Nano-IGZO layer for EGFET in pH sensing characteristics

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Abstract

In-Ga-Zn-O (IGZO) was widely applied in the substrate of TFT to replace a-Si in recent year. In this study, IGZO layer with thickness of 70 nm is first proposed as a pH sensing membrane directly on P-type Si substrate acting as an extended gate of conventional extended-gate field-effect Transistor (EGFET). Material criteria of extended gate electrode are low resistance and high capacitance. Therefore, Ar/O2 ratio was modified in rf sputtering with IGZO target. Post deposition anneal was also performed to check the sheet resistance and pH sensing performance. EGFETs were measured in standard pH buffer solution by using B1500A and constant voltage constant current (CVCC) circuit. Similar IDS-VGS curves including transconductance (Gm) and substrate swing (S.S.) are obtained in various sputtering conditions of IGZO compared to commercial NMOSFET in CD4007. pH application range is only between pH 2 to pH 10. IGZO-EGFET prepared by Ar/O2 ambience of 24/1 in sputtering can have a sensitivity of 59.5 mV/pH. Lower sensitivity and linearity can be observed in the samples with RTA treatment at higher temp and in O2 ambience. N2 anneal at 500°C can be used to improve pH sensing performance for IGZO-EGFET prepared by Ar/O2 ambience of 20/5 in sputtering. Nano-IGZO layer is verified to be the sensing membrane in EGFET to have a high sensitivity of 59.5 mV/pH for the first time. More studies on enlargement pH application range and minimization of non-ideal effect still need to be investigated.

Introduction

Amorphous indium-gallium-zinc oxide (α-IGZO) was firstly proposed as the channel material of thin-film transistors (TFTs) on polyethylene terephthalate (PET) substrate with a Hall mobility exceeding 10 cm2V−1S−1. [1] It can be a candidate to replace amorphous silicon (α-Si) in TFT applications with advantages of high mobility, wide band gap and high transmittance rate on flexible substrate. [2-3] In the meantime, α-Si was proposed as the sensing material of ion-sensitive field-effect transistor (ISFET) [4-5] with narrow application range and high drift. Another field effect sensor platform which called extended-gate field-effect transistor (EGFET) was derived from ISFET, and its configuration is composed of a sensor electrode and a conventional metal-oxide-semiconductor field-effect transistor (MOSFET). The sensor electrode is connected on the gate of MOSFET and extended from MOSFET by a metal signal line, which is an easy and reliable method in encapsulation due to most electrical signals are away from the measurement environment. Therefore, interference from the environment including light-induced drift on ISFET can be also minimized with easy process and low cost [6]. Although α-Si can be used as the material for the ISFET, the sensing performance of α-Si can be performed in pH 1 to 7, which is not acceptable for real applications. To study the pH sensing properties of IGZO, a systematic investigation of preparation of IGZO electrode by rf reactive sputtering is carried out based on EGFET and corresponding measurement platform.

Experimental

IGZO electrode based on the electrolyte-insulator-semiconductor (EIS) structures with a single-layer sensing membrane were fabricated as the extended gate of EGFETs to investigate hydrogen ion sensing properties. IGZO layer was deposited by radio frequency (rf) sputtering directly on p-type (100) silicon wafer after standard RCA cleaning. The IGZO target with atomic ratio of 1:1:1:4 and 99.9% purity was used for the first time. More studies on enlargement pH application range and minimization of non-ideal effect still need to be investigated.
Results and Discussion

