Topic 3. Mechanisms, Modeling and Simulation

# Nanowire size dependency of silicon nanowire field-effect transistor based pH sensor

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## Summary

In this paper, we investigate the effects of nanowire size on the sensitivity of silicon nanowire (SiNW) ISFET. The changes of on-current ($I_{ON}$) according to pH level are measured in the fabricated SiNW ISFETs with various lengths and widths. As a result, it is revealed that the $I_{ON}$ gets more abruptly changed as the length/width becomes smaller, respectively. Through TCAD simulation analysis, the width dependence on the $I_{ON}$ change can be explained that the target molecules located at the edge region along the channel width direction has the stronger influence on the $I_{ON}$ change than that at the center region due to the electric field concentration at the edge region. Also, the length dependence on the $I_{ON}$ (or conductance) change can be simply understood by the different channel resistance of the ISFETs with various lengths.

***Keywords : Ion-sensitive field effect transistor (ISFET), Silicon nanowire (SiNW) pH sensor***

## Results and Discussion

We fabricated SiNW sensors with a liquid gate for pH detection. The Schematics of the SiNW sensor is presented in Fig. 1. The details of the fabrication and the measurement procedure were demonstrated in the previous report [1]. Fig. 2 shows the transfer curves measured at various pHs. As pH level gets increased, more negative charges ($OH^-$ ions) are bound on the gate oxide of the SiNW ISFET and thus the transfer curve is shifted in the right direction. Fig. 3 shows the SiNW width dependence on the $I_{ON}$ extracted from Fig. 2. The SiNW with narrower channel width tends to have higher sensitivity. The sensitivity is defined as the relative current or conductance change at fixed gate voltage (Overdrive voltage = 0.1 V). This tendency can be understood by the results of TCAD simulations (using Synopsys Sentaurus). Fig. 4 indicate the simulated electron density (e-density) of the SiNW crossed along the channel width direction. Figs. 4(a) and (b) show that more electrons are accumulated at the edge of the SiNW because electric field (e-field) is concentrated at the edge region. As the width of the SiNW becomes smaller, the portion of the edge region (higher e-field region) increases as compared to the SiNW with larger width. Moreover, the SiNW with narrower width can have the more concentrated e-field in the channel by the better gate controllability. Figs. 4(c) and 4(d) prove that the e-density is more abruptly changed in the SiNW with smaller width due to the larger edge portion and concentrated e-field when the number of $OH^-$ or $H^+$ ions on the gate oxide is varied, which leads to the more sensitive $I_{ON}$ change.

Additionally, the channel length dependence on conductance change is investigated. Fig. 6 shows the relative conductance changes of the SiNWs with various lengths according to pH variation. Although the absolute amount of conductance change according to pH level remains the same regardless of the length, the initial conductance increase as the length decreases [2]. Consequently, sensitivity corresponding to relative conductance change is improved as channel length becomes shorter because conductance/initial conductance ratio is declined.

## References

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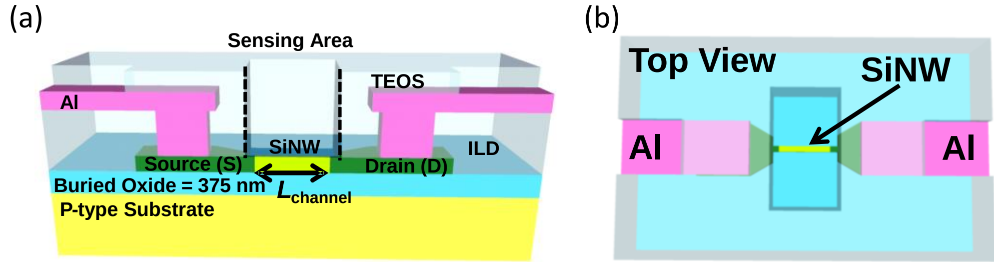
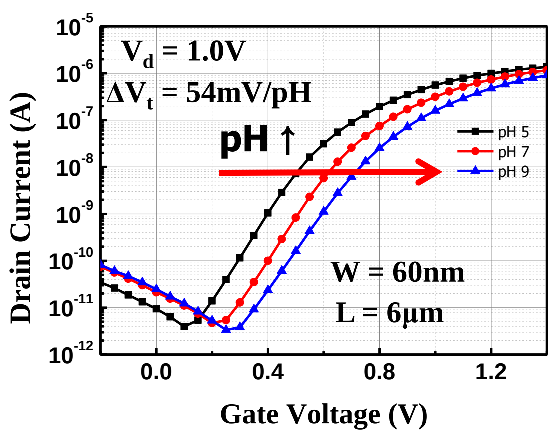



