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TEMPERATURE MEASUREMENT USING A CH_x/POROUS SILICON/SI STRUCTURE ENCAPSULATED IN A CO₂ RICH ENVIRONMENT

ABSTRACT

This work reports on the possible use of microporous silicon as a temperature sensor. This work is based on previous published works [7, 8, and 9]. The device is based on hydrocarbon group (CH_x) / porous silicon (PS) /Si structure. The porous sample was coated with hydrocarbons groups deposited by the plasma of methane /argon mixture. Current–voltage characteristics have been investigated as a function of temperature in the range 20⁰C-70⁰C. The results show that for a constant voltage in the range 0.7-1V, the current increases linearly with the environment temperature reaches a maximum at 70⁰C and then stabilizes. This result suggests that the developed structure can be used for sensing temperatures not exceeding 70⁰C.

Key words: *porous silicon, temperature sensor, carbon dioxide.*

INTRODUCTION

Porous silicon (PS) exhibits a high surface to volume ratio and rich electrical and optical properties. It is considered as a promising material fabricating chemical sensors, thermal microsensors, photodetector devices and solar cells [1, 2, 3, 4]. The use of such PS components requires stable and reproducible layers with good electrical contacts. However, the published results in this field are still controversial [5, 6]. On one hand, these disparities can be explained by the complexity of the medium and by the strong dependence of PS parameters with the preparation processes. On the other hand, the electrical properties depend on the metallic contact and deposition method [7, 8]. Some definitions are established from previous studies. First, the rectifying behavior increases with the porosity while the sensitivity decreases [9]. Second, the sensitivity of a structure to different vapors is usually evaluated by the ratio $\Delta I / I_0 = (I_{gas} - I_0) / I_0$, where I_{gas} and I_0 are the current intensity in the presence and absence of gas, respectively [10]. Therefore, it is interesting to prepare structures with high and bias independent saturated current. Generally, there are two categories of temperature sensors. The first one, based on direct contact [12, 13, 14] and the second one based on a non intrusive technology [15, 16]. Both of them are based on sensitive element. Their relatively high cost and complex manufacturing processes reduced their scope of use. For all these reasons we

focus on sensors that measure temperature through electrical responses (I, V, C). In this paper, we propose a sensor with a cheapest and easiest manufacturing process and resistant to moisture thanks to its protective cover. Finally, our results have been compared we compare measurements provides by our sensor with that established by an industrial certified (EN 50 081-1, EN 50 082-1), sensor (TESTO 925) to validate our results.

SAMPLE ELABORATION AND EXPERIMENTAL TECHNIQUE

Porous silicon layers have been obtained on p-type (100) Si wafers (1-10 Ω cm resistivity). The electrochemical etching solution was prepared by adding 50Vol. % of ethanol to 50 % of HF aqueous solution (49 wt. %). The etching time was adjusted in order to obtain a porosity ranging from 40% to 85%. The Porous silicon layer thickness was varied from 1 to 10 μ m. The CH_x films were deposited on the porous layer using a methane/argon mixture in an RF (13.5 MHz) synchronized triode reactor. More details on the deposition procedure are described elsewhere [17, 18]. A gas sensor structure of (5x5) x 10⁻² cm² cell was formed (Fig. 1).

Fig. 1. Schematic diagram of the sensor

Metallic contact was achieved by deposition of 99, 99% pure Al on the backside of the PS sample. The Al contact on the CH_x layer was in the form of the frame of about 250 μ m wide sides. The structure was placed in a stainless steel vacuum chamber (1.43 x 10⁻³ m³ vol) maintained at room temperature and connected by a valve to bottle containing CO₂ gas. Capacitance measurements were performed using an EG&G model 410 (C-V) plotter impedance meter [19].

RESULTS AND DISCUSSION

Current-voltage characteristics

The current voltage (*I-V*) characteristics of the CH_x/PS/Si structure, were analyzed for a (-1V) to (+3V) bias voltage change against CO₂ with varying temperatures. Fig. 2

shows the dependence of current I as a function of temperature measured at various concentration of CO_2 pressure. For figs. 2 and 3 we observe a variation of the current for different CO_2 gas pressure (500, 600 and 1200 ppm) and for different temperatures (20°C to 70°C) [20]. In Fig. 2, we see ΔI with increasing gas temperature. In addition at constant temperature, ΔI increases with increasing the gas concentration. Moreover, Fig. 3 also shows that the ΔI changes are more pronounced for higher temperatures. The temperature favors the gas adsorption.

