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Influence of Pt Gate Electrode Thickness on the Hydrogen Gas Sensing Characteristics of Pt/In_2O_3/SiC Hetero-Junction Devices

S. Kandasamy, *W. Gao, A. Holland, W. Wlodarski, *T. Katsube
Sensor Technology Laboratory, School of Electrical and Computer Engineering,
RMIT University, City Campus, GPO Box 2476V, Melbourne 3001, Victoria, Australia
*Katsube Research Laboratory, Department of Information and Computer Science,
Saitama University, 225 Simoookubo, Sakuraka Saitmasi, Saitamaken 338 8750, Japan
E-mail: sasikaran@ieee.org

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Abstract: Hetero-junction Pt/In_2O_3/SiC devices with different Pt thickness (30, 50 and 90nm) were fabricated and their hydrogen gas sensing characteristics have been studied. Pt and In_2O_3 thin films were deposited by laser ablation. The hydrogen sensitivity was found to increase with decreasing Pt electrode thickness. For devices with Pt thickness of 30 nm, the sensitivity gradually increased with increasing temperature and reached a maximum of 390 mV for 1% hydrogen in air at 530°C. Atomic force microscopy (AFM) analysis revealed a decrease in Pt grain size and surface roughness for increasing Pt thickness. The relationship between the gas sensing performance and the Pt film thickness and surface morphology is discussed. *Copyright © 2007 IFSA.*

Keywords: Hydrogen, Hetero-junction, Sensor, Pt, In_2O_3, SiC

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1. Introduction

Hydrogen is an excellent candidate for use as a clean and renewable source of energy. However its low mass and high diffusivity makes it difficult to store and transport. Also, it is highly flammable in concentrations exceeding 4% by volume. As a result, safety remains a top priority in all aspects of hydrogen usage. Thus the development of sensors for monitoring and detection of hydrogen is vital [1].

Indium oxide is a promising gas sensitive material as it has shown to respond to both oxidizing and reducing gases such as O_3 [2], NO_2 [3], CO [4] and H_2 [5]. Metal oxide silicon carbide (MOSiC) based gas sensors have been previously investigated [6]-[11]. These sensors consist of a thin catalytic transition metal layer such as platinum (Pt) or palladium (Pd), deposited on top of an oxide/insulating layer on SiC. Hydrogen molecules dissociate on the catalytic metal surface and the atomic species diffuse through the catalytic metal, forming a dipole layer at the metal-metal oxide interface resulting in a voltage drop. This voltage drop is seen as a shift in the current-voltage (*I-V*) characteristic of the device. The gas response is usually measured as a change in voltage when the device is held at constant current [12], [13].

In this paper, the influence of the Pt thin film thickness on the hydrogen gas sensing properties of Pt/In_2O_3/SiC hetero junction devices is studied. The device's sensitivity toward hydrogen was found to increase with decreasing Pt electrode thickness.

2. Experimental

The hetero-junction sensors were fabricated on n-type 6H-SiC wafers (Cree Research Co.) with a 10 μm thick epitaxial layer and donor concentration of $1.7\times10^{16}\text{cm}^{-3}$. Ni was thermally evaporated on the back side of the wafer and annealed at 800°C for 3min in vacuum to form an ohmic contact.

The In_2O_3 and Pt thin films were deposited by laser ablation. A Nd:YAG (λ=532 nm, 5-7 ns) source with an output power of 50-70 mW and laser repetition rate of 10Hz was employed to ablate the respective sources (both were 99.99% purity) at room temperature. The distance between the target and the source was 60 mm. The thickness of the resulting metal oxide (In_2O_3) thin film was 50~60 nm. Devices with different Pt electrode thicknesses (30, 50 and 90nm) were fabricated.

A multi-channel gas calibration system was used, that allowed the fabricated hetero-junction devices to be exposed to different concentrations (0.06, 0.125, 0.25, 0.5 and 1%) of hydrogen gas. The gas flow rate was kept constant at 0.2 litres/min and the operating temperature was varied (using a micro-heater) between 250 and 650ºC. Exposure to the analyte gases caused a change in the Schottky barrier height and hence a shift in the device's *I-V* characteristic. Thus, the response was measured as the change in voltage when the device was operated in constant current mode.

The voltage shift was recorded using a HP 33104A multi-meter and *I-V* characteristics were measured using a Keithley 2600 source meter. The grain size and surface roughness were examined using a NanoScope III Atomic Force Microscope (AFM) in taping mode.

