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The low temperature polysilicon (LTPS) thin film MOS Schottky diode on glass substrate for low cost and high performance CO sensing applications

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ABSTRACT

The Au/SnO_2/n-LTPS MOS Schottky diode prepared on a glass substrate for carbon monoxide (CO) sensing applications is studied. The n-LTPS (n-type low temperature polysilicon) is prepared by excimer laser annealing and PH_3 plasma treatment of an amorphous Si thin film on glass substrate. The developed Schottky diode exhibits a high relative response ratio of ~546% to 100 ppm CO ambient under condition of 200 °C and −3 V bias. The response ratio is better than the reported SnO_2 based resistive type CO sensors of 100% and 37%, respectively on poly-alumina and glass substrates or comparable to 390% of Pt-AlGaN/GaN Schottky diode CO sensor. Thus, the Au/SnO_2/n-LTPS Schottky diode has the potential to develop a low cost high performance CO sensor.

1. Introduction

Carbon monoxide (CO) is a poisonous gas and can be easily released from biomass burning or combustion of fuels. Besides, it is highly dangerous in poorly ventilated spaces, thus requiring a gas sensing device to detect such toxic gas. Conventionally, most of the CO gas sensors are prepared in resistive type with ceramic or thick film metal oxide resistor such as SnO_2, TiO_2, and ZnO as sensing material for their high response to CO gas and have unique features of thermal stability and high chemical resistance [1–3].

Recently, to improve the response time, CO gas sensors are also prepared with metal gated microelectronic structure, such as MOSFET, MOS capacitors, and diodes etc. [4,5]. Besides, the metal gated device has the other advantages of small size, low-cost, batch-fabricated and an array-fabricated for multi-species detection [6–8]. Specifically, the thin film type metal gated microelectronic sensor could offer easy fabrication, mechanical toughness, high selectivity and preferable micromation [9].

In this paper, we report the development of a new thin film type metal gated microelectronic device with the low temperature polysilicon (LTPS) thin film on a glass substrate for low cost CO sensing applications in details. Since the cost for material and device preparation is lower as compared to that of commonly used bulk Si or III–V compound. In addition, other aspects of the CO sensing device, including operation mechanism, response and recovery time are also investigated.

In the past, the LTPS has been successfully used in preparing the high-speed thin film transistor (TFT) for large area TFT-LCD [10,11]. In addition, for its low cost, we have also employed it to prepare the mass market type H_2 gas sensor [4]. To our knowledge, this is the first time to apply the material for CO sensing.

2. Sensor design and fabrication

2.1. Design consideration

Fig. 1 shows the schematic diagram of the developed Au/SnO_2/n-LTPS MOS Schottky diode. The thin SnO_2 layer is a low cost and highly sensing material to CO gas. Besides, SnO_2 has a high band gap larger than 3.0 eV [12], which could improve the Schottky contact barrier to suppress the off current without CO ambient, thus enhancing the sensitivity. Furthermore, according to the report in a previous research [13], the Au (gold) doping in SnO_2 could affect both the particle size and the degree of crystallinity of SnO_2, thus decreasing the operation temperature. Therefore, in this work, we used Au as electrode to expect that the Au may diffuse into SnO_2 to induce the same behavior. Besides, Au is stable in CO gas, thus it can not be corroded easily to degrade the sensor's sensing function.

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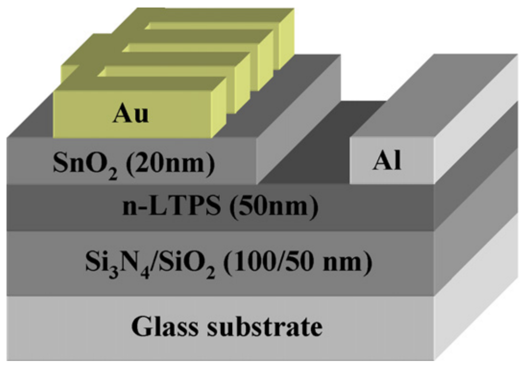

Fig. 1. The schematic cross section of the developed Au/SnO_2/n-LTPS MIS Schottky diode.

2.2. Device fabrication

To prepare the LTPS thin film, firstly, an undoped amorphous Si layer (50 nm) was deposited by a plasma enhanced CVD system on glass substrate with the pre-coated buffer layers of Si_3N_4 (100 nm)/SiO_2 (50 nm), and followed by an excimer laser anneal. Before the ELA treatment, a de-hydrogen step was applied to prevent a surface ablation in poly-Si from the severe hydrogen outgassing. However, the de-hydrogen step also generates a large number of traps in the grain boundaries, thus, needing an extra PH_3 gas plasma treatment in a PECVD system to passivate the traps with both H and P atoms. The plasma treatment was implemented under 250 °C, 60 s and 90 W for substrate temperature, time, and RF power, respectively. After the plasma treatment, we find the LTPS is also doped into an n-type LTPS (n-LTPS) by the phosphorus in the plasma, and thus increasing the free electron number. Then, the sensing element of 20 nm SnO_2 and the Schottky contact electrode of 20 nm Au layer with comb configuration were sequentially deposited on the top of the n-LTPS by RF sputtering and evaporation, respectively. Finally, forming an ohmic contact of 5000 Å Al (aluminum) metal on the top of the n-LTPS without the SnO_2 layer underneath to complete the Au/SnO_2/n-LTPS MOS Schottky diode.

