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

Analysis of Dissimilarities in Current Drift on n-channel and p-channel pH-sensitive SiNW ISFET

Sihyun Kim[1], Dae Woong Kwon[1], Ryoongbin Lee[1], Dae Hwan Kim[2], and Byung-Gook Park[1]
[1]Inter-University Semiconductor Research Center (ISRC) and Department of Electrical Engineering and Computer Science (EECS), Seoul National University, Seoul 151-742, Korea
[2]School of Electrical Engineering, Kookmin University, Seoul 136-702, Korea
si1226@snu.ac.kr

Summary

The drift effect (slow current change during detection) is considered as one of the obstacles of silicon nanowire (SiNW) ISFET for commercialization as chemical/biomedical sensors [1]. The underlying physical causes of the drift effect are thoroughly analyzed with fabricated SiNW ISFETs by measuring time-dependent drain current (I_D) under various pHs and liquid gate biases. The measurement results show that the I_D of n-channel ISFET increases gradually during the measurement time (t_M), whereas that of p-channel ISFET decreases continuously throughout the t_M. Considering the dependence on pH value and gate bias, these phenomena can be explained by the field-enhanced diffusion of hydrogen species into the gate insulator (n-channel) and the chemical reaction of hydroxide ions on the insulator (p-channel), respectively. Furthermore, it is found that the I_D of p-channel SiNW is permanently degraded though the I_D of n-channel SiNW can be recovered after the measurement. This might be the result of hydroxide-related reaction that can degrade silicon oxide permanently in the same manner they do in standard clean 1 (SC1).

Experiment methods

Top-down fabrication method was used for SiNW ISFETs, which enables CMOS-compatible process and accurate alignment of nanowires. CMOS devices were co-integrated with SiNW ISFETs as shown in Fig. 1 (a). All the processes were conducted simultaneously except for the sensing area opening step. The measurement system for pH sensing is described in Fig. 1 (b). Polydimethylsiloxane (PDMS) microfluidic channel was used for inlet/outlet of the solution and applying liquid gate bias. The surface of the channel was treated with 3-aminopropyltriethoxysilane (3-APTES) self-assembled monolayers (SAM) to protect sensing oxide and to obtain the linearity of sensitivity.

Measurement results

Transient measurements were conducted to investigate the drift effect of the fabricated n-channel SiNW ISFET (n-SiNW) and the p-channel SiNW ISFET (p-SiNW) under various pH and liquid gate bias (V_{LG}) conditions. Fig. 2 (a) shows the transient characteristics of n-SiNW in pH 9 solution with V_{LG}=1.35 V and V_D=1 V. The drain current (I_D) increases progressively during the measurement, and the transfer curve is shifted in the negative direction after the transient measurement (inset of Fig. 2 (a)). Considering the direction of the threshold voltage (V_T) shift and the pH dependence (shown in [2]), the drift phenomenon of n-SiNW is caused by the H^+ ions which diffuse into the sensing oxide and then trapped by the buried sites.

On the other hand, P-SiNW shows completely different results. The I_D decreases throughout the transient measurement and the transfer curve is negative-shifted with degraded subthreshold swing (SS) as shown in the Fig. 2 (b) and its inset. Moreover, the amount of drift becomes larger with higher pH values (higher OH^- concentration) and larger V_{LG}s (Figs. 3 (a) and (b)). It should be noted that the I_D reduction of p-SiNW is permanent in contrast to the case of n-SiNW. Based on these results, the slow response of p-SiNW seems to be the result of the response between hydroxide ions and the sensing oxide [3] because Hydroxide ions are known to have the capability to etch the silicon oxide, which is the main mechanism of SC1 cleaning.

