Development and characterization of TiO_2 based Pd-GATE MOSFET Hydrogen sensor

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The development and characterization of Pd-gate MOSFET hydrogen sensor having TiO_2 as gate oxide, has been presented. The response of the fabricated sensor on exposure to hydrogen gas at room temperature has been studied. Also, the temperature dependent response of the device has been studied.

Key words: Pd-Gate, sensor, TiO_2.

1. INTRODUCTION

To fulfil the demand for better environmental control and safety, silicon-based gas sensors utilizing catalytic metals such as palladium, platinum or other noble metals as the gate material for an MOS capacitor, transistor or Schottky barrier diode have been extensively used for detection of hydrogen, hydrocarbons, alcohol vapours, hydrogen sulphide, ammonia and carbon monoxide [1,2]. Earlier, there have been a number of studies on Pd-gate MOS hydrogen sensors using SiO_2 as the gate insulator [3,4,5]. Despite considerable studies, the mechanism of the hydrogen sensing by Schottky and MIS diode has not yet been clarified. Recently, a Pd-gate MOSFET with SiO_2 as gate insulator has been reported for the detection of hydrogen gas [7]. Sensing characteristics and temperature dependent behaviour of Pd/TiO_2/Si MOS Hydrogen sensor have been reported earlier [8,9].

2. EXPERIMENTAL METHODS

The titanium oxide based Pd-gate MOSFET (Pd/TiO_2/p-Si Transistor) was fabricated using standard NMOS processes, except for the gate was prepared using palladium and the SiO_2 was replaced by TiO_2. For the fabrication of the device, the substrates of the specifications (p-type of resistivity 2-3 ohm-cm and orientation <100>) were used. The channel length of the MOSFET was taken to be 50μm.

The sensing behaviour of the fabricated titanium dioxide based Pd-gate MOSFET gas sensor upon exposure to hydrogen gas was measured by monitoring the change in the drain current keeping the gate voltage constant. The variation of the drain current upon exposure to hydrogen gas at different drain to source voltage was measured and the results are shown in Figure 1. The hydrogen gas concentration was varied from 0 to 8% in nitrogen ambient.

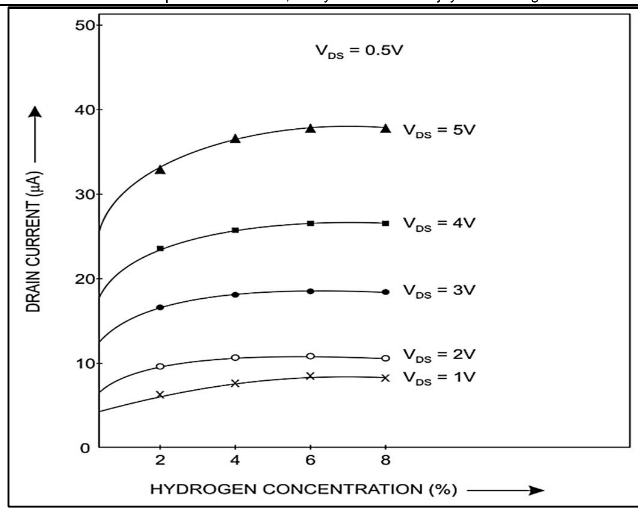

Fig. 1: Variation of drain current with H_2 concentration.

3. RESULTS AND DISCUSSIONS

The maximum change in the drain current was observed at 5% of H_2 concentration and above this concentration, the drain current practically remains constant for a given drain to source voltage.

