Available online at www.sciencedirect.com
SCIENCE DIRECT®
Sensors and Actuators B 114 (2006) 334–343
SENSORS AND ACTUATORS B CHEMICAL
www.elsevier.com/locate/snb

Hysteresis compensation of a porous silicon relative humidity sensor using ANN technique

Tariqul Islam [1], Hiranmay Saha *

IC Design and Fabrication Center, Department of E.T.C.E., Jadavpur University, Kolkata 700032, India

Received 17 January 2005; received in revised form 27 May 2005; accepted 27 May 2005
Available online 3 August 2005

Abstract

This paper presents a simple technique based on well-known multilayer perceptron (MLP) neural network with back propagation training algorithm for compensating the significant error due to hysteresis in a porous silicon relative humidity sensor. The porous silicon humidity sensor has been fabricated, and its hysteresis with increasing and decreasing relative humidity has been determined experimentally by a novel phase detection circuit. Simulation studies show that the artificial neural network (ANN) technique can be effectively used to compensate the hysteresis of the porous silicon sensor for relative humidity (%RH) measurement. A hardware implementation scheme of the hysteresis compensating ANN model using a micro-controller is also proposed. Simulation studies show that the maximum error is within ±1% of its full-scale value.
© 2005 Elsevier B.V. All rights reserved.

Keywords: Humidity sensing; Porous silicon humidity sensor; Hysteresis effect; Compensation of hysteresis effect using ANN; Hardware implementation of ANN model

1. Introduction

Recent advancement in miniaturization especially in silicon micro technology has encouraged researchers to develop miniaturized humidity sensors. Miniaturization of sensors and actuators offers general advantages with respect to batch fabrication and reduction of cost. The requirements for good humidity sensors for practical applications are (i) good sensitivity over a wide range of humidity and temperature; (ii) short response time; (iii) good reproducibility; (iv) very small hysteresis; (v) negligible temperature dependence and; (vi) low cost. Today most of the humidity sensors are based on capacitive technique [1]. Since the discovery of the photoluminescence property of porous silicon in 1990, researchers have shown increasing interest to develop gas or vapour sensors using porous silicon (PS) materials [2–3]. The porous silicon is an electrochemical derivative of crystalline silicon, which has many useful properties for sensor applications. It has sponge-like structure with pore dimensions varying from nano to micro to meso. It offers very high surface to volume ratio and its morphology and pore structures can be engineered for high sensitivity and selectivity to water molecules [3]. Along with high sensitivity and selectivity to water vapour, it also offers good response time [3]. Due to its high surface to volume ratio, it adsorbs a larger amount of foreign molecules on to its surface when exposed to an ambient having certain concentration of water vapors. These vapors molecules after adsorption, diffuse into the porous bulk and get condensed in the pores having a radius smaller than the Kelvin radius [4]. Vapors or gases penetrating into its pores can affect several physical properties of PS such as conductivity, dielectric constant and photoluminescence. Based on the conductivity and dielectric constant changes, many vapour or gas sensors have been developed [5,6]. Though PS has potential in developing CMOS compatible humidity sensors, it does not draw much attention for commercial applications.

* Corresponding author. Tel.: +91 33 24146217; fax: +91 33 24146217.
E-mail addresses: tariq940@rediffmail.com (T. Islam), hsaha@vsnl.net, juicc@vsnl.com (H. Saha).
[1] On leave from Electrical Engineering Department, J.M.I., New Delhi 110025, India.

0925-4005/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.snb.2005.05.022

This is due to highly oxidizing nature of the PS layer. A freshly prepared PS layer can easily get oxidized in the normal atmosphere replacing Si–H bonds with Si–O bonds. The result is the slow formation of a SiO_2 layer around the voids. Thus, with the passage of time, the pore morphology of PS will be changed and in developing PS humidity sensors, it is difficult to fulfill all the requirements for good sensors such as nonlinearity, reproducibility, environment effect, aging and hysteresis [7]. Piecewise linearization of the response for a PS humidity sensor using hardware circuitry has been reported [2]. The temperature error compensation using refreshing resistors around the PS sensor layer has been reported with some success [8]. Very recently, a technique based on artificial neural network (ANN) was proposed to compensate the temperature error of a porous polysilicon relative humidity sensor [9]. However, to the best of our knowledge, the problem of hysteresis in the porous silicon humidity sensor has been reported but no acceptable and better practically feasible solution to fix the problem has been suggested [10].