*Fig. 1: Device schematics of SiNW pH sensor. (a) Front view (b) Top view.*



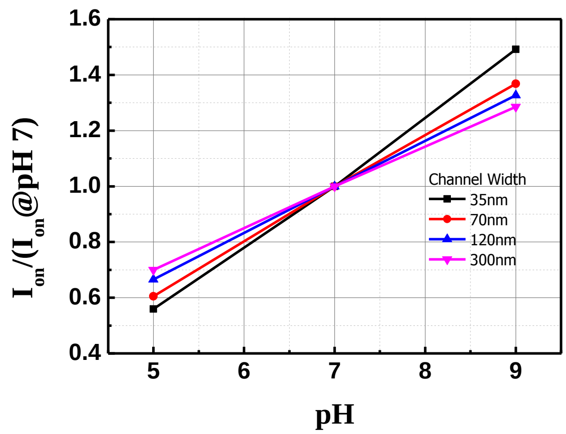
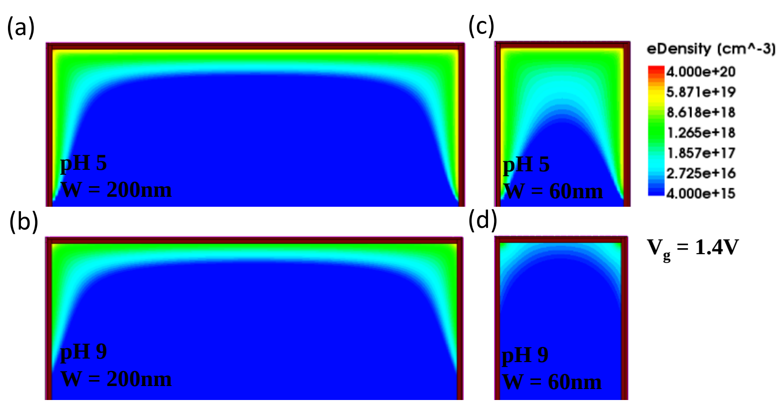




*Fig. 2: Transfer curves of n-type pH sensor. Fig. 3: On-current* dependence *on pH with various widths.*



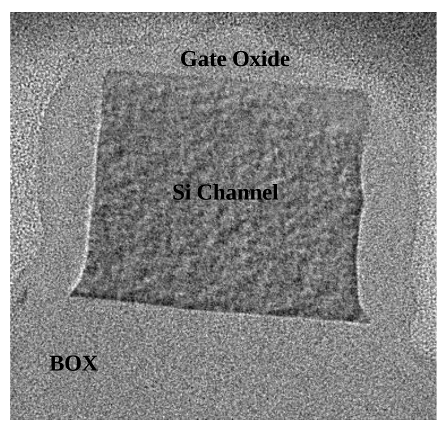




*Fig. 4: Simulated electron density. Fig. 5: TEM image of SiNW along channel width direction.*

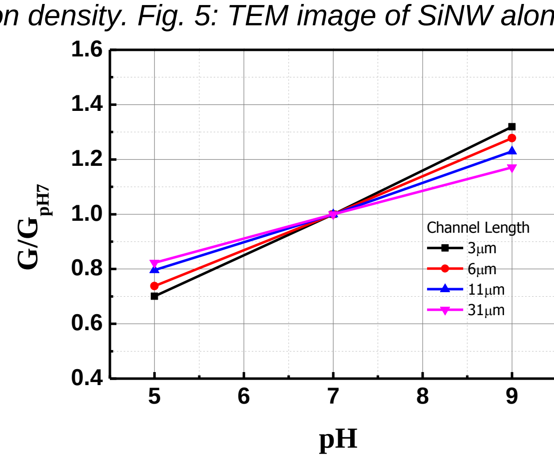



*Fig. 6: pH dependence on conductance extracted from SiNWs with various lengths.*