Ultrasonics 52 (2012) 747–752

Contents lists available at SciVerse ScienceDirect

Ultrasonics

journal homepage: www.elsevier.com/locate/ultras

ZnO thin film with nanorod arrays applied to fluid sensor

Walter Water [a,b,*], Shih-En Chen [b], Teen-Hang Meen [a,b], Liang-Wen Ji [b]

[a] Department of Electronic Engineering, National Formosa University, Yunlin 632, Taiwan
[b] Institute of Electro-Optical and Materials Science, National Formosa University, Yunlin 632, Taiwan

ARTICLE INFO

Article history:
Received 6 July 2011
Received in revised form 1 February 2012
Accepted 1 February 2012
Available online 15 February 2012

Keywords:
Zinc oxide
Nanorod arrays
Love wave
ST-cut quartz
Fluid sensor

ABSTRACT

A ZnO guiding layer with nanorod arrays grown on a 90°-rotated ST-cut (42°45) quartz substrate was used to fabricate a Love wave fluid sensor. ZnO nanorod arrays synthesized on the guiding layer enhance the sensitivity of the flow rate. ZnO thin films were deposited by radio frequency magnetron sputtering and ZnO nanorod arrays were then synthesized on the thin films via the hydrothermal method. The crystalline structure and surface morphology of ZnO thin films and nanorod arrays were examined by X-ray diffraction and scanning electron microscopy. The effects of the thickness of ZnO thin film and the surface morphology of ZnO nanorod arrays on the sensitivity of flow rate were investigated. A linear response between flow rate and the return loss of the sensor with one-port resonator type can be obtained by adjusting the thickness of ZnO thin film and the length of nanorod arrays.

1. Introduction

Surface acoustic wave (SAW) devices have been applied to a broad spectrum of sensors, including photo sensors, liquid sensors, gas sensors, pressure sensors, temperature sensors, biosensors, and flow sensors, due to their high sensitivity, high accuracy, low cost, and simple structure [1,2]. SAW devices can also be used to make zero-power remote wireless devices and applied to moving or harsh environments [3,4]. The sensing mechanism of SAW devices uses the interactions between the surface acoustic wave and physical, chemical, or electrical variations in the environment. A sensing layer is important for collecting and amplifying the targeted variations and enhancing sensitivity. However, in liquid environments, longitudinal bulk modes, Rayleigh surface waves, and most Lamb-wave modes cannot propagate due to strong radiation loss. SAW-based sensors that use shear horizontal (SH-SAW) polarized mode, thickness shear mode (TSM), shear horizontal acoustic plate mode (SH-APM), and Love mode have been applied in liquid environments [1].

A Love wave is a guided SH-SAW. Love wave sensors can be designed to have the highest sensitivity among acoustic sensors due to the wave guiding effect [5]. Love waves propagate in a structure consisting of a substrate and a guiding layer. The acoustic waves generated in the substrate are coupled with the surface guiding layer. In order to obtain the high sensitivity of a Love wave sensor, the guiding layer must have a low shear velocity and low acoustic absorption and the substrate must have the SH-SAW polarized wave mode and a high shear velocity [6]. The ZnO/90°-rotated ST-cut (42°45) quartz structure has been employed in Love wave liquid sensors because it has good temperature stability and the surface skimming bulk wave (SSBW) generated by the substrate has a relatively high shear velocity in SH-SAW modes [7,8]. ZnO nanorods have much larger length-to-diameter and surface-to-volume ratios than those of ZnO bulks and ZnO films. Arrays of one-dimensional (1-D) ZnO nanorods have attracted attention due to their piezoelectrical, photoelectrical, and semiconductor properties [9–15]. ZnO nanorods can be synthesized using various approaches, such as metal organic chemical vapor deposition [16], magnetron sputtering [17], vapor–liquid–solid process [18], and the hydrothermal method [19–21]. The hydrothermal method has a low synthesis temperature (<100 °C) and a simple process, and it produces ZnO nanorods of excellent quality.

