INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 39 (2014) 20313–20318

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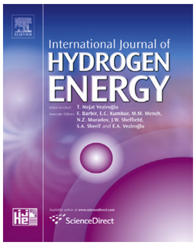

Hydrogen sensing characteristics of Pd/SiO_2-nanoparticles (NPs)/AlGaN metal-oxide-semiconductor (MOS) diodes

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ARTICLE INFO

Article history:
Received 22 August 2014
Received in revised form
30 September 2014
Accepted 4 October 2014
Available online 25 October 2014

Keywords:
Nanoparticles NPs
MOS
Schottky barrier height
Sensing response
Specific surface area

ABSTRACT

A Pd/SiO_2-nanoparticles (NPs)/AlGaN metal-oxide-semiconductor (MOS) structure is used to fabricate interesting Schottky diode-type hydrogen sensors. The employment of SiO_2-NPs could effectively increase the specific surface area of Pd catalytic metal and the Schottky barrier height. Good hydrogen sensing performance is obtained. Experimentally, as compared to a conventional Pd/AlGaN MS diode, a significant 34.5-fold improvement on hydrogen sensing response is obtained under an introduced 1% H_2/air gas at 300 K when a 10 wt% concentration of SiO_2-NPs is employed in the studied device. Yet, the increase in SiO_2-NP concentration relatively deteriorates the ability to detect very low hydrogen concentration levels ($\leqq$1 ppm H_2/air). In addition, the increase in SiO_2-NP concentration creates a decrease and increase on response and recovery time constants of transient behaviors, respectively.

Introduction

It is known that leakage detection of specific gases into the environment, e.g., CO, NO_2, NO, NH_3, H_2S, and H_2, is an important issue for chemical industries, semiconductor fabrications, laboratories, etc. Recently, based on its benefits of renewable, sustainable, and clean properties, hydrogen has become one of the candidates for replacement of petroleum fossils to develop friendly environments [1,2]. However, hydrogen gas is dangerous due to its inherent autoignition and explosive nature when the hydrogen concentration is greater than 4.65 vol% [3]. Therefore, in order to *in-situ* detect and monitor hydrogen leakages, the development of high-performance hydrogen sensors is important and indispensable.

Over the past years, different types of hydrogen gas sensors, e.g., metal-oxide-semiconductor (MOS), surface acoustic wave, optical fiber, resistor, field-effect transistor, and Schottky diode, have been widely fabricated and studied [4–6]. Compared to Si-based devices, an AlGaN/GaN-based material system shows advantages of a wide energy

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http://dx.doi.org/10.1016/j.ijhydene.2014.10.022

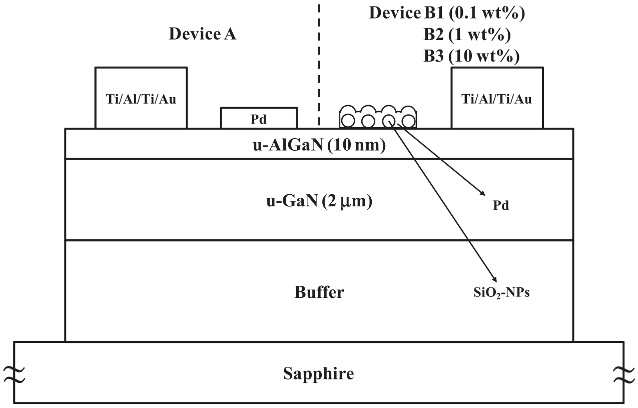

Fig. 1 – Schematic cross section of Devices A, B1, B2 and B3.

bandgap, high chemical stability, and operational capability in high-temperature environments [7–10]. Moreover, the AlGaN/GaN heterostructure demonstrates a high-density two-dimensional electron gas (2-DEG) due to its piezoelectric and spontaneous polarizations [11,12]. The AlGaN/GaN material system, with excellent characteristics of a high electron saturation velocity, high electric field breakdown and high thermal conductivity, provides a promise for high-power and high-frequency electronic devices and high-performance gas sensing applications [7–12].

