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Pd-Gated a-Si:H Thin Film Transistors for Hydrogen Detection

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Top-gate a-Si:H Thin Film Transistors (TFTs) with metal gate insulator of Pd have been fabricated and succesfully operated as hydrogen sensors. The sensitivity mechanism of such devices resides in the catalytic behaviour of Pd towards H_2-molecules and in the formation of a H-dipole at the Pd/a-SiO_2 interface, which influences the threshold voltage of the transistor. The measured H-response is similar to that relative to c-Si Pd-gated MOSFET. The obtained results show as possible promising application the use of a-Si:H TFTs in the field of chemical sensor.

1. INTRODUCTION

In the past few years there has been a growing interest in particular solid state devices capable to detect chemical species in different environments[1]. Recently hydrogenated amorphous silicon (a-Si:H) based devices have been coonsidered for the application in this field[2,3]. In particular, since the tremendous progress made by the a-Si:H thin-film transistors (TFTs) technology, the possibility to apply such devices as chemical sensors has become very attractive. The advantages related to low-temperature process, relatively simple technology, different kind of substrates (glass, kapton, etc.) and the possibility of fabricating arrays over large area certainly make the a-Si:H chemical TFTs (CHEMTFT) possible candidates for some specific application in the field of chemical sensors. Furthermore, the relatively limited speed response of a-Si:H TFTs is not a problem for such application considering the long time constants (seconds or minutes) involved to reach equilibrium between the sensitive material and the liquid or gaseous specie to be measured. We present here, for the first time, Pd-gated a-Si:H TFTs successfully operating as hydrogen sensors.

2. DEVICE FABRICATION AND CHARACTERISTICS

To meet the requirement of a gate electrode in direct contact with the ambient, we choose the top-gate configuration (see Fig.1) for our Pd-gated devices. Top-gate staggered structure TFTs were fabricated depositing by Plasma Enhanced CVD in a radial flow, hot-wall reactor 300 nm thick a-Si:H as active layer at 250 ^{0}C of substrate temperature. As gate insulator 100 nm thick a-SiO_2 was sequentially deposited by a mixture of SiH_4+N_2O and He. The electrical properties of this material are similar to those relative to thermal silicon dioxide, with breakdown fields exceeding 10 MV/cm and no significant charge injection up to fields of 5-6 MV/cm[4,5]. Ohmic source-drain contacts were formed by previous n^+ a-Si:H deposition and patterning. The geometrical parameters of the devices are: channel width W = 200 μm, channel lengths L = 20, 10, 5 and 2.5 μm. The Pd-gate electrode, 300 nm thick, was sputter deposited at a low RF-power density, to avoid the creation of defects in the underlying gate

Fig.1 Schematic of top-gate structure.

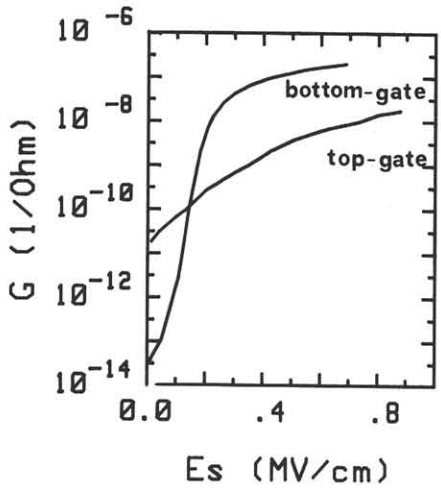

Fig.2 Sheet conductance, G, measured for low source-drain voltage, vs the semiconductor surface electric field, E_s, for top and bottom-gate structures

insulator. On the other hand, e-beam evaporated Pd-films showed poor adhesion over the a-SiO_2. The temptative to improve it by heating the substrate up to 250 °C produced an intermixed a-SiO_2/Pd interface with the probable formation of Pd-oxide and Pd-silicide, which prevented the H_2 sensitivity of the structure. As already shown for a-Si:H TFTs employing silicon nitride as gate insulator, the top-gate structure is systematically worse than the bottom-gate one[6,7]. A possible explanation is related to an increase of tail states in the a-Si:H, close to the insulator/semiconductor interface[7]. This seems also to be the case for our devices, where a-SiO_2 is used as gate insulator. In fact, as shown in Fig.2, a comparison of the sheet conductance, G = $I_{ds}L/W$ (where I_{ds} is the drain current measured for low source-drain voltage, V_{ds}) vs the semiconductor surface electric field, E_s, for top and bottom-gate structures, fabricated by using the same materials, clearly demonstrates the superiority of the latter devices. The field effect mobility, deduced by saturated characteristics, is .97 cm^2/Vs for the bottom-gate structure, about a factor five better than for top-gate devices (.2 cm^2/Vs). Typical output characteristics for top-gate devices are shown in Fig.3.

