Temperature Dependence of Sensing Properties of GaAs-Based Transistors with Metal-Semiconductor-Metal Hydrogen-Sensitive Sensors

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***Abstract*—In this paper, we address the temperature dependences of sensing properties of a GaAs-based bipolar transistor with a metal-semiconductor-metal hydrogen-sensitive sensor. Experimental results reveal that (1) response times obtained from the sensing base and collector currents in 0.01% H_2/N_2 are 350 s and 400 s at 50°C; (2) Only a power consumption of 0.25 to 1.25 μW is required in a standby mode; and (3) the sensing collector current gain in 1% H_2/N_2 is increased from 900 at 25°C to 1910 at 50°C, then to 2010 at 80°C and finally to 2890 at 110°C.**

Keywords-hydrogen; transistor; Schottky; sensor.

I. INTRODUCTION

Hydrogen has been widely used as an energy carrier, while its flammable and explosive properties make the safety an important issue. After the report on detection of hydrogen using a Si-based metal oxide semiconductor (MOS) structure [1], metal-semiconductor (MS) diodes and field-effect transistors (FETs) [2][4] combined with catalytic metals were employed as hydrogen-sensitive sensors. Commonly accepted sensing sequences for the MS-type sensors are as follows: the hydrogen molecules are adsorbed and dissociated at the metal surface, followed by forming a dipole layer at the MS interface. Therefore, a lowering of Schottky barrier height due to the dipole layer brings about an increased current [4]. However, these forward-biased MS-type sensors in a standby mode generally produce quite large power consumption. In this work, GaAs-based bipolar transistors were fabricated with MSM hydrogen-sensitive sensors to evaluate temperature dependence of sensing properties. Experiments and measurements about the proposed hydrogen sensor are described in Section II. In Section III, experimental results including key merits, such as sensitivity and response time, are addressed. Finally, conclusions are drawn in Section IV.

II. EXPERIMENTS

A GaAs-based transistor together with a MSM hydrogen-sensitive sensor was proposed in this work. Figure 1(a) shows cross sectional view of the proposed sensor. Structured parameters can be found in [5]. Fabrication of the GaAs-based transistor started with performing the emitter and the base mesas in the transistor region. The emitter, the collector, and the base Ohmic contacts were formed by depositing AuGeNi and AuZn upon the cap, the sub-collector and the base layers, respectively. The base-emitter and the base-collector junction areas are $A_E = 2.56\times10^{-4}$ cm^2 and $A_C = 1.76\times10^{-3}$ cm^2, respectively. The MSM hydrogen-sensitive sensor is fabricated with two Schottky electrodes formed by depositing a 30 nm Pd mixture on the collector layer. The sensing area of each multiple-finger electrode is 8×10^{-4} cm^2, resulting in a MSM structure with a diode current smaller than 5×10^{-8} A. Common-emitter current gains of our GaAs-based bipolar transistor are generally smaller than unity when the base current is smaller than 10^{-7} A. Thus, such small diode current will not be amplified by the GaAs-based bipolar transistor and low power consumption is expected for our sensor in a standby mode.

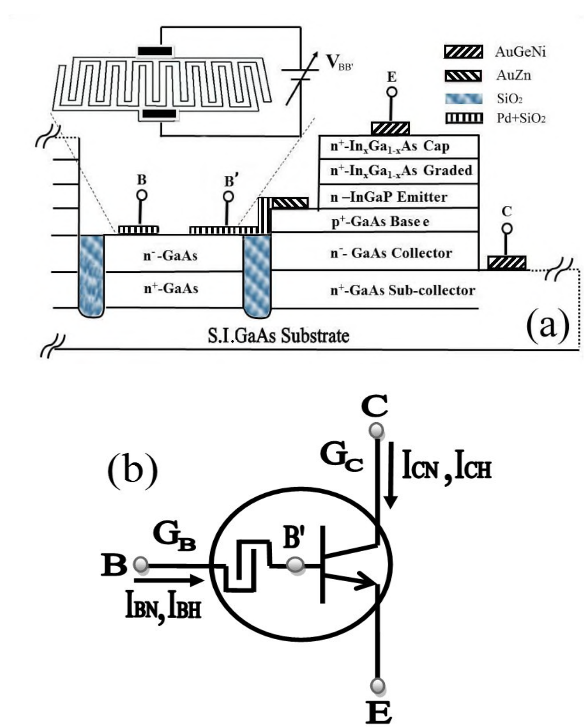

Figure 1. (a) Schematic cross-sectional view and (b) equivalent circuit symbol of the proposed hydrogen sensor.

Figure 1(b) shows an equivalent circuit symbol of the proposed sensor. In order to carry out our hydrogen detection, a custom-made, 235 ml flow-through test chamber was used. The test temperatures were at 25°C, 50°C, 80°C, and 110°C. Various hydrogen-containing gases with specific gas concentrations of 0.01% to 1% H_2/N_2 were employed at a flow rate of 500 sccm (Standard Cubic Centimeter per Minute). Static and dynamic sensing currents were measured using a HP semiconductor parameter analyzer.

