Available online at www.sciencedirect.com
ScienceDirect
Solid-State Electronics 51 (2007) 1018–1022
SOLID-STATE ELECTRONICS
www.elsevier.com/locate/sse

A hydrogen leakage detection system using self-powered wireless hydrogen sensor nodes

J. Jun [a], B. Chou [a], J. Lin [a], A. Phipps [a], X. Shengwen [a], K. Ngo [a], D. Johnson [a], A. Kasyap [a], T. Nishida [a], H.T. Wang [b], B.S. Kang [b], F. Ren [b,*], L.C. Tien [c], P.W. Sadik [c], D.P. Norton [c], L.F. Voss [c], S.J. Pearton [c]

[a] Department of Electrical and Computer Engineering, University of Florida, Gainesville, FL 32611, United States
[b] Department of Chemical Engineering, University of Florida, Gainesville, FL 32611, United States
[c] Department of Materials Science and Engineering, University of Florida, Gainesville, FL 32611, United States

Received 27 August 2006; accepted 30 May 2007

The review of this paper was arranged by Prof. Y. Arakawa

Abstract

A self-powered wireless hydrogen sensor node has been designed and developed from a system level approach. By using multi-source energy harvesting circuitry such as scavenged or "reclaimed" energy from light emitting and vibrational sources as the source of power for commercial low power microcontrollers, amplifiers, and RF transmitters, the sensor node is capable of conditioning and deciphering the output of hydrogen sensitive ZnO nanorods sensors. Upon the detection of a discernible amount of hydrogen, the system will 'wake' from an idle state to create a wireless data communication link to relay the detection of hydrogen to a central monitoring station. Two modes of operation were designed for the use of hydrogen detection. The first mode would sense for the presence of hydrogen above a set threshold, and alert a central monitoring station of the detection of significant levels of hydrogen. In the second mode of operation, actual hydrogen concentrations starting as low as 10 ppm are relayed to the receiver to track the amount of hydrogen present.

Keywords: Wireless; Self-powered; Hydrogen sensing system; Remote sensing

1. Introduction

There is currently great interest in the development of hydrogen sensors for applications involving leak detection in hydrogen fuel storage systems and fuel cells for space craft [1–4]. One of the most important aspects desired by the end user for such a sensor is – the ability to selectively detect hydrogen at room temperature with the presence of air in the ambient. In addition, for most of these applications, the sensors are also required to have very low power consumption and minimal weight. Due to the intrinsic characteristics of nanostructures, they naturally become formidable candidates for this type of sensing. Since the power requirement for operating the sensor is extremely small, the sensor and a leakage detecting transmitting system can be run off of energy harvesting devices.

ZnO-based nanorods have many unique characteristics which make them fundamentally appropriate candidates for the sensing of hydrogen. ZnO is a material currently used in the detection of pH, humidity, UV light, and gas, and has shown to change resistance with respect to both temperature and hydrogen exposure [5–8]. Because of its wide bandgap of 3.2 eV, the ease of synthesizing nanostructures, the availability of heterostructures, and the bio-safe characteristics of this material, ZnO is a most

* Corresponding author.
E-mail address: ren@che.ufl.edu (F. Ren).

0038-1101/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.sse.2007.05.019

attractive material for the specific sensing application at hand. With ZnO nanorods placed in an array, as a gas sensor, they are able to create a larger chemically sensitive surface-to-volume ratio which is needed for high sensitivity in hydrogen sensing. ZnO nanorods can also be produced cheaply, and are highly compatible with other microelectronic devices [9–11].

In this paper, we report a ZnO nanorods-based hydrogen sensing system which consists of nanorod sensor, solar and vibrational energy harvesting devices with power management circuits, a sensor interface, microcontroller, and the RF front end of the sensor system. The design and optimization of the detection circuitry, digital processing considerations, and modulation scheme to maintain an accurate and reliable system with a minimal amount of energy scavenged will be discussed.

