Li-doped ZnO Piezoelectric Sensor for Touchscreen Applications

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***Abstract*—Piezoelectric sensors based on highly (002)-oriented Li-doped Zinc Oxide (LZO) thin films are fabricated on Pt/Ti/SiO_2/Si substrates using a Radio Frequency (RF) magnetron sputtering technique with DC-bias voltages ranging from 0 ~ 25 V. The DC-bias voltage modifies the microstructure and thickness uniformity of the LZO films, and therefore changes their piezoelectric properties. The optimal value of the piezoelectric coefficient is obtained for a DC-bias of 20 V. The observation results suggest that the superior piezoelectric property is the result of an improved crystallization of the LZO film rather than a greater thickness uniformity. The feasibility of the optimal LZO-based piezoelectric sensor for touchscreen applications is demonstrated by means of a simple experiment.**

***Index Terms*—DC-bias, Li-doped, piezoelectric, sensor, touchscreen, zinc oxide (ZnO)**

I. INTRODUCTION

Touchscreen interactive devices have attracted developing concern in recent decades due to an increasing demand for computer, communication, and consumer electronics [1]. Touchscreens work on various operating principles, including resistive [2], capacitive [3], infrared [4], optical imaging [5], strain gauge [6], Surface Acoustic Wave (SAW) [7], and Acoustic Pulse Recognition (APR) [8]. Among these various techniques, SAW and APR use a simple piezoelectric method to transfer or detect signals, and thus have a broad range of applications owing to their lower cost, superior optical performance, higher durability, and easier integration [9]. However, such sensors require additional elements, such as reflectors and transducers, to measure the variation of the acoustic wave amplitude. Moreover, the presence of dust may change the behavior of the ultrasound waves traveling on the surface of the device.

Accordingly, the present study synthesizes piezo-electric sensors for touchscreen applications based on Li-doped Zinc Oxide (LZO) thin films deposited on Pt/Ti/SiO_2/Si substrates. The LZO films are prepared using a Radio Frequency (RF) magnetron sputtering method with various DC-bias voltages in the range of 0 ~ 25 V. The effects of the DC voltage on the microstructure (orientation and crystallinity) and thickness uniformity of the LZO thin films are systematically explored. The results show that the DC-bias-induced growth of the LZO microstructure has a greater effect on the piezoelectric properties of the film than the thickness uniformity. The feasibility of the proposed Li-doped piezoelectric sensors for touchscreen applications is demonstrated experimentally.

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II. EXPERIMENTAL PROCEDURES

The target for the RF magnetron sputtering system was synthesized using reagent-grade ZnO and Li_2CO_3 powders with purities in excess of 99.99%. Full details of the synthesis process are available in a previous study by the present group [10]. LZO films were deposited on Pt/Ti/SiO_2/Si substrates at room temperature in a 25% oxygen (O_2, purity: 99.995%) and 75% argon (Ar, purity: 99.995%) mixed gas atmosphere. The deposition process was performed using a constant RF power of 120 W and various DC-bias voltages in the range of 0 ~ 25 V. During the deposition process, the substrate was rotated continuously at a speed of 30 rev/min.

The crystalline structure and orientation of the LZO films were investigated by means of standard θ-2θ X-ray Diffraction (XRD) measurements performed using CuKα radiation at 40 kV and 30 mA (D8 Discover, Bruker). The piezoelectric coefficients (d_{33}) of the LZO films were determined using an atomic force microscope (AFM, Veeco, Nanoscope SPM) in piezoresponse mode. Finally, the thickness of the LZO films was measured by an α-step profiler (AS500, KLA-Tencor).

III. RESULTS AND DISCUSSION

Fig. 1 presents schematic illustrations of the RF magnetron sputtering process with and without the use of a DC-bias voltage, respectively. In both cases, the ionized argon molecules randomly strike the target and excite negatively-charged LZO particles which are then deposited on the substrate. In the sputtering process performed using only the RF power, the LZO particles are prone to disarray, as shown in Fig. 1(a). However, for the sputtering process performed with both a RF power and a positive DC-bias, the LZO particles are more orderly arranged as a result of the attractive force between the positively-charged substrate and the negatively-charged LZO particles (see Fig. 1(b)).

Fig. 2 shows the XRD patterns of the LZO films synthesized using different DC-bias voltages (shown in a previous study by the present group [11]). All of the films have a strong (002)-oriented peak. In other words, the

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films have a hexagonal structure and good crystallinity. The intensity of the peak increases as the bias voltage is increased to 20 V. However, impurity phases (i.e., (110) and (101)-oriented peaks) are observed in the sample synthesized using a higher bias voltage of 25 V. The formation of these phases can be attributed to a strong static electricity effect in the presence of a high DC-bias, which is consistent with that reported for the variation of crystalline structure of the Ni films in [12].