This paper addresses issues of hysteresis effect on the performance of a PS humidity sensor. The sensor with time rate independent hysteresis error has been output, which depends not only on the input but also on its previous trajectory. Ideally the sensor should have no hysteresis. A typical thermally carbonized porous silicon relative humidity sensor has the maximum hysteresis of approximately 30% [7]. The hysteresis is a common problem in humidity sensor application based on adsorption. It is related to pore structure, pore morphology and how the presence of moisture changes this geometry. Very large hysteresis was observed without compensation because of improper out-diffusion of water from the porous layer [10]. In several ways one can minimize the hysteresis error such as widening the pore size in PS structure by changing the formation parameters. Pores of large dimensions (greater than 5 nm) should reduce the response time, but sensitivity of the sensor is also affected [7,11]. Another method, by integrating a thermo resistor, might solve the hysteresis problem partly [1,10,12]. The continuous refreshing by heating of the sensing layer reduces the hysteresis but also decreases the sensitivity [10]. However, the heating element for hysteresis effect compensation will change the long-term stability due to changes of capacitance and resistance of the sensor. Another possible solution is the storing of the correction factors in the form of lookup table in the memory of a micro-controller corresponding to each output of the humidity sensor. This correction factor should be added or subtracted from the sensor output for increasing %RH. Recently, a new approach based on artificial neural network was proposed for compensating the hysteresis error of a magneto resistive sensor [13]. Both ascending and descending characteristics of the sensor are modeled by ANN and by comparing sensor's present output voltage with previous output the magnetic field intensity H has been obtained from the corresponding ANN model [13]. Compensation of the hysteresis error of an accelerometer for telemedicine application using ANN has also been proposed [13,14]. This paper presents a technique based on ANN to compensate the hysteresis error for porous silicon relative humidity sensor. Though in principle, it can be utilized for any sensor, presently it is applied for a PS humidity sensor since the hysteresis problem is more pronounced for the PS humidity sensor working on the adsorption and desorption principle.

Artificial neural network is now a well-known technique for modeling the sensor behavior to approximate functional relationship between input and output of a sensor [14–17]. The features, which make ANN suitable are that they can be trained to learn any function, provided that enough information is given during training process coupled with judiciously selected neural models. This self-learning ability of the ANN eliminates the use of complex mathematical analysis. The inclusion of a semilinear sigmoidal activation function in the hidden layer neurons offers a nonlinear mapping ability for approximating the nonlinear hysteresis behavior of a porous sensor. Another interest of the ANN model is that the model parameters can be updated on-line to accommodate changing operating conditions. For modeling the sensor behavior for hysteresis compensation, a multilayer perceptron (MLP) ANN structure with %RH and the actual sensor output corresponding to the case of decreasing RH are used as input to the MLP, while the sensor output corresponding to the increasing RH is used as desired output of the sensor. The free parameters of the MLP structure such as weights are adjusted iteratively so that input and output can be mapped accurately. The free parameters will be used to estimate the output of the sensor for decreasing RH. A hardware implementation scheme of the ANN model is also discussed.

2. Humidity detection with porous silicon and its fabrication

2.1. Sensing of humidity

The working principle of porous silicon based capacitive humidity sensor is that water molecules are first adsorbed from the environment into the porous layer, then water molecules diffuse into the porous sheet, stick randomly at the surface and condense in all micropores with a radius smaller than the Kelvin radius. The condensed water vapour in porous layer leads to a change in dielectric constant as well as conductivity of the porous layer and hence the capacitive impedance of the layer changes as a function of the moisture uptake, which is directly related to the ambient moisture concentration. The sensitivity, linearity and response time of these sensors are the function of the morphology, the thickness of the dielectric, and also the geometry of the contacts [2,6].

2.2. Fabrication of PS sensor

The porous silicon moisture sensor has been fabricated on a polished silicon wafer ($2.5\,cm \times 2.5\,cm \times 0.5\,mm$), with

Download English Version:

https://daneshyari.com/en/article/751777

Download Persian Version:

https://daneshyari.com/article/751777

Daneshyari.com