Materials Science in Semiconductor Processing 74 (2018) 51–56

Contents lists available at ScienceDirect

Materials Science in Semiconductor Processing

journal homepage: www.elsevier.com/locate/mssp

Ag metal mid layer based on new sensing multilayers structure extended gate field effect transistor (EG-FET) for pH sensor

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ARTICLE INFO

Keywords:
Ag metal
EGFET
PH
Hysteresis
Multilayers

ABSTRACT

This study focus on the effectiveness of ZnO/Ag/ZnO (ZAZ) multilayers films thickness on electrical properties of pH sensor and structural properties such as XRD, AFM, the multilayers structure ZnO/Ag/ZnO deposit on glass substrate by using RF and DC magnetron sputtering system at different thickness (200/100/200) nm, (100/50/100) nm, XRD results indicated that the multilayers have polycrystalline phase for Ag metal. ZnO/Ag/ZnO was tested as EGFET for the first time the effect of multilayers thickness on chemical sensitivity, linearity and hysteresis voltage were demonstrated and found 0.62μA$^{1/2}$/pH, 99.92%, 5.4 mV for multilayer thickness (200/100/200) nm while 0.25 μA$^{1/2}$/pH, 97%, 3.2 mV at multilayers thickness (100/50/100) nm respectively.

1. Introduction

Multilayers structure attracted attention due to its advantages made it suitable for many application such as flat panel display [1] light emitting diode, multilayers most useful method to reduce the resistivity of single layer semiconductor ZnO, inserting thin layer of metal such as Ag [2,3], Cu [4,5], Mo [6], between two layers ZnO play a major role in enhancement properties of ZnO single layer such as resistivity of multilayers structure according to the Eq. (1):

$$\frac{1}{R_{Total}} = \frac{2}{R_{ZnO}} + \frac{1}{R_{Ag}} \cong \frac{1}{R_{Ag}} \quad (1)$$

Where R_{Total} the total resistivity of the multilayers

R_{ZnO} The resistivity of ZnO layer

R_{Ag} The resistivity of the Ag metal layer.

Multilayers structure films can use as electrode for several devices biosensor applications such as pH sensor, many methods to detection pH measurements such extended gate field effect transistor (EGFET) use an alternative device to ion sensitive field effect transistor (ISFET) firstly presented by Bergleved in 1970 as small dimension semiconductor device [7].the different between the ISFET and EGFET that the gate replaced by sensing materials membrane.

The most important properties of this structure are the stability of electrical properties [1] and the possibility of controlling multiple resistance [13]. Also, the addition of metal between the two layers of oxide enhances the hydroxyl groups on the surface of the oxide, which makes it more attractive to the hydrogen ion, and thus increase its efficiency as a pH sensitive membrane [14].

Several research about utilize metal oxide as sensing membrane in extended gate felid effect transistor (EGFET) for pH sensor such as Zinc oxide [8] palladium oxide [7] titanium oxide [9].

According to a comparison [8]between the use of ZnO as EGFET with ZnO/Si Nanowires as EGFET the later was better in sensitivity and linearity this enhancement in electrical properties of EGFET attributed to high surface to volume ratio. The measurement of sensing membrane performance obeys the quantum theory (Site binding model) surface potential φ as seen in Eq. (2):[10]

$$2.303(pH_{pzc} - pH) = \frac{q\varphi}{KT} + \sinh^{-1}\frac{q\varphi}{KT\beta} \quad (2)$$

Where pH_{pzc} is pH value at point of zero charge, K Boltzmann constant, T absolute temperature

The chemical sensitivity β depended on the number of surface site per unit area N_s according to the Eq. (3):

$$\beta = \frac{2N_s q^2 (k_b/k_a)^{\frac{1}{2}}}{KTC_{DL}} \quad (3)$$

Where $K_a K_b$ are constant, C_{DL} the electrical capacitance.

From Eq. (2) high N_s leads to higher β.

In this paper, we report the synthesis of ZAZ sandwich multilayers at different thickness as sensing membrane in EGFET for pH sensor in buffer solution range value (2→12), this research work of utilizing multilayers sandwich as extended gate in FET application was firstly presented.

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http://dx.doi.org/10.1016/j.mssp.2017.10.011
Received 15 April 2017; Received in revised form 25 August 2017; Accepted 10 October 2017
1369-8001/

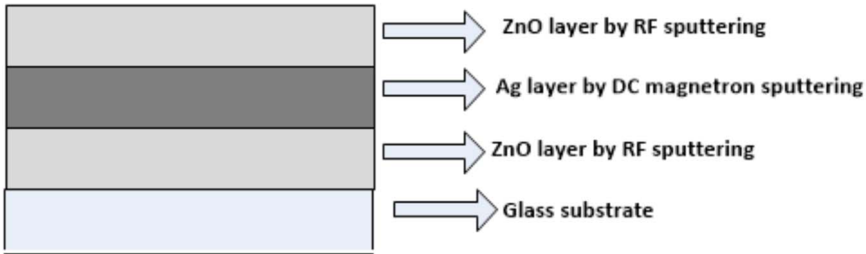

Fig. 1. Schematic of multilayers ZAZ growth process.

