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TiN on ITO/glass substrate for pH-sensitive extended gate field-effect transistors

Yin-Fa Chen[1], Chun-Hui Chen[2], Jung-Ruey Tsai[3,*] and Chia-Ming Yang[1,2,4,5*]

[1] Institute of Electro-Optical Engineering, Chang Gung University, Taiwan
[2] Department of Electronic Engineering, Chang Gung University, Taiwan
[3] Department of Photonics and Communication Engineering, Asia University,Taiwan
[4] Biosensor Group, Biomedical Engineering Research Center, Chang Gung University, Taoyuan, Taiwan
[5] Department of General Surgery, Chang Gung Memorial Hospital at Linkou, Taiwan
Phone: +886-3-2118800-5960 E-mail: cmyang@mail.cgu.edu.tw

Abstract

A TiN prepared by dc sputtering directly on ITO/glass with different Ar/N_2 ratio is used to investigate the pH sensing performance based on EGFET and CVCC configuration. pH sensitivity, linearity, drift and hysteresis is approximately 50 mV/pH, 99.8%, 0.9 mV/h and 0 mV for the 30% TiN-EGEFT. This proposed low-temperature process could be a candidate of pH sensing membrane fabrication on ITO/glass or ITO/PET.

1. Introduction

Extended gate field-effect transistor was invented by Spiegel [1], which is derived from ion-sensitive field-effect transistors (ISFETs) [2]. With this extended structure, the manufacture and encapsulation can be dramatically simplified, especially beneficial in the research and application. Some material were proven as a promising material for extended gate, including SnO_2[3], IGZO[4], ITO[5], and TiO_2[6]. However an industry-compatible material and process with an acceptable sensing performance is not well obtained. In this study, titanium nitride (TiN), a barrier layer of contact hole used in CMOS and DRAM technology, with the superior properties including thermal stability and low resistivity is investigated by using gas flow rate adjustment in rf sputtering.

2. Experiments

Indium tin oxide (ITO) on glass with resistivity of 5 ohm-cm were used the conductive substrate. (RLO-F7、Ruilong、Taiwan) A glass shielding hardmask was capped on ITO/glass during TiN deposited in rf sputter. The exposed ITO is defined as the contact to commercial transistor, JFET(J113、Vishay、USA). The sputtering condition was set with dc power of 150W and process pressure of 8 mTorr. The flow rate of Ar and N_2 was set in the ratio as 20, 30 and 40% as shown in Table 1. The purity of Ti target is 99.99%. An encapsulation was fabricated with red epoxy and PDMS. Detail process is shown in Fig. 1(a). The schematic plot and picture of sample is shown in Fig. 1(b) and (c), respectively. A constant current constant voltage circuit with microprocessor and wifi transmission was used to measure 4 EGFETs in parallel. [7] A output voltage can be directly obtained per min for each EGFET. A self-developed program is used to monitor the response of 4 EGFETs simultaneously as shown in Fig. 1(d)

3. Results and Discussion

As shown in Fig. 2(a), pH response of 20% TiN-EGFET can be seen with a stable status within 5 min in the same pH solution then a clear step with pH increases. pH sensitivity and can be calculated as 50.4 mV/pH and 98.7%, respectively. For 30% TiN-EGFET, pH sensitivity and linearity is 50 mV/pH and 99.8%, respectively. For 40%-TiN EGFET, pH sensitivity and linearity is 50.2 mV/pH and 99.6%, respectively. There is no clear difference between 20%, 30% and 40%. It could be concluded that N ratio may not be the most important index. However it could be an evidence that N_2 ratio keep in 30% could be have a good process window. To confirm the stability of TiN layer, the long-term response (drift) and hysteresis were also performed. As shown in Fig. 3, the time-dependent response for 10 h of 3 different TiN-EGFET shows a difference level in the beginning, which could be the sample difference. A drift coefficient could be calculated of output voltage versus time. The lower drift coefficient means the better stability. In the 3 samples, the drift coefficient is all lower that 0 mV/h. A hysteresis with a loop of pH 7-4-7-10-7 was performed to verify the memory effect. Hysteresis width is defined as the last output voltage of 1st and 3rd loop of pH 7 solution. Hysteresis width of all 3 groups are less than 2 mV, which could be an acceptable range for a promising pH sensitive membrane. With this low-temperature process, dc sputtered TiN could be a potential pH sensing membrane on ITO/PET, which could be used to combine flexible substrate into wearable sensors.

