Impedance Measurements of Ethanol Sensing with Vanadium oxide / Porous Si / Si Structure

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Abstract – The paper deals with a gas sensing device based on Vanadium oxide (V_2O_5)/ **Porous** Si (PS) /Si structure used to detect Ethanol gas at different concentration. The V_2O_5 thin films were deposited on porous silicon by the sol-gel (Dip-coating) technique. The Vanadium oxide has been produced from vanadium alcoxide precursor. Current-voltage and admittance characterizations show that the sensor characteristics are modified in the presence of gases. Conductance measurements at low frequencies indicate the presence of interface states.

Keywords- vanadium oxide; porous silicon; gas sensor.

I. INTRODUCTION

During the two last decades, the interest in environment issues, particularly in pollution, has become a major key factor in the industrial development. Recently, immense efforts have been done in the development of sensing devices based on porous silicon (PS) [1, 2]. Because of its high reactivity and high specific surface (200-600 m^2/cm^3), porous silicon has been shown to be an interesting base material for gas sensing application [3, 4]. Porous silicon has been found highly sensitive against organic vapours such as methanol, ethane, propane or ethanol and acetone [3, 5-8]. However, PS-based sensors showed a relatively long response time, and a degradation of the structure due to porous silicon surface oxidation .Many recent efforts that are devoted to materials exploration for better sensor performance have appeared.

Metal oxides have been widely exploited as sensing elements in semiconductor gas sensors, because they provide featured active sites to adsorb gas molecules and catalyze reactions. Their surface states and chemical reducibility favor gas sensor operation at low temperatures.

Presently, only transition-metal oxides with d_0 or d_{10} electronic configurations (e.g., SnO_2 and ZnO with d_{10}; TiO_2 and V_2O_5 with d_0) find their real gas sensor application [9].Vanadium oxides have attracted attention because of their potential applications as chemical sensors and as the active components of various electrical and optical devices [10]. Thin films of vanadium oxides for ethanol sensor applications with the best sensitivity and selectivity were been prepared by several authors [11, 12]; however, the mechanism sensing is not yet fully understood.

In the present work, we will present current-voltage, capacitance and conductance results of a gas sensing device based on Vanadium oxide (V_2O_5)/Porous Si (PS) /Si structure subjected to ethanol vapor.

II. EXPERIMENTAL

Porous silicon (PS) was obtained by electrochemical etching of p-type silicon wafer (450 µm thickness, 1 - 10 Ωcm resistivity). The etching solution was prepared by adding 50 vol. % of ethanol to 50 vol.% of HF aqueous solution (49 wt. %).Current density and etching time were varied to obtain porosity ranging from 40 to 75% and thickness of PS layer 2 - 15 µm, respectively. Nanostructured vanadium pentoxide films deposited on PS surface were prepared by mixing vanadium (V) oxytriisopropoxide ($VO(OPr^i)_3$) (Sigma Aldrich) with isopropanol (Pr^iOH)) in presence of acetylacetate. The obtained gel was deposited by dip coating technique and dried in air at room temperature.

Current-voltage and impedance spectroscopy are employed for electrical characterizations of the sensor in a controlled gas environment.

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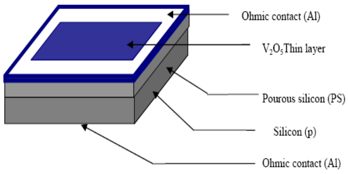

Figure 1. A schematic diagram of the V_2O_5/PS/Si sensor.

Sensor prototype structure of 5 mm x 5 mm cells was realized (Figure 1).

III. RESULTS AND DISCUSSION

III.1 Current-voltage characteristics

The current-voltage (I-V) characteristic of V_2O_5/PS/Si structure, shown in Figure 2, was measured in air environment and ethanol vapor environment. The current response of the devices shows generally that for bias potential values less than 1 V, an ideality factor of 1.72 is calculated. The value of the ideality factor n as obtained here could indicate that the current transport mechanism consists of both the trap-assisted tunneling and the thermionic emission [13, 14].