3. Results and discussions

3.1. Sensing current–voltage curves

For the sensing characterization, firstly, the sample is put into a closed chamber with a constant air flow (about 100 sccm), then the flow is switched to a CO/air mixture gas, then returned to a pure air flow always at the same flow rate. The CO/air mixture gas is prepared by a gas supplier with various CO concentrations mixed in air. During measuring, the chamber is kept at a pressure less than atmospheric pressure (100 Torr) for safety consideration [14], and controlling both air flow and the bottle temperature to obtain a relative humidity of 40% (with ±5% R.H. in accuracy) at the inlet of the sample cell. The relative humidity level of the air is controlled constantly by purging about half of the total air flow through a temperature controlled bottle containing water [15], and is measured with a humidity sensor (Honeywell HIH-3610).

Fig. 2 shows the measured current–voltage (*I–V*) curves with a HP4145B semiconductor parameter analyzer under 200 °C with and without CO ambient for both forward and reverse biases. Besides, for clear comparison, we plot both forward and reverse currents in same polarization side [16]. Without CO ambient, the device shows a typical Schottky diode characteristic with low leakage current and flat *I–V* curve under reverse bias. But, under a CO ambient, more remarkable sensing current than that forward bias is found under reversed bias. This is due to the small barrier height

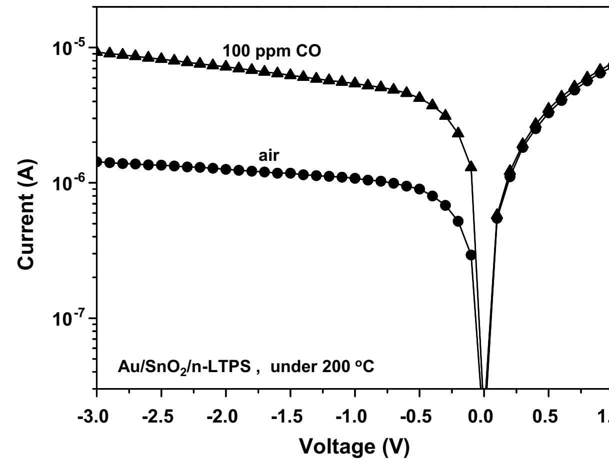

Fig. 2. Forward and reverse current–voltage (*I–V*) characteristics of the Au/SnO_2/n-LTPS MOS Schottky diode under 200 °C with and without CO gas ambient.

under forward bias, which leads the barrier lowering and thus the increase of current under CO ambient becomes less significant as compared to that under reverse bias (see Section 3.4). Therefore, in this case all of sensing studies are based on the reverse bias for it opens the possibility of use in commercial applications.

3.2. Relative response ratio

Fig. 3 gives the measured *I–V* curves under 200 °C as a function of ambient CO concentration for various reverse biases. Under a fixed bias, all of the sensing currents increase with increasing CO concentration firstly, and then becomes saturated beyond 1000 ppm owing to the CO coverage effect on the SnO_2 surface. Besides, the sensing currents increase very slightly with bias, thus having a wide operation window. In addition, Fig. 3 inset shows the corresponding relative response ratio (S_r) for various CO concentrations based on the *I–V* curves. The S_r is another important figure of merit for CO sensing and has been defined as $(I_{CO} - I_{air})/I_{air}) \times 100\%$ [17], where I_{CO} and I_{air} are the reversed currents measured respectively in CO and air atmosphere. The S_r increases linearly with CO concentration to have a value of 1431% at 1000 ppm, and then becomes saturated beyond the concentration.

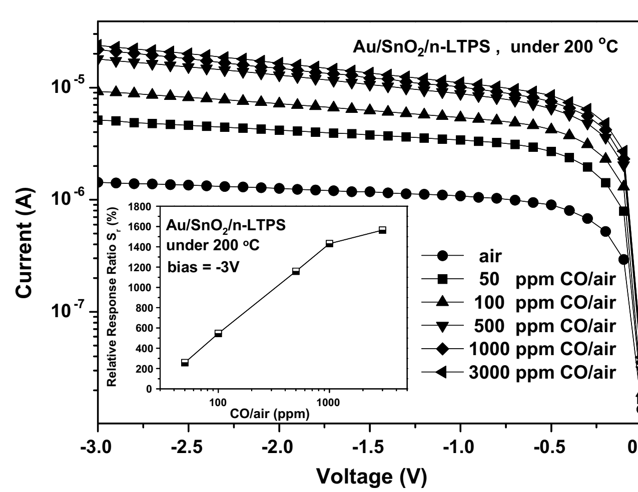

Fig. 3. Current–voltage (*I–V*) characteristics of Au/SnO_2/n-LTPS MOS Schottky diode under reversed biases and 200 °C for various CO concentrations ambient. The insert gives the corresponding the relative response ratio (S_r) for various CO concentrations.