Top-Down Silicon Nanowire FETs for Biosensors

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Abstract

We demonstrated silicon nanowire (SiNW)-complementary metal-oxide-semiconductor (CMOS) hybrid biosensors for voltage output on a 6" silicon-on-insulator wafer using a wafer-level top-down process with a conventional back-end process. Firstly, SiNW-CMOS hybrid common-source amplifier biosensor shows the voltage-defined sensitivity can be individually controlled and maximized by the gate voltage of the metal-oxide-semiconductor field-effect transistor (MOSFET). Secondly, complementary SiNW biosensor exhibits an output voltage swing of 162 mV/pH which is 1.6 times larger than single SiNW sensor counterparts with a resistive load. Therefore, the proposed circuit and fabrication method is expected to be a promising solution for a very sensitive voltage readout scheme for the mass production of biosensors.

Keywords: Silicon nanowire FET, biosensors, top-down fabrication, voltage readout

1. Introduction

Recently, silicon nanowire field-effect transistor (SiNW FET) has attracted great attention as a new biosensor thanks to big advantages in terms of high sensitivity, and to a possibility for integrating with complementary metal-oxide-semiconductor (CMOS) circuits [1-2]. To successfully industrialize a top-down-processed SiNW FET-based biomolecule diagnosis system, in addition to high sensitivity, a noise-tolerant output with low-power consumption is also required. Furthermore, for robust signal processing with good noise tolerance, a voltage output is more advantageous than a current output from biosensors. Nevertheless, the approach for boosting the output voltage-defined sensitivity of top-down SiNW-based biosensors has rarely been demonstrated or discussed. In this work, we propose SiNW-CMOS hybrid biosensors for voltage output and implement them on a 6" silicon-on-insulator wafer using a conventional CMOS process technology through a wafer-scale top-down process [3-4].

2. Experimental

The proposed SiNW-CMOS hybrid biosensors were fabricated on boron-doped 6" SOI wafers. The fabrication process is illustrated in Fig. 1(a). The cross-sectional view of the SiNW-CMOS hybrid part is shown in Fig. 1(b). The proposed SiNW-CMOS hybrid common-source amplifier (CSA) biosensor and complementary SiNW biosensor are shown in Fig. 2(a) and (b), respectively.

3 . Results and Discussion

Figure 3(a) shows the measured voltage transfer curves (VTC) of the SiNW-CMOS hybrid CSA for different pH levels. We verified the measured time-varying output voltage (V_{OUT}) with a change in the pH levels at a fixed V_{LG}, as shown in Fig. 3(b). Figure 4 shows that we can improve the voltage-defined sensitivity, which is defined as the shift of V_{OUT} with the varying pH, by controlling V_{GS} of individual metal-oxide-semiconductor field-effect transistor (MOSFET) devices. The pH-dependent VTCs are shown in Fig. 5(a) as functions of V_{LG}. The transient voltage output $V_{OUT}(t)$ with time-varying pH values was also measured at a fixed V_{LG} of −1.65 V, as shown in Fig. 5(b). The proposed scheme is found to effectively overcome the ideal Nernstian limit so as to maximize the sensitivity beyond the highest limit attainable by a single SiNW device. The calculated $|\Delta V_{OUT}/V_{DD}|$ from the analytical model (by lines) is compared with the experimental results shown in Fig. 6. The proposed scheme promises to efficiently boost the sensitivity of a single SiNW sensor and make the voltage output immune to the individual sensitivity (in terms of $\Delta I/I$) of single SiNWs.

4. Conclusion

The top-down SiNW-CMOS hybrid biosensor was demonstrated with application to hydrogen ion sensors. The proposed fabrication process and circuit scheme are expected to potentially expedite the realization of low-cost highly sensitive battery-powered SiNW-CMOS hybrid diagnosis chips in the near future.

