Extended Abstracts of the 2012 International Conference on Solid State Devices and Materials, Kyoto, 2012, pp372-373

High Performance Amorphous InGaZnO Based Dual-Gate Ion-Sensitive Field-Effect Transistors

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1. Introduction

The ion-sensitive field-effect transistors (ISFETs) is an integrated device composed of a conventional ion-selective electrode and a metal-oxide semiconductor field-effect transistors (MOSFETs). Bio-chemical sensors based on the ion-sensitive field-effect transistors (ISFETs) have been intensively investigated because of their potential; compatibility with complementary metal-oxide-semiconductor (CMOS) technologies, disposability, and label-free sensing of bio-molecules.

In recent years, system on glass (SOG) technology will be strongly required to realize high quality ubiquitous health care system using smart phone or point of care systems. Among various promising materials, IGZO (compound mixture of In_2O_3 : Ga_2O_5 : ZnO = 1 : 1 : 1) is very good candidates for next generation thin film devices because of high mobility, transparent characteristic and low temperature process. [1] Meanwhile, high sensitivity to specific bio-molecules will be also required in future biosensor. Nevertheless, the conventional single-gate (SG) type ISFETs sensor have exposed chronic problem in sensitivity, the Nernstian *p*H response of 59 mV/pH which highlighted poor signal to noise ratio for biosensor application.

In this study, we proposed a-IGZO based dual-gate (DG) ISFETs with excessively larger sensitivity (119.3 mV/pH). This enhanced sensitivity by DG operation strongly reinforces the signal-to-noise ratio for the biological sensors application.

2. Experimental details

At first, the p-type silicon wafer was cleaned by standard RCA process. And then SiO_2 of 100 nm was grown by oxidation. Subsequently, a-IGZO channel layer of 70 nm was deposited by RF sputter under following conditions of 100W, 6 mTorr and Ar 30 sccm flow. Progressively, a 10-nm-thick Ti and a 100-nm-thick Au for source/drain electrodes were deposited by e-beam evaporator. A 100 nm–thick of Ta_2O_5 as a gate dielectric was deposited by RF sputter. After that, a 150-nm-thick Al for the top gate electrode and a 150-nm-thick extended Ti gate for the chemical reaction layer were deposited by e-beam evaporator. Finally, a post deposition annealing was carried out at 400 ^oC for 30 min in a N_2 ambient. The current versus voltage curves for the various pH buffer solutions were measured by a commercial Ag/AgCl reference electrode and a 4156B electrode characteristic.

3. Results and discussions

Figure 1 shows the schematic of fabricated Ti extended gate ISFET on a-IGZO channel layer. The Ta_2O_5, a gate dielectric, play also an important role as passivation layer on channel region to prevent damages from humid, optical light. [2]

Figure 2 shows the transfer characteristic (I_D-V_G) measured by top gate TFT. The channel width and length are 20 µm and 2 µm respectively. The excellent electric characteristics were observed with a low leakage current (< 10^{-12} ~ 10^{-13}) and good on/off current ratio of 1.92×10^6 and subthreshold swing (SS) of 99 mV/dec. (Inset) shows the output characteristic (I_D-V_D) of top gate IGZO TFT measured by top gate sweep method. Gate voltage was increased in step of 0.25 V. Measured parameter of the device are summarized in Table 1.

Figure 3 presents the transfer curve and linearity for a conventional SG mode under different pH buffer solutions. The drain voltage set as 50 mV. As a result, device exhibited generally reported sensitivity of 52.05 mV/pH with linearity of 99.1%. In contrast, the sensitivity shown in figure 4 was largely improved in dual-gate operation, 119.3 mV/pH, which is an overwhelming value of the theologically limit of 59 mV/pH. Enhanced sensing margin be supported by the classical coupling relation between top and bottom gate oxide. [3]

Figure 5 shows the non-ideal effect parameters of drift rate and hysteresis width using SG and DG operation mode. Drift rate measured in the pH 7 buffer solution for 12 h. As a result, a drift rate of 1.13 mV/h and 13.2 mV/h were observed in the SG operation and DG operation mode respectively. The hysteresis widths shown in the inset of Fig. 5 were measured by the pH buffer solution loops, 7-10-7-4-7 for 60 min by SG (5.89 mV) and DG (42.5 mV) mode.

4. Conclusions

We have fabricated DG ISFETs based on a-IGZO channel layer with high performances, in particular, largely enhanced sensitivity beyond Nernst response limit. IGZO substrate with transparent characteristic and possibility of large area process is very promising material for SOG biosensor application in the future.

Acknowledgements

This research was supported by the Converging Research Center funded by the Ministry of Education, Science and Technology (No. 2011K000694)

References

[1] K. Nomura, et al, nature, No 7016 (2004)488
[2] D. H. Cho, et al, Journal of the Korean Physical Society, (2009)531-534
[3] Hyun-June Jang, et al, Applied Physics Letters 100, (2012)

Table 1. Electrical characteristics of the top gate TFT and sensing properties of the EG ISFET obtained SG, DG operation mode.

