Journal of Applied Sciences

ISSN 1812-5654

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 10 (16): 1797-1801, 2010
ISSN 1812-5654

The Sensing Performance of Hydrogen Gas Sensor Utilizing Undoped-AlGaN/GaN HEMT

[1]Mazuina Mohamad, [1]Farahiyah Mustafa, [1]Shaharin Fadzli Abd Rahman, [1]Mastura Shafinaz Zainal Abidin,
[1]Nihad K. Ali Al-Obaidi, [1]Abdul Manaf Hashim, [2]Azlan Abdul Aziz and [2]Md. Roslan Hashim
[1]Material Innovations and Nanoelectronics Research Group,
Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia
[2]Nano-Optoelectronics Research Lab, School of Physics, Universiti Sains Malaysia,
11800 Minden, Penang, Malaysia

Abstract: High temperature operation and long term stability are important requirements for gas sensor. The response of Pt-circular Schottky diodes fabricated on undoped AlGaN/GaN high-electron-mobility-transistor (HEMT) structure to hydrogen gas at various temperatures, ranging from 25 to 200°C has been investigated. A 5 nm-thick of catalytic Pt Schottky contact is formed by electron beam evaporation. Both forward and reverse currents of the device increase upon exposing to hydrogen gas. Although a slight change of forward and reverse current is obtained at room temperature upon exposure to hydrogen but both currents drastically increase with the increase of temperatures. The time-transient characteristics show the average current increment and decrement speed of 27.6 and 17.6 nA sec^{-1}, respectively at constant forward bias of 1 V and temperature of 200°C.

Key words: Schottky diode, AlGaN/GaN, HEMT, gas sensor, hydrogen

---

INTRODUCTION

In view of increased use of fuel cells as a new clean and viable energy source to replace petroleum, hydrogen sensors are strongly demanded to avoid hazardous explosion. Since, so-called sensor networks are making a rapid progress, the sensor material is preferably a semiconductor which can realize an integrated on chip with ultra low power processing electronics and wireless RF circuit such as used for radio frequency identification (RFID) chip (Usami and Ohki, 2003). Until now, there have been many reports on chemicals sensors using metal-oxide compound semiconductors, such as SnO_2 and ZnO (Yamazoe and Miura, 1992; Morrison, 1982). However, the sensing mechanism of these compound semiconductors is related to various defects such as oxygen vacancy and metal vacancy.

High temperature operation and long term stability are important requirements for gas sensor. Silicon-based gas sensors cannot be operated above 250°C, preventing them for applications at high temperature (Luther *et al*., 1999). GaN and SiC based materials are known as wide-bandgap semiconductors that show great promise for electronic devices operating at high temperatures. Simple Schottky diode or field-effect-transistor structure fabricated on GaN and SiC (Casady *et al*., 1998) are sensitive to a number of gases, including hydrogen and hydrocarbons (Kim *et al*., 2003a). To make such gas sensors, a catalytic metal such as Pd or Pt can be used since they show stable sensing response and also suitable for high temperature operation.

AlGaN/GaN heterojunction has been shown to form a potential well and a two-dimensional electron gas (2DEG) at the lower heterointerface. These structures are well-known for possessing high electron mobility in the 2DEG channel, highest sheet carrier concentration among III-V material system, high saturation velocity, high breakdown voltage and good thermal stability. The expected advantages of using undoped-AlGaN/GaN compared to doped structures are; (1) lower gate leakage current, (2) lower pinch-off voltage and (3) less noise due to less impurities in AlGaN barrier layer. These are the reasons why many groups prefer non-modulation doped nitride HEMT structures (Rizzi and Lüth, 2002). In addition, higher mobility can be obtained by undoped-material compared to doped material. Therefore, it is expected to provide faster time-transient sensing response. The mobility of the studied material was confirmed to be two times higher than n-doped AlGaN/GaN structure reported in ref.

