CURRNET-MIRROR TYPE SILICON NANOWIRE BIOSENSOR WITH PROGRAMMABLE CURRENT REFERENCE

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ABSTRACT

In this paper, the current-mirror type silicon nanowire (SiNW) biosensor is demonstrated with well-established CMOS technology. We adopted the programmable current reference to eliminate environmental factors compromising the precision of detected bio-signal. Consequently, the voltage output sensitivity of 49.6 mV/pH was attained with immunity to environmental factors, such as PVT variation, receptor species, and a variety of chemical conditions of electrolyte solution.

KEYWORDS: Silicon nanowire (SiNW), Ion-sensitive field effect transistor (ISFET), CMOS technology, Biosensor, pH sensor, Real-time detection, Label-free, PVT variation, Read-out circuit, Current-mirror, Programmable current reference

INTRODUCTION

Silicon nanowire (SiNW) has been considered attractive and promising device for the configuration of ion-sensitive field effect transistor (ISFET) as a real-time label-free biosensor by virtue of its high sensitivity, cost-effectiveness, and compatibility with CMOS technology [1-2]. However, the precision of detected bio-signal, i.e., the concentration of discrete biomolecule (Q_{target}) in human serum or blood, would be paramountly compromised with the variation of environmental factors, such as PVT (process, supply voltage, and temperature), receptor species, and a variety of chemical conditions of electrolyte solution which are altered with specific analyte. It makes the design of robust read-out circuit challenging.

Therefore, we hereby demonstrate the current-mirror type SiNW biosensor by adopting a programmable current reference. It is ascertained that the ΔV_{OUT} is a function of only Q_{target} regardless of $I_{SiNW,initial}$ (the I_{SiNW} before the binding of biomarker) which changes not only with the variations abovementioned but also with analyte by analyte.

THEORY

The schematic diagram of proposed current-mirror type SiNW biosensor is shown in Figure 1(a).

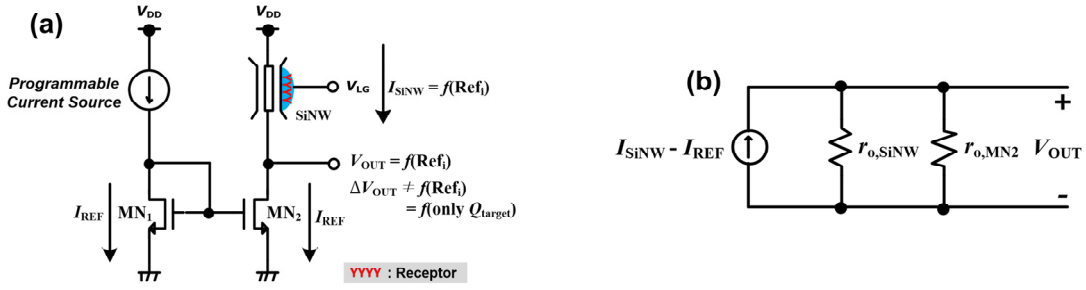

Figure 1: (a) Schematic diagram and (b) small-signal model of the current-mirror type SiNW biosensor

The reference current (I_{REF}) through MN_1 is replicated on MN_2. Based on the small-signal model shown in Figure 1(b), the voltage output (V_{OUT}) can be expressed as following equation (1).

$$V_{OUT} = (I_{SiNW} - I_{REF}) \cdot (r_{o,SiNW} \,||\, r_{o,MN2}) \quad (1)$$

If the ΔI_{SiNW} is defined as $\Delta I_{SiNW} = I_{SiNW}$(after the binding of biomarker) - $I_{SiNW,initial}$, the ΔV_{OUT} (= the V_{OUT} after the binding of biomarker - $V_{OUT,initial}$) is determined only by Q_{target} and it is immune to $I_{SiNW,initial}$ although the $V_{OUT,initial}$ changes either analyte by analyte or with PVT variation as depicted in Figure 2.

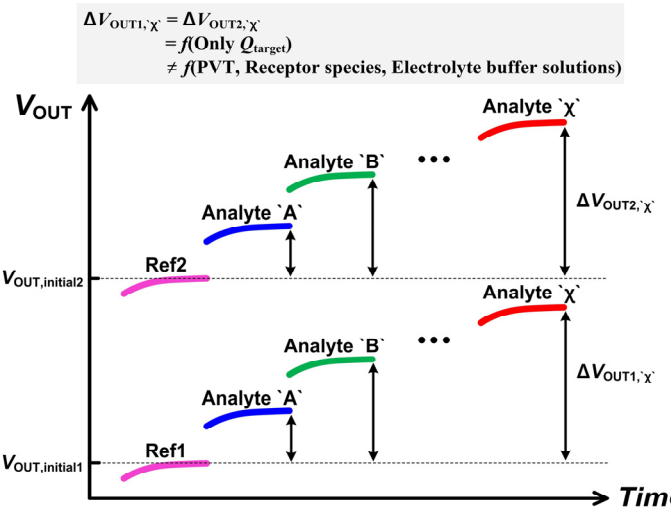

Figure 2: Concept of immunity to environmental factors such as PVT variation, receptor species, and a variety of chemical conditions of electrolyte solution

EXPERIMENTAL

The process integration of SiNW and CMOS read-out circuit has already and successfully been demonstrated in our previous works [3-5]. A 3-D bird's eye view, a TEM image, and process details are also elucidated in Figure 3. The surface functionalization using 3-aminopropyltriethoxysilane (APTES) and measurement set-up with semiconductor parameter analyzer (4156C, Agilent) are identical to [3-5].

