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The influence of calcium doped ZnO films on Love wave sensor characteristics

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Abstract

The effects of different concentrations of Ca doped ZnO films crystalline structure on Love wave sensor characteristics were investigated in this research. Calcium doped ZnO films with *c*-axis preferential orientation have been grown on the ST-cut quartz substrate by RF magnetron sputtering technique. Crystalline structures and surface characteristics of films were examined by X-ray diffraction (XRD), scanning electron microscopy (SEM) and atomic force microscopy (AFM); the sensitivity, electromechanical coupling coefficient, dielectric constant, and temperature coefficient of frequency of devices were measured. Sensor sensitivity increases obviously with increasing of Ca dopants but the sensitivity will be reduced when Ca over-doped.

Keywords: ZnO; ST-cut quartz; Love wave; RF magnetron sputtering technique

1. Introduction

In recent years, research on bio-sensors has sprung up, and using acoustic wave devices for both physical and chemical analysis in liquid environment has become a trend [1–11]. In a liquid environment, longitudinal bulk wave, Rayleigh wave and most Lamb waves have a strong radiation loss. Love waves which are SH-polarized guided waves, can be designed to show one of the highest sensitivities among all known acoustic sensors due to the waveguiding effect [4,6]. The condition for the existence of Love wave is that the shear velocity in the layer should be smaller than the shear velocity in the substrate. The overlay material must have a low shear velocity and a low acoustic absorption. The high sensitivity of Love-mode sensors is due to the fact that the phase velocity of the layer is much smaller than that of the substrate [4–6]. Leaky waves of 36° YX-$LiTaO_3$ and surface skimming bulk waves of ST-cut quartz have been used as substrates; typically ZnO, fused silica (SiO_2), and polymethylmethacrylate (PMMA) have been used to construct the layered structure for the Love wave sensor. PMMA shows high acoustic losses as well as poor chemical and temperature resistance. Sensor with ZnO film guiding layer have higher sensitivity than fused silica (SiO_2) [10,11], due to the shear velocity of ZnO being smaller than SiO_2.

ZnO shows a wide range of scientific and technological applications [12–14]. ZnO films have also widely been used in acoustic devices due to their strong piezoelectric effect [15,16]. ZnO films can be deposited by various techniques; such as sol–gel process [17], spray pyrolysis [18], molecular beam epitaxy (MBE) [19], chemical vapor deposition (CVD) [20], and magnetron sputtering technique [21–25]. Sputtering is the most commonly technique used to obtain good orientation and uniform films which can have a single-crystal morphology even when deposited on an amorphous substrate or at a low substrate temperature.

ZnO thin films have been widely investigated and applied in communication devices, but only few reports regards Love wave sensor [10,11]. It has been experimentally demonstrated that a rough surface increases the resonant frequency shift, due to the inertial contribution of the liquid mass rigidly coupled to the surface and the additional viscous energy dissipation caused by the nonlaminar motion in the liquid [26–28]. At the same thickness, a sensor with rough and porous guiding layer has a higher sensitivity than smooth and dense guiding layer [11]. The influ-

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ence of fluorine doped SiO_2 guiding layer on mass sensitivity of Love-mode sensor has been reported by Harding [29]. It is the motivation of this paper to investigate the crystalline structures and the roughness of the ZnO film with different concentrations of Ca dopants. The effects of Ca concentrations on the performance of ZnO guiding layer for Love wave sensor applications will be evaluated.

2. Experimental

ZnO films were deposited by RF magnetron sputtering system using a ZnO target (99.9%). Ca doped ZnO targets prepared by adding $CaCO_3$ (99.5% Wako) and firing at 900 °C for 3 h. The substrates were thoroughly cleaned with organic solvents and dried before loading in the sputtering system. The chamber was pumped down to 1.5×10^{-5} Torr using a diffusion pump before introducing the premixed Ar and O_2 sputtering gases. Throughout all experiments, the target was presputtered for 15 min under 150 W RF power before the actual deposition began, in order to remove any contamination on the target surface and make the system stable and reach optimum condition. The sputtering parameters are listed in Table 1.

The crystalline structure and the orientation of the ZnO films were investigated by X-ray diffraction (Rigaku Dmax 2000). The power of the XRD (Cu Kα radiation) was fixed at 40 kV and 30 mA and the XRD diffraction angles (2θ) were measured from 20° to 60°. Surface morphology of ZnO films were investigated by scanning electron microscopy (Hitachi S-4700) and atomic force microscopy (DI D3100) techniques.

The Love wave devices were fabricated on 12 mm × 13 mm and 0.5 mm thick 42°45′ ST-cut quartz substrate with propagation direction perpendicular to the crystallographic *x*-axis. The input and output IDTs consisted of 30 finger pairs with electrode width of 10 μm and separation of 10 μm, i.e. a periodicity of 40 μm. The IDT aperture was 4 mm and the center-to-center separation of the IDTs was 6.2 mm. The structure and pattern of the Love-mode device are shown in Fig. 1. The IDTs were made of 200 nm sputtered aluminum. The quartz devices support surface skimming bulk waves (SSBW) with 126 MHz center frequency. An network analyzer (Agilent 8722) was used for device characterization.

Theoretical analyses and experimental results have shown that the maximum sensitivity of Love wave sensor depends on the optimum ratio of guiding layer thickness and wave length [4–6,10,11]. The optimum ratio in our system is about 0.05 (2 μm), and the thickness of ZnO films in our experiments is about 2 μm. The center frequencies of Love wave sensors are 110–112 MHz and the phase velocities are 4400–4480 m/s.

Table 1
Sputtering parameters

Parameter	
Target composition	ZnO, concentration (0–10 mol%), dopant (Ca)
Target–substrate distance (mm)	50
Sputtering gas	Ar/O_2 (4/3)
RF power (W)	100
Working pressure (mTorr)	10
Substrate	Quartz
Thickness (μm)	2.0

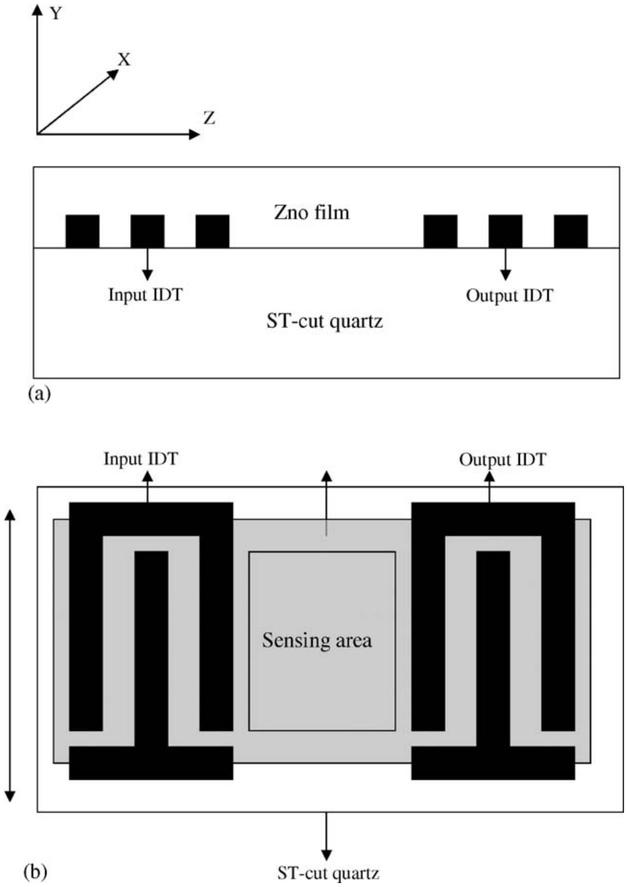

Fig. 1. (a) Cross-section view, and (b) top view of a ZnO/IDT/quartz Love wave sensor.

3. Results and discussions

3.1. X-ray diffraction

Fig. 2 shows the X-ray diffraction patterns of ZnO films with different Ca concentrations doped. The peak at 34.2° corresponds to (0 0 2) plane reflections from hexagonal type ZnO. The intensity of the (0 0 2) orientation of the 1 mol% Ca dopant ZnO film is smaller than that of pure ZnO film, and the full width of half maximum (FWHM) increases. As the Ca concentration is increased to 5 mol%, the (0 0 2) orientation degenerates obviously and an un-identified peak (45.7) generated.

3.2. SEM and AFM

Fig. 3 shows the SEM top view of ZnO films doped with different concentrations of Ca dopants. In Fig. 3a and b, the surface morphology of 1 mol% Ca doped ZnO appears uniform and smooth. In Fig. 3b, the triangular island structure is clearly visible and the surface morphology of 5 mol% Ca dopants is rougher than that of 1 mol% Ca dopants. Based on the results of