3. HYDROGEN DETECTION

The basic principle of H_2 sensitivity in Pd-gated devices is connected with the dissociation of H_2 molecules on the catalytic metal surface and on the subsequent adsorption and diffusion of H atoms throughout the metal itself.

This process is reversible in the presence of O_2. In fact, at the metal surface, chemical reactions between O_2 and H_2 take place with H_2O, OH, H_2O_2 formation until all the H present in the Pd film is completely removed[8]. The hydrogen sensitivity has been demonstrated to be related to a change in the contact potential at the Pd/SiO_2 interface[9] induced by one of these mechanisms: a) formation of a dipole layer by H atoms at the metal/insulator interface[8], b) formation of a Pd-hydride with lower work function[10]. The hydrogen-induced variation of the contact potential produces in a MOSFET structure a change in the threshold voltage[11]. The response to 1 % H_2 in N_2 gas mixture was measured at room temperature with the TFT operating in the common drain configuration. For constant source-drain current, since for $V_g = V_{ds}$ the device operates in

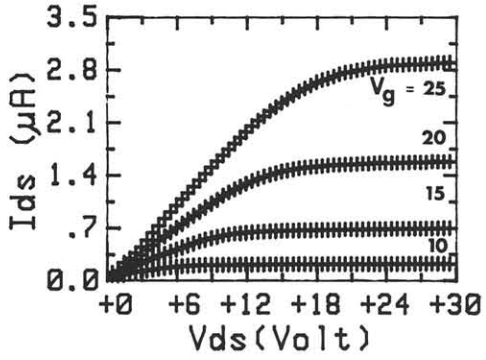

Fig.3 Source-drain current, I_{ds}, vs drain voltage, V_{ds}, of Pd-gated TFT with L=20 μm and W=200 μm for different gate voltages V_g.

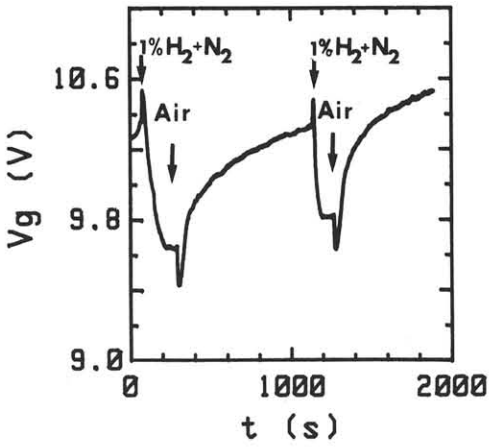

Fig.4 Measured V_g variations to (1% H_2+N_2)-exposure and subsequent interruption for the Pd-gated TFT operating in common drain configuration. The I_{ds} was kept constant at .2 μA.

the saturation regime (see Fig.3), the measured gate voltage change corresponds directly to the threshold voltage change, ΔV_{th}. A Keithley 225 current generator was used to keep I_{ds} constant and V_g was monitored with a Keithley 617 electrometer. The hydrogen-nitrogen gas mixture was injected locally near the gate area by using a needle connected to the gas line. The measured V_g variations to H_2-exposure and subsequent interruption are shown in Fig.4. As can be seen V_g rapidly decreases as hydrogen is admitted, with a response time around 60 seconds, and the interruption of the H_2-flux produces a slow recovery of the initial condition, since air is the background pressure. The maximum ΔV_{th} observed is around .6 V, a value that is in good agreement with previous experiments on c-Si Pd-gated MOSFET[8,11].

4. CONCLUSIONS

Top-gate a-Si:H TFTs have been fabricated by using Palladium as gate electrode. The electrical characteristics of these devices, although inferior to those relative to the bottom-gate structure, are still good enough for the application as hydrogen sensors. In fact, the devices respond correctly to the admission of small quantities of hydrogen in the surrounding atmosphere with a relatively fast time response, considering the room temperature operation.

The use of a higher temperature of operation (100 - 120 °C) could, in principle, improve the time response, reducing also the problems deriving from water adsorption on the Pd-gate. However, the instability of the threshold voltage becomes faster with increasing temperature[10]. In fact, threshold voltage shift under constant gate bias is still an open problem in the a-Si:H TFTs. A detailed study of instability mechanisms in our top-gate devices is in progress.

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