References

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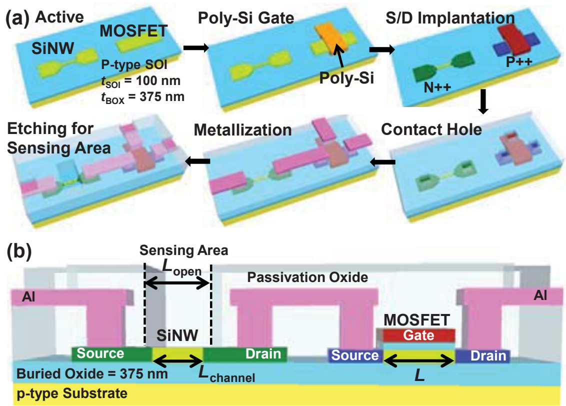

Figure 1. (a) Fabrication flow of for the integration of SiNW biosensors with MOSFETs. (b) Cross-sectional view of the SiNW-CMOS hybrid part [3].

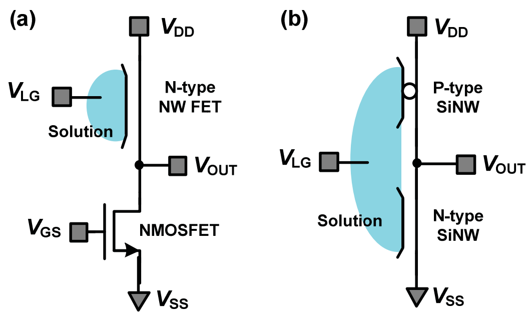

Figure 2. Schematic diagrams of (a) SiNW-CMOS hybrid common-source amplifier (CSA) biosensor [3] and (b) complementary SiNW biosensor [4].

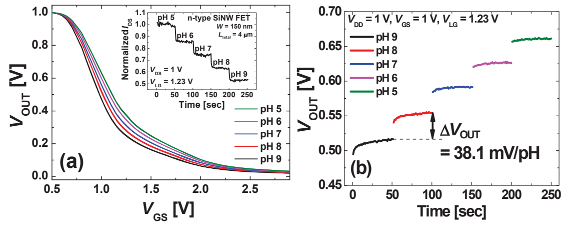

Figure 3. (a) VTC of the SiNW-CMOS hybrid CSA as a function of the pH level. The inset shows the normalized I_{DS} of the SiNW FET for varying pH values. (b) The measured time-varying V_{OUT} with a change in the pH level at a fixed V_{LG} [3].

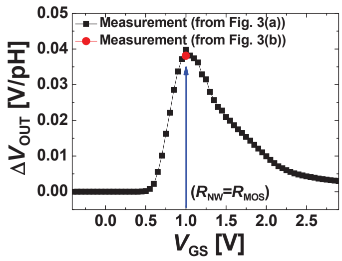

Figure 4. (a) ΔV_{OUT} as a function of V_{GS} from the experimental data (Figs. 3(a) and (b)). R_{NW} is the effective resistance of the SiNW FET, and R_{MOS} is the effective resistance of the NMOSFET [3].

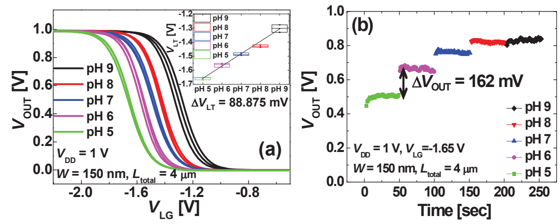

Figure 5. (a) VTC of complementary SiNW biosensors for different pH levels. The inset shows an error bar of V_{LT} for each pH level. (b) Transient V_{OUT} on changing the pH level for a fixed V_{LG} [4].

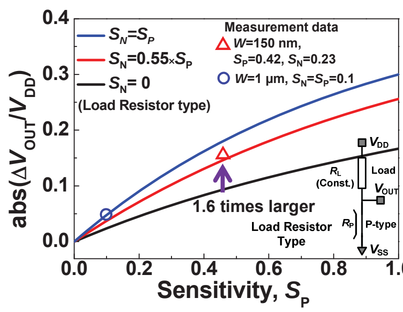

Figure 6. Calculated and measured $|\Delta V_{OUT}/V_{DD}|$ (S_N/S_P are the sensitivity of n-/p-type SiNW biosensors). $S_N = 0.55 \times S_P$ and $S_N = 0$ corresponding to the proposed complementary SiNW biosensor and a single SiNW counterpart, respectively [4].