The Implementation of Polysilicon Nanowire based Biomolecular Sensor System-on-Chip

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ABSTRACT

In this work, polysilicon nanowire (poly-Si NW) based biosensor is integrated with analog and digital circuits monolithically for the first time. The chip is implemented by TSMC 0.35μm 2P4M CMOS process and simply post-etching process. In this chip, the chopper differential-difference amplifier (DDA)-based analog front-end (AFE), successive approximation register analog-to-digital converter (SAR ADC), and wireless acquisition circuits are built-in to improve remote detection capability and quality.

KEYWORDS

Polysilicon, nanowire, CMOS

INTRODUCTION

Si NW based biosensors have been proved that have high potential as chemical and bio-molecules sensors [1-2]. Because of fabrications and cost issues, however, these benefits have not been implemented by considering potential applications. In this work, the poly-Si NW based DNA detection SoC is fabricated by commercial CMOS process to address these issues.

EXPERIMENT

Briefly, the poly-Si NW based biosensor is realized by N+ poly2 layer. On the top of biosensors, only inter-layer-dielectric (ILD) is designed to facilitate the post process. After regular CMOS process, the ILD is removed by etching in post process. Fig. 1 illustrates the post process and SEM image of on-chip sensor. To improve the signal quality of the biosensors, low-noise chopper DDA-based AFE is designed and adopted. In addition, temperature sensor is also implemented to compensate temperature drift. Then the signal is converting by the following 10-bit SAR ADC. Finally, the digitized sensing data is processed by the digital controller and transmitted to external devices through the OOK transmitter. Fig. 2 shows the system diagram of the developed poly-Si NW based DNA detection SoC.

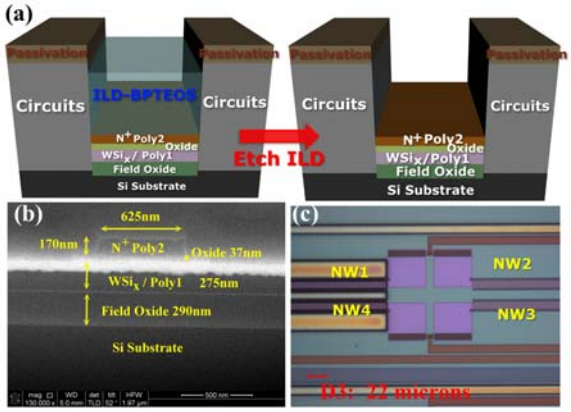

Fig.1 (a) Layers information of poly-Si NW baesd SoC and post process: Dry and wet etching. (b) SEM image of biosensor which pre-treated by focused-ion-beam (FIB) (c) Top view of poly-Si NW based biosensor.

RESULTS AND DISCUSSION

To examine the developed biosensor SoC, HBV DNA is employed. To confine the testing sample, the bonding pad and wires are covered by Epoxy. Following, the surface immobilization process of HBV probe DNA is required to functionalize the poly-Si NW sensor. The experimental setup can be shown in Fig. 3. Since the DNA hybridization will deplete the electrons in N-type NW, the detection can be achieved by measuring NW resistance. To measure the resistance change, as shown in Fig. 4, only NW1 and NW4 expose to HBV target DNA; NW2 and NW3 are passivated by ILD/Si_3N_4 to achieve better sensitivity. Fig. 5(a) shows the sensitivity evaluations of output voltage of AFE versus HBV target DNA with different concentration. This result clearly demonstrates the functionality of poly-Si NW biosensor and interface circuits. The limit-of-detection (LOD) is identified as 10fM.

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Moreover, Fig. 5(b) shows the selectivity test of DNAs with different base-pairs (bp). Both of these results show the developed biosensor performance can satisfy most of the clinical needs.

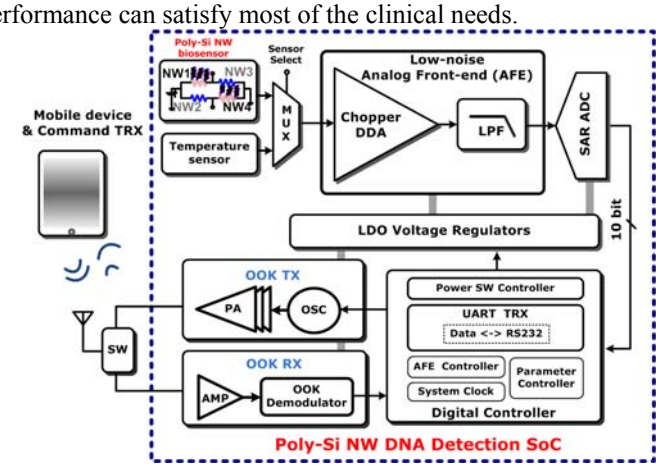

Fig.2 system diagram of the developed poly-Si NW based DNA detection SoC.