Generally, for Schottky diode-type hydrogen sensors, a key factor of the sensing action is the adsorption of hydrogen molecules on the catalytic metal (e.g., Pd, Pt) surface under a hydrogen-contained ambience [13,14]. Thus, the morphology of a Pd (Pt) surface determines the number of active adsorption sites and plays a crucial role in sensing performance. In recent years, nanostructures, e.g., nanorod, nanotube, nanosphere, and nanofiber, have been widely studied and reported [15–18]. It is well known that nanostructures could produce larger surface-to-volume ratios and increase surface adsorption sites [15]. Therefore, the employment of nanostructures is expected to cause improved gas sensing performance. In this work, Pd/SiO_2 nanoparticle (NPs)/AlGaN metal-oxide-semiconductor (MOS) Schottky diode-type hydrogen sensors are fabricated and investigated. The related hydrogen sensing properties and temperature-dependent behaviors of the studied devices are presented.

Experimental procedure

The schematic diagrams of studied Pd/SiO_2-NPs/AlGaN MOS Schottky diode-type hydrogen sensors are shown in Fig. 1. These samples were grown on a 2-in c-plane sapphire substrate by a metal organic chemical vapor deposition (MOCVD) system. The epitaxial structure included a buffer layer, a 2 μm-thick undoped GaN layer, and a 10 nm-thick undoped $Al_{0.3}Ga_{0.7}N$ active layer. After epitaxy, mesa isolation was performed by an inductively-coupled-plasma reactive ion etching (ICP-RIE) system. Ohmic contacts were produced by evaporating 10 nm/150 nm/10 nm/100 nm-thick Ti/Al/Ti/Au metals sequentially followed by a rapid thermal annealing (RTA) process at 900 °C for 4 min in an N_2 atmosphere. Then, SiO_2-NPs with different concentrations of 0.1, 1, and 10 wt%, dispersed in a methanol solution, were spin-coated on Schottky contact regions. A 20 nm-thick catalytic Pd metal was evaporated to form the desired Schottky contact with an effective area of 2.05×10^{-3} cm^2. Finally, 150 nm-thick Au pads were made for the electrical feed-through. The studied Pd/SiO_2-NPs/AlGaN Schottky diode-type hydrogen sensors, with different concentrations of 0.1, 1, and 10 wt% of SiO_2-NPs, were denoted as Devices B1, B2 and B3, respectively. For comparison, a conventional Schottky diode-type hydrogen sensor, fabricated by the same process only without the employment of SiO_2-NPs, i.e., the Pd/AlGaN metal-semiconductor (MS) contact structure, was also included in this study and denoted as Device A, as shown in Fig. 1.

Results and discussion

Fig. 2(a) and (b) show SEM images of SiO_2-NPs (1 wt%) coated on an AlGaN surface without and with Pd metal passivation, respectively. The average particle size without Pd passivation (Fig. 2(a)) was 72.7 ± 7.3 nm whereas the other one (Fig. 2(b)) was 87.4 ± 9.7 nm. It is known from Fig. 2(b) that a uniform Pd metal passivation on the surface of SiO_2-NPs was obtained. Fig. 3(a), (b), and (c) show SEM images on surfaces of Pd/SiO_2-NPs/AlGaN structures with SiO_2-NPs concentrations (C_{SiO_2}) of 0.1, 1, and 10 wt%, respectively. Clearly, the blank area was reduced with the increase of C_{SiO_2}. Therefore, the effective Pd/SiO_2-NPs/AlGaN MOS and Pd/AlGaN MS areas in a Pd/SiO_2-NPs/AlGaN MOS diode are increased and decreased,

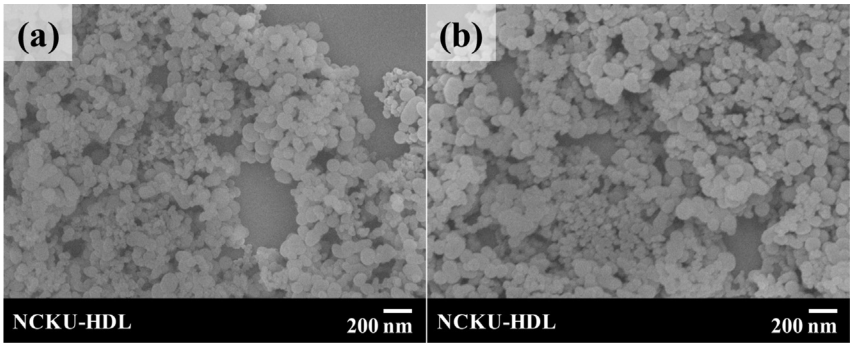

Fig. 2 – SEM images of SiO_2-NPs (C_{SiO_2} = 1 wt%) (a) without and (b) with a Pd passivation layer.