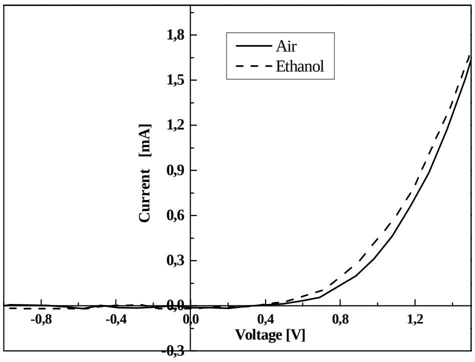

Figure 2. I-V characteristics of the structure against ethanol vapor at a concentration of 160 ppm.

A rectifying behavior is also observed when the ethanol vapor is in contact with the structure with no change in the shape of current-voltage curve, only a change in current magnitude at fixed potential in observed.

III.2 Capacitance and conductance measurements

The current-voltage characteristic does not provide sufficient information to model the device operation. Complementary information's can be obtained from the small signal impedance measurements . The measurements were made as a function of frequency in the range 1 Hz - 100 kHz.

Figure 3a which gives the variations of the capacitance versus bias (C-V) at constant frequency of 1 kHz shows that it behaves as Metal-Insulator-Semiconductor (MIS) structures as observed by several authors for Al/PS/Si structure [15]. The capacitance decreases monotically and stabilizes at potential values lower than -1 V. When the gas is in contact with the ethanol vapor a large variation of the capacitance is observed, as shown in Figure 3b. For structure biased negatively C decreases monotically with bias voltage.

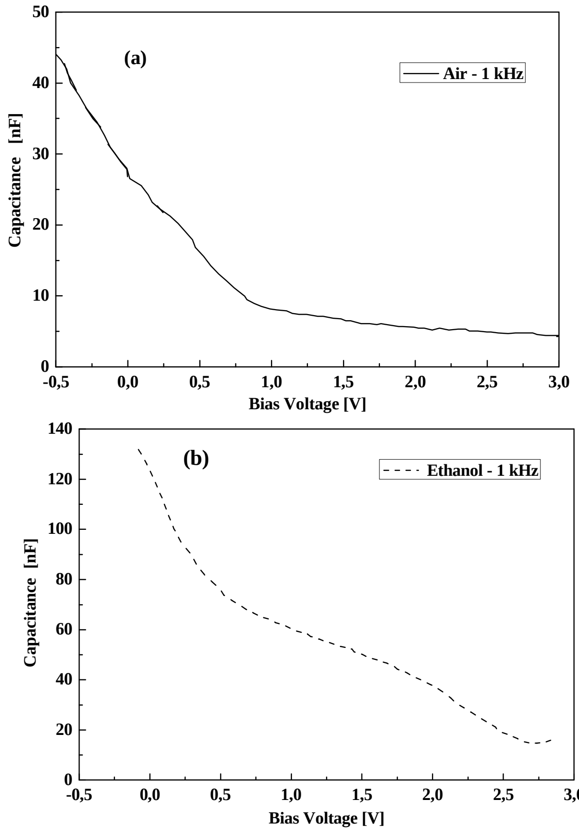

Figure 3. Variation of the capacitance vs. bias voltage at constant frequency of 1kHz, (a) under air, (b) ethanol vapor.

Figure 4 shows the dependence of the conductance on the voltage at 1 kHz frequency before and after introducing ethanol vapor. One can note that the introduction of ethanol vapor onto sensitive V_2O_5/PS surface causes, here again, changes in the conductance measurement. The conductance variations were seen to increase monotically with negative bias voltage when the gas is in contact with the device, the conductance value decreases with bias voltage. However a change in the variation shape of the conductance has been observed at low frequencies between 10 and 100 Hz, as shown in Figure 5, where it shows that in the potential range (0 - -1.5 V) the conductance presents a large "cavity" centered at about - 0.4 V.

