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The investigation of IGZO Sensing Membrane Applied in electrolyte-insulator-semiconductor (EIS) biosensors

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Abstract- In this paper, the electrolyte-insulator-semiconductor (EIS) biosensor device with the IGZO sensing membrane sputtering in different ratio process gas (Ar and O_2) has been investigated. It can be seen that the IGZO sensing membrane after RF sputtering in the gas ratio (Ar:O_2 = 23:2) annealed at 500°C has a better sensitivity and linearity in comparison with the other condition.

I. Introduction

In recent years, there were a lot of electrochemical sensors to be used to detect hydrogen ions such as ion-sensitive field effect transistor (ISFET), extended gate field-effect transistor (EGFET), which have numerous advantages such as miniaturization, chip-circuit design and low cost in manufacturing [1].

In 2004, the team of H. Hosono first proposed that the IGZO was applied to the TFT. IGZO thin films were applied to active layer materials of TFTs due to its good electrical properties and high mobility on flexible substrate [2].

In this thesis, IGZO was deposited on a silicon substrate by RF sputtering with two different gas ratio (Ar:O_2=23:2 and Ar:O_2=25:0). Then, we discuss the physical analysis includes XRD (X-ray diffraction), XPS (X-ray photoelectron Spectroscopy). The electrical analysis includes the C-V curve, hysteresis voltage, drift rate and sensitivity.

II. Experiment

The EIS structures of a IGZO sensing membrane was fabricated on a 4-in p-type (100) Si wafer. 50nm SiO_2 was grown on the wafer by thermal dry oxidation at 850°C. Then ~50 nm IGZO film was deposited on the Si substrate by reactive sputtering in two different ambient ratio (Ar:O_2 = 25:0 and Ar:O_2 = 23:2). After deposition, rapid thermal annealing (RTA) was performed in O_2 ambient for 30s at 500°C. After that, the back-side contact of the Si wafer was deposited by Al film with 300nm-thick. Then, using adhesive silicone gel to define sensing window. Finally, the samples were fabricated on the copper lines of PCB by silver gel. Epoxy package was used to separate the EIS structure in Fig.1.

III. Results and Discussion

To study the crystalline structural and chemical formation of IGZO film in two different ambient ratio effects, Fig.2(a-h) illustrate the In 3d, Ga 2p, Zn 2p, and O 1s spectra for the sensing films in different ambient ratio annealed at 500ºC to 800ºC. In addition, In 3d peak located at 453eV and 445.5eV in the ambient ratio of Ar:O_2 =23:2 are stronger than the peak in the ambient ratio of Ar:O_2 =25:0 can be seen at 500ºC. Ga 2p peak located at 1144.9eV and 1118eV in the ambient ratio of Ar:O_2 =23:2 are also stronger than the peak in the ambient ratio of Ar:O_2 =25:0 can be seen at 500ºC. Zn 2p peak located at 1045.4eV and 1022.2eV in the ambient ratio of Ar:O_2 =23:2 are also stronger than the peak in the ambient ratio of Ar:O_2 =25:0 can be seen at 500ºC. Then O 1s spectra of IGZO film exhibited a smaller oxygen vacancies peak intensity in the ambient ratio of Ar:O_2 =23:2 at 500ºC. This result indicates that the IGZO in the ambient ratio of Ar:O_2 =23:2 could reduce SiO_2 and oxygen vacancies.

Figure 3(a-d) show C-V curves in different conditions of two different ambient ratio (Ar:O_2 = 25:0 and Ar:O_2 = 23:2). The reference capacitance shift of the IGZO membrane in the ambient ratio of Ar:O_2 =23:2 at 500ºC was 56.51mV/pH. Moreover, the threshold voltage shift of the IGZO membrane in the ambient ratio of Ar:O_2 =25:0 at 500ºC was 41.49mV/pH.

Fig.4 shows hysteresis voltage of the above samples. The hysteresis voltage in two different ambient ratio (Ar:O_2 = 25:0 and Ar:O_2 = 23:2) are 14.9mV and 4.48mV after RTA treatment at 500ºC, respectively. The drift effects of the IGZO sensing membrane was measured by C-V curve in pH 7 buffer solution for 12 hours as shown in Fig. 5. The drift rate in two different ambient ratio (Ar:O_2 = 25:0 and Ar:O_2 = 23:2) are 3.81mV and 0.48mV after RTA treatment at 500ºC, respectively. It can be seen that the IGZO sensing membrane in the ambient ratio of Ar:O_2 =23:2 after RTA treatment at 500ºC has the lowest drift rate of all. The comparison of IGZO sensing membrane in two different ambient ratio (Ar:O_2 = 25:0 and Ar:O_2 = 23:2) for hysteresis voltage, and drift rate were shown in TABLE 1.