	Threshold voltage (V)	Subthreshold swing (mV/dec)	Maximum on/off current ratio	
Top gate TFT	-0.63	99	1.92 x 10^6	
	Sensitivity (mV/pH)	Linearity (%)	Hysteresis voltage (mV)	Drift rate(mV/h)
SG mode	52.05	99.1	5.89	1.13
DG mode	119.3	99.1	42.5	13.2

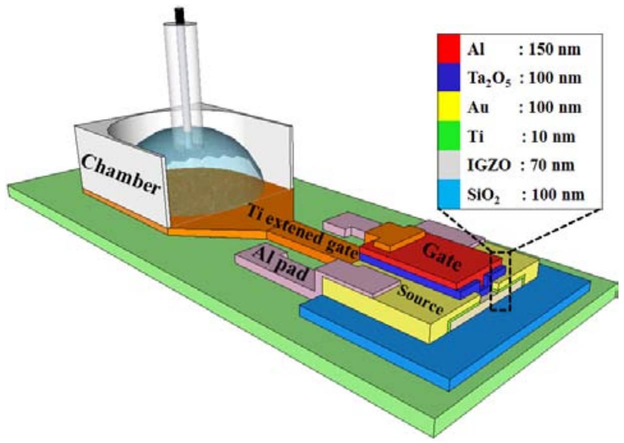

Fig. 1 Schematic of Ti extended gate ISFET.

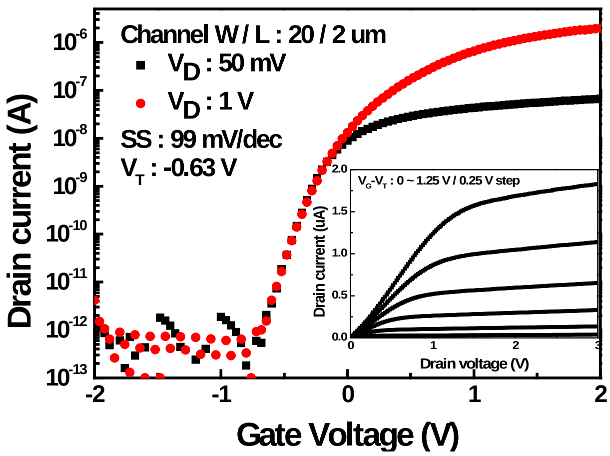

Fig. 2 The transfer characteristics of a top gate type a-IGZO TFT. The channel width and length are 20 µm and 2µm, respectively. The inset showed output characteristic of top gate type IGZO TFT. Gate voltage was increased in steps of 0.25 V.

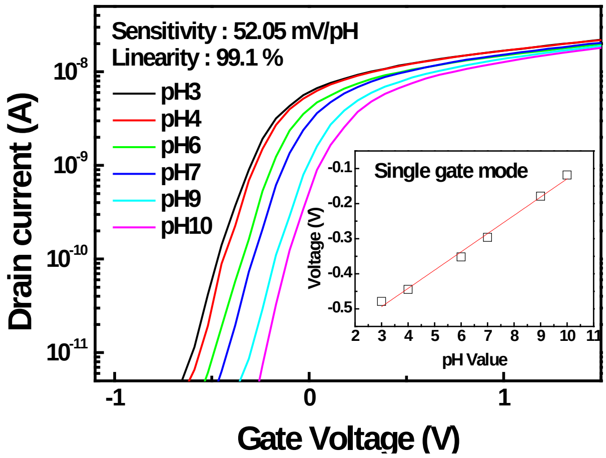

Fig. 3 Transfer curve of ISFET for different pH buffer solution. The drain bias is set at 50 mV. The inset indicates responsive voltages dependence on pH buffer solutions.

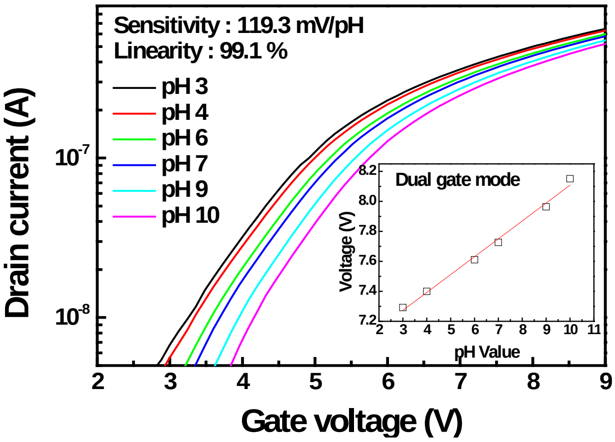

Fig 4. Transfer curve of dual-gate a-IGZO ISFET. The inset indicates responsive voltage dependence on pH buffer solutions.

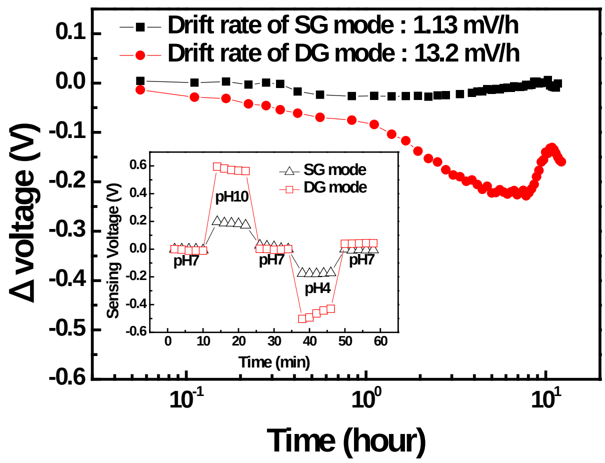

Fig 5. Drift rate by the SG and DG operation mode measurements in pH 7 buffer solution for 12 h. The inset presented hysteresis phenomenon for three pH buffer solutions changes measured by SG and DG sweep modes.