2. Methodology

2.1. Growth of ZnO/Ag/ZnO multilayers film process

(1 cm × 3 cm) dimension slides glass substrates were used to deposit ZAZ multilayers thin film; glass slide was ultrasonically cleaned in acetone de -ionized water, and then dried with nitrogen gas

The growth process consists of three steps first n-type ZnO layer on glass substrate second step represented by deposit Ag metal layer on ZnO layer finally deposit ZnO layer on Ag layer so the three layers become ZnO/Ag/ZnO were carried out using (HHV Auto 500 vacuum coater with turbo molecular pumping system, RF and DC magnetron sputtering system). The base pressure was 4.35×10^{-5} mbar and pressure during working for ZnO target was 6.75×10^{-3} mbar and for Ag target was 5.6×10^{-3} mbar. RF and DC power it has been fixed at 100 W all multi-layers were fabricated used ZnO target (99.999% purity) and Ag target (99.999% purity). Thickness of multilayers ZnO/Ag/ZnO controlled by sputter time and set to be (200/100/200) nm and (100/50/100) nm. Fig. 1 illustrated the growth process of ZnO/Ag/ZnO multilayers.

2.2. ZnO/Ag/ZnO multilayers film characterization

The crystalinity structure of ZnO/Ag/ZnO multilayers film were investigated by PANalytical using X-ray diffractometer (XRD) equipped with CuKα source (λ = 0.15418 nm) .nanoscope analysis dimension edge, buker Atomic force microscopy (AFM) used to determined the morphology and roughness of the multilayers film. [FEI NOVA Nano SEM450, field emission scanning electron microscope (FE-SEM)] was used to examine the top view of ZnO/Ag/ZnO multilayers at different thickness.

2.3. Characterization the performance of multilayers EGFET as pH sensor

After characterized the structural properties of ZnO/Ag/ZnO multilayers pH system as seen in Fig. 2 used to determined the electrical properties of the multilayer as EGFET for pH sensing the system consist of two Keithley 2400, personal computer (pc) communication by USB port to analysis and save data(I-V) curves. Two SourceMeters is used for synchronization during measurement and to collects I-V curves at the various current levels are obtained. The first SourceMeter connects between the drain and the source of MOSFET, and it is set to measure drain-source current and sweep voltage. While the second one connects between the gate and source to apply bias voltage.

A commercial MOSFET HEF4007 UBD, Ag/AgCl reference electrode connected to the gate of MOSFET to calculate the performance of multilayers device, cavity of sensing film membrane (ZAZ) films and finally set of pH buffer solutions from 2 to 12 value.

As seen in schematic of pH system the gate of MOSFET connected to ZAZ sensing membrane immersed in pH buffer solution.

3. Results and discussion

3.1. Multilayers structures properties

Before examine the electrical properties of ZnO/Ag/ZnO as EGFET for pH sensor applications the structural properties represented by X-Ray diffraction analysis and atomic force microscopy measurement (AFM) were investigated, the spectrum of XRD analysis reveals that the (ZAZ) multilayers at different thickness (200/100/200) nm and (100/50/100) nm have same phase and the spectrum consist of many peaks corresponding to ZnO and Ag metal, from Fig. 3 can observed that (002),(103) intensity peak corresponding to ZnO this with hexagonal structure and lattice constant a = b = 3.2535 Å, c = 5.2151 Å while Ag metal have many intensity peaks (111),(200),(220),(311) this means that Ag metal polycrystalline with cubic structure and lattice constant 4.0861 Å.

ZnO/Ag/ZnO multilayers films have good moroghology and durability because of the method of deposition but any films have many deviations in its morphology represented like hillocks and valleys there by affected on the performance of films device, consequently determined the quality of films plays important role, surface irregularity named (surface roughness) one of surface deviations. Ra the Roughness Average of a surfaces measured microscopic peaks and valleys, 3D image AFM indicated that Ra increasefrom0.6–0.97 nm with increase the thickness of multilayers films from (100/50/100)nm to (200/100/200) nm the results implies that higher thickness leads to higher value of Ra (roughness average) (Fig. 4).

Fig. 6a,b FESEM images for (ZAZ) multilayers at different thickness can observed the different between two images Fig. 5a showed that the grain of multilayers like ngaad grapes clustered however multilayers at thickness (100/50/100) nm Flat circular granules this attributed to deposition method and physical properties of combine structure ZnO/metal/ZnO.

3.2. Multilayers electrical properties

Electrical properties represented by sheet resistance and hall mobility of ZAZ multilayers at two case of thickness were characterized in Table 1 Good enhancement in electrical properties, decrease in sheet resistance from 11.22(Ω/sq) to 8.93 (Ω/sq) attributed to transition film from continuous state to distinct islands of Ag metal atoms(aggregated state)[15].

When increasing the thickness of Ag layer without changing the thickness of ZnO, this leads to increased electrical conductivity of the membrane. On the other hand, the surface roughness will be constant, as the surface roughness of the ZnO increases with increasing thickness. Increasing of the sensing area is a critical factor to enhance the sensitivity value (Eq. (3)) By increasing of metal and semiconductor layers, both the electrical conductivity and sensing area will be enhanced [15]. In addition, increasing the semiconductor thickness layer reduces the hydration phenomenon on the surface, giving more stability to the current value [16].

Figure of merit for ZnO/Ag/ZnO multilayers were calculated using Haak equation as expressed in Eq. (2):