A guiding layer with a rough surface or nanorods has been shown to enhance Love wave sensor sensitivity [22,23]. The nanorods increase the interaction between the propagating wave and surface perturbations of the liquid, but excessively long nanorods induce strong radiation loss and have no sensing ability. This study utilizes the one-port resonator element to analyze the reflecting wave (S_{11}). Nanorod arrays are used to enhance the reflecting wave. The effects of nanorods morphology on the sensitivity and response function of the flow rate were investigated.

* Corresponding author at: Department of Electronic Engineering, National Formosa University, Yunlin 632, Taiwan. Tel.: +886 5 6315640; fax: +886 5 6315643.

E-mail address: wwater@nfu.edu.tw (W. Water).

0041-624X/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.ultras.2012.02.001

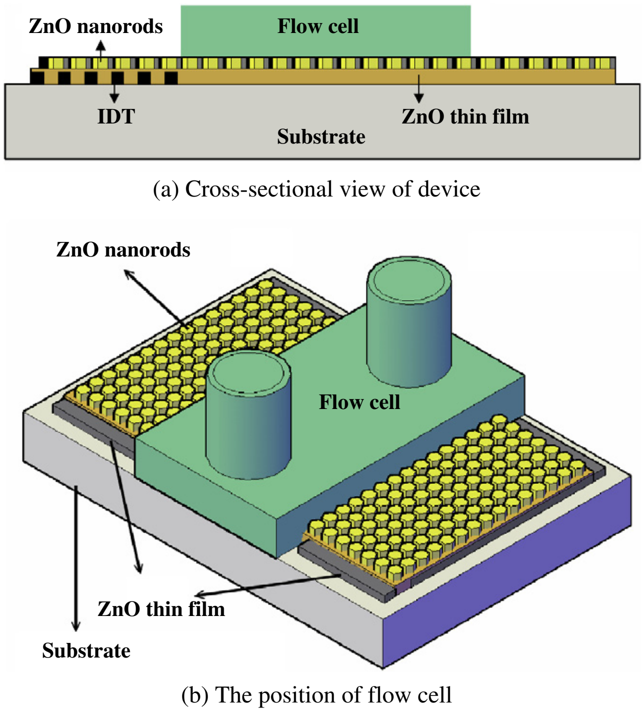

Fig. 1. Structure of Love wave device and flow cell.