2. Sensor device fabrication

ZnO nanorods were grown by nucleating on a Al_2O_3 substrate coated with Au islands. For nominal Au film thicknesses of 20 Å, discontinuous Au islands are realized after annealing. The nanorods were deposited by molecular beam epitaxy (MBE) with a base pressure of 5×10^{-8} mbar using high purity (99.9999%) Zn metal and an O_3/O_2 plasma discharge as the source chemicals. The Zn pressure was varied between 4×10^{-6} and 2×10^{-7} mbar, while the beam pressure of the O_3/O_2 mixture was varied between 5×10^{-6} and 5×10^{-4} mbar. The growth time was ~2 h at 600 °C. The typical length of the resultant nanorods was 2–10 μm, with typical diameters in the range of 30–150 nm.

Contacts to the multiple nanorods were formed using a shadow mask and sputtering of Al/Ti/Au electrodes. The separation of the electrodes was ~30 μm. To enhance the device's sensitivity to hydrogen, catalytic coatings or dopings of Pt or Pd were used to further increase the ZnO nanorods hydrogen sensing mechanisms. Au wires were bonded to the contact pad for current–voltage (*I–V*) measurements.

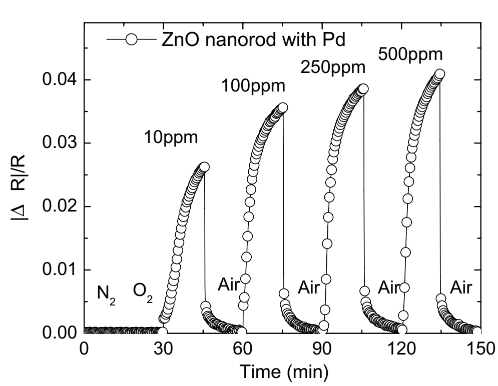

Fig. 1. Transient response of Pd coated ZnO nanorods for different hydrogen dopings.

3. Results and discussion

Fig. 1 shows the transient response to different dopings of hydrogen for ZnO nanorods coated with Pd. Note that no currents were measured through the discontinuous Au islands and no thin film of ZnO on the sapphire substrate was observed with the growth condition for the nanorods. Therefore, the measured currents were due to transport through the nanorods themselves. The *I–V* characteristics from the multiple nanorods were linear with typical currents of 0.8 mA at an applied bias of 0.5 V.

The challenge in designing the interface between a sensor and the analog-to-digital (A/D) converter of a system was to obtain an accurate real world signal with the limitations of low power and reduced voltage swings. Given that the ZnO nanorod's initial response to any exposure of hydrogen was distinct and immediate, this intrinsic characteristic served as an ally for the successful detection of hydrogen. Since the ZnO nanorod's resistance changed with respect to how much and how long the device has been exposed to hydrogen, the most popular and accurate way of detecting resistance changes was through the use of Wheatstone Resistive Bridges, as illustrated in Fig. 2a. The main objective of the Wheatstone Resistive Bridge stage is to detect the differences in resistance between a ZnO nanorod and a passivated ZnO nanorod. The passivated ZnO nanorod was encased with silicon nitride. By using a passivated ZnO nanorod encased in glass to be the resistor, only the resistance changes caused by exposure to hydrogen was detected, and not from other variables such as temperature. With no hydrogen present, the passivated and exposed ZnO nanorods were similar in resistance, and the output voltage of our sensor to A/D converter

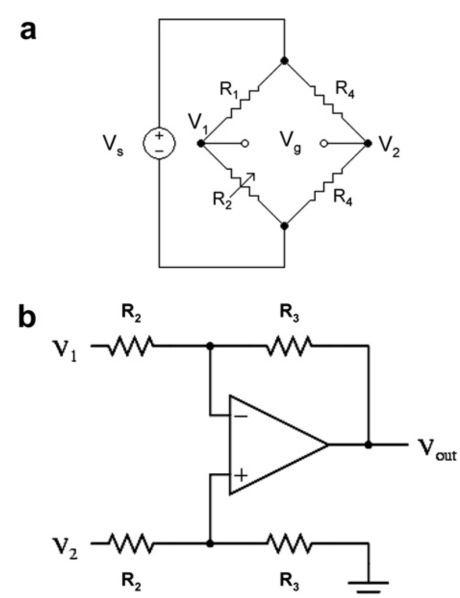

Fig. 2. (a) Circuit schematics of a Wheatstone Resistive Bridge and (b) circuit schematics of a difference amplifier.