III. RESULTS AND DISCUSSION

Response time is an important feature for a gas sensor. Figure 2 shows the transient current response of the proposed sensor, called hydrogen sensing transistor, to the introduction and removal of various hydrogen-containing gases at 50°C. The hydrogen sensing transistor is biased at V_{BE}=2 V and V_{CE}=5 V. Notice that I_{BN} (I_{CN}) and I_{BH} (I_{CH}) are the base (collector) currents in N_2 and hydrogen-containing ambiences, respectively. Due to limited measurements, the two transient currents were not recorded during the same run. The measured I_{BH} starts to increase at the time when a 1% H_2/N_2 gas is introduced. After saturation in the I_{BH}, air gas is used to completely remove the 1% H_2/N_2 and the I_{BH} returns to its baseline. Measurements were repeatedly performed in ambiences cycled from air/N_2 to other hydrogen-containing gases and then back to air/N_2. It is found that I_{BH} saturates at 2.84×10^{-6} A in 1% H_2/N_2 while I_{CH} is much larger (1.4×10^{-4} A). This is reasonable since I_{BH} is amplified by the GaAs-based transistor. We also find that t_as obtained from I_{BH} and I_{CH} depend on both hydrogen concentration and ambient temperature. The response times defined in [4] in 0.01% H_2/N_2 are 350 s and 400 s from I_{BH} and I_{CH} at 50°C. Obviously, the proposed sensor produces good repeatability since I_{BH} and ICH were not recorded at the same run while they respond well to various hydrogen-containing gases.

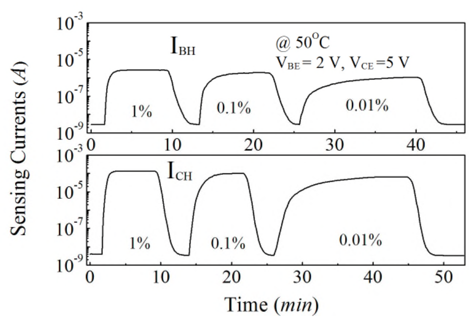

Figure 2. Transient current response of the hydrogen sensing transistorpure.

Figure 3 shows temperature dependences of sensing properties of the GaAs-based hydrogen sensing transistor. Basically, our hydrogen sensing transistor is formed by connecting the base electrode of the GaAs-based transistor with the MSM hydrogen-sensitive sensor. Eventually, the base current is mainly dominated by the MSM diode which has its current independent of biased voltage. Thus, a constant V_{BE} = 3.0 V is now employed to bias the hydrogen sensing transistor. Instead of a conventional base current, N_2 and various hydrogen-containing gases are now used as input signals while sensing collector currents (I_{CN} and I_{CH}) are employed as output signals. When the hydrogen sensing transistor is subjected into a N_2 ambience, it is in a standby mode. Figure 3(a) is indicative of I_{CN} = 0.05, 0.1, 0.15, and 0.25 µA at 25°C, 50°C, 80°C, and 110°C, respectively. Only a power consumption of 0.25 to 1.25 µW is required for our hydrogen sensing transistor. When the hydrogen sensing transistor is in a hydrogen-containing ambience, a dipole-induced current occurring in the MSM hydrogen-sensitive sensor will act as the base current (I_{BH}) that is then amplified by the GaAs-based transistor to I_{CH}. As a result, relative high static sensing collector currents are expected. Figures 3(b) to 3(d) show I_{CH} versus V_{CE} characteristics of the hydrogen sensing transistor subjected into various hydrogen-containing ambiences for 5-fold t_a. Experimental results reveal that I_{CH} in 1% H_2/N_2 at V_{CE} = 3.0 V is increased from 45 µA at 25°C to 191 µA at 50°C, then to 301 µA at 80°C and finally to 723 µA at 110°C. Estimated sensing collector current gains (G_C) are as high as 900, 1910, 2010, and 2890 for the hydrogen sensing transistor in 1% H_2/N_2 at 25°C, 50°C, 80°C, and 110°C, respectively. Even if the proposed sensor is in a 0.01% H_2/N_2 ambience, G_C = 360 (850) is still obtained at 25°C (110°C).

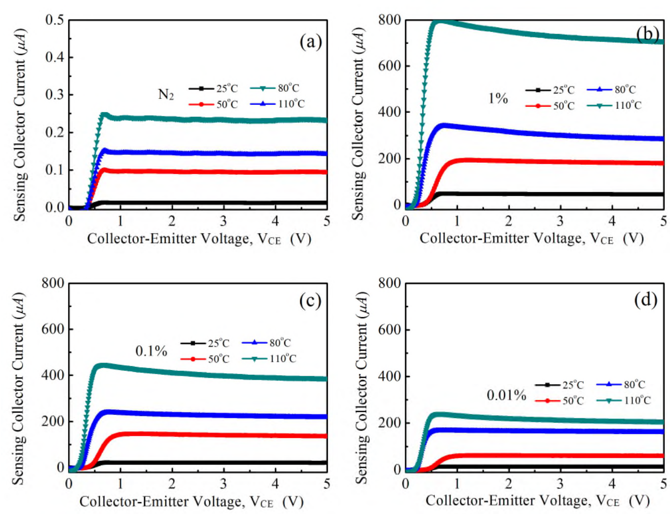

Figure 3. Sensing properties of the GaAs-based hydrogen sensing transistor at (a) 25°C, (b) 50°C, (c) 80°C, and (d) 110°C, respectively.

IV. CONCLUSIONS

Hydrogen sensing properties of a GaAs-based hydrogen sensing transistors in the common-emitter mode were studied. Hydrogen-containing gases, instead of the base currents were employed as input signals. Common-emitter characteristics (I_{CH} vs. V_{CE}) show sensing current gains of 900 and 2890 in 1% H_2/N_2 at 25°C and 110°C. Besides, a low detection limit of 100 ppm of the proposed sensor was also presented.

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