NOISE-IMMUNE SILICON NANOWIRE/CMOS HYBRID BIOSENSOR USING TOP-DOWN APPROACH

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ABSTRACT

A noise-immune silicon nanowire (SiNW)/complementary metal-oxide-semiconductor (CMOS) hybrid biosensor is demonstrated by using a conventional wafer-scale top-down technology. We propose a new sensing metric, the direct voltage output of the biosensor combined with the n-/p-type SiNWs and CMOS circuitry, for robust signal processing. Finally, the noise-immune digitized signals from the time-varying pH levels are successfully obtained with low power consumption for mobile diagnosis systems.

KEYWORDS: Silicon nanowire, Top-down fabrication process, Real-time detection, Label-free, Biosensor, pH sensor, Noise cancellation, Complementary metal-oxide-semiconductor (CMOS) technology

INTRODUCTION

Recently, silicon nanowire field-effect transistors (SiNW FETs) have attracted considerable attention as new biosensors by virtue of their high sensitivity and short detection times [1-4]. Furthermore, they can simply be fabricated by a conventional CMOS process, and thus can be monolithically integrated with CMOS readout through the same process steps [5]. However, noise-immune output signals and low-power consumption are required to successfully industrialize a top-down-processed SiNW FET-based biomolecule diagnosis system. In this work, we newly propose a noise-immune top-down SiNW/CMOS hybrid biosensor for highly sensitive mobile diagnosis systems.

THEORY

A schematic view of the SiNW/CMOS hybrid biosensor is shown in Figure 1(a). There are two stages in the biosensor. The first stage is the complementary (p- and n-type) SiNW block for sensing the target biomolecules in the electrolyte and amplifying the signal. The second stage is the CMOS inverter block for a noise cancellation. Noise can be reduced by the inherent characteristics of the inverter chain as explained in Figure 1(b).

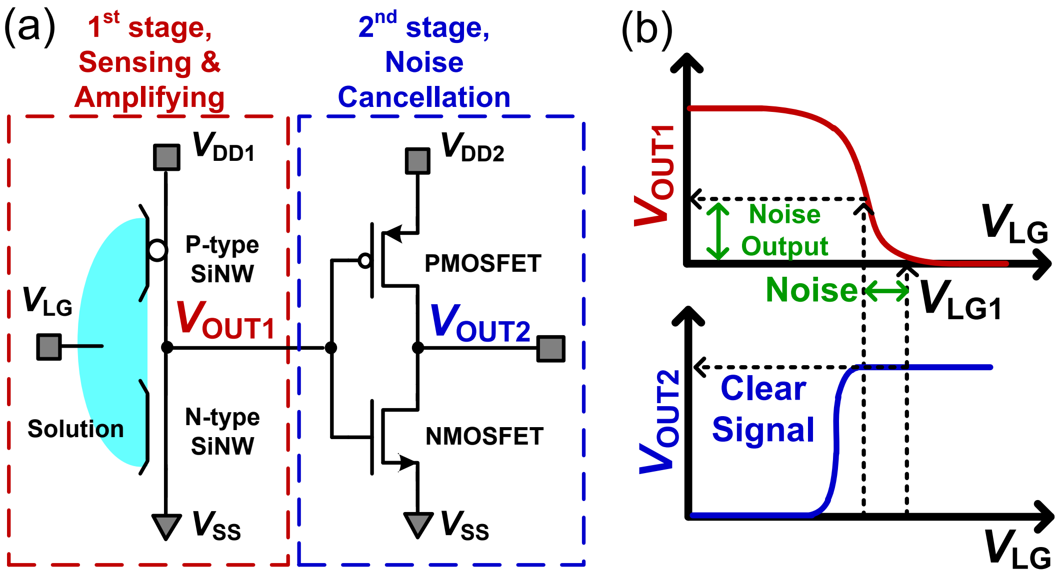

Figure 1: (a) Schematic diagram of the proposed SiNW/CMOS hybrid biosensor. 0.1-M potassium phosphate buffers (pH 5 ~ 9) were used as pH solutions and the Ag/AgCl reference electrode is used as the liquid gate voltage (V_{LG}). (b) Noise propagation in the SiNW/CMOS hybrid biosensor.

EXPERIMENTAL

The proposed SiNW/CMOS hybrid biosensor was fabricated on boron-doped 6” SOI wafers by using the conventional wafer-scale top-down approach. The fabrication process is illustrated in Figure 2(a). The cross-sectional view along the channel of the SiNW biosensor is shown in Figure 2(b). Figure 2(c) presents scanning electron microscopy

(SEM) images of the first stage in the biosensor (i.e., a complementary SiNW block). The SiNW surface was functionalized with 3-aminopropyl-triethoxysilane (APTES) to introduce the amine ($-NH_2$) surface. The electrical characteristics of the biosensor were measured using a semiconductor parameter analyzer (4156C, Agilent).

