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Development of highly sensitive aqueous chemical sensor using double-gate In-Ga-Zn-O nanofiber thin-film transistor

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Abstract

In this paper, we fabricate a high sensitivity chemical sensor based on a double-gate (DG) field-effect transsitor (FET) using In-Ga-Zn-O (IGZO) nanofiber (NF). Transparent and flexible IGZO NFs were formed as FET channel layer using electrospinning technology. The sensitivity of DG IGZO NF ion-sensitive FET (ISFET) applied a separated sensing membrane was greatly improved by increase of capacitive coupling by the DG sturcture and IGZO NFs which has large surface area. The fabricated IGZO NF DG ISFET sensor had a high sensitivity of 998.04 mV/pH higher than Nernst limit (59 mV/pH). Therefore, the IGZO NF DG ISFET chemical sensor fabricated in this study is expected to be widely applied to wearable future biosensor application.

1. Introduction

Recently, the electronic market has grwon to be an evolutionary form that can provide various functions closer to human being such as health, medical, fitness, and wellness. Thease wearable electronic products basically require sensing technology, and the biosensor market is contimuosly increasing. Ion-sensitive field-effect transistors (ISFETs) are widely used for enzyme based, immune, DNA, and cell-based sensors as advantages of larbel-free, sensitive, real-time, selective detection in solution and compatibility with complementary metal-oxide semsiconductor (CMOS) technology. However, conventional ISFET have challenges in detecting small signals such as DNA and protein because ISFET have samll sensitivity limit of 59 mV/pH (Nernst sensitivity) at room temperature. In order to overcome the problem of low sensitivity, double-gate (DG) structure ISFETs using silicon-on-insulator (SOI) or amorphous In-Ga-Zn-O (a-IGZO) as channel layer has been proposed [1-2]. DG sturcutre ISFET can exceed the Nernst limit by capacitive coupling of top and bottom gate oxide [3]. However, since Si-based and a-IGZO are too rigid to apply to wearable electronic devices, even if they have excellent electrical characteristics and stability. As a solution to overcome rigid problems, planar materials can be formed into nanowires (NWs) and nanofibers (NFs). The NFs fabricated by electrospinning method has advantage of an ultra-thin, high productivity, connectivity, and large surface-to-volume ratio and improves the physical and chemical limitations by forming bulk materials into one-dimensional nano materials. In particular, the large surface-to-volume ratio of NFs amplifies the capacitive coupling than planar structure resuling in higher sensitivity in DG ISFET.

Therefore, in this study, we fabricated DG ISFET using IGZO NF which is transparent, flexible and compared with IGZO planar.

2. General Instructions

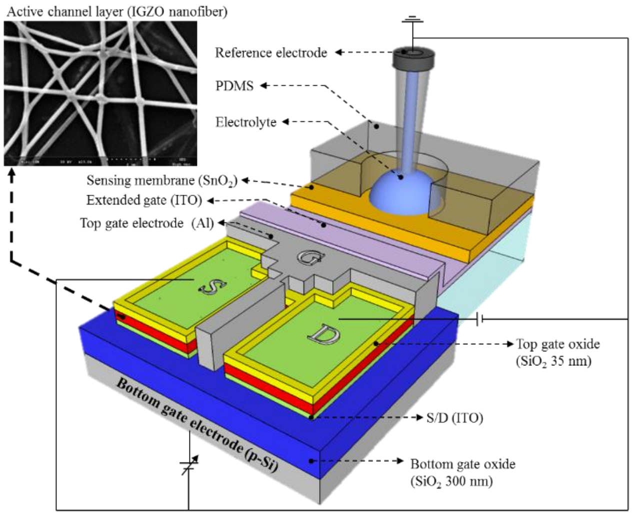

Fig. 1 Schematic illustration of double-gate IGZO NF FET in DG mode sensing and SEM image of IGZO NF.

Fig. 1 shows schematic illustration of DG IGZO NF FET in DG sensing mode and a scanning electron microscope (SEM) image of IGZO NFs. To fabricate DG IGZO NF FET sensor, 300 nm thermal oxide was grown on (100) p-type Si wafer. 100 nm ITO (In_2O_3:SnO_2 = 9:1 mol%) was deposited by radio frequency (RF) magnetron sputtering method to form source /drain (S/D) electrodes. To form the active channel layer, a solution blended IGZO precusors and PVP was electrospun. In order to remove the polymer matrix and improve the electrical properties, the calcination process was carried out by microwave irradiation at 1000 W for 2 minutes. Then, wet-etching was perfomed using photolithography and buffer oxide etchant (BOE) 30:1 solution for active channel definition. 30-nm-thick SiO_2 was deposited by RF magenetron sputtring for top gate oxide. Finally, 150 nm Al top gate electrode was deposited using e-beam evaporator. Separate extended gate was also fabricated. 150 nm ITO and 50 nm SnO_2 sensing membrane were sequentially deposited on a glass substrate and polydimethylsiloxane (PDMS) reservoir was attatched. All emasurements were conducted in a dark box to avoid light and noise.

