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Hydrogen-Sensing Behaviors of an InAlAs-Based Schottky Diode with a Pt Catalytic Thin Film

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1. Introduction

In recent years, hydrogen has been applied widely as an energy carrier. However, the flammable and explosive properties of hydrogen gas make the safety be an important issue. Thus, the development of hydrogen sensors to detect leaks and monitor gas purity has attracted much attention. Si-based hydrogen sensors [1-2] exhibit the advantages of low cost and highly matured techniques. Nevertheless, the III-V compound semiconductor-type Schottky diodes show some benefits including higher detection sensitivity, shorter response time, and higher operating temperature limit due to their wider bandgaps. For example, various semiconductor materials, such as GaAs [3] InP [4], AlGaAs [5] and InGaP [6], have been applied to detection of hydrogen or other gas for a long time. In this work, we report the planar fabrication and characterization of an interesting hydrogen sensor, based on a Pt/$In_{0.52}Al_{0.48}As$ metal-semconductor (MS) Schottky diode, with a thin Pt film. The used InAlAs material, with a larger bandgap than GaAs, is expected to exhibit high-sensitivity sensing capability and to increase the turn-on and breakdown voltage. It is known that the InAlAs material plays an important role on InP-based high electron mobility transistors (HEMTs) [7] for microwave applications. Therefore, the studied Pt/InAlAs device also provides the promise for practice integrated circuit (IC) and micro-electro-mechanical system (MEMS) applications.

2. Results and Discussion

The studied Pt/$In_{0.52}Al_{0.48}As$ Schottky diode was grown by a metal organic chemical vapor deposition (MOCVD) system on a (100) oriented semi-insulated (S.I.) InP substrate. Figure 1 depicts the schematic cross-section and SEM picture of the studied device. The epitaxial structure consisted of a 500-nm-thick InP undoped buffer layer and a 300-nm-thick n-$In_{0.52}Al_{0.48}As$ ($n=1\times10^{17}$ cm^{-3}) active layer. The Pt metal thickness in this work was about 5 nm.

Figure 2 illustrates the corresponding current-voltage (I-V) curves of the studied device under different hydrogen concentrations at 50, 90 and 160°C. The flowing rate is 500 cm^3/min at ambient pressure. It is observed that the studied device exhibits superior I-V properties with a large turn-on voltage and small reverse leakage current. The current substantially increases with increasing hydrogen concentration. This studied device exhibits significant hydrogen detecting capability under the applied bi-directional bias. At lower temperature, the current variation is smaller than that at higher temperature. Contrarily, the sensitivity at lower temperature is larger than that at higher temperature. Moreover, the current variation under reverse bias voltage is superior to that under forward bias voltage at 160°C.

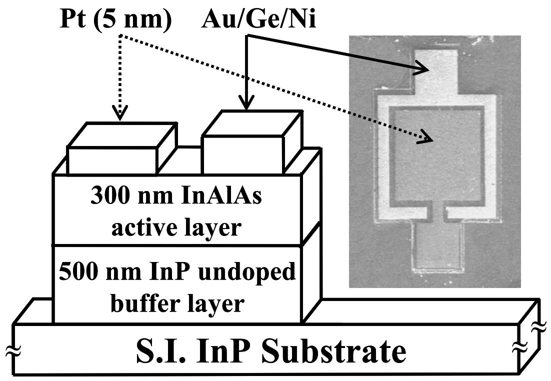

Fig. 1 Schematic cross section and SEM picture of the studied 5-nm-Pt/$In_{0.52}Al_{0.48}As$ Schottky diode-type hydrogen sensor.

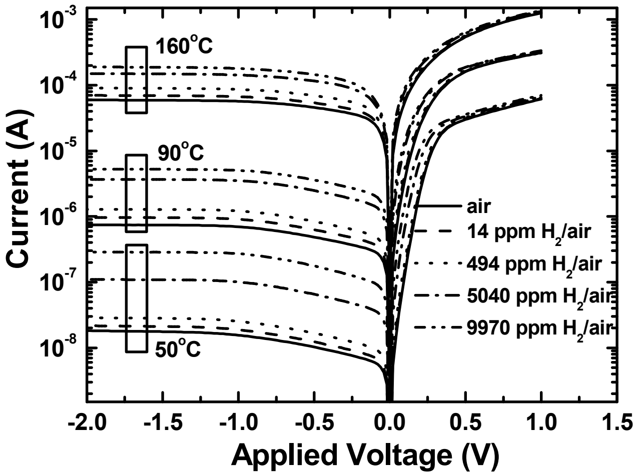

Fig. 2 Measured I-V characteristic curves of the studied 5-nm-Pt/$In_{0.52}Al_{0.48}As$ MS Schottky diode under different concentrations of hydrogen gases at 50, 90, and 160℃, respectively.

