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High performance of silicon nanowire based biosensors using the solution-processed Al_2O_3 sensing membrane

Tae-Eon Bae and Won-Ju Cho

Department of Electronic Materials Engineering, Kwangwoon University, 447-1, Wolgye-dong, Nowon-gu, Seoul, Korea 139-701, Phone: +81-2-940-5163, E-mail address: chowj@kw.ac.kr

Abstract

High performance silicon nanowire (SiNW) sensors with SiO_2/Al_2O_3 (OA) sensing membrane using a solution process were fabricated. Compared with the vacuum-processed SiO_2 membrane, the solution-processed OA membrane improved sensing performances. Therefore, the SiNW sensors with solution OA sensing membrane are very promising to biological sensors application.

1. Introduction

The silicon nanowire (SiNW) is expected to be a very promising transducer for detecting biological and chemical species in terms of the ultra-high sensitive, label-free, real-time detection, and CMOS compatibility. [1] Moreover, the conductance of the SiNW channel is easily modulated by a small amount of surface charge. The sensing characteristics of SiNW sensors are mainly determined by the inherent properties of the sensing membrane. In a previous work, the SiO_2 material was usually used as sensing membrane on SiNWs-based sensors. In general, for deposition of SiO_2 sensing membrane, vacuum-processed deposition methods such as sputtering or oxidation are used. However, these process techniques require very expensive equipments, high fabrication cost and long process time despite a good performance.

In this study, we realized the SiNW sensors with SiO_2/Al_2O_3 (OA) sensing membrane using solution based process. Particularly, the thin SiO_2 and Al_2O_3 layers are designed for good interface property and strong immunity against the reactive chemical solutions, respectively. Also, the solution-deposition process provides great advantages in terms of low cost, simplicity, high throughput, and high performance.[2] Furthermore, it can be easily applied to the large-area electronic devices unlike vacuum-process methods.

2. Experimental

P-type silicon-on-insulator (SOI) substrates with a thickness of 100 nm top silicon layer (8.5-22 Ω·cm) were used for fabrication of SiNW by the “top-down” method. The initial top Si layer was thinned down to 40 nm by dry oxidation and wet etching, and then implanted with 3×10^{13} cm^{-2} of boron ions at 8 keV to form a p-type channel layer. After activation of implanted boron atoms at 950 °C for 30 min in a nitrogen ambient, a 5-nm-thick SiO_2 layer as buffer oxide was grown by thermal oxidation. As the Al_2O_3 precursor solution, aluminum chloride ($AlCl_3$) of 0.2 mol was prepared and dissolved it in 2-methoxyethanol (2ME) of 20 mL. The Al_2O_3 layer was conducted by spin-coating at 6000 rpm for 30 s and the film was heated to improve the adhesion using oven at 180 °C for 10 min. The coating-heating procedure was repeated two times to obtain the Al_2O_3 layer with a thickness of 25 nm. Fig. 1 shows a schematic diagram of spin-coating method. After deposition of Au/Cr/Al (50 nm/5 nm/50 nm) for metal electrodes, a forming gas annealing at 450 °C for 30 min in a 2 % H_2/N_2 ambient was conducted. Finally, the reservoir for the injection of the pH buffer solutions was mounted on the top of SiNW sensors using polydimethylsiloxane (PDMS).

3. Results and discussions

The optical micrographs of fabricated SiNW sensor chips on a 2 cm × 2 cm area and scanning electron microscopy (SEM) image of a SiNW channel with a 150-nm-width and 20-μm-length are shown in Figure 2 (a) and (b), respectively.

Fig. 3 presents the channel sensitivity for different pH buffer solutions of the oxidation SiO_2 membrane and the solution OA membrane. As the *p*H level increases, the silicon channel surfaces charged more negatively, which in turn induces accumulation of holes within the p-type nanochannel. Also, the solution-processed OA membrane reveals higher pH sensitivity than the vacuum-processed SiO_2 membrane. The relation between channel width and pH sensitivity is shown in Figure 4. Obviously, the sensitivity of the OA membrane is higher than that of the SiO_2 membrane irrespective of SiNW channel width.

Fig. 5 shows the drift rate of the different sensing membrane to predict the long-term stability in pH 7 buffer solution for 12 h. The solution OA membrane exhibited more stable drift behavior (1.64 nA/h) than the oxidation SiO_2 membrane (4.33 nA/h). This is because the Al_2O_3 membrane is more robust to the hydration during contact with an aqueous solution. Consequently, the solution OA sensing membrane shows higher quality characteristics in terms of the sensitivity, the hysteresis width, and the drift rate as summarized in Table I.

