Java programming language has been used for program development because performing of a significant amount of calculations hasn't been required. The parser is located at the top level. Its main task is parsing of SVRF input file. Conventionally the file is divided into two parts – SVRF context and rules. Context is conditionally constant. The output files are generated by SVFR generator based on the context and the rules. Context and few rules are certainly included into each output file.

Management of the output files generation process can be carried out by the user or by module of manager. In initial SVRF the user can create groups of rules. Then in the process of parsing data about groups will also be extracted and transferred to the generator.

The parser performs processing in two stages. During the first stage all the rules and rule groups are extracted. The names of rules and groups are stored in the symbol table. At the second stage check showing that such names are not found anywhere else in the generated context is carried out. Otherwise the program operation is stopped because clean context couldn't be formed. A clear context is a context without names of rules and their derivatives (rules group names), so it can be used with any rule. SVRF generator creates output files based on groups of rules that are provided to it by the parser or the manager. The generator operation algorithm is simple – the context is placed at the beginning of each output file and the group of rules is placed behind it.

Generated SVRF files are sent to the manager. Task of the manager is copying of all the files required for run to the cluster, start of verification, measurement of each file verification time, collection of results from the cluster and their transfer to the log analyzer. SSH protocol and OpenSSH client are used to access the cluster. PBS Torque is used to run tasks on the cluster.

V. CONCLUSIONS

Real digital and digital-to-analog devices with high and ultrahigh degree of integration are substantially "parallel" objects, whereas the software in CAD structure intended to simulate and verify them are successive to a greater extent. In this connection the development of parallel simulation and verification technology for digital electronic devices by using supercomputing infrastructure seems to be quite perspective.

The developed technology and the software allow to reduce costs and the development time of VLSI topology as a result of multiple reduction of the time required on the process of VLSI simulation and topology verification.

REFERENCES

[1] ISE Design Suite, http://www-mtl.mit.edu/researchgroups/Well/.
[2] http://www.thefreelibrary.com/Model+Technology+and+Platform+Computing+Corp.Dramatically+Increase.

APPROACHES TO IMPLEMENTATION OF THE ION-SENSITIVE FIELD-EFFECT TRANSISTOR COMPACT MODELS

Dao Dinh Ha
Le Quy Don Technical University, Hanoi, Vietnam, ha.dao.dinh@bsuir.by

I. INTRODUCTION

The detection of toxic chemicals/biomolecules is of paramount importance for medical applications, environmental monitoring, food and pharmaceutical industries. Chemical/biological sensors based on ion-sensitive field-effect transistor (ISFET) offer several advantages, such as, higher sensitivity, lower cost, and smaller size. In this paper, different FET structures and detection principles are discussed. Conventional structure with the gate metal removed and an optional recognition element membrane deposited on top of the gate. We develop a physics-based (Verilog-A) compact model of ISFET sensors. The Verilog-A implementation would allow ISFET integration with complex signal processing circuits, and prediction of the integrated performance.

Unfortunately, very poor reliability/stability of these sensors in the fluidic environment has been a key roadblock to the commercialization of technology. Figure 1-A shows the structure of a traditional ISFET with the gate metal removed and an optional recognition sensing layer deposited on top of the gate [1]. The sensing layer of the transistor is directly exposed to the ionic solution. Ions from the solution can penetrate into the gate oxide, causing voltage-dependent hysteresis in the measured characteristics. Since, the sensing mechanism relies on the induced change in conductance/threshold voltage; this hysteresis can lead to false positives [2].