Corresponding Author: A.M. Hashim, Material Innovations and Nanoelectronics Research Group,
Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia
Tel: +607-553-6230 Fax: +607-556-6272

(Matsuo *et al*., 2005). The 2DEG concentration and mobility of the samples at room temperature are 6.61×10^{12} cm^{-2} and 1860 $cm^2/Vsec$, respectively.

In this study, the sensing characteristics of hydrogen gas sensor utilizing Pt/AlGaN/GaN HEMT structure studied at various temperatures are reported.

EXPERIMENTAL

An undoped-AlGaN/GaN HEMT structure used for hydrogen gas sensor is shown in Fig. 1. The AlGaN/GaN epitaxial layers are grown by metal organic chemical vapor deposition (MOCVD) on 430 μm-thick c-plane sapphire substrate. The epitaxial structures consist of a 25 nm-thick undoped AlGaN, a 2 μm-thick undoped GaN and a buffer layer.

Figure 2a and b shows the device structure fabrication after certain processes, the device fabrication process starts with 100 nm-thick SiO_2 deposition using plasma-enhanced chemical vapor deposition (PECVD) at 280°C with a $SiH_4/NH_3/He$ gas system to act as mesa patterning mask. Then, a mesa is formed by inductive-coupled plasma (ICP)-assisted reactive ion beam etching with a Cl-based gas system consisting of BCl_3, Cl_2 and Ar gases. The etching pressure is 5 mTorr and the etching rate is around 0.1 μm min^{-1}. Next, the removal of SiO_2 mask is carried out before ohmic contact formation.

The ohmic contacts are formed by deposition of Ti/Al/Ti/Au (20 nm/50 nm/20 nm/150 nm) multilayers followed by rapid thermal annealing at 850°C for 30 sec in N_2 ambient. After that, the device surface is covered with

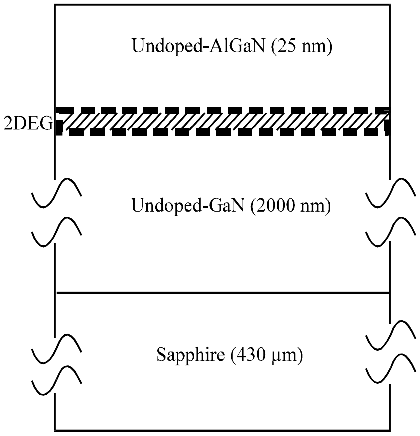

Fig. 1: Material structure used for hydrogen gas sensor

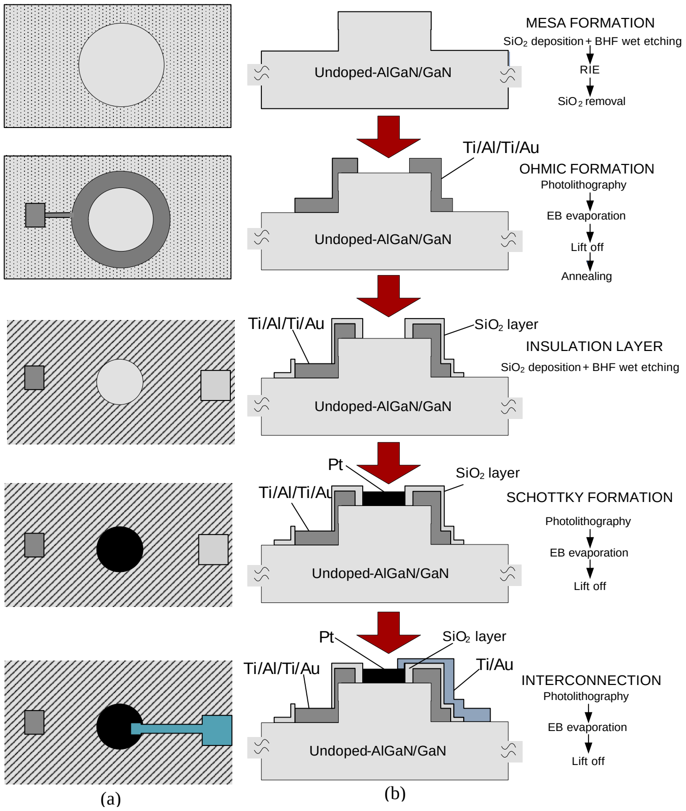

Fig. 2: Schematic structure after each step of fabrication process. (a) top view and (b) cross-sectional view