As shown in the Fig. 2, $I_{DS}$-$V_{GS}$ curves of NMOSFET in CD4007 and EGFETs with IGZO-electrode prepared by different Ar/O$_2$ ratio had similar behaviors. A NMOSFET had lower threshold voltage ($V_T$) and EGFETs with more O$_2$ flow had higher V$_T$ which could be explained by more O composition and more dielectric-like properties. The coupling capacitance of extended gate can be higher and then higher V$_T$ is presented. However this V$_T$ shift will not affect the pH sensing performance. Fig. 2 shows a typical pH-dependent response of $I_{DS}$-$V_{GS}$ curves of IGZO-EGFET prepared by Ar/O$_2$ of 24/1. V$_{GS}$ in same $I_{DS}$ increases with pH increases, which means the hydrogen ions binding on the IGZO surface makes the surface potential difference and corresponding V$_T$ shift. Output voltage ($V_{out}$) is calculated by interpolation of $I_{DS}$-$V_{GS}$ curves for $I_{DS}$= 1 uA as shown in the inset of Fig. 2. Sensitivity and linearity can be calculated by linear fitting between $V_{out}$ and corresponding pH of buffer solution used in measurement. Fig. 4 shows the pH-dependent $V_{out}$ response for IGZO-EGFET prepared by different Ar/O$_2$ ratio. Ideal pH response is 59.6 mV/pH from Nernst equation as shown in Fig. 3. As shown in Fig. 4, higher or lower Ar/O$_2$ flow makes lower sensitivity and non-linear response, especially in basic buffer solution. The mechanism is still waiting more material analysis to prove including XPS and AFM. Calculated sensitivity and linearity of IGZO-EGFET of different Ar/O$_2$ ratio are shown in Fig. 5. The highest sensitivity of 59.5 mV/pH and linearity of 99.7% are observed in the group with Ar/O$_2$ ratio of 24/1 by a linear fitting from pH 2 to 10. However, sensitivity and linearity are both decreased with O$_2$ increase and decrease. Because the low sensitivity and linearity in the group with Ar/O$_2$ ratio of 20/5, additional post deposition anneal was used to improve the pH sensing performance. As shown in Fig. 6, sensitivity and linearity can be increased by anneal, but too high temperature makes lower sensitivity and linearity. Although sensitivity and linearity were both improved, final performance is still far from real applications. In addition, time-dependent output response of IGZO-EGFET with Ar/O$_2$ ratio of 24/1 for pH 4 and 6 are shown in Fig. 7. Drift coefficient is calculated by linear fitting $V_{out}$ from 120 to 300 min. Drift coefficient of IGZO-EGFET with Ar/O$_2$ ratio of 24/1 are 0.75 and 0.21 for pH 4 and 6, which is comparable to other sensing material. Since the pH sensing performance can be changed by minor adjustments in rf sputtering process and RTA didn’t help to improve to an acceptable criterion, further investigation on material analysis for mechanism study is also suggested.

Conclusions

IGZO layer is verified to be the sensing membrane in EGFET to have a high sensitivity of 59.5 mV/pH for the first time. IGZO electrodes prepared by Ar/O$_2$ ambience of 24/1 in sputtering can have a sensitivity of 59.5 mV/pH. However, sensitivity and linearity could decrease a lot even only a minor modification of Ar/O$_2$ ratio. With RTA treatment, lower sensitivity and linearity can be observed in the samples with higher temp and O$_2$ ambience. Drift coefficient of IGZO-EGFET with Ar/O$_2$ ratio of 24/1 are 0.75 and 0.21 for pH 4 and 6, respectively. More studies on enhancement pH application range and process stability still need to be investigated.

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Fig. 3 $I_{DS}$-$V_{GS}$ curves of EGFETs with IGZO-electrodes with Ar/O$_2$ ratio of 24/1 measured in various pH buffer solutions.

Fig. 4 pH dependent output voltage of EGFETs with IGZO-electrodes with different Ar/O$_2$ ratio.

Fig. 5 The calculated pH sensitivity and linearity of EGFETs with IGZO-electrodes with different Ar/O$_2$ ratio.

Fig. 6 The calculated pH sensitivity and linearity of EGFETs with IGZO-electrodes with Ar/O$_2$ ratio of 24/1 and 20/5 annealed with N$_2$ and O$_2$ ambience at different temperature.

Fig. 7 Time-dependent output voltage of EGFET with IGZO-electrode with Ar/O$_2$ ratio of 24/1 measured in pH 4.

References


