Characterization, Modeling, and Correction of Drift in Complementary pH ISFET's

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Abstract

Recently, a physical model has been presented which quantitatively describes the threshold voltage instability, commonly known as drift, in *n*-channel Si_3N_4-gate and Al_2O_3-gate pH ISFET's [1,2,3]. The origin of drift is postulated to be associated with the relatively slow chemical modification of the gate insulator surface as a result of exposure to the electrolyte. The chemical modification of the surface is assumed to result from a transport-limited reaction whose rate is modeled by a hopping and/or trap-limited transport mechanism known as dispersive transport. The change in the chemical composition of the insulator surface leads to a decrease in the overall insulator capacitance with time, which gives rise to a monotonic temporal increase in the threshold voltage. Based on the expression for the threshold voltage of an ISFET, Fick's first law of diffusion, and the dispersive transport theory, the expression for drift is given by [3]

$$v_{drift}(t) = v_{drift}(\infty)\left(1-\exp\left(-(t/\tau)^{\beta}\right)\right) \qquad (1a)$$

$$v_{drift}(\infty) = -(Q_D + Q_I + Q_{inv})x_{SL}(\infty)\left(\frac{\varepsilon_{ins}-\varepsilon_{SL}}{\varepsilon_{ins}\varepsilon_{SL}}\right) \qquad (1b)$$

where Q_I is the effective charge per unit area induced in the semiconductor by the various types of charges that may be present in the insulator, Q_D and Q_{inv} represent the charge stored in the semiconductor depletion layer and the inversion charge respectively, ε_{ins} and ε_{SL} are the dielectric constants of the chemically-modified surface layer, and the pH-sensitive respectively, $x_{SL}(\infty)$ is the final thickness of the modified surface layer, τ is the time constant associated with structural relaxation, and β is the dispersion parameter characterizing dispersive transport satisfying $0<\beta<1$.

As is evident from the attached figures, (1) fits the measured drift data for *n*-channel Al_2O_3-gate and Si_3N_4-gate pH ISFET's with a high degree of accuracy (typical coefficients of correlation of 0.999) based on optimization of $x_{SL}(\infty)$, τ and β within each parameter's physically meaningful range. The proposed model can also be supported by independent experimental evidence based on characterization of complementary (*p*-channel and *n*-channel) ISFET's. The direction of gate voltage drift depends on the sign of the charge terms in (1). While the sign of Q_D and Q_{inv} is determined based on device polarity, the sign of Q_I depends on the insulator charge as well as the density and the nature of surface states (i.e. donor type or acceptor type). Under typical ISFET biasing conditions and assuming the value of Q_I falls in the typical range encountered in CMOS integrated circuit technology, the gate voltage drift is expected to occur in opposite directions for *n*-channel and *p*-channel pH ISFET's. This prediction is to be evaluated based on measured drift results for complementary ISFET's. Feasibility of a circuit technique for correction of drift based on the drift behavior of complementary ISFET's will also be discussed.

References

[1] S. Jamasb, S. D. Collins, and R. L. Smith, "A Physical Model for Drift in Al_2O_3-gate pH ISFET's", Proc. 9th Int. Conf. Solid-State Sensors and Actuators (Transducers '97), Chicago, USA, June 15-19, 1997.

[2] S. Jamasb, S. D. Collins, and R. L. Smith, "A Physical Model for Threshold Voltage Instability in H+-sensitive FET's (pH ISFET's)", IEEE Trans. on Electron Devices, vol. 45, No. 6, June 1998.

[3] S. Jamasb, S. D. Collins, and R. L. Smith, "A Physical Model for Drift in pH ISFETs", Sensors and Actuators B: Chemical (49) (1-2) (1998) pp. 146-155.

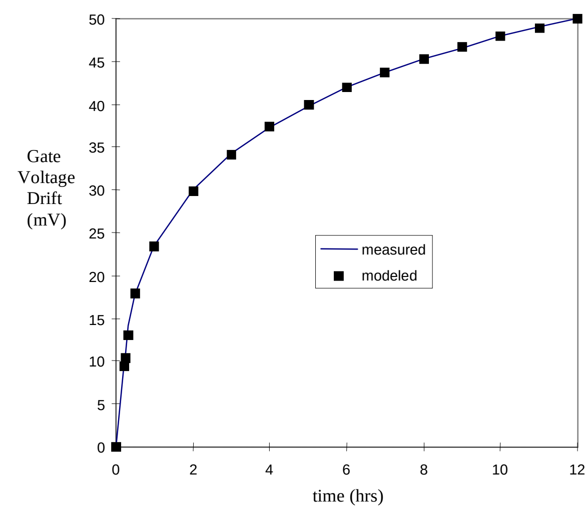

Fig. 1 Aluminum oxide pH ISFET Drift

Feedback Mode, I_D=100uA, pH=7

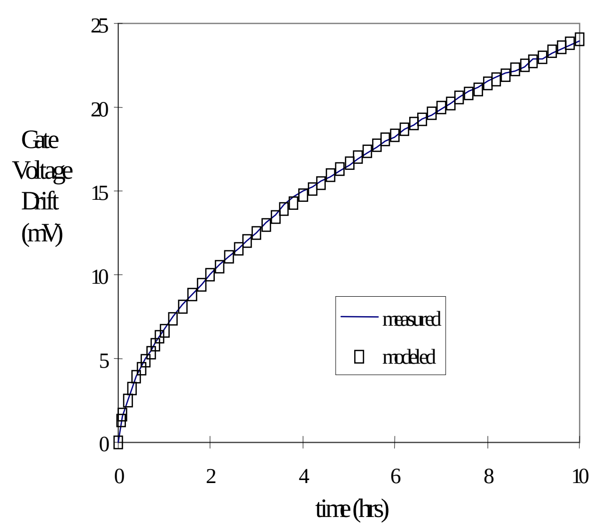

Fig. 2 Silicon-nitride-gate pH ISFET Drift Characteristics

Feedback Mode, I_D=100uA, pH=7