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# Characteristics of a New Resistive-Type Hydrogen Sensor

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## 1. Introduction

Due to the good linear property of electrical characteristics, the resistive-type gas sensors have been used extensively for applications in detecting high hydrogen concentration in percentage range at high operating temperature around 200-450$^{o}$C [1]. Generally, most of the reported resistive gas sensors utilize a change of surface conductivity produced by semiconducting oxide-based structures, e.g., $SnO_2$, ZnO, $WO_3$, and $In_2O_3$ [2]. Nevertheless, the considerable drawbacks of these devices are their insensitivity to lower hydrogen concentration below several thousand ppm level and lower operating temperature such as room temperature. Alternatively, the resistive devices based on different hydrogen-sensing mechanism allow the operating temperature close to room temperature, such as 3C-SiC, GaN resistive hydrogen gas sensor, and single-wall carbon nanotubes (SWNTs) with Pd [3-4]. In this work, a novel and interesting three-terminal-controlled active resistor-type hydrogen sensor, based on good properties in linear region of an AlGaAs-based pseudomorphic high electron mobility transistor (PHEMT) in combination with the catalytic Pd metal, is demonstrated. Comparing with the conventional resistive hydrogen sensors, this new Pd/oxide/AlGaAs resistive-type hydrogen sensor shows many advantages including low resistance, low voltage (<0.3 V), low detection limit of hydrogen concentration (<4.3 ppm $H_2$/air), low temperature operation, low power consumption, high conductance, large current variation (several mA level), high sensitivity, three-terminal-controlled active device, and easy integration with other devices.

## 2. Results and Discussion

The studied device was grown on a (100) oriented semi-insulated (S.I.) GaAs substrate by a metal organic chemical vapor deposition (MOCVD) system. The epitaxial structure consisted of a 5000 Å-thick GaAs undoped buffer, a 150 Å-thick undoped $In_{0.15}Ga_{0.85}As$ strained channel, a 45Å-thick undoped $Al_{0.24}Ga_{0.76}As$ spacer, a Si planar-doped sheet with the doping concentration of $\delta(n+) = 3x10^{12}cm^{-2}$ as a carrier supplier layer, a 200 Å-thick n-$Al_{0.24}Ga_{0.76}As$ ($n=3x10^{17}cm^{-3}$) Schottky contact layer, and a 600 Å-thick n+-GaAs ($n+=2x10^{18}cm^{-3}$) cap layer.

Figure 1 depicts the schematic cross section of the studied device. Under a small applied drain-source voltage $V_{DS}$, the current $I_D$ flows from the drain to source terminal through the channel. An equivalent circuit diagram is also illustrated in Fig. 1, where $R_S$ and $R_D$ are source and drain contact resistances, and $R_{ch}$ is the channel resistance which acts as a varistor.

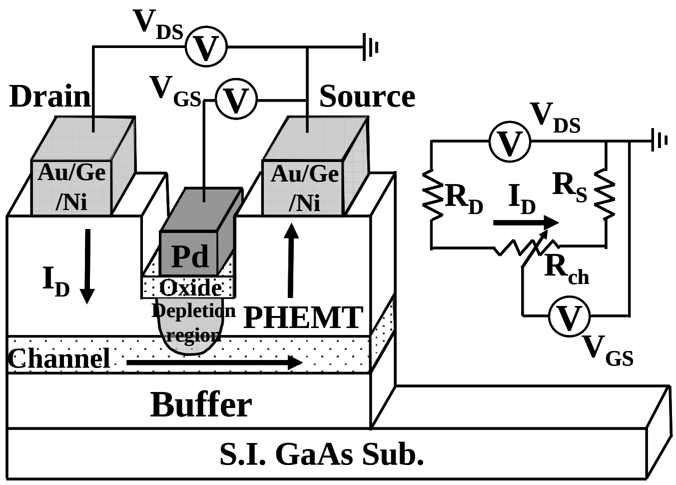


Fig. 1 Schematic cross-section and equivalent circuit of the studied resistive hydrogen sensor

Figure 2 shows the drain current $I_D$ versus drain-source voltage $V_{DS}$ in linear region at air and under different-concentration hydrogen species at 30$^{o}$C. The applied gate-source voltage $V_{GS}$ are 0, -0.3, and -0.6 V, respectively. The sensing mechanism of different applied $V_{GS}$ bias is based on the modulation of two-dimensional electron gas (2DEG) and channel resistance resulting from the polarization of dipolar layer and the lowering gate Schottky barrier which leads to the increment of drain current and reduction of resistance [5]. Clearly, with the modulation of gate-source voltage $V_{GS}$, the device can serve as a multi-scope varistor which shows the benefits of many operating points and controllable baselines to provide flexibility and controllability for specific requirements in hydrogen-sensing applications. As seen in Fig. 2, good linear properties and significant current variations are found for the studied resistor-like hydrogen sensor. Also, the current variation is proportional to drain-source voltage $V_{DS}$ in linear region. Even under a very low hydrogen concentration of 4.3 ppm $H_2$/air, the considerable current changes can be observed easily.

