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Topic 1. Chemical Sensors Applications (format "IMCS_Topic")

Circuit Modeling of Ion Sensitive Field Effect Transistors with Current Drift

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Summary

In terms of the application of ion sensitive field effect transistors (ISFETs) to integrated circiuts, the macro model of ISFETs is required. Although several models have been reported [1,2], there is no electrical model that reflects the time-dependent drian current (I_D) change (drift effect). We propose the electrical model which can reflect the drift effect and can be expressed by the combiantion of electrical cicuit components. In the proposed model, R_1 represents the resistance of the electrolyte and the FET can be approximated by the capacitances C_1 (capacitance of pure gate oxide in which hydrogen ions move very slowly) and C_2 (capacitance by gate oxide with defects in which hydrogen ions move relatively faster). Furthermore, the movement of hydrogen ions in the defective oxide is represented by R_2 and the current drift is modeled as the parallel combination of the C_2 and the R_2 because the drift effect is strongly related to hydrogen ion movement through defective gate oxide or Helmholtz layer. Consequently, the ISFET with current drift can be modeled by the series connection of the R_1, the parallel combination of the C_2 and the R_2, and the C_1. Also, the measured time-dependent current of the ISFET is successfully fitted to the proposed model.

Results and Discussion

To verify the validity of the proposed compact model, fabricated silicon nanowire (SiNW) ISFETs are measured transiently at fixed liquid gate bias (V_{LG}) and drain bias (V_D) of 1 V. Figs. 1 (a) and (b) show the schematics of the SiNW ISFET and the measurement system for pH sensing, respectively. The details of the fabrication and the measurement procedure were demonstrated in the previous report [3].

Firstly, we presume that the long time constant of the I_D drift is related to the effect of hydrogen ion movement through oxide or Helmholtz layer (HL). To model this effect, we set up a simple circuit as shown in Fig. 2(a) where R_1 represents the resistance of the electrolyte and the FET can be approximated as capacitances, C_1 and C_2. C_2 is the capacitance by gate oxide with defects in which the hydrogen ions move relatively faster than that of pure oxide. C_1 is the capacitance of the pure oxide in which the hydrogen ions move very slowly. R_2 represents the ion movement through the defective oxide. The low diffusion constant in the oxide causes the bottleneck of the ion motion. The slow movement of hydrogen ions in the defective oxide is modeled as the parallel combination of the C_2 and the large resistance R_2. The parameters for the circuit model are summarized in Table 1(a).

The input loop needs to be considered for the analysis of the response to the V_{LG} (a unit step function). According to Kirchhoff's law, the V_{LG} is expressed by the circuit components, C_1, C_2, R_1, R_2 and the voltage across HL (V_G). By using Laplace transform for $V_{LG} = V_G$ with some approximation that drift term (C_2, R_2) are much larger than rapid changing term (C_1, R_2), we obtain the relation between V_{LG} and V_G as shown in the equation of Fig. 2(a). The physical measning and notation of the parameters in the equation are summarized in Table 1(b). However, the voltage drifft cannot be measured directly in the experiment. Thus, the I_D is calculated by the equation of Fig. 2(b) including the proposed model and the calculated I_D is compared with measured data as shown in Fig. 2(b). It is verified that the model consisting of only electrical circuit compoenets reflects sucessfully the drift effect related to hydrogen ion reaction.

Acknowledgment

This work was supported by the Brain Korea 21 Plus Project in 2016 and National Research Foundation of Korea through the Ministry of Science, ICT and Future Planning (Grant No. 2013R1A1A2065339).