Fig. 2. Current variation as a function of temperature for different CO_2 gas pressure

Fig. 3. Current variation as a function of concentration for different temperatures

Fig. 4. Sensitivity as a function of bias voltage for different gas pressures at $T = 25^\circ\text{C}$

Fig. 5. Sensitivity as a function of bias voltage for different temperatures at room pressure

Fig. 4 shows that the best sensitivity is obtained for a bias voltage of 0.45 V. In addition, the sensitivity increases with the gas temperature. In fact, it's depicts the sensitivity as a function of bias voltage for different CO_2 gas concentrations. It is shown that the best relative responses ($\Delta I/I_0$) are obtained for a low applied bias voltage (0.45 V). In addition, it was shown that the sensitivity of the sensor varies with temperature as observed by several authors [21]. It shows that the sensitivities increase with gas pressure for different temperatures. The evolution of the sensitivity of the sensor as a

function of polarization for different temperatures is presented in Fig.5. It is clear that for a constant concentration of gas the current increases with the temperature, as shown in Fig. 6.

Fig. 6. Electrical characteristics of Al/Si/Si/CH_x/Al for different temperatures

Fig. 7. Variation of the sensitivity as a function of gas temperature at V=0.45 volt

Fig. 7 shows the sensitivity of the sensor as a function of temperature at a constant bias voltage of 0.45 V, where it indicates, that $\Delta I/I_0$ of the structure is increases as the temperature increases. This variation in the sensor's current increases also when the concentration of CO₂ gas is increased.

Capacitance measurements

Chemical sensors based on porous silicon layers are generally used to examine the chemical concentrations in liquid or gas phases by observing the device capacitance variation.

Fig. 8. C (V) of the sensor for different temperature of CO₂ gas (p=500 ppm) at 1MHz

The effects on capacity are attributed to the variation of the dielectric constant due to the filling of the pores by gaseous species. The involved sensing mechanisms are generally associated with a change in the free carrier concentration in the porous layer due to adsorbed molecules (or change in the dielectric constant due to gas condensation inside the pores) upon variation of the temperature [22]. The characterization of the sensor is undertaken at 1MHz. Fig. 8, shows that, for different temperatures the introduction of CO₂ gas at 500 ppm pressure induce a change in the capacitance–voltage values [23]. One can observe that the sensor behaves as a metal insulator semiconductor (MIS) structure as observed by several authors [9, 11]. For the Al/CH_x/PS/p-Si/Al structure biased negatively, the capacitance decreases with bias voltage reaches a maximum at about – 1 volt then stabilizes. The high relative capacitance variations (ΔC) are shown for a bias voltage higher than – 1 volt. However, the (ΔC) is positive for CO₂, confirming the behavior obtained on the I–V characteristics. In order To validate our system we used a reference sensor (TESTO 925).The comparison is given in table 1.

Table 1. Comparison of experimental results at ($v=0.45$ volt) with referential sensor measures

I (V) (μA)	T(°C) (Al/CH _x /SiP/Si/Al)	T. (TESTO 925). (°C)	Error (°C)
12.30	28.3	30	1.7
13.17	33.8	35	1.059
14.21	39.0	40	1.14
16.29	44.1	45	1.43
17.33	49.5	50	1.30
18.37	54.7	55	0.98
19.41	60.0	60	0.95

Fig. 9. Comparison of experimental results at ($v=0.45$ volt) with reference sensor measures

Fig.9 shows that our sensing device gives good results comparing with TESTO's measures. According with table 1, the relative error is between 1.61% and 3.04%. We observe that, more the temperature is greater; smallest is the relative error of temperatures measures of Al/CH_x/SiP/Si structure.

CONCLUSION

To summarize, we prepared an Al/CH_x/PS/Si/Al structure, encapsulated in a CO₂ gas controlled environment. The results show that the developed sensor responds in the temperature range 20-70°. In addition, the developed sensor can operate at low voltage in the (+0.5 - +1) V range demonstrating a good sensitivity. Also, we observe that the current variation has the same evolution as the temperature (increasing and decreasing), but this parameter does not affect the evolution of the capacitance behavior of the sensor. Finally, we compared our results with a referenced one. This result suggests that the developed structure can be used for sensing temperatures not exceeding 70°C. Finally, the structure has been found to be reversible.

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