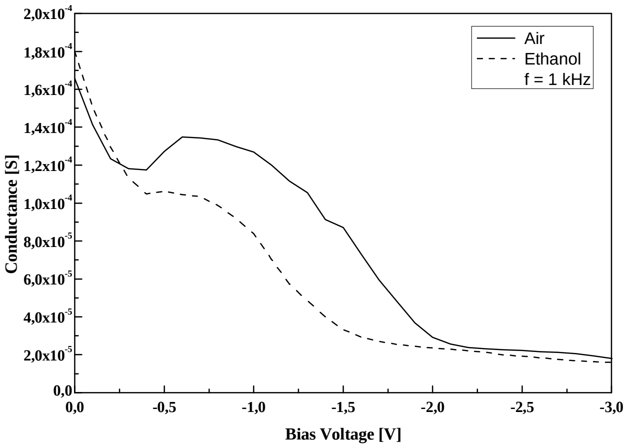

Figure 4. Variation of the conductance vs. bias voltage at constant frequency of 1 kHz under air and ethanol vapor.

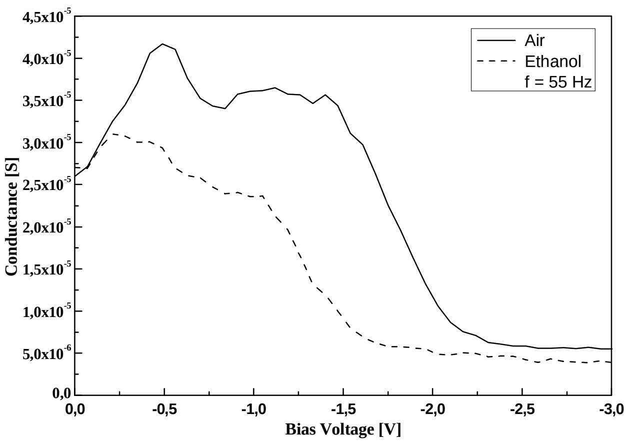

Figure 5. Dependence of the conductance on the voltage at constant frequency of 10 Hz.

This behavior could be related to the presence of interface states distributed in this bias potential range. This statement is confirmed by contacting the structure with the gas ethanol. In this case the interface states are filled with charges due to adsorption of ethanol vapor. In principle the evaluation of an interface density of states can be obtained from the dependence of the conductance G, divided by the frequency: G/ω as a function of w. From the G/ω curve it is easy to calculate the density of the interface state [15, 16].

The capacitance and conductance as a function of frequency at a bias potential of -1 V are shown in Figure 6. It is shown that the capacitance is higher for very low frequencies then decreases monotically to low values for higher frequencies (Figure 6a).

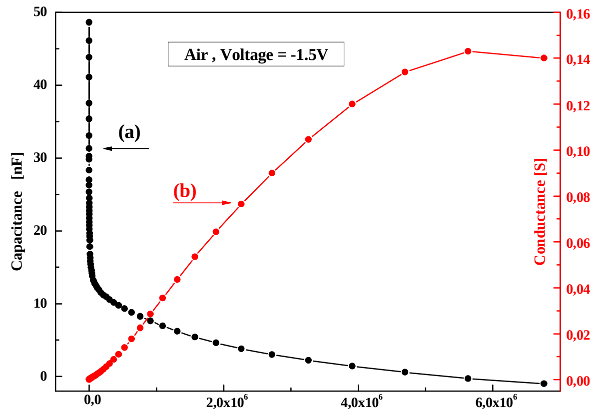

Figure 6. Capacitance and conductance of the V_2O_5/PS/Si structure as a function of frequency.

The conductance is seen to increase linearly in the range 1 Hz to 1 kHz then tend to stabilize for higher frequency values (Figure 6b). It is clear that more results are needed in order to understand this behavior and elaborate an equivalent electrical circuit of the structure.

VI. CONCLUSION

In this work, we reported on the deposition of vanadium oxide on porous silicon and the application of V_2O_5/PS/Si as structure for ethanol vapor sensing. Capacitance, conductance and current-voltage measurements show that the device response is modified by the ethanol vapor on the V_2O_5/PS surface. The results of impedance measurements at low frequency clearly demonstrate the presence of interface states at -0.4V.

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