4. Conclusion

dc sputtered TiN layer is firstly applied on ITO/glass substrate. pH sensitivity could be achieved to 50 mV/pH. With the highly stable performance of low drift and hysteresis in TiN layer prepared by different N_2 ratio, this proposed low-temperature process could be easily applied from glass substrate to flexible substrate such as PET.

References

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Table 1 pH sensing performance comparison of 3 different TiN EGFET.

$Ar:N_2$	Percentage (%)	Drift (mV/Hr)	Hysteresis (mV)	Ha (mV)	Hb (mV)	Sensitivity (mV/pH)	Linearity (%)
40:10	20	0.62	1	1	0	50.4	98.67
35:15	30	0.98	0	-2	2	50.0	99.76
30:20	40	0.38	2	1	1	50.2	99.57

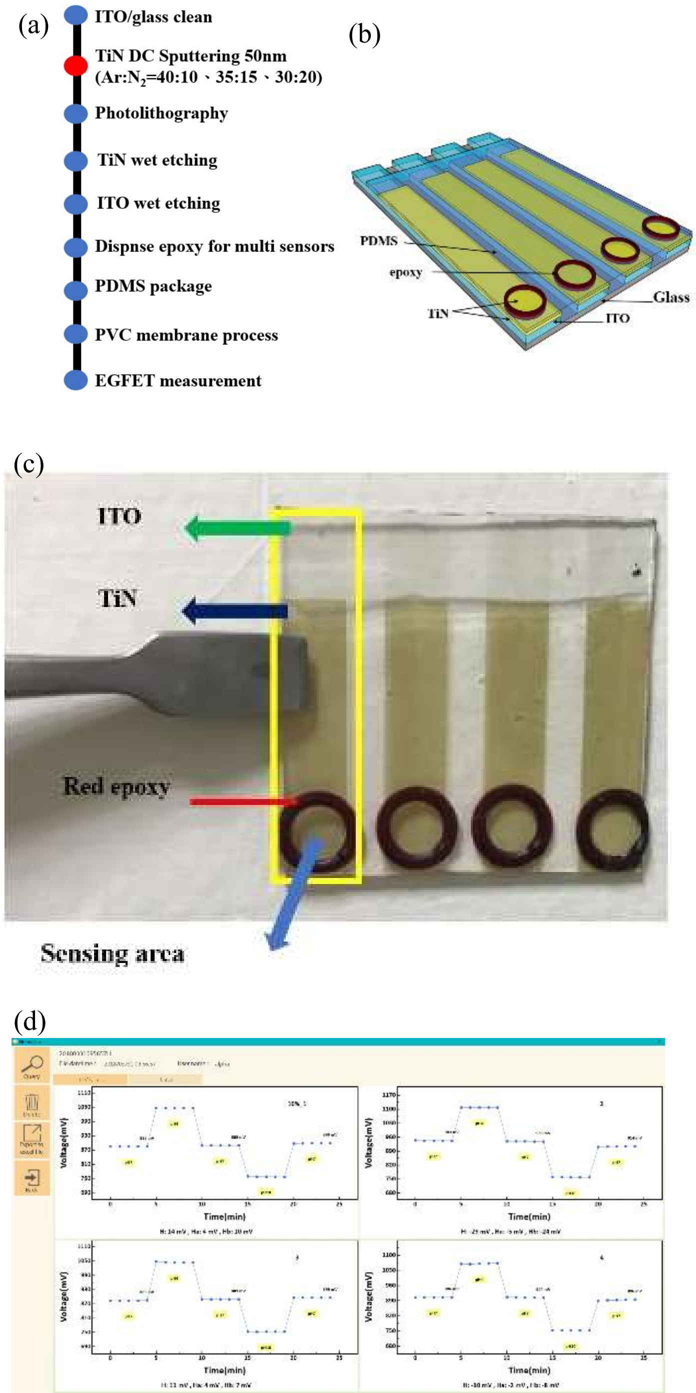

Fig. 1 (a) process flow, (b) schematic plot, (c) picture, and (d) self-developed program and interface of 4 TiN extended gates.