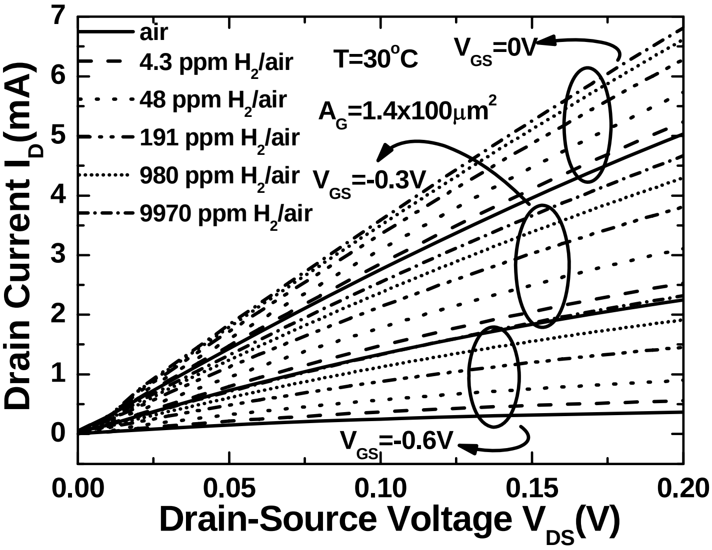


Fig. 2 Drain current $I_D$ versus drain-source voltage $V_{DS}$ in linear region of a PHEMT at air and under different-concentration hydrogen species at 30°C.

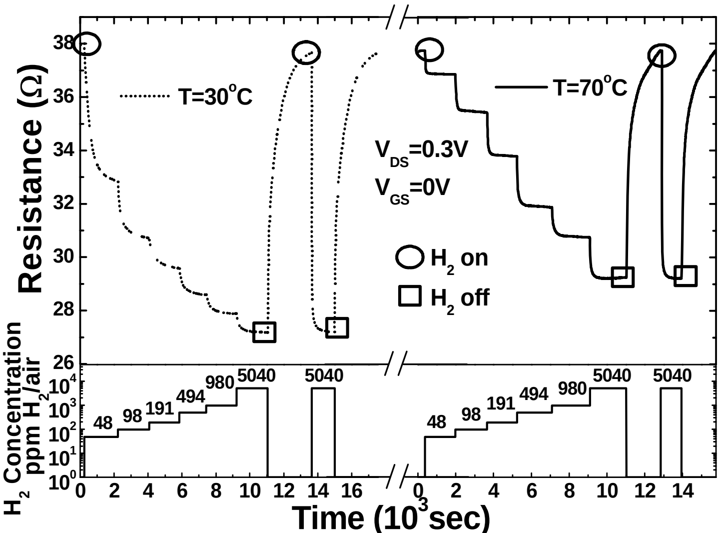


Fig. 3 The transient response curves in continuously varying hydrogen concentrations of the studied device at 30 and 70°C.

Figure 3 shows the transient response curves of the studied device at 30 and 70°C. The reduction of resistance is plotted as a function of time upon exposure to various hydrogen gases under the fixed biases of $V_{DS}$=0.3V and $V_{GS}$=0V. The hydrogen concentration is varied from 48 to 5040 ppm $H_2$/air without air purge between detection process to allow the desorption of hydrogen from the device surface. After finishing the detection process of the 5040 ppm $H_2$/air gas, the measurement cycle of this hydrogen gas is repeated once again to evaluate the reproducibility and stability of this work. Obviously, the reversible, repeatable and concentration-dependent response curves are observed as shown in Fig. 3. The response curves demonstrate larger resistance variation at room temperature. However, on the other hand, the remarkable plateau responses and shorter response time are found at 70°C. The reduction of resistance variation and response time can be attributed to the lower hydrogen coverage [6] and higher response rate at higher temperature [7]. This provides the potentiality in specific applications that require a hydrogen sensor to work reliably under a continuously varied $H_2$ atmosphere environment without purge cycle between the states of changing hydrogen concentrations [3]. The response time under the 5040 ppm $H_2$/air is only 28 s at 70°C.

## 3. Conclusion

In summary, a new resistive-type hydrogen sensing device based on the operation in linear region of a Pd/oxide/AlGaAs PHEMT is fabricated and studied. The studied device exhibits advantages of high detection sensitivity, small resistance, lower detection limit (<4.3 ppm $H_2$/air), low operating temperature (room temperature), and small operating voltage (<0.3V). It shows the reversible, repeatable, and concentration- dependent response curves. With proper integration with other devices, the studied resistive hydrogen sensor provides the promise for low-power GaAs IC and micro-electro-mechanical system (MEMS) applications.


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