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Experimental analysis on the setup/hold time in readout condition of Si nanowire FET-based biosensors for detecting ion and/or biomolecule in analyte solution

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Si nanowire (SiNW) ion-sensitive field-effect transistor (ISFET)-based biosensor is the fundamental building block for real-time label-free detection of ion and/or biomolecule in analyte solution as well as the point-of-care application [1]. However, a transient response of SiNW FET has been more rarely investigated than the DC response and sensitivity in spite of its importance in perspective of the design of readout circuits. In detail, the motion of ions in analyte is retarded [2] and the ion penetration into SiNW frequently evokes the long-term drift [3]. In this work, the setup (t_S)/hold time (t_H) is defined and eperimentally analyzed in terms of its dependences of the rising time (t_R) of liguid gate voltage (V_{LG}), the pH value of electrolyte, and the gate load capacitance (C_G) in top-down processed SiNW FETs [4]. In real SiNW FET array, the V_{LG} feels significantly large C_G due to many SiNWs (not accessed but dummy) sharing the electrolyte solution [Fig. 1(a)]. Therefore, the C_G is intentionally changed by modulating the area of photoresistor (PR) which covers the sensor chip. The t_S and t_H is individually defined by the maximum of $dI_{SiNW}(t)/dt$ and the time at $dI_{SiNW}/dt<5$ nA/s [Fig. 1(b)]. As the t_R increases, t_S increases [Fig. 1(c)]. The t_S also increases in case of higher C_G [Fig. 1(e)]. The difference of (t_H–t_S) becomes independent of the pH value especially in the case of long t_R [Fig. 1(f)]. Our findings can be summarized as follows. The transient response of $I_{SiNW}(t)$ can be decomposed into three parts: 1) the bias t_R-controlled duration (t_1=0~t_S), 2) the ion movement-controlled duration (t_2=t_S~t_H), and 3) the long-term drift duration (t_3=t_H~). In the case of long t_R, the t_2 becomes shorter and the pH-dependence of t_2 becomes weaker [Fig. 1(d) and (f)] because the ions have the time enough to move in response to the variation of V_{LG}. The t_1 becomes shorter in lower C_G, which is very important suggestion about the way to improve the readout speed. The t_H is more sensitive to the pH value [5] rather than to C_G or t_R. Our result is potentially useful for the design of timing margin (t_S/t_H) in readout circuits in biosensing systems.

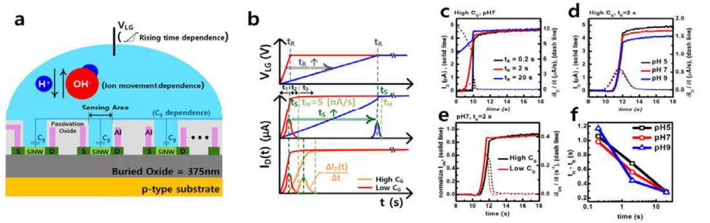

Fig. 1. Schematics illustrating (a) the measurement configuration and (b) the definition of t_R, t_S, and t_H. Measured (c) t_R-, (d) pH-, and (e) C_G-dependences of $I_{SiNW}(t)$ and $dI_{SiNW}(t)/dt$. (f) The t_R and pH-dependence of t_2 (=t_H–t_R).

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