3. Results and Discussion

Fig. 1 shows the *I-V* characteristics of a Pt/In_2O_3/SiC hetero-junction device (with a 30nm Pt electrode) operated at 530ºC for 0.2 and 1% hydrogen gas introduced into a synthetic air ambient. The slope of the curve in air (0% H_2) is larger when compared to that of hydrogen in air. Thus the series resistance component of the device is smaller in ambient containing hydrogen. At a constant current of 1mA, voltage shifts of 240 and 360 mV for 0.2 and 1% hydrogen were observed. The corresponding change in the effective barrier height was calculated to be 34.62 and 54.4 meV.

The voltage shifts of the Pt/In_2O_3/SiC devices with different Pt electrode thickness (30, 50 and 90 nm) btained when exposed to 1% hydrogen as a function of temperature are shown in Fig.2. The device with the 30 nm Pt layer shows a higher sensitivity when compared to devices with 50 and 90 nm Pt layers. This is attributed to the faster diffusion rate of atomic hydrogen through the thinner metal layer to reach the metal-metaloxide interface. In addition the rate of diffusion increases for increasing temperature. Thus the diffusion time of hydrogen across the catalytic metal film depends on the Pt electrode thickness. A similar dependence of hydrogen diffusion on Pt thickness for Pt/GaN Schottky diodes has been reported [14]. For devices with 30 nm thick Pt electrodes, the maximum voltage shift of 390 mV was observed for 1% hydrogen in air at 530°C. Devices with 50 and 90 nm of Pt also exhibited maximum voltage shift of 320 and 140 mV, respectively at 530°C. This clearly shows that the sensitivity of the hetero-junction devices increases with decreasing Pt thin film thickness.

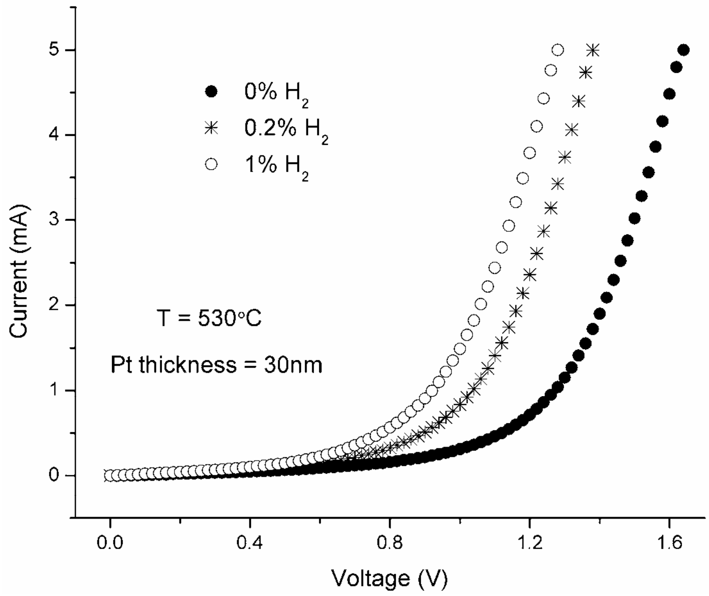

Fig. 1. *I-V* characteristics of a $Pt/In_2O_3/SiC$ device with a Pt film of 30nm at 530°C.

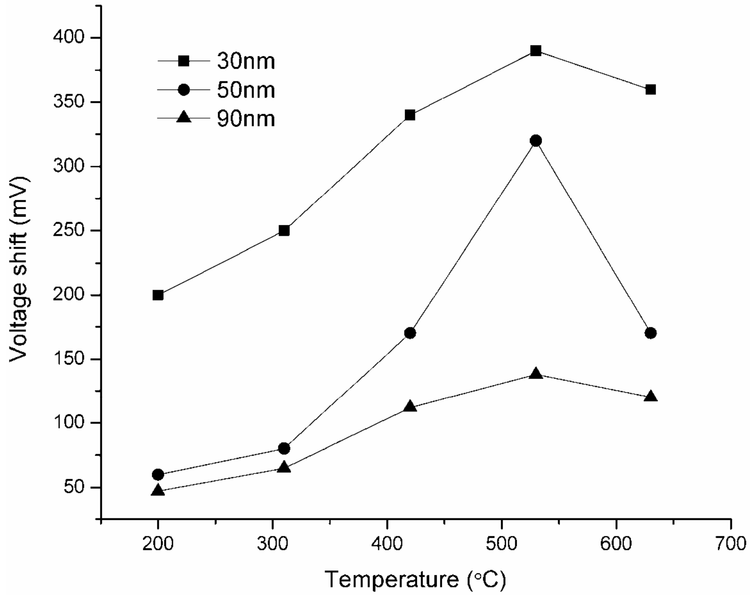

Fig. 2. Voltage shift of $Pt/In_2O_3/SiC$ hetero-junction devices with different Pt electrode thickness (30, 50 and 90 nm) as a function of temperature.