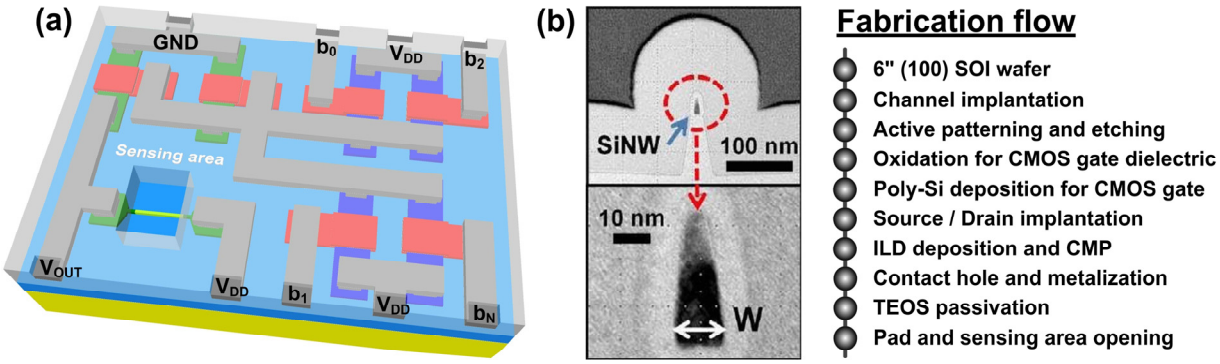

Figure 3: (a) 3-D bird's eye view of the fabricated current-mirror type SiNW biosensor (b) Transmission electron microscope (TEM) image of the SiNW and process details

RESULTS AND DISCUSSION

Figure 4(a) illustrates the measured time-varying V_{OUT} with a change in the pH value of electrolyte solution. As seen in Figure 4, controlling pH value emulates the change of Q_{target} in the analyte. It should be noted that, the increase in 1 level of pH value corresponds to the decrease in V_{OUT} by 49.6 mV regardless of the initial pH level. Therefore, it is validated that the current-mirror type SiNW biosensor provides a robust scheme for detecting Q_{target} regardless of $I_{SiNW,initial}$.

Practically, the proposed scheme can be potentially utilized (with the configuration in Figure 4(b)) as a method for cancelling the PVT variation as well as the entire variability before applying analyte includ-

ing some biomarkers to the biosensors. In Figure 4(b), the $I_{SiNW,initial}$ is read-out and it is programmed, which is fed to the parallel PMOS (MP_0~MP_N) determining I_{REF} by the binary code (b_0~b_N).

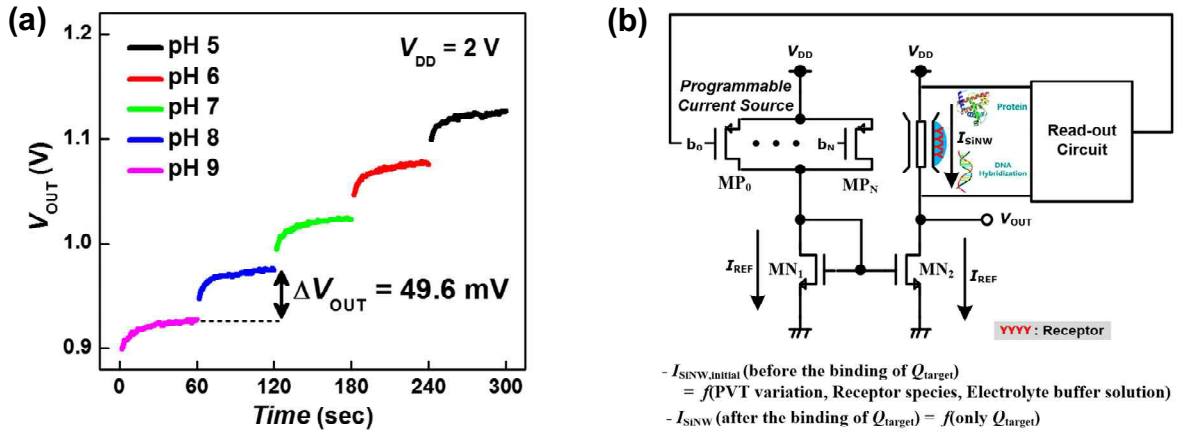

Figure 4: (a) Measured time-varying V_{OUT} with a change in the pH value of electrolyte solution (b) Application system adopting the proposed current-mirror type SiNW biosensor

CONCLUSION

The current-mirror type SiNW biosensor has been proposed to detect the concentration of discrete biomolecule (Q_{target}) regardless of $I_{SiNW,initial}$ compromised by environmental factors, such as PVT (process, supply voltage, and temperature), receptor species, and a variety of chemical conditions of electrolyte solution and it is demonstrated with the variation of pH value. We strongly believe that the proposed scheme can be an efficient method for cancelling the environmental noise in the disposable and/or droplet-type biosensor applications also contributing to the field of bio-sensing to some extent.

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