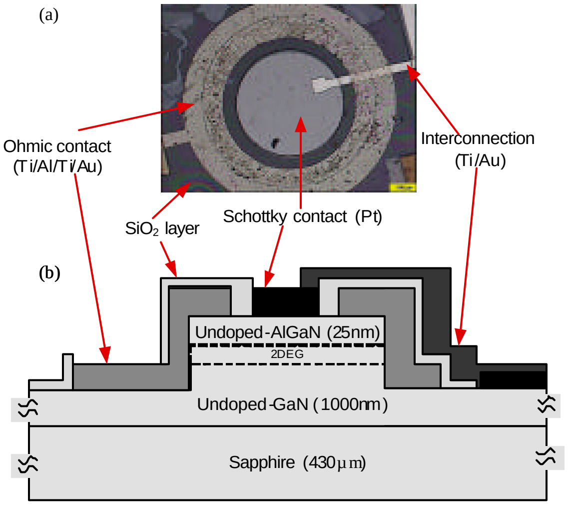

Fig. 3: (a) Fabricated device (top view) and (b) schematic of cross sectional device structure

300 nm-thick SiO_2 film using PECVD in order to realize a planar connection from circular Pt Schottky contact to external contact pad for electrical measurement purpose. Consequently, this SiO_2 dielectric layer at Schottky contact area is etched out using BHF etchant so that a Schottky contact can be formed on AlGaN surface. Then, Pt circular Schottky contact with a thickness of 5 nm and a diameter of 600 µm is formed by electron-beam evaporation. Finally, Ti/Au is deposited to form an electrical interconnection from Schottky contact to external circuit. The completed fabricated device is shown in Fig. 3.

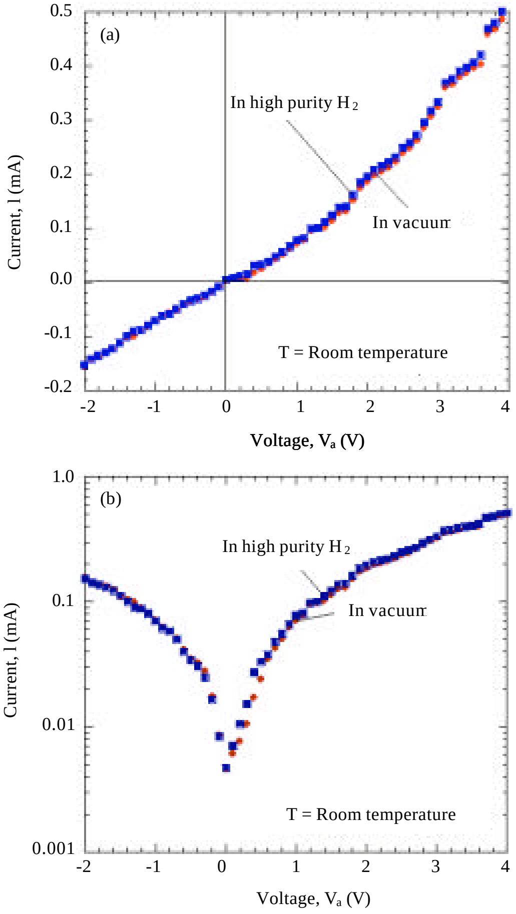

Fig. 4: I-V characteristics of fabricated gas sensor measured at room temperature in vacuum and high purity hydrogen ambient (a) linear and (b) semilog axes

THE SENSING PERFORMANCE

The current-voltage (I-V) measurement is carried out to evaluate the response to hydrogen gas. Typical I-V characteristics measured in vacuum and high purity hydrogen ambient at room temperature are shown in Fig. 4a and b. It can be understood here that the rectifying characteristics of fabricated diode degrade towards ohmic-like characteristics where large reverse currents are generated.