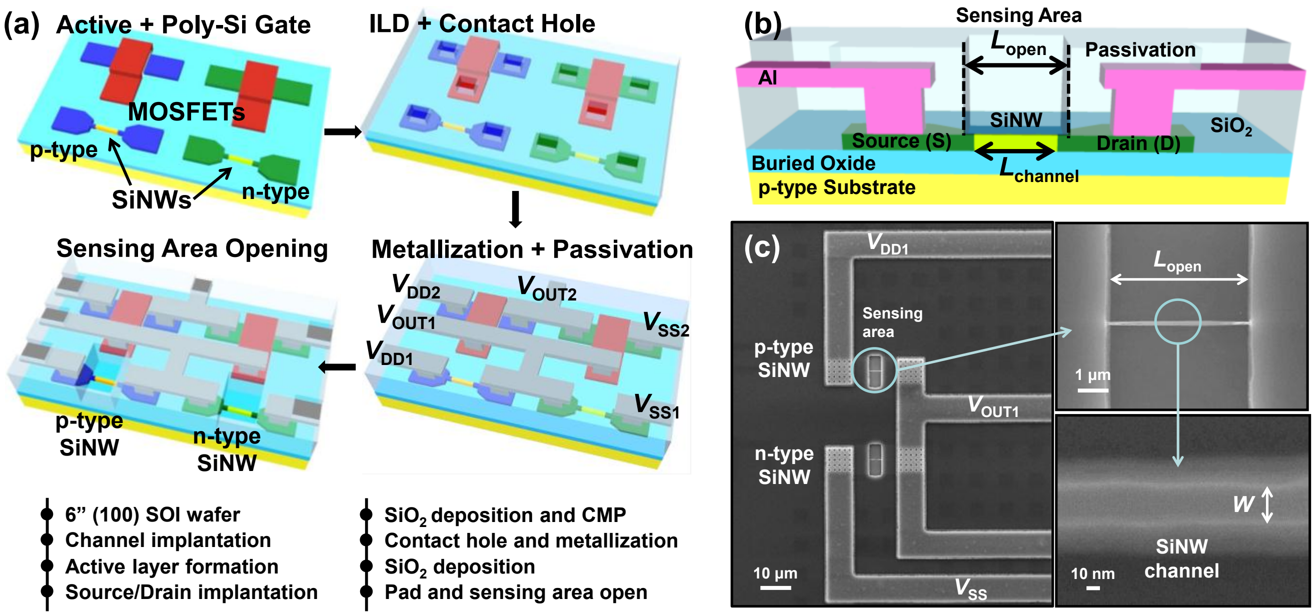

Figure 2: (a) Fabrication flow of the proposed SiNW/CMOS hybrid biosensor. (b) Cross-sectional view of the SiNW biosensor. (c) SEM images of the first stage of the biosensor, as shown in Figure 1(a). The final width (W), height, and open length of the SiNWs are 35 nm, 80 nm, and 4 μm, respectively.