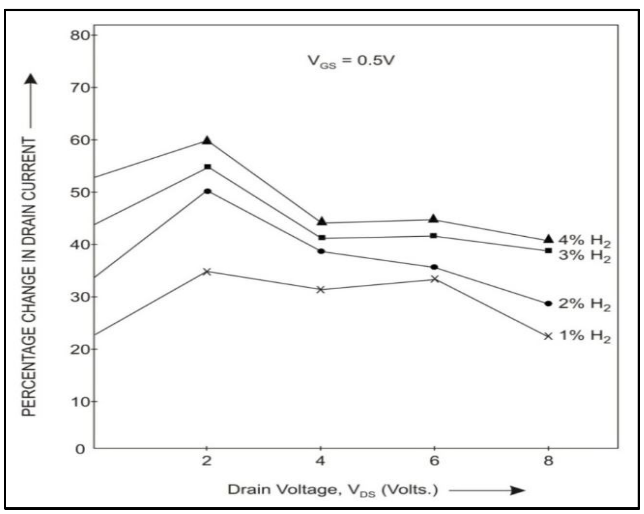

Fig. 2: Variation of percentage change in drain current with V_{DS}.

The evaluation of the percentage change in the drain current has been made with the help of the results shown in Figure 2 and its variation against the drain to source voltage V_{DS} for different hydrogen concentration is shown in Figure 3. The percentage change is found to be larger at lower values of the drain to source voltages. Also, the percentage change in the gate voltages for different hydrogen concentration (1%, 2%, 3% etc.) has been shown in Figure 3.

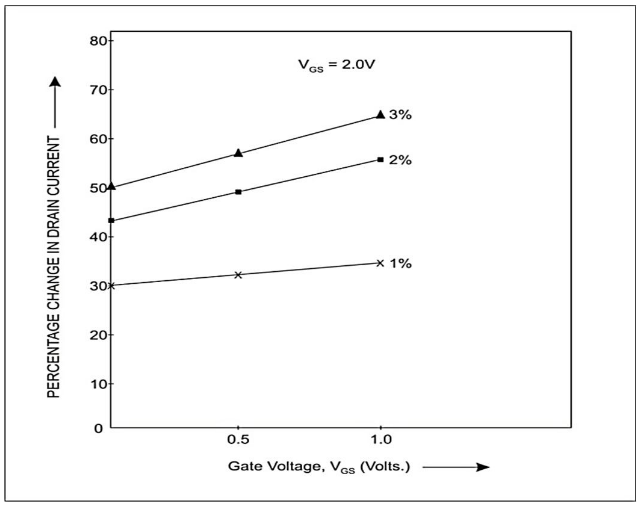

Fig. 3: Percentage change in drain current with V_{GS}.

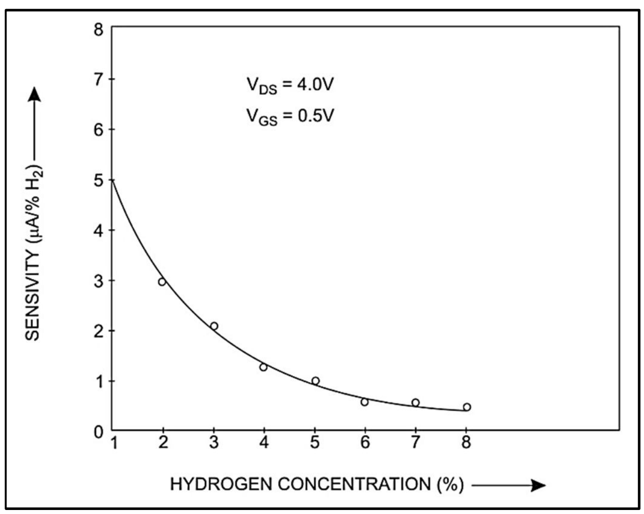

Fig. 4: Sensitivity v_s H_2 gas concentration at Room temperature.

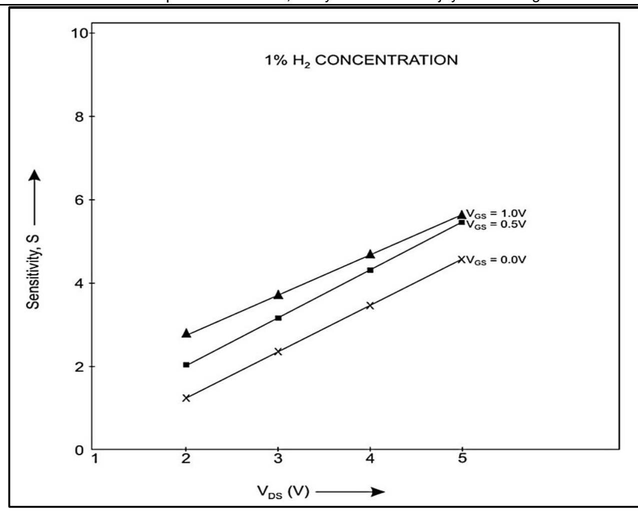

Fig. 5: Sensitivity v_s drain voltage V_{DS}.