Figure 3 illustrates the Schottky barrier height variation ($\Delta\phi_b$) as a function of temperature under different hydrogen concentrations. The studied device exhibits a relatively large reduction of ϕ_b magnitude under high hydrogen concentration regime. The change of Schottky barrier height indeed confirms that the existence of a dipolar layer at the interface between Pt metal and semiconductor causes the modulation of electrical characteristics in a hydrogen-containing ambience. The Schottky barrier height variation $\Delta\phi_b$ is decreased from 100.0 to 8.7 meV in 9970 ppm H_2/air gas as temperature is increased from 30 to 200°C.

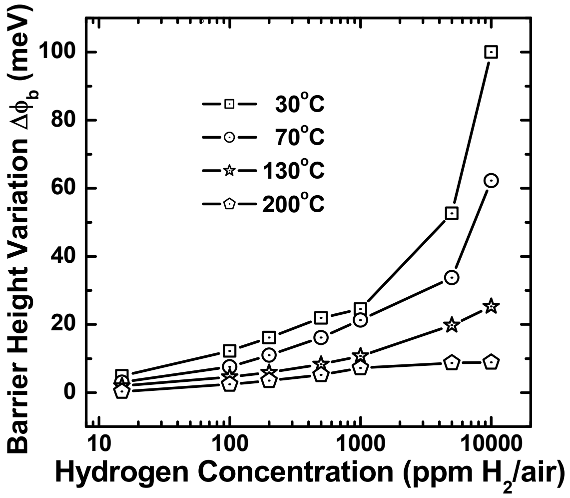

Fig. 3 Schottky barrier height variation ($\Delta\phi_b$) as a function of temperature with various hydrogen concentrations ranging from 14 to 9970 ppm H_2/air.

The relationship between the S_r(%) and the reverse bias under different hydrogen concentrations at 30°C is shown in Fig. 4. Under a constant bias voltage, the relative sensitivity ratio S_r(%) can be defined as:

$$S_r(\%) = \frac{I_{H_2} - I_{air}}{I_{air}} \times 100\% \quad (1)$$

Comparing with the S_r(%) values under forward bias in our measurements, the S_r(%) values is more stable and excellent under a wide reverse voltage range varied from -0.5 V to –5 V because of the small reverse leakage current and the large breakdown voltage. The S_r values substantially enhance by increasing the hydrogen concentration. This performance is an important factor for sensor applications.

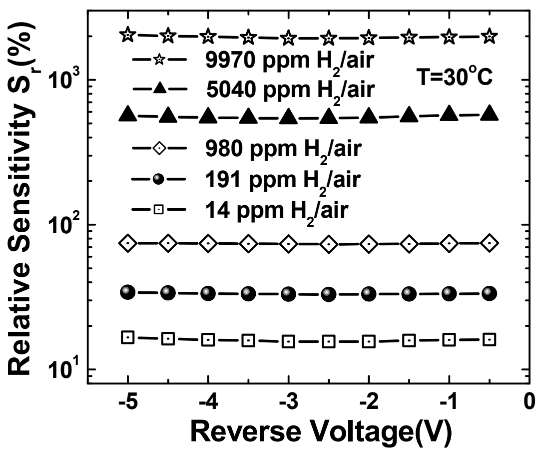

Fig. 4 Relationship between the relative sensitivity ratio S_r(%) and reverse bias under different hydrogen concentrations at 30°C

3. Conclusions

An interesting hydrogen sensor based on a Pt/$In_{0.52}Al_{0.48}As$ Schottky diode with a thin (5 nm) Pt catalytic metal has been studied and presented. Due to the inherent properties of Pt (high work function) and $In_{0.52}Al_{0.48}As$ (large bandgap), the studied device demonstrated the considerable benefits including lower hydrogen gas detection limit (<14 ppm H_2/air), higher sensitivity (~2000% in 9970 ppm H_2/air), wide operating temperature range ($\geq$200°C), and widespread reverse voltage operating regime (-0.5~-5 V). Therefore, based on the benefit of integration with InP-based devices, the studied sensor device provides the promise for high-performance hydrogen sensor, IC, and MEMS applications.

Acknowledgements

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