As shown in Fig. 4a and b, both the forward and reverse currents show a slight change of current upon exposure to hydrogen. The slight change of current may due to the diffusion rate for hydrogen atom through the catalytic metal is very slow at room temperature (Kim *et al*., 2003b). Thus, it can be said that the sensitivity of gas sensor is quite low at room temperature.

The responses of the fabricated diodes are also investigated at various temperatures ranging from room temperature to 200°C. As shown in Fig. 5, a large current

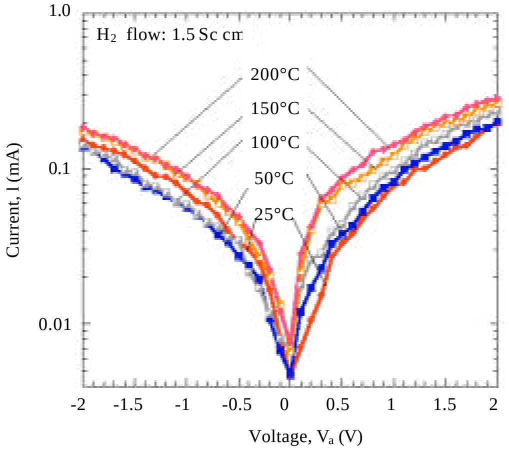

Fig. 5: I-V characteristics of fabricated gas sensor measured in high purity hydrogen ambient at room temperature, 50, 100, 150 and 200°C

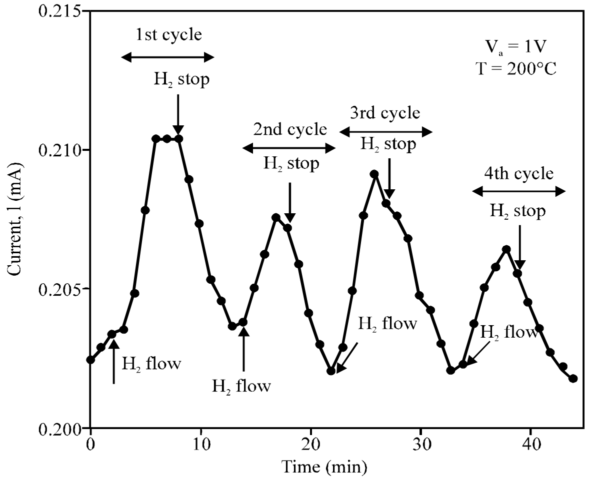

Fig. 6: The cyclic time response of current at T = 200°C and V = 1 V for the Pt/AlGaN/GaN Schottky diode

change by the same amount of H_2 concentration is observed as the temperatures increase up to 200°C. This change is considered to be due to more effective catalytic dissociation of H_2 on the Pt surface can be realized at higher temperature (Song *et al*., 2005). However, as shown in Fig. 4a and b, the device shows ohmic-like characteristics where large reverse currents are generated. We suggest that it should be a reason for discrepancy where the curve of reverse current measured at room temperature show higher values than reverse current measured at 50 and 100°C.

Figure 6 shows the time-transient response measured temperature of 200°C and forward bias, V_a of 1 V. It can be seen that there is sufficient cracking of H_2 for the diode to be a sensitive gas sensor. The slopes are very steep which show that the response of the sensor is relatively fast at each cycle. Figure 7 shows the increment and decrement speeds of current at each cycle. The data are extracted from the slopes at each cycle shown in Fig. 6. Constant speed is obtained at each cycle where the average of increment and decrement speed of current is estimated to be 27.6 and 17.6 nA sec^{-1}, respectively. These increment and decrement speeds of current correspond to the hydrogen adsorption and desorption rates, respectively. The increment speed is much faster than the decrement speed for each cycle meaning that the absorption of H_2 is faster than desorption. This is because a desorption process requires thermal energy supply, leading to a longer decrement time.