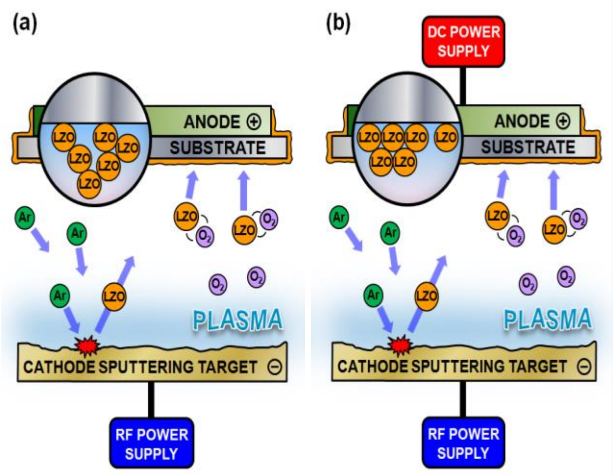


Figure 1. Schematic illustrations of ion deposition in RF magnetron sputtering system: (a) without DC-bias, and (b) with DC-bias.

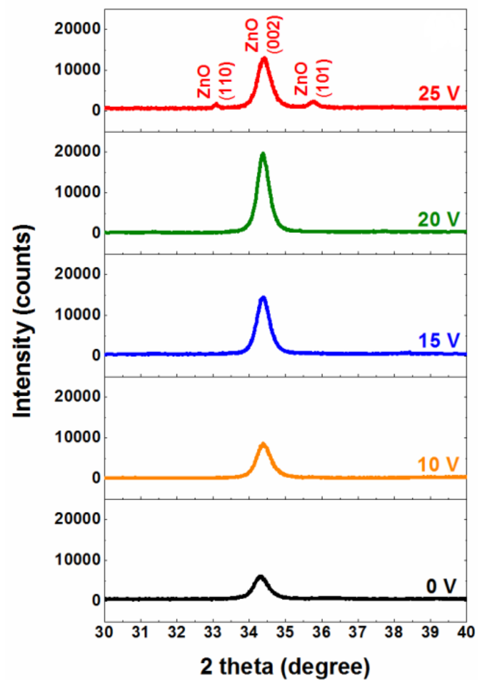


Figure 2. X-ray diffraction patterns of LZO films deposited using various DC-bias voltages.

Fig. 3 shows the variation of the Peak Intensity Value (PIV), Full Width at Half Maximum (FWHM), and piezoelectric coefficient (d_{33}) of the LZO samples deposited using different DC-bias voltages (also shown in a previous study by the present group [11]). Note that in measuring the d_{33} values, the AFM integrated tip was scanned over an area measuring 2 μm × 2 μm with a DC voltage in the range of 1 to 5 V. The d_{33} values were then calculated from the slope of the piezoresponse signal compared with that of an un-doped ZnO film with a theoretical d_{33} value of 5.3 ~ 8.6 pm/V [13]. It is observed that the d_{33} coefficient has a maximum value of 19.42 pm/V in the sample prepared with a DC-bias of 20 V, but falls to approximately 16.27 pm/V for a higher bias voltage of 25 V. This tendency is consistent with that reported for ZnO-based thin films in [14]. It is noted that the tendency of the piezoelectric coefficient d_{33} is similar to that of the PIV, which implies that the piezoelectric property of the film is correlated with the microstructure. However, the tendency of the FWHM value is the opposite of that of the d_{33} and PIV values. The smaller value of the FWHM at higher bias voltages infers a more dense grain structure and lattice arrangement of the LZO film under higher bias conditions.

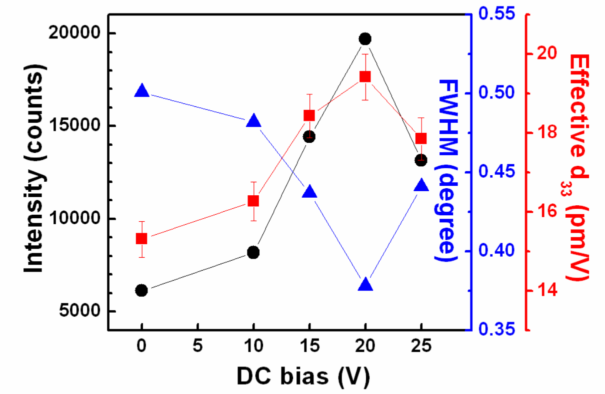


Figure 3. Peak intensity values of X-ray diffraction patterns, FWHM, and piezoelectric coefficients d_{33} of LZO films deposited using various DC-bias voltages.

Fig. 4 shows the measurement process used to evaluate the thickness of the LZO films (also shown in a previous study by the present group [11]). Note that each measured region (i.e., up, down, right and left) has dimensions of 1.5 cm × 0.1 cm and the yellow arrows indicate the α-step measurement direction. For each film, the average thickness (AT) and standard deviation (SD) were computed respectively as:

$$\bar{X} = \frac{1}{N}\sum_{i=1}^{N} X_i \tag{1}$$

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(X_i - \bar{X})^2} \tag{2}$$

where X indicates the measured thickness value, N indicates the number of measurements performed in each region, and σ indicates the SD of each measurement. The AT and SD results for the various films are listed in Table I and Table II, respectively (also shown in a previous study by the present group [11]). As expect, the average thickness of the films increases with an increasing bias voltage. In other words, the application of a DC-bias voltage increases the deposition rate of the sputtering system. By contrast, the SD of the film thickness reduces with an increasing DC-bias voltage, which implies that the DC-bias improves