4. Conclusion

We fabricated high performance SiNW sensors with SiO_2/Al_2O_3 (OA) stacked sensing membranes using a solution process. Compared with the vacuum-processed SiO_2 membrane, the solution-processed OA membrane has better sensing characteristics such as higher sensitivity, lower hysteresis width and drift rate. Therefore, the SiNW sensors with solution OA sensing membrane are very promising to biological sensors application in terms of low cost, simplicity, high throughput, high performance, and large process area.

Acknowledgements

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References

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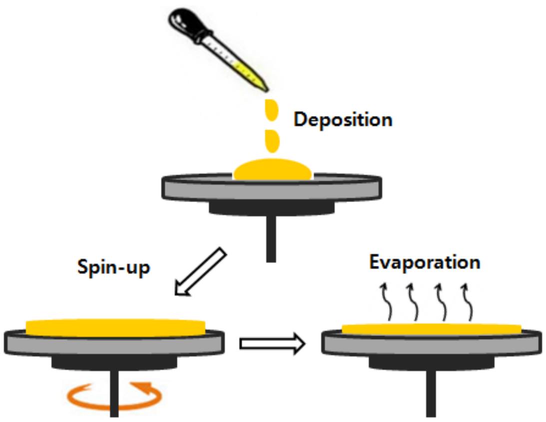

Fig. 1. Schematic diagram of spin-coating method.

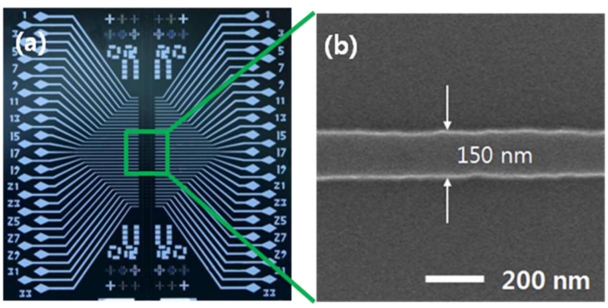

Fig. 2. (a) Optical micrographs of a 2 cm× 2 cm single chip containing 33 channels and (b) magnified SEM image of 150 nm-wide and 20 μm-long SiNW.

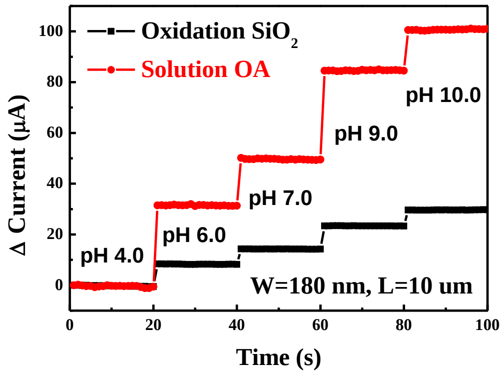

Fig. 3. Real-time channel current in different pH of the buffer solutions with oxidation SiO_2 and solution OA sensing membrane..

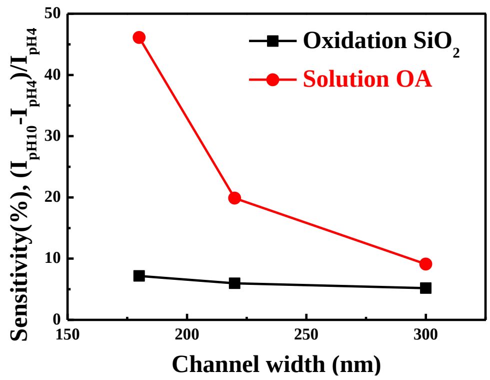

Fig. 4. Channel widths versus pH sensitivity for SiO_2 and OA membrane.

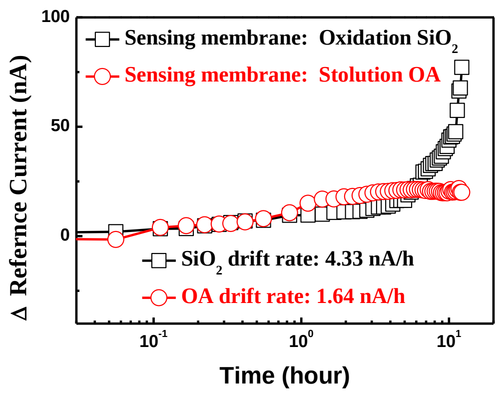

Fig. 5. Drift rate in pH 7 buffer solution with the SiO_2 and OA sensing membrane, for 12 hours.

Table I. Sensing properties of the SiNW pH sensor with the oxidation SiO_2 and solution OA sensing membranes..

Sensing membrane	Sensitivity (nA/pH)	Linearity (%)	Hysteresis width (nA)	Drift rate (nA/h)
Oxidation SiO_2	4.96	99.5	1.30	4.33
Solution OA	16.18	99.9	0.46	1.64