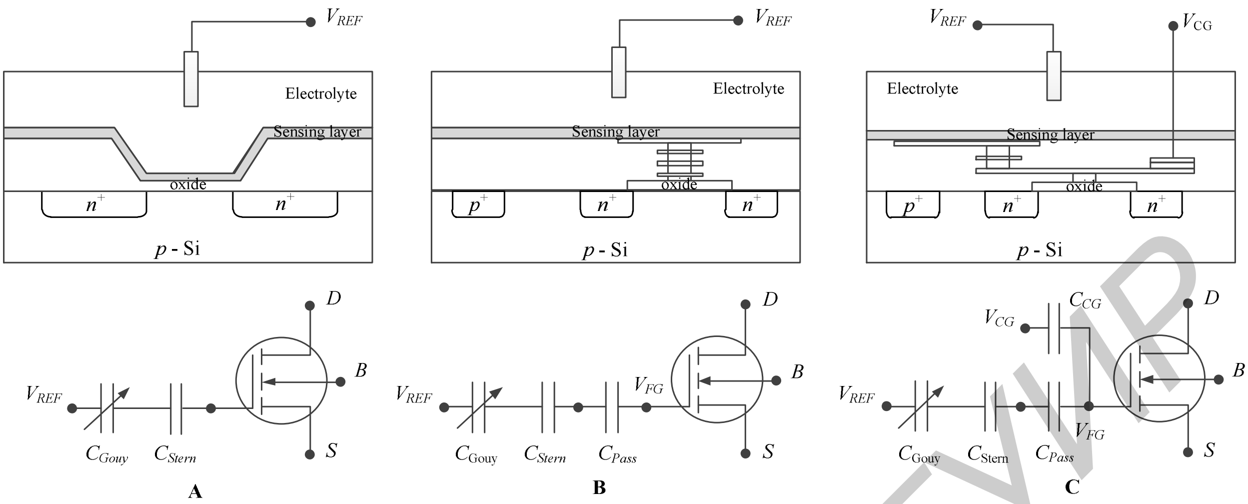


Figure 1 – Different sensor structures and equivalent circuits.
A) Traditional ISFET. B) Extended gate ISFET. C) Control-gate ISFET.

The unmodified ISFET variant is created by extending the metal gate up to the top layer of the chip. On top of this gate, a sensing layer is deposited. This approach allows unmodified CMOS processes to use this sensing layer. This structure is shown in Figure 1-B. Extended-gate ISFET promise to improve reliability by isolating the sensor Asensor from the transducer Aox [3].

Figure 1-C shows the structure ISFET variant, the ion-sensitive floating gate field-effect transistor (ISFGFET) [4]. The ISFGFET employs a floating gate (F_G) between the sensing gate (SG) and the underlying transistor structure. Additional control gate (C_G) is capacitively coupled to the F_G. Both gates can be used to modulate the FET channel conductance.

II. COMPACT MODEL

Therefore, in this paper, we develop a physics-based compact model for ISFET-based pH sensors, implemented in Verilog-A. Compared with a SPICE-based model, a Verilog-A implementation has several advantages.

Verilog-A models are described at higher levels of abstraction, so that future improvements/generalization are easily implemented.

It allows the use of limiting functions, such as limexp, which improves the convergence of the simulator running the model.

Furthermore, one can integrate nonelectrical components, such as a microelectromechanical system sensor, in Verilog-A.

The sensor is modeled as two decoupled circuit elements i.e. pH dependent nonlinear voltage source and a transistor.

PH dependent voltage source: The potential (ψ_0) i.e. the difference between the reference electrode voltage (V_{REF}) and effective gate voltage (V_{geff}) is a function of the pH. Therefore, the pH dependence of the sensor can be captured using a pH dependent voltage source. In the model, pH is represented as an external voltage source (VpH) to enable transient and small signal analysis with respect to pH in circuit simulator

Transistor: The second element in the model involves a classical MOSFET transistor with gate, source, and drain terminals.

The gate of the transistor is actuated by effective gate voltage which is responsive to the pH of the solution.

$$V_{FG(ISFET)} = V_{REF} + \psi_0;\ V_{FG(EGFET)} = V_{REF} + \frac{\psi_0}{1+\xi};\ V_{FG(ISFGFET)} = V_{REF} + \frac{C_{CG}V_{CG}}{C_{TOT}} + \frac{C_{SG}\psi_0}{C_{TOT}}$$

where $\xi = 1/(1+215\cdot(A_{ox}/A_{sensor}))$ and $C_{TOT} = C_{CG} + C_{SG} + C_{OX}$