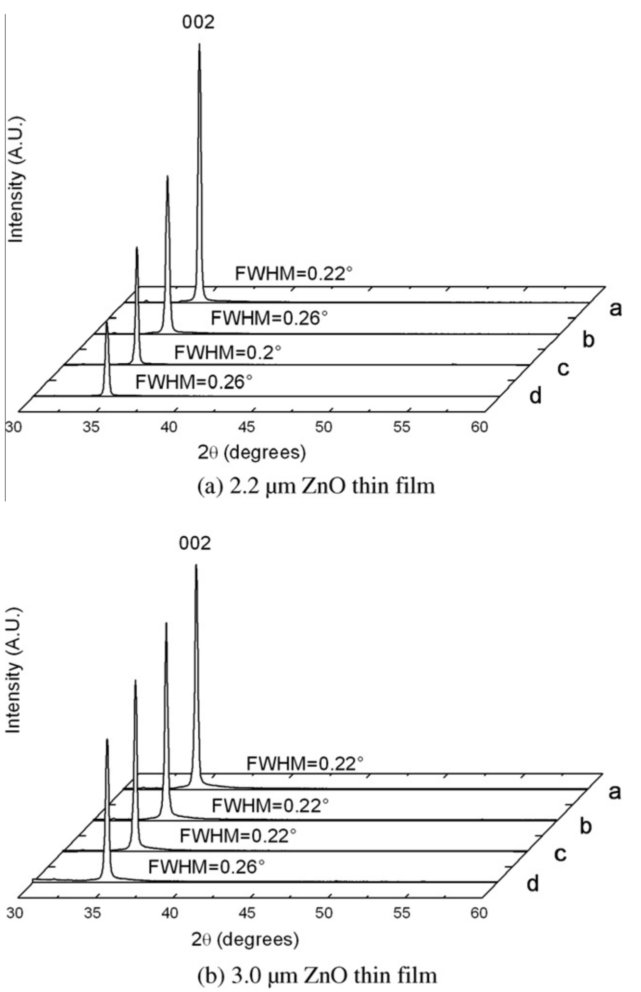

Fig. 2. X-ray diffraction patterns of pure ZnO film (a-line), ZnO film with nanorods synthesized for 3 h (b-line), ZnO film with nanorods synthesized for 6 h (c-line), and ZnO film with nanorods synthesized for 12 h (d-line).

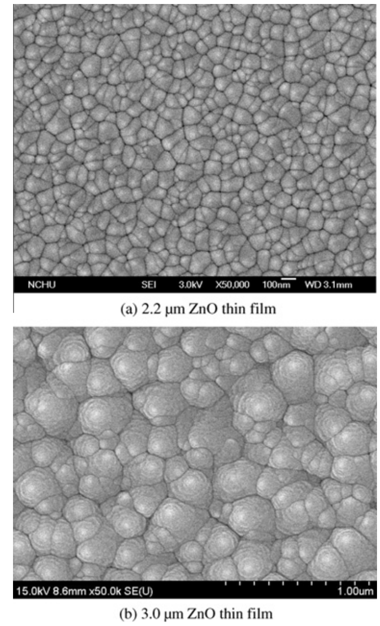

Fig. 3. Surface SEM images of ZnO films with thicknesses of 2.2 and 3.0 μm.

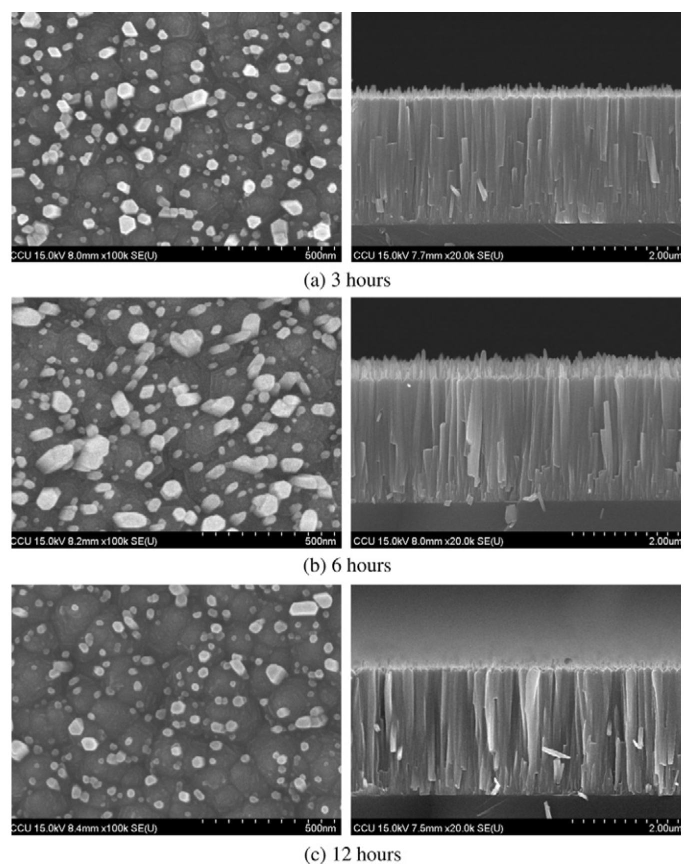

Fig. 4. SEM images of ZnO nanorods grown on 2.2-μm-thick ZnO films for (a) 3 h, (b) 6 h, and (c) 12 h.

2. Experimental details

Love wave devices were fabricated on a 42°45 ST-cut quartz substrate with a propagation direction perpendicular to the crys-