Fig. 3 shows the hydrogen response characteristics of a $Pt/In_2O_3/SiC$ hetero-junction device with a 30 nm thick Pt thin film electrode. The device was exposed to different hydrogen gas concentrations between 0.06 and 1% in an ambient containing synthetic air. The above response curves were obtained with fixed exposure and recovery times of 5 and 15 minutes, respectively. The voltage shifts for 0.06, 0.25 and 1% were 100, 250 and 390 mV respectively. Following each successive pulse, the sensor returned to the same baseline value, whereas the sensors with 50 and 90 nm thick Pt electrodes exhibited drift in their baseline voltage. In addition the sensor with a 30 nm Pt film showed excellent repeatability.

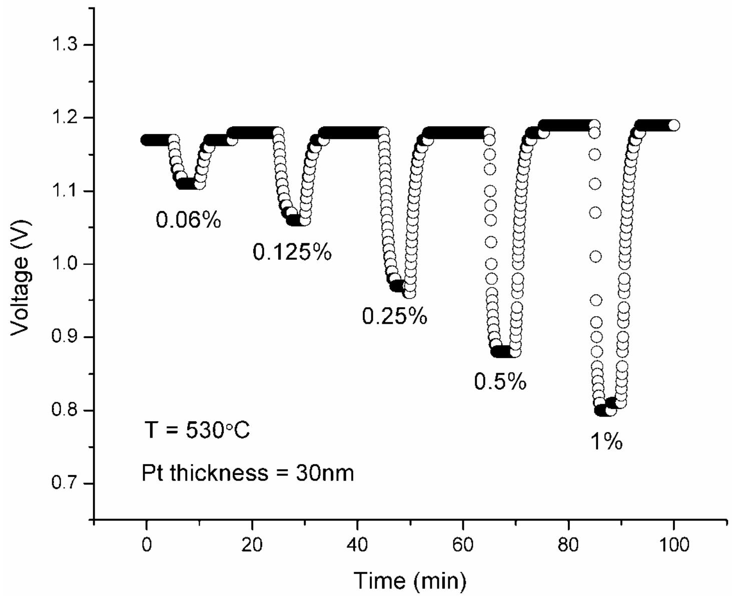

Fig. 3. Dynamic response characteristics of a Pt/In_2O_3/SiC hetero-junction device (with a 30 nm Pt thin film) operated at 530°C.

The hydrogen coverage ratio for different Pt gate electrode thickness as a function of hydrogen partial pressure when operated at 530ºC is compared in Fig.4. A linear relationship between coverage ratio and the square root of hydrogen partial pressure is clearly evident, illustrating a Langmuir-type adsorption of hydrogen gas [15], [16]. The maximum hydrogen coverage was found for the device with the thinnest Pt electrode (30 nm). This signifies the dependence of hydrogen surface coverage on the Pt electrode thickness, making the microstructural properties which include grain size, grain and thin film density, surface roughness and porousity of the Pt film of critical importance.

The AFM scan in Fig.5 show the three dimensional surface morphology of the Pt thin films deposited on In_2O_3/SiC. The surface of the 30 nm Pt thin film is composed of grain with dimensions between 10 and 20 nm and with a surface roughness of approximately 10nm, making them porous and granular in structure. The 50 and 90 nm thin films have grain dimensions ranging between 7-10, and 3-5 nm, respectively. The 90 nm thin film is compact with a smooth surface and uniform grain distribution. The surface roughness is about 2nm. The average grain size and the root mean square (RMS) surface roughness decreases as the thickness of the Pt thin film increases. The porosity and the grain geometry of the 30nm Pt thin film are believed to significantly affect the hydrogen sensing characteristics largely due to an increase in the specific surface area available for gas interaction. Thin film features such as grain density and grain size have been reported as reasons for increased sensitivity [14].

4. Conclusions

The hydrogen gas sensing properties of Pt/In_2O_3/SiC hetero-junction devices with different Pt electrode thicknesses have been studied. The device with 30 nm thick Pt thin films exhibited higher sensitivity, larger surface coverage ratio and smaller response time when compared to devices with 50 and 90 nm Pt films. The linear relationship between coverage ratio and the square root of hydrogen partial pressure illustrates Langmuir-type adsorption of hydrogen gas. The AFM analysis revealed that the average grain size and RMS surface roughness decreased for increasing thickness of Pt thin films. The increase in specific surface area due to grain size and surfaces roughness for thinner Pt thin films leads to a faster diffusion rate and thereby higher hydrogen response.