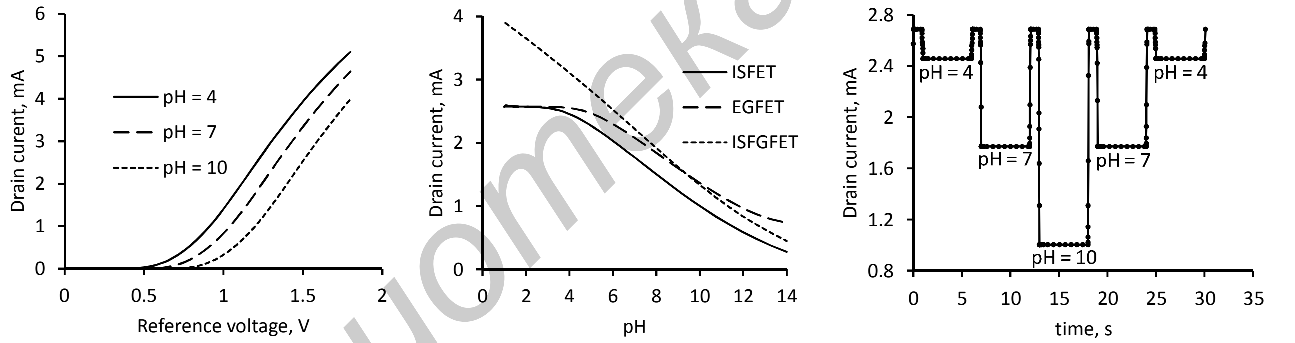
The ISFGFET has two gates, the sensing gate (S_G) and a control gate (C_G) which are capacitively coupled to a common floating gate (F_G). The corresponding gate potentials are ψ_0 for the S_G and V_{CG} for the C_G. The device operation can be described by considering the F_G potential (V_{FG}) of a floating gate FET.

Table 1 – Compact model for the pH sensor

Model equations	Number
$\sigma_{dl} + \sigma_{surf} + \sigma_{mos} = 0$	1
$AOH_2^+ \leftrightarrow AOH + H_s^+,\ AOH \leftrightarrow AO^- + H_s^+$	2
$\sigma_{surf} = q([AOH_2^+] - [AO^-]) = -2qN_{OH}\dfrac{(\tanh(x_1))}{\left(10^{\frac{\Delta pK}{2}}\operatorname{sech}(x_1) + 2\right)}$	3
$\sigma_{dl} = -\sqrt{8kT\varepsilon_w n_0}\sinh\left(\dfrac{q\psi_0}{2kT}\right)$	4
$\psi_0 = \dfrac{2kT}{q}\operatorname{asinh}\left(\dfrac{\sigma_{surf}}{\sqrt{8kT\varepsilon_w n_0}}\right) + \dfrac{\sigma_{surf}}{C_{stern}}$	5

The net gate-charge can be calculated by the charge neutrality (Eq. (1) of Table 1) requirement in the system. The surface charge due to protonation or deprotonation of surface-groups is dictated by the reactions taking place at the interface (Eq. (2) of Table 1). The net surface charge can be expressed in terms of the surface potential (ψ0) as given in Eq. (3), (5) of Table 1. There is an additional capacitance (Cstern) in addition to the oxide capacitance (Eq. (5) of Table 1).

III. RESULTS AND DISCUSSION



a b c

Figure 2. a – the simulation I-V characteristics with pH values of 4, 7 and 10 (pKa=-2; pKb=6; NOH = $5\cdot10^{15}$ cm^{-2}; C_{stern} = 20 μF/cm^2). b – the dependence I_{DS} as a pH function for different structure ISFET (V_{REF} = 1.2 V, V_{DS} = 0.5 V); c – Output current ISFET as a function of time. Surface charge becomes more negative as pH increases from 4 to 10.

Figure 2 shows the simulation characteristics pH sensor. For higher pH, the amount of proton concentration in the solution is small. This leads to de-protonation of the surface (AOH) groups and results in a net negative charge on the surface. Therefore, the threshold voltage increases and the I_{DS} curve shifts to the right. The sensitivity S = 42,67 mV/pH from pH 4 to pH 7 and S = 52,67 mV/pH from pH 7 to pH 10. Figure 2-B shows the dependence IDS as a function of pH for different structure ISFET. ISFGFET sensor has the highest sensitivity 0.25 mA/pH.