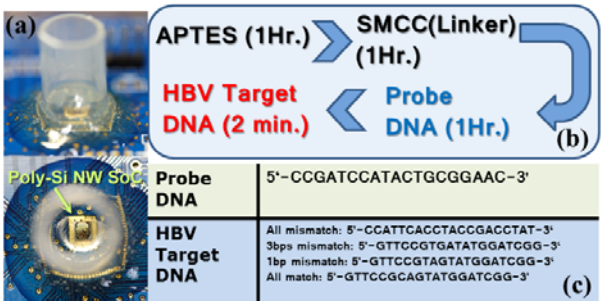

Fig.3 (a) SoC is passivated by AB glue and fluid channel, (b) Surface immobilization and hybridization steps, (c) HBV DNA sequences

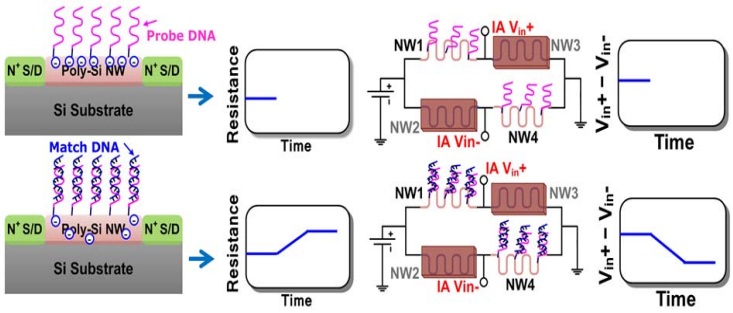

Fig.4 DNA sensing mechanism of poly-Si NW based biosensor.

CONCLUSION

In summary, poly-Si NW based HBV DNA detection SoC is realized in 0.35μm CMOS standard process followed by post-process steps for the first time. Experimental results show the label-free detection limit is about 10fM and has ability to distinguish one base-pair (1bp) mismatch HBV target DNA. In addition, the implementation is used commercialized CMOS process; the low-cost mass production is probable. As a consequence, the developed poly-Si NW based biomolecular sensor SoC has the potential for applications of point-of-care technology (POCT). Fig. 6 shows performance and photo of this SoC.

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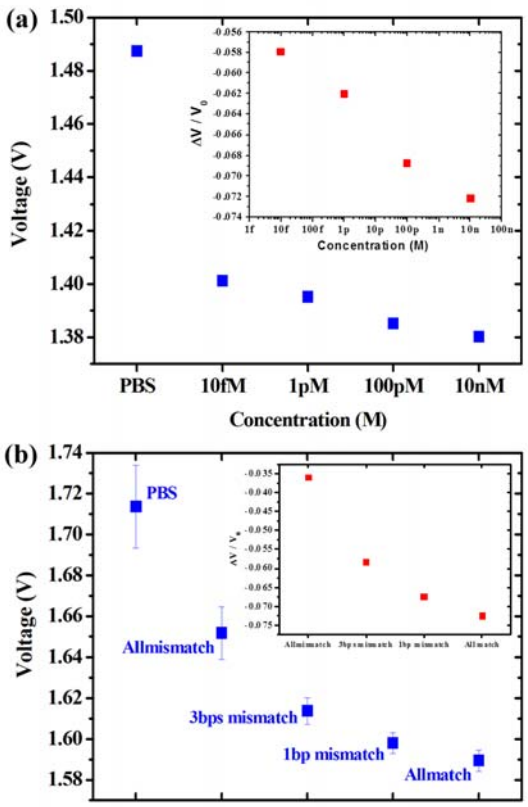
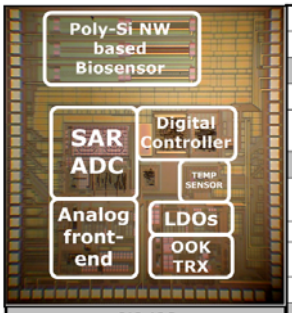


Fig. 5 (a) Sensitivity and (b) selectivity test results of the developed poly-Si NW based DNA detection SoC. Inset shows the normalized results. (V_0 is the baseline, PBS; V is the sensing results, respectively. Then $\Delta V=V-V_0$)



Technology	TSMC 0.35μm CMOS
Chip Area	6.26 mm²
DNA sensor	
Structure	N-type Poly-Si NW
Dimension (width, thickness)	625/170 nm
Analog Front-end (AFE)	
Power Consumption	IA: 387μW @ 3 V LPF: 130μW @ 3 V
CMRR	137dB
Unit-Gain BW of DDIA	1.7MHz
Chopping Freq.	10kHz
Temperature Sensor	
Power Consumption	194.2μW @ 3V
R-squared Value	0.9999
Temperature Range	-20~120℃

SAR ADC	
Resolution	10 bits
Conversion Rate	100KSPS (Max)
ENOB	9.4 bit @ 0.57kHz
Power Consumption	1.8μW @ 1KSPS 20μW @ 10KSPS

Fig. 6 Chip photo and performance

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