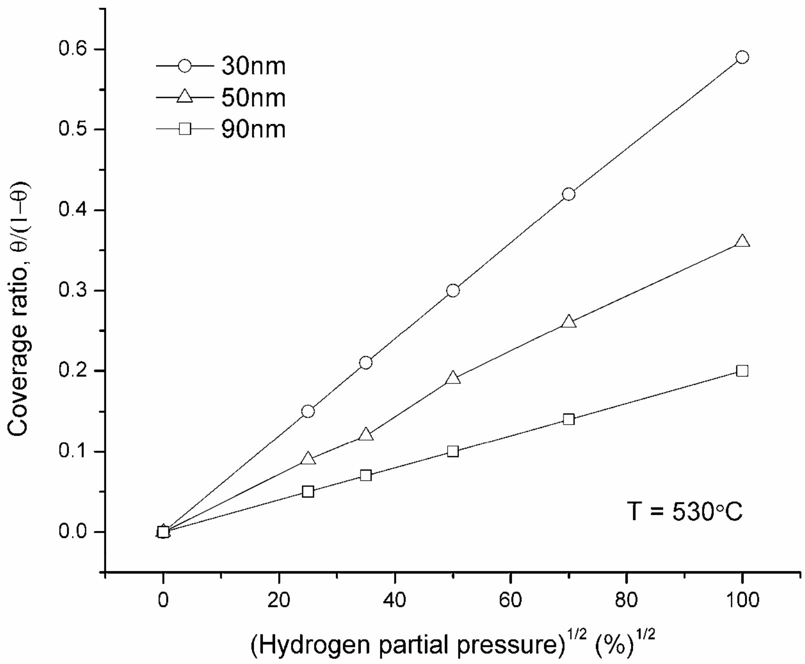

Fig. 4. Coverage ratio versus the square root of the hydrogen partial pressure at 530ºC

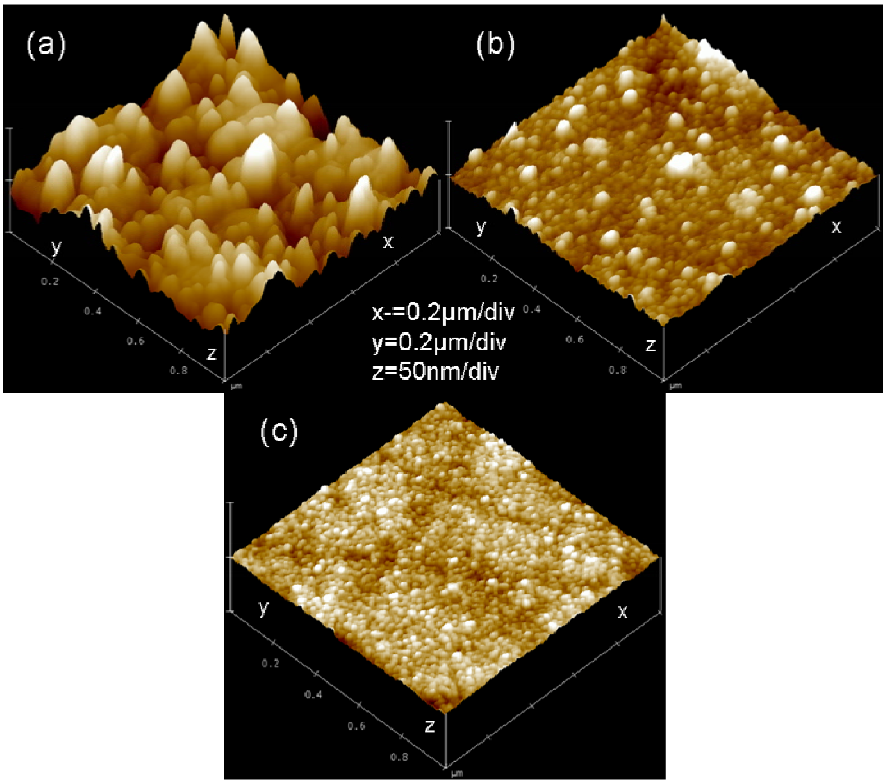

Fig. 5. AFM surface images of (a) 30, (b) 50 and (c) 90 nm of Pt thin films deposited on In_2O_3/SiC.

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Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726- 5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

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Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
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- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
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- Technologies and materials;
- Nanosensors;
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Contact Person

Susana Escriche
Fundació UPC. Edifici Vèrtex
Plaça Eusebi Güell, 6, 08034 Barcelona
Tel.: +34 93 401 08 94
E-mail: susana.escriche@fundacio.upc.edu

Course Instructor

Prof. Sergey Y. Yurish,
Centre de Disseny d'Equips Industrials (CDEI),
Universitat Politecnica de Catalunya (UPC-Barcelona)
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