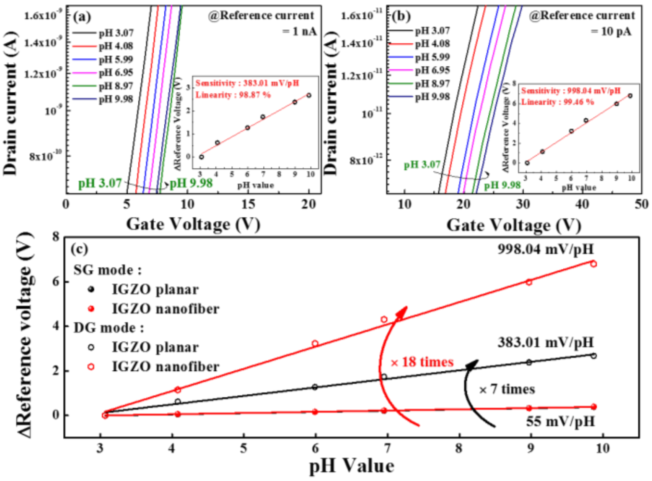

Fig. 2 I_D-V_G curves of (a) the IGZO planar pH sensor, (b) the IGZO NF pH sensor under DG mode and (c) change in reference voltage (V_R) of the plnar and NF of IGZO pH sensors for pH 3 to 10 under SG and DG sensing mode.

Fig. 2 shows the I_D-V_G curves of the DG structure (a) IGZO planar, (b) IGZO NF FETs under various pH buffer solutions in DG mode. The I_D-V_G curves were shifted in the positive direction as the pH solution changed from 3 to 10. Fig. 2(c) shows the shift in the reference voltage (ΔV_R) of the IGZO planr and NF FET sensor in single (SG) and DG mode with varying pH. The IGZO planar and NF sensors had a sensitivity of 55 mV/ pH similar to the Nernst limit (59.5 mV/pH) in the SG sensing mode. Significantly, the sensitivity of the IGZO planar and NF FET sensors in the DG sensing mode was amplified by 7 and 18 times than SG sensing mode, and its sensitivity were 383.01 and 998.04 mV/pH respectively. In the DG sensing mode, capacitive coupling occurs by a sereies capacitor of top-gate oxide/ channel/ bottom gate-oxide structure. The realationship of the capacitance of each part is as follows [3-4]:

$$\Delta V_{th}^{B} = \frac{C_{IGZO} C_{TOX}}{C_{BOX}(C_{IGZO} + C_{TOX})} \Delta V_{th}^{T} \qquad (1)$$

where ΔV^T_{th} is the top gate sweep threshold voltage shift, ΔV^B_{th} is the bottom gate sweep threshold voltage shift, and C_{IGZO}, C_{TOX}, and C_{BOX} are the IGZO depletion capacitance, top gate oxide capacitance, and bottom gate oxide capacitance per unit area, respectively. Therefore, the sensitivity of fabricated ISFET sensor is increased by DG structure. Notably, DG IGZO NF sensor has the highest sensitivity becuase IGZO NF has a larger surface- to-volume ratio, which leads to increase top gate capacitance and capacitive coupling compared to IGZO panar.

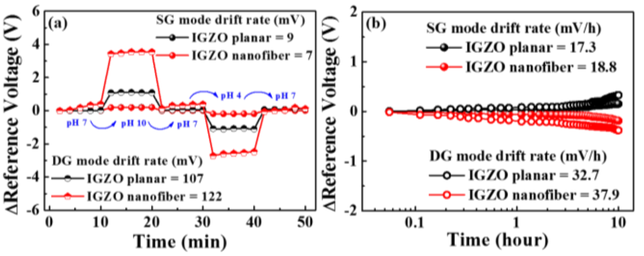

Fig. 3 (a) Hysteresis effect and (b) drift effect of the double-gate structure IGZO pH sensor.

Reliability and stability of fabricated ISFET were carried out by hysteresis and drift measurements in pH sensing. Fig. 3(a) shows the results of the hysteresis effect measurements caused by the internal defect sites of the sensing membrane in a pH = 7→10→7→4→7. The measured hysteresis voltage is 107 and 122 mV in the IGZO planar and NF sensor, respectively. The drift effect is cause during long-term pH measurements by the slow chemical reaction of the electrolyte surface and sensing membrane, which changes the dielectric constant of the insulator surface and changes the capacitance of the entire insulator. Fig. 3(b) is the drift effect results measured at pH 7 for 10 hours, and the change in ΔV_R indicates the long-term stability of the sensor. Both IGZO planar and NF sensor had a similar and stable 32.7, 37.9 mV/h

3. Conclusions

We fabricated a high sensitivity DG structure IGZO NF ISFET chemical sensor and analyzed the sensitivity accroding to various pH soultions. The capacitive coupling which amplify the sensitivity was more occured in IGZO NF ISFET sensor due to the large surface-to-volume ratio than IGZO planar. The IGZO NF ISFET sensor had a sensitivity of 998.04 mV/ pH higher than the Nernst limit (59.5 mV/pH) in DG sensing mode. Therefore, proposed IGZO NF ISFET chemical sensor is expected to be widely used in wearable biosensors with its transparent, flexible, and high sensitivity advantages.

Acknowledgements

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References

[1] Lim, C. M., Lee, I. K., Lee, K. J., Oh, Y. K., Shin, Y. B., & Cho, W. J., Science and Technology of advanced MaTerialS 18(1) 17-25 (2017)

[2] Ahn, M. J., Lim, C. M., & Cho, W. J., Semiconductor Science and Technology 32(3) 035003 (2017).

[3] J. C. Chou and L. P. Liao, Thin Solid Films 476 (2005).

[4] O. Knopfmacher, A. Tarasov, W. Fu, M. Wipf, B. Niesen, M. Calame, and C. Schonenberger, Nano Letters 10(6) 2268 (2010).