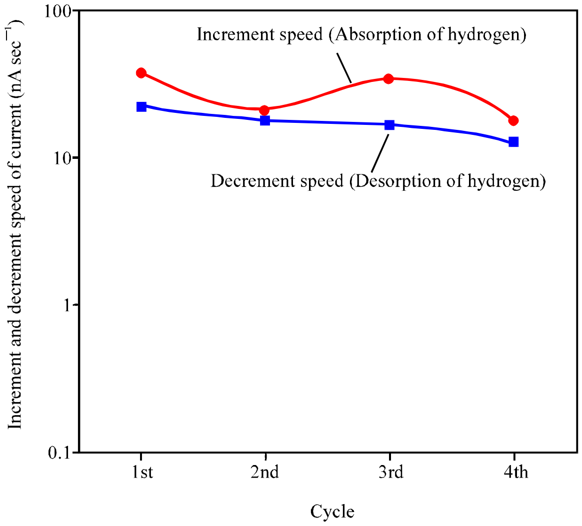

Fig. 7: Increment and decrement speed of current during absorption and desorption of hydrogen

CONCLUSION

Pt-circular Schottky diode was successfully fabricated for gas sensor application. Both the forward and reverse currents of the device increase upon exposure to hydrogen and both currents also increase with the temperature. This indicates that the diffusion rate for hydrogen atom through the Pt metal is enhanced with the increase of temperature. The time transient response shows a constant current increment and decrement speed for each cycle where the average of increment and decrement speed is estimated to be 27.6 and 17.6 nA sec^{-1}, respectively. The increment speed is much faster than the decrement speed for each cycle, meaning that the absorption process of H_2 is faster than desorption process.

ACKNOWLEDGMENTS

The authors wish to extend their thanks for the support provided by the Ibnu Sina Institute, Universiti Teknologi Malaysia and Nano-Optoelectronics Research Laboratory, Universiti Sains Malaysia. This work was supported by the Ministry of Science, Technology and Innovation under Science Fund Grant 03-01-06-SF0281. We wish to thank our colleagues for useful discussions, particularly, Assoc. Prof Dr. Zulkafli Othman at Universiti Teknologi Malaysia.

REFERENCES

Casady, J.B., A.K. Agarwal, S. Seshadri, R.R. Siergiej and L.B. Rowland *et al.*, 1998. 4-HSiC power devices for use in power electronic motor control. Solid State Electron, 42: 2165-2176.

Kim, J., B.P. Gila, G.Y. Chung, C.R. Abernathy, S.J. Pearton and F. Ren, 2003a. Hydrogen-sensitive GaN schottky diodes. Solid State Electron, 47: 1069-1073.

Kim, J., F. Ren, B.P. Gila, C.R. Abernathy and S.J. Pearton, 2003b. Reversible barrier height changes in hydrogen-sensitive Pd/GaN. Applied Phys. Lett., 82: 739-741.

Luther, B.P., S.D. Wolter and S.E. Mohney, 1999. High temperature Pt schottky diode gas sensors on n-type GaN. Sensorsr Actuators B: Chemical, 56: 164-168.

Matsuo, K., N. Negoro, J. Kotani, T. Hashizume and H. Hasegawa, 2005. Pt Schottky diode gas sensors formed on GaN and AlGaN/GaN heterostructure. Applied Surface Sci., 244: 273-276.

Morrison, S.R., 1982. Semiconductor gas sensors. Sensors Actuators, 2: 329-341.

Rizzi, A. and H. Lüth, 2002. III-V semiconductor interface properties as a knowledge basis for modern heterostructure devices. Applied Phys. A: Mater. Sci. Process., 75: 69-77.

Song, J., W. Lu, J.S. Flynn and G.R. Brandes, 2005. AlGaN/GaN Schottky diode hydrogen sensor performance at high temperatures with different catalytic metals. Solid State Electron., 49: 1330-1334.

Usami, M. and M. Ohki, 2003. The μ-chip: An ultra-small 2.45 GHz RFID chip for ubiquitous recognition application. IEICE Trans. Electron., E86-C: 521-528.

Yamazoe, N. and N. Miura, 1992. Some basic aspects of semiconductor gas sensors. Chem. Sensor Technol., 4: 19-42.