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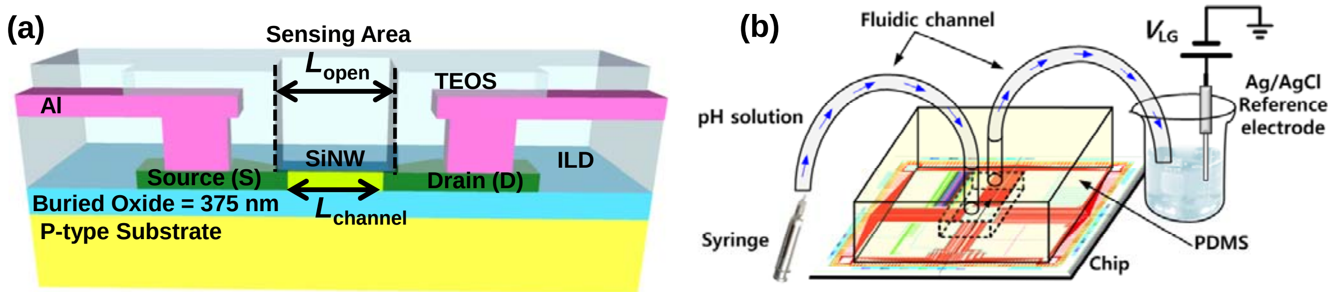

Fig. 1: (a) Schematic diagram of fabricated SiNW ISFET. (b) Measurement system for pH sensing

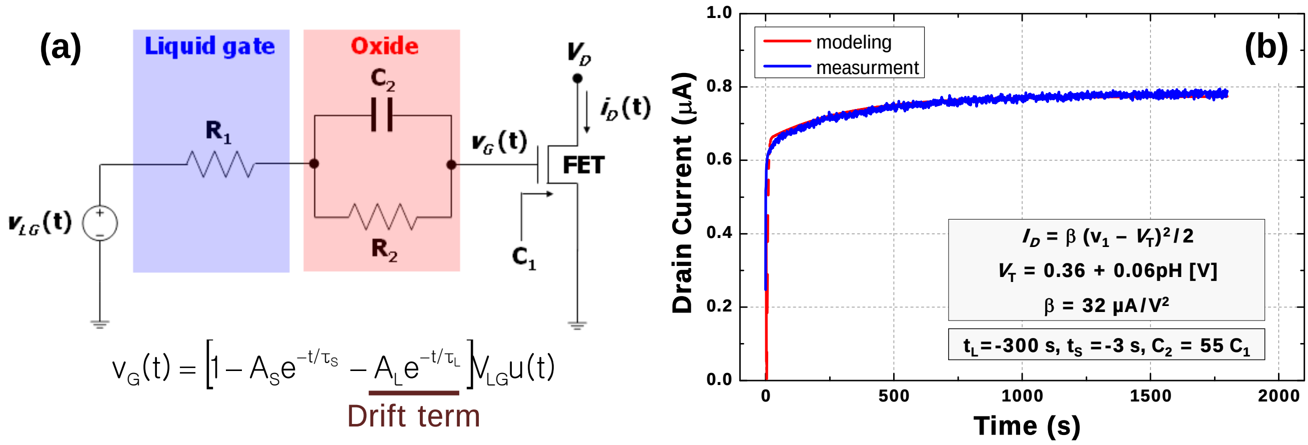

Fig. 2: *(a) A schematic model including drift effect. It is composed of electrical components. (b) Comparison of measured and calculated currents byusing proposed model.*

(a)

Notation	Component	Reaction rate
C1	Gate capacitance without H+ movement	Fast response
R1	Resistance of electrolyte	
C2	Gate capacitance with H+ movement	Slow response
R2	Resistance of H^+ at oxide	

(b)

Notation	Components	Physical meaning
τ_L	$(C_1 + C_2)R_2$	long time constant
τ_S	$C_1 C_2 R_1 / (C_1 + C_2)$	short time constant
A_L	$\frac{C_2}{C_1 + C_2}$	initial state for τ_L
A_S	$\frac{C_1}{C_1 + C_2}$	initial state for τ_S

Table. 1: (a) Parameters for electrical circuit model. (b) Notations for simple expression and its componets and physical meaning.

References

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