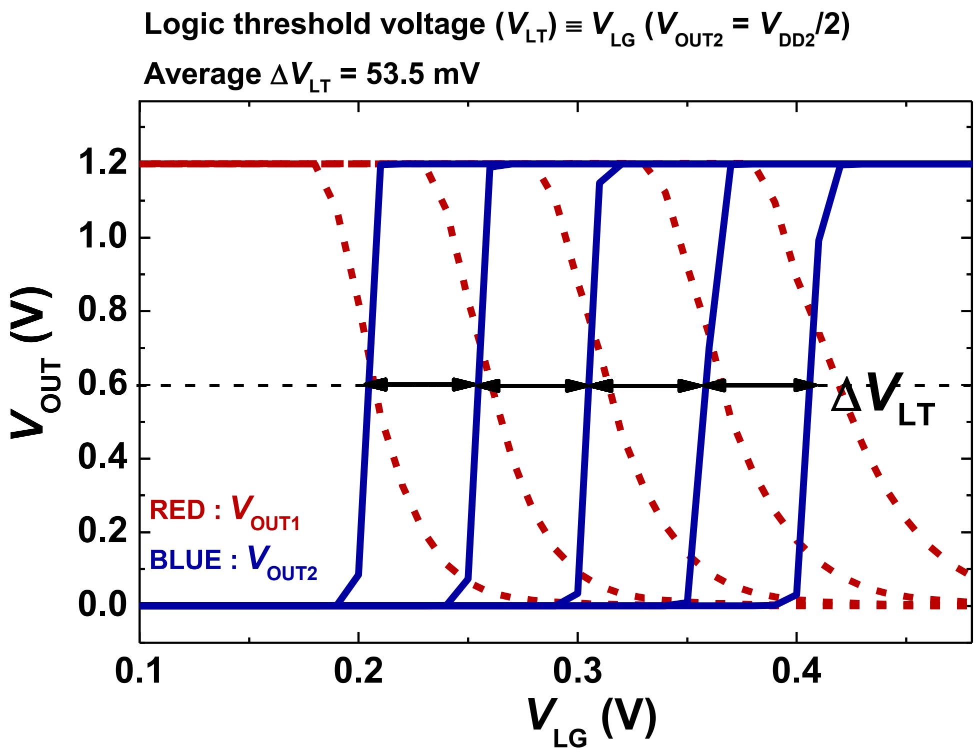

Figure 3: Voltage transfer curves of the SiNW/CMOS hybrid biosensor corresponding to the different pH levels (V_{DD1} = V_{DD2} = 1.2 V). The logic threshold voltage (V_{LT}) is defined as the liquid-gate voltage (V_{LG}) when V_{OUT2} is half of V_{DD2}. The measured shift of the logic threshold (ΔV_{LT}) is approximately 53.5mV/pH.

RESULTS AND DISCUSSION

The voltage transfer curves of the proposed biosensor are directly measured as a function of the liquid gate voltage (V_{LG}) and pH levels as shown in Figure 3. Furthermore, the transient output voltages of the biosensor are measured corresponding to the different pH levels in Figure 4. As expected, the noisy V_{OUT1} is transformed into a clear binary code in V_{OUT2}. Therefore, the biosensor proposed here can obtain noise-immune digitized bio-signals, arising from high inverter gain of hybrid structure. Furthermore, our proposed biosensor yields very low static power dissipation of approximately 160 pW during the sensing operation, whereas a single SiNW biosensor dissipates power at a rate that is 10^3 larger (274 nW).

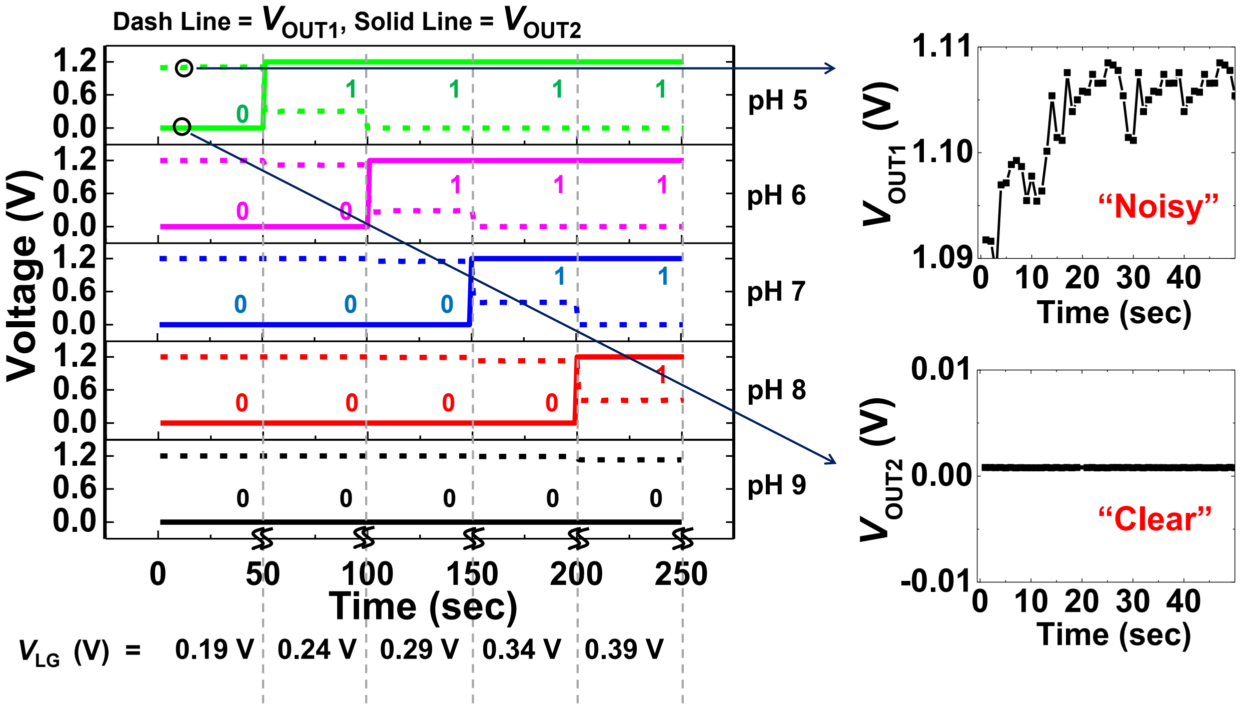

Figure 4: Transient responses of V_{OUT1} (dashed line) and V_{OUT2} (solid line) according to the pH levels in the SiNW/CMOS hybrid biosensor.

CONCLUSION

The top-down SiNW/CMOS hybrid biosensor is demonstrated with application to hydrogen ion sensors. The results confirm that the noise-immune digitized voltage-output signals from the time-varying pH levels are successfully obtained with low power consumption. 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.

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