, and transmission gates as sensor enable. The calibration algorithm is synthesized into a Field Programmable Gate Array (FPGA).The system shall be used to measure the pH and ionized Calcium (Ca^{2+}) of a solution and forms part of a urine stone prediction platform. The *ISFETs* used are from ITE-Poland and shall be used to measure pH; while the Ca^{2+} *EGFET* sensors consist of a thin film of SnO_2/ITO/Glass and the immobilized Ca^{2+} *ionophore* on polyvinyl chloride (PVC). Performance verifications using known pH buffer solutions of 4 - 10 confirm the functionality of the system using both *FET* sensors along with the *AFE's* sensor enable and disable. Furthermore, $CaCl_2$ buffer concentrations of 0.1m – 1 Mol also confirm the functionality of the fabricated Ca^{2+} biosensors. An on-chip version of the *AFE* using *TSMC* 0.35µm *CMOS 2P4M* Technology the circuit is also presented.**

Keywords*— Electronic Tongue, ISFET, EGFET, pH, Ionized Calcium, Potentiometric Sensor Interface

I. INTRODUCTION

Urolithiasis or urinary stone formation is one of the highly impacting factors in our society and has evolved to a widespread disease for the past 3 decades. It is said that about 10% of people will experience kidney stones in their lifetime and about 50 – 70% of those will have recurrences [1]. Furthermore, for those who have this history, there is a 10% cumulative chance of recurrence for each year after the first stone formation [2]. The economic loss of the society attributed to *urolithiasis* is estimated to be up to billions of US dollars [3]. Urolithiasis prevention not only mitigates the patients' condition but also reduces health expenses [4].

The latest and well accepted factors causing urolithiasis are: 1. Primary precipitation of calcium phosphate (CaP) at high nephron levels; 2. CaP dissolved in low urine pH; 3. High ion-activity products of CaOx (supersaturation); 4. Low pH, low citrate and high ion-strength of urine causing large CaOx crystals; and 5. anatomical, as well, as hydrodynamic factors pertaining to stone retention. [5]. Several methods of assessing the risk of crystallization and recurrent stone formation has been detailed in [6]. One such method is the Bonn-Risk Index which is based on the potentiometric detection of the Ionized Calcium (Ca^{2+}) together with an optical determination of the triggered crystallization of CaOx in unprocessed urine [6]. By combining measurements of pH and Ca^{2+}, a platform can be built to aid in urinary stone prediction. To implement this, the proponents propose an electronic tongue system which utilizes an array consisting of ion sensitive field effect transistors (*ISFET*S), and enzyme extended gate FETs (*EEGFET*s) for the detection of pH and Ca^{2+} respectively. The system has been implemented on-board with a digital back-end that controls the analog front-end (AFE) interfaced to the sensors and performs calibration. The AFE has also been implemented on-chip using TSMC 0.35um CMOS 2P4M Mixed Mode Technology.

This paper is organized as follows: Section I presents the background information about urolithiasis to which this system shall be utilized; Section II discusses the operating principles of the two *FET* sensors, the AFE readout circuit design, and the synthesized Application Specific IC; Section III presents the experimental and HSPICE simulation results; and Section IV presents the conclusion and future works.

II. FET SENSORS AND POTENTIOMETRIC READOUT CIRCUIT

A. *Ion Sensitive Semiconductor Sensors*

The Ion-Sensitive and Enzyme Extended Gate FETs are similar to the *MOSFET* except that their gates have been modified from polysilicon into ion-sensitive layers. The materials for these layers are summarized in Table I. Both *FETs* utilize a reference electrode that effectively forms the gate.

TABLE I. H+ ION SENSING MATERIALS [7]

Material	***Sensitivity (mV/pH)***	***Range (pH)***	***Hysteresis (mV)***	***Drift (mV/Hr)***
SiO_2	37 - 48	4 - 7	Unstable	Unstable
Si_3N_4	46 - 56	1-13	3	1
Al_2O_3	53 - 59	1 -13	0.8	0.1 – 0.2
Ta_2O_5	56 - 59	1 - 13	0.2	0.1 – 0.2
$PbTiO_3$	53 - 58	2 - 12	3 - 5	0.5-1
SnO_2	56 - 58	1 - 12	1.91	--

The governing equations for these *FET* chemical sensors follow the drain current equation of a *MOSFET* except that the