English
Research Express@NCKU Volume 10 Issue 6 - September 11, 2009
[http://research.ncku.edu.tw/re/articles/e/20090911/3.html]

An investigation of Love wave devices based on ZnO:Mg/$LiNbO_3$ structure

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Sensors and Actuators B: Chemical
Volume 132, Issue 1, 28 May 2008, Pages 312-318

SAW devices have found wide application in sensors for detection in gas and liquid environment [1,2]. In liquid environment, Rayleigh surface waves have a displacement component perpendicular to the substrate where exist a compressional waves leading to a strong radiation loss [3]. For this reason, shear horizontal (SH) polarized waves are preferred because they do not couple elastically with ideal liquids and make no radiation loss [3-5]. SH modes can be converted into Love modes by means of a layer acting as a guide. The basic structure of Love wave devices is illustrated in Fig. 1. Due to the waveguide effect, Love waves will be very sensitive to surface perturbations and high sensitivity to surface loading can be achieved. The condition for the existence of Love wave modes is that the shear velocity of the overlay material is less than that of the substrate [3]. Leaky waves of 64° YX-$LiNbO_3$ [6] have been utilized as substrates because of the large electromechanical coupling coefficient (k^2 = 11.3 %), fast shear velocity (4478 m/s) and negative temperature coefficient of frequency (TCF) [7]. Zinc oxide (ZnO) has low acoustic absorption, low loss, and high chemical, mechanical and thermal stability. Besides, the shear velocity of ZnO (2747 m/s) [8] is lower than that of SiO_2 (2850 m/s) [3] making it suitable candidate for the guiding layer.

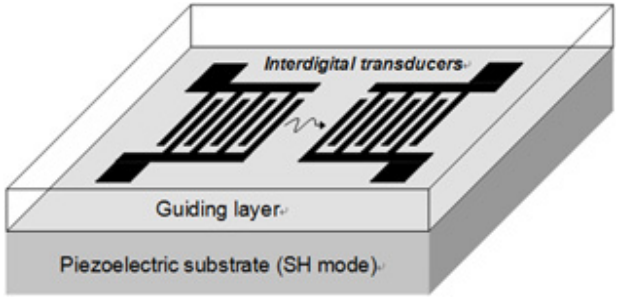

Fig. 1. The basic structure of Love wave devices.

Recently, several groups have used the ZnO films as the guiding layer for Love wave devices [5,8]. The influence of Ca and Sr doped ZnO/ST-cut quartz on Love wave sensor characteristics also has been studied further by Water [9,10] et al. A great deal of research have been reported that Mg doped ZnO (MZO) films

possess attractive properties for potential applications in novel optoelectronic and nanoelectronic devices [11]. However, it is not found that MZO thin films are fabricated as Love mode devices for liquid or gas media sensing applications. Therefore, we investigate the effect of the substrate temperature on the properties of Mg doped ZnO films on 64 ° YX-$LiNbO_3$ substrates by RF magnetron sputtering technique in this study. And the characterizations of Love wave device in ZnO/$LiNbO_3$ structure are presented.

MZO thin films were deposited on the polished 64 ° YX-$LiNbO_3$ substrates by RF magnetron sputtering using 3 mol% Mg doped ZnO (99.9 %) targets. Sputtering was carried out in argon and oxygen mixed gas atmosphere by supplying RF power. The substrate was heated to attain the desired deposition temperature. In our experiment, the “unheated” substrate would exhibit a stable temperature about 150 ° C at the end of sputtering process. The Love wave devices were fabricated on 12 mm × 13 mm and 0.5 mm thick 64 ° YX-$LiNbO_3$ substrates.

Fig. 2 shows the XRD patterns of the MZO films with different substrate temperature. The films, except for 350 ° C, show a pronounced 34.4 ° corresponding to the (002) plane of ZnO, indicative of the hexagonal wurtzite structure. The results reflect that better crystallite structure tends to be formed in the high substrate temperature [29], which provides enough energy to make it possible to have good c-axis orientation. With over-heating the substrate the (002) peak intensity decreases because too much energy results in growth and appearance of random orientations, such as (100) and (101) peak seen at 300 and 350 ° C.