The sensitivity of the fabricated sensor has been evaluated and the variation of the same against the hydrogen concentration is shown in Figure 4. Also, the variation of sensitivity with the drain to source voltage V_{DS} and the gate voltage V_{GS} has been evaluated as it is shown in Figure 5.

The temperature dependent sensitivity of the sensor has been shown in Figure 6. From this figure, it may be stated that the sensitivity of increases with the increases of temperature within the range of observation i.e., up to 100^{o}C. The fabricated sensor based on Pd-gate MOSFET having TiO_2 as gate insulator, was found to be sensitive to hydrogen gas at room temperature. The change in the drain current upon exposure to hydrogen gas (Figure 1) could be attributed to the change in the gate-metal work function because of the fact that the drain current is dependent on the threshold voltage, which in turn, depends on the gate-metal work function.

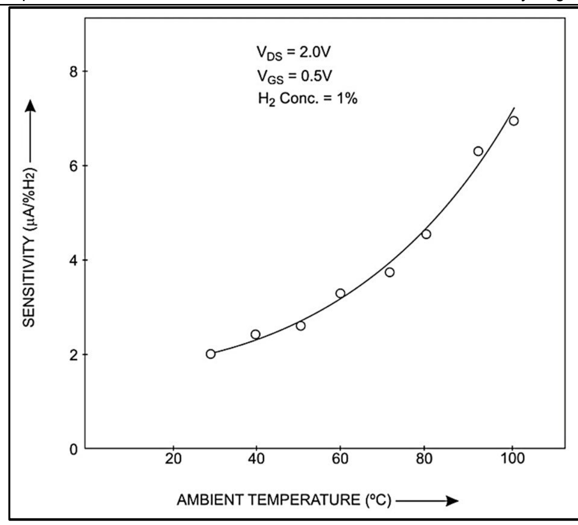

Fig. 6: Temperature dependent sensitivity.

The percentage change in the drain current of the fabricated sensor decreases at high drain to source voltages, as evident form Figure 3. The maximum percentage change was observed at lower drain to source voltages (1-3 volts). This decrease in percentage change at higher drain to source voltages may be due to the effective lateral field. Also, the percentage change in the drain current is found to be almost independent or slightly increasing linearly with the gate voltages.

The plot of the sensitivity against hydrogen concentrations shows a decrease in the sensitivity at lower values of concentration (Figure 4) and a tendency of saturation at higher values. The device has been found to me most sensitive at 1% of hydrogen gas i.e. at the first exposure. Such variation in the sensitivity may be due to either logarithmic or square root dependence of the threshold voltage to the partial pressure of hydrogen gas, as reported earlier [1,2,4]. The variation of the sensitivity with the drain to source voltage, V_{DS} is found to be almost linearly increasing for different gate voltages, V_{GS} (Figure 5). A linear increase in the sensitivity has also been observed with the gate voltage V_{GS} but with a slower rate. It is evident from the Figure 6 that the sensitivity of the Pd-gate MOSFET sensor having titanium dioxide as gate insulator, increases with the increase of ambient temperature. The temperature dependent response was measured only upto 100°C. The increase in the sensitivity of the device is primarily due to the increase in adsorption sites which increases the number of dissociated hydrogen atom and also due to increase in diffusion of hydrogen atom in titanium dioxide.

4. CONCLUSIONS

The sensing mechanism in Pd-gate MOSFET having TiO_2 as gate oxide is analogous to that having SiO_2 [7]. The larger percentage change in the case of TiO_2 based device is expected due to high polarizability of TiO_2 lattice and high diffusibility of hydrogen in titanium dioxide.

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