Fig.6 study potassium ion concentration controlled in a range between 10^{-5} and 10^{-1}M. The sensitivity values of the IGZO film in two different ambient ratio (Ar:O_2 = 25:0 and Ar:O_2 = 23:2) are 5.91mV/pK and 14.17mV/pK after RTA treatment at 500ºC, respectively. Therefore, the IGZO sensing membrane in the ambient ratio of Ar:O_2 = 23:2 after RTA treatment at 500ºC has better sensitivity and linearity for potassium ions detection.

IV. Conclusion

In this study, the IGZO sensing membrane in the ambient ratio (Ar:O_2 = 23:2) after annealing at 500ºC shows a higher sensitivity, higher linearity, higher H+ selectivity, lower hysteresis voltage and lower drift rate than the sample in ambient ratio (Ar:O_2 = 25:0). Therefore, it can be confirmed that the IGZO sensing membrane in the ambient ratio (Ar:O_2 = 23:2) is not only improved the bonding intensity and stabilized crystalline structure but also formed a stronger lattice to enhance the peak intensity.

V. References

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[2] H. Yabuta, M, Sano, K. Abe, T. Aiba, T. Den, and H. Kumoni, “High-mobility thin film transistor with amorphous InGaZnO4 channel fabricated by room temperature rf-magnetron sputtering ,”Applied Physics Letters, vol. 89, pp.112123-1-3, 2006.

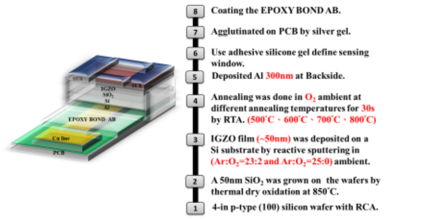


Fig. 1 The process flow of IGZO sensing membrane by reactive sputtering in two different ambient ratio ($Ar:O_2$ = 25:0 and $Ar:O_2$ = 23:2).

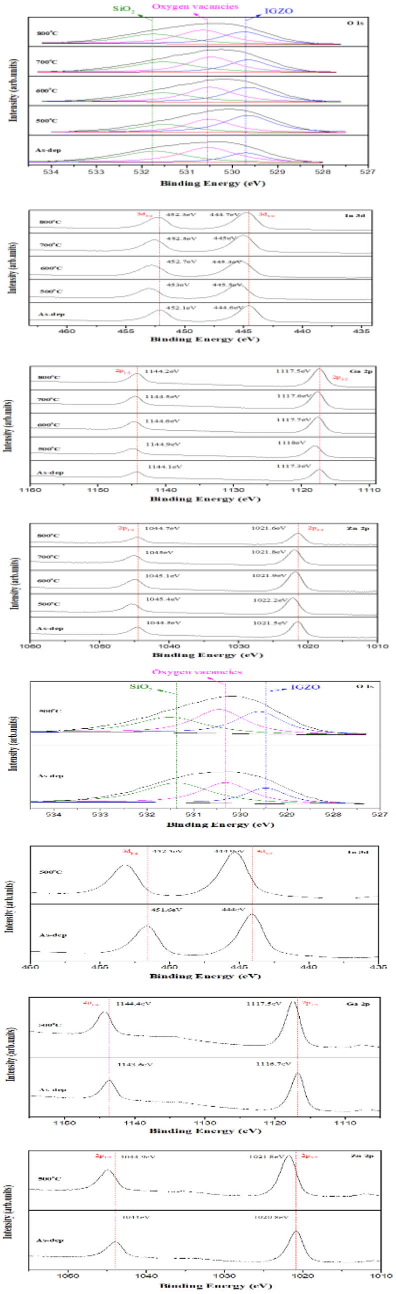
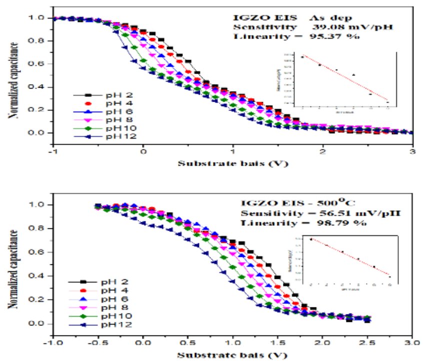


Fig. 2 XPS results of IGZO film (a) O 1s, (b)In 3d, (c)Ga 2p, and(d)Zn 2p in ambient ratio of $Ar:O_2$=23:2 (e) O 1s, (f)In 3d, (g)Ga 2p, and(h)Zn 2p in ambient ratio of $Ar:O_2$=25:0.



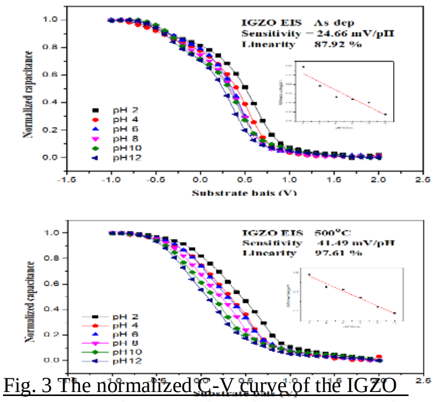


Fig. 3 The normalized C-V curve of the IGZO sensing membrane and with RTA (a)As-dep (b)500°C in ambient ratio of $Ar:O_2$=23:2, and (c)As-dep (d) 500°C in ambient ratio of $Ar:O_2$=25:0 the inset figure represents the sensitivity and linearity.