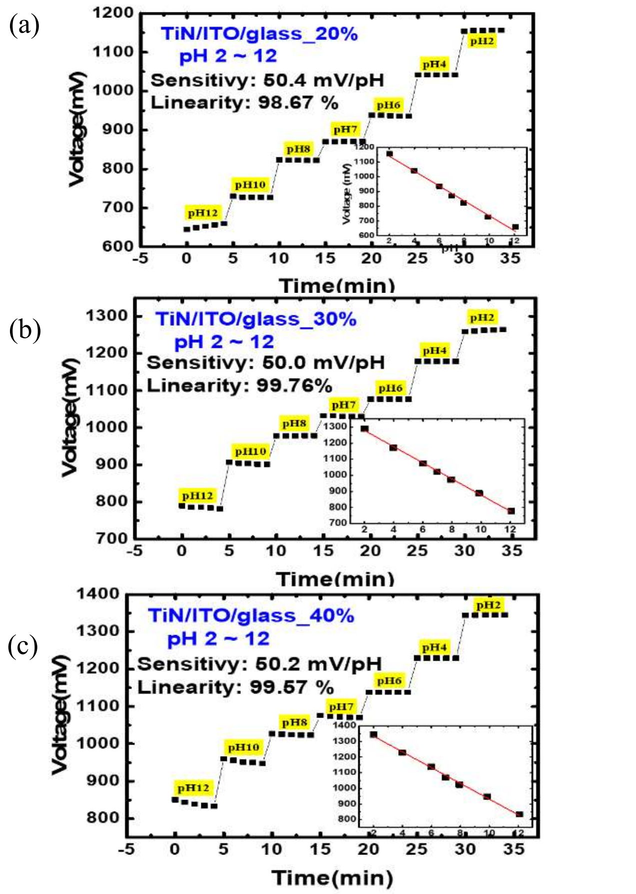

Fig. 2 pH dependent output voltage versus time and pH buffer solution for (a) 20%, (b) 30% and (c) 40% TiN-EGFET. Inset shows the linear fitting between pH and output voltage.

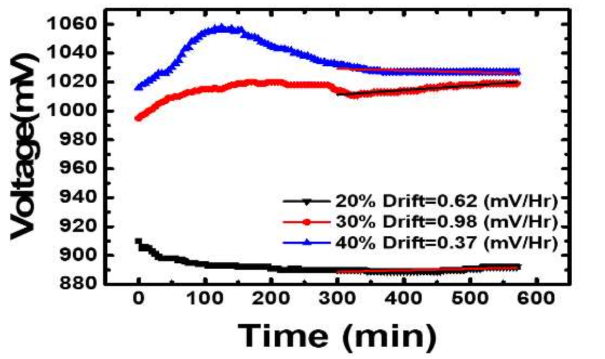

Fig. 3 Long-term response of 3 different TiN EGFET.

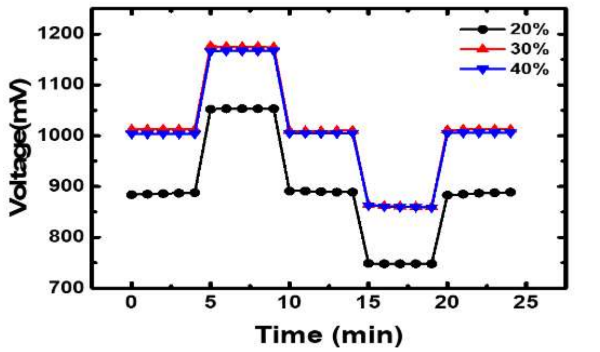

Fig. 4 Hysteresis response of 3 different TiN EGFET.