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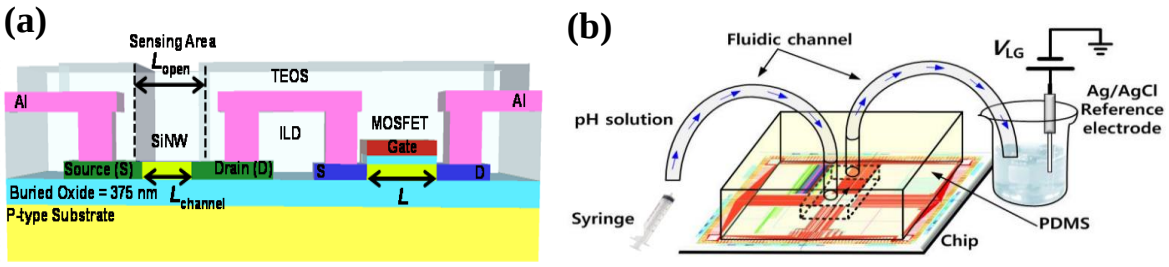

Fig. 1: (a) Schematic diagram of fabricated CMOS co-integrated SiNW ISFET. (b) Measurement system for pH sensing

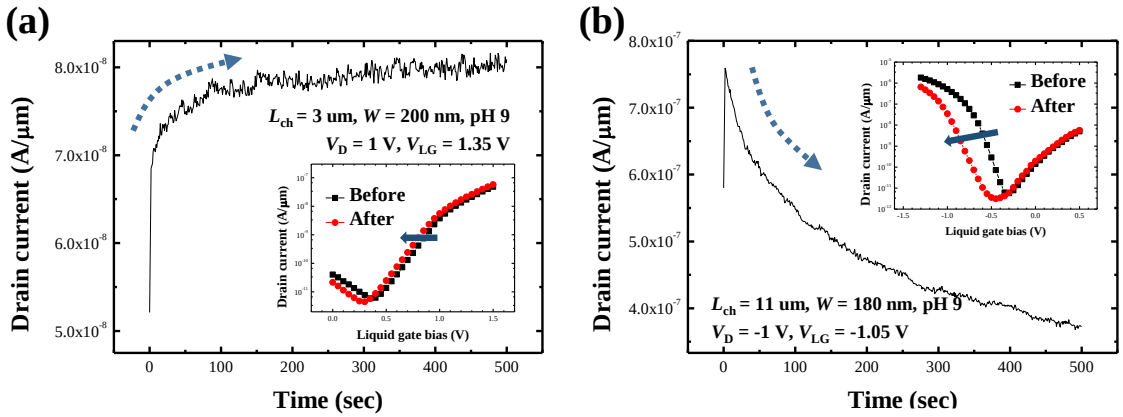

Fig. 2: Transient characteristics of (a) n-SiNW and (b) p-SiNW exposed to pH solution at fixed biases, and transfer curve change (inset)

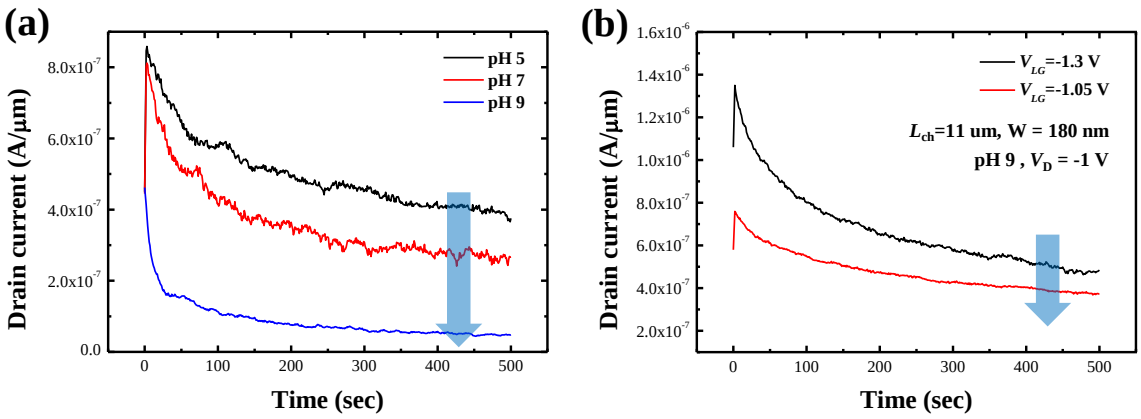

Fig. 3: Transient characteristics of p-SiNW (a) measured in various pH values, and (b) at different liquid gate biases.

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