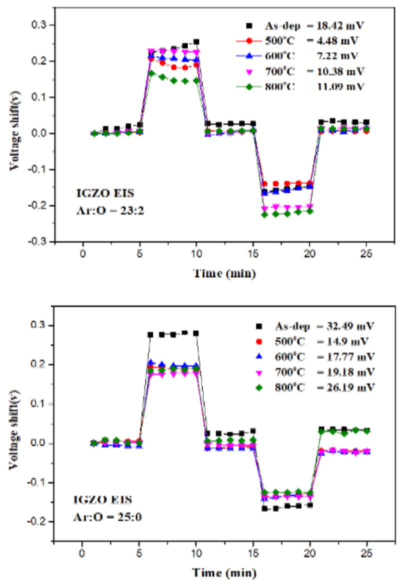


Fig. 4 Hysteresis of IGZO sensing membrane (a) in ambient ratio of $Ar:O_2$=23:2 (b) in ambient ratio of $Ar:O_2$=25:0 during the pH loop of 7→4→7→10→7 over a period of 25 minutes.

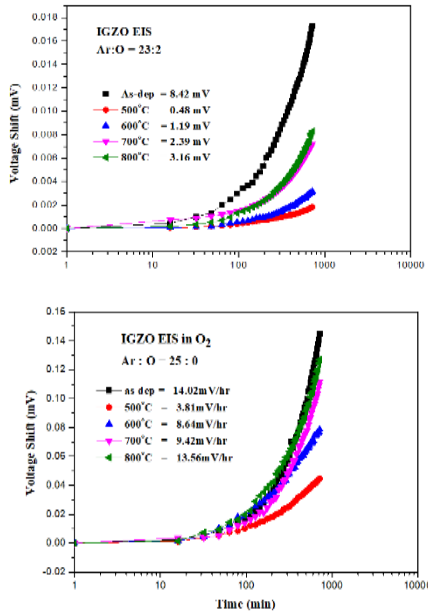


Fig. 5 Drift voltage of IGZO sensing membrane (a) in ambient ratio of $Ar:O_2$=23:2 (b) in ambient ratio of $Ar:O_2$=25:0, then dipped in pH 7 buffer solution for 12 hours.

TABLE 1 The sensing performance of IGZO sensing membrane in two different ambient ratio ($Ar:O_2$ = 25:0 and $Ar:O_2$ = 23:2).

IGZO(23:2)	As-dep	500	600	700	800
Hysteresis voltage (mV)	18.42	4.48	7.22	10.38	11.09
Drift rate (mV/hr)	8.42	0.48	1.19	2.39	3.16
IGZO(25:0)	As-dep	500	600	700	800
Hysteresis voltage (mV)	32.49	14.9	17.77	19.18	26.19
Drift rate (mV/hr)	14.02	3.81	8.64	9.42	13.56

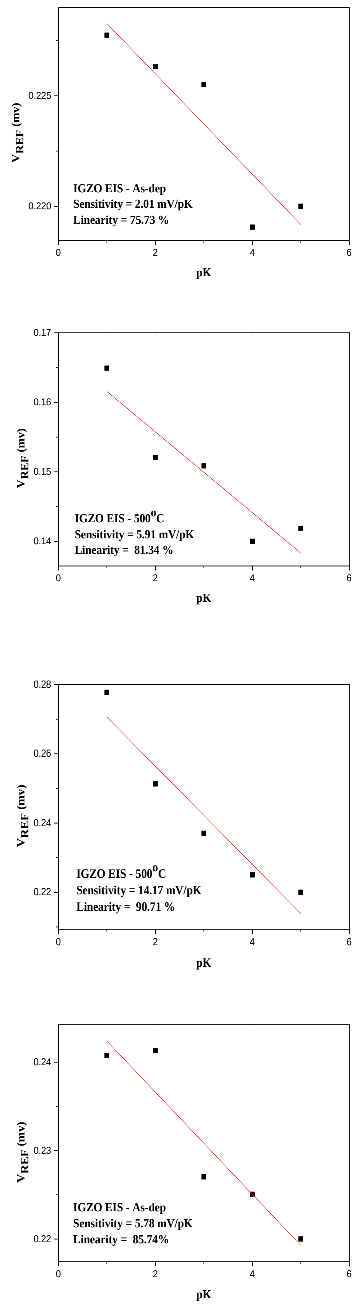


Fig.6The potassium ion (K^+) properties of IGZO sensing membrane (a)As-dep (b)500°C in ambient ratio of $Ar:O_2$=25:0, and (c)As-dep (d) 500°C in ambient ratio of $Ar:O_2$=23:2 ($Ar:O_2$ = 23:2 and $Ar:O_2$ = 23:2)..