IV. CONCLUSIONS

In this paper, different FET structures and detection principles are discussed. Conventional structure with the gate metal removed and an optional recognition element membrane deposited on top of the gate. Unmodified CMOS ISFET where a passivation layer is used as the sensing layer. Control-gate assisted FET to tune the operation point and the charging of both the surface and the fluidic part. Constructions based on additional series capacitors at the input suffer from attenuated sensitivity due to the capacitive division.

ACKNOWLEGMENTS

This work was supported by the grants 1.8.05 of Belarusian National Scientific Research Program “Informatics, Space, Safety” and 3.2.01 Belarusian National Scientific Research Program «Photonics, Opto- and Microelectronics».

REFERENCES

[1] Y. Hu, P. Georgiou. A robust ISFET pH-measuring front-end for chemical reaction monitoring, IEEE Transactions on Biomedical Circuits and Systems 8. 2014. PP. 177–185.
[2] M. Kaisti. Hand-held transistor based electrical and multiplexed chemical sensing system, ACS Sensors. 2016.
[3] M. Spijkman. Dual-gate thin-film transistors, integrated circuits and sensors, Advanced Materials. 2011. PP. 3231–3242.
[4] F. Ahmad, S. Hashsham. Miniaturized nucleic acid amplification systems for rapid and point-of-care diagnostics. A review, Analytica Chimica Acta. 2012. PP. 1–15.

CALCULATING AND MODELING OF INTEGRATED DISPLACEMENT SYSTEMS FOR PRECISION EQUIPMENT OF MICRO- AND NANOELECTRONICS

I. Dainiak, V. Kuznetsov, S. Karpovich
Belarusian State University of Informatics and Radioelectronics, Minsk, Belarus

I. INTRODUCTION

Today coordinate displacement systems based on actuating parallel kinematics mechanisms have wide applications in the fields of realizing of precision motions with number of degrees of freedom up to six inclusive [1–3]. These systems consist of actuating mechanism, drives and control system, but the actuating mechanism is main part which determines the technical characteristics of displacement system. Parallel mechanisms have many possible structural configurations [4, 5] in contrast to sequential mechanisms which have fixed number of structural implementations. As result we can say that the specific topology of parallel kinematics mechanism directly determines its kinematic characteristics.

It should be noted that there is a considerable number of applications where it is necessary to implement motions with only four or five degrees of freedom, for example, multi-axis milling machines, cutting, welding, engraving machines for processing parts using laser tools. As the research results [6…8] show, such a stock of kinematic mobility gives a higher rigidity of the mechanical structure on the whole, and this fact is often used to improve the accuracy characteristics of realizable displacements. Thus the parallel kinematics mechanisms can be used in precision equipment for micro- and nanoelectronics.

II. RECONFIGURABLE PARALLEL KINEMATICS MECHANISMS FOR DISPLACEMENT SYSTEMS

The investigation of parallel mechanisms in terms of the possibility of their structural reconfiguration is actual task for design of equipment. Such mechanisms, with the ability to structural reconfiguration, allow us to change their structure in order to adapt to the requirements of new tasks and the environment. As such requirements may be, for example, a change in the degree of mobility, restrictions on the force torque characteristics or parameters of the workspace.

The main idea of constructing reconfigurable mechanisms of parallel kinematics is based on the use of modularity and uniformity of components (kinematic chains, nodes) of their structure. By mechanical detachment of one, two or three kinematic chains, the original mechanism can be reconfigured into a new mechanism of parallel kinematics with five, four or three degrees of freedom, respectively.

Kinematic analysis of any actuating spatial mechanism, including parallel kinematics, is based on the investigation of the position functions of all links obtained from the condition of closure of the kinematic chain consisting of input links and structural groups, the attachment of which to the latter does not change the overall mobility.

In the most general case, the actuator consists of a structural group including a platform and six connecting rods with spherical pairs (Figure 1).