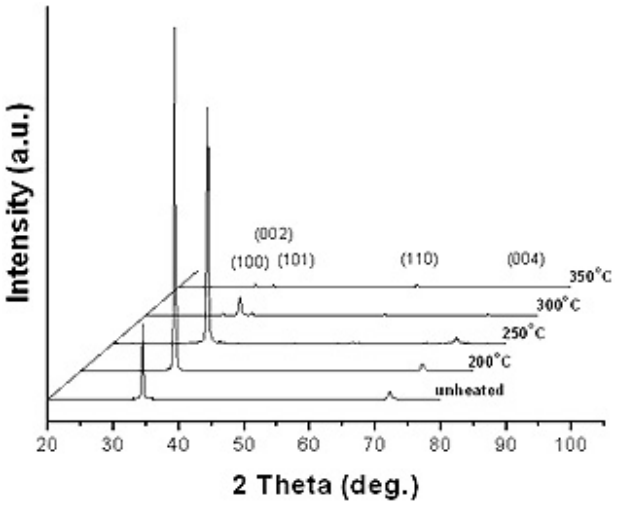

Fig. 2. The XRD patterns of the MZO films with different substrate temperature.

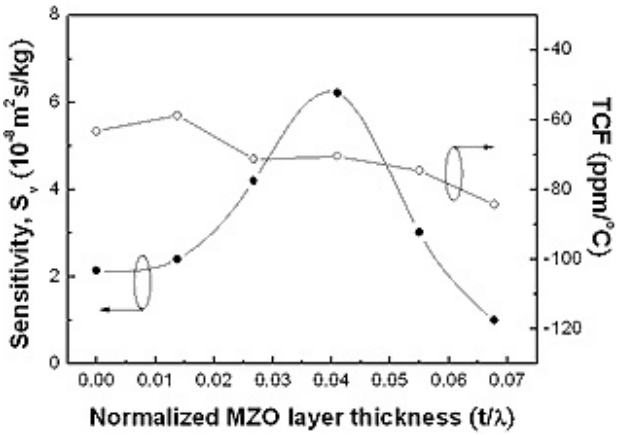

Fig. 3. Variation of the sensitivity and TCF with respect to normalized MZO layer thickness.

For sensor applications, 1.5 μL DI water was used to drop on the sensing area. There is an optimum of t/λ (t is MZO film thickness, λ is wave length) in terms of the sensitivity S_v for any system. Fig. 3 shows the variation of the sensitivity and TCF with respect to normalized MZO layer thickness. The sensitivity reaches the maximum at t/λ = 0.04. The maximum sensitivity of MZO/$LiNbO_3$ is 6.21×10^{-8} m^2s/kg, which is higher than the literature [4] reported the SiO_2/Quartz (4.8×10^{-8} m^2s/kg) and SiO_2/$LiTaO_3$ (1.8×10^{-8} m^2s/kg) structures. The TCF value of 64 ° YX-$LiNbO_3$ is approximately -81 ° C/ppm [7], and that of the ZnO film is negative [8]. In our experiment, the TCF value of MZO/$LiNbO_3$ increases gradually from ~-64 (t/λ = 0) to -84 ° C/ppm (t/λ = 0.068) with increasing MZO film thickness. An appropriate thickness of MZO film can not be found to obtain a zero TCF for Love wave devices.

The sensitivity vs. substrate temperature is shown in Fig. 4 (a). The thicknesses of MZO films are almost 1.6 μm (t/λ = 0.04). The excellent sensitivity of MZO/$LiNbO_3$ appears at unheated temperature. The sensitivity is proportional of the phase shift Δϕ as sensing in the same liquid medium. For the measurement of the phase shift, 1.5 μL glycerol solution was used to drop on the sensing area. Fig. 4 (b) shows the phase shift as a function of glycerol solution at different substrate temperature. The unheated MZO films on $LiNbO_3$ substrates have a large phase shift than the heating films based structure. Many reports indicate that rough and porous surface enhances additional mechanisms of coupling between acoustic wave and a liquid or gas motion, such as the generation of a nonlaminar motion, the conversion of the in-plane surface motion into the surface-normal liquid motion, and the trapping of liquid by cavities and pores [5,9,10]. However, it is discovered that the phase shift do not increase with the surface roughness. The root-mean-square roughness (Rq) of unheated, 200, 250, and 350 °C are 7.42, 19.72, 39.05 and 31.41 nm, respectively. We could infer that poor crystal quality of films and too rough surface will inhibit the propagation of the Love wave to make the phase shift decreases and result in the deterioration in the performance of devices in liquid media instead [10]. On the other hand, it is also observed that at the same substrate temperature, the phase shift increases with increasing the concentration of the glycerol solution due to the viscosity effect upon the wave propagation [10].

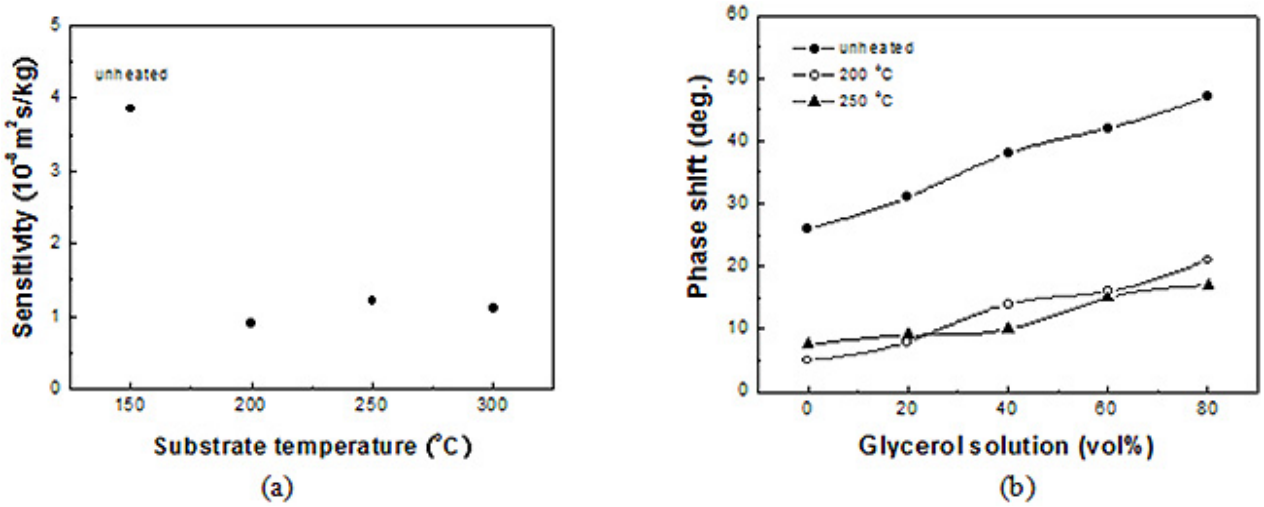

Fig. 4. (a) The sensitivity vs. substrate temperature. (b) The phase shift as a function of glycerol solution at different substrate temperature.

In conclusion, the better crystallite structure of MZO deposited on 64 ° YX-$LiNbO_3$ is formed at a substrate temperature of 200 °C. The surface roughness increases with the increase of substrate temperature. MZO/$LiNbO_3$ structures based Love wave acoustic devices have been successfully manufactured and operated. An appropriate thickness of MZO film for Love wave device can obtain the maximum sensitivity. Higher sensitivity is also obtained at unheated substrate-temperature. Too poor crystal quality of films and rough surface will result in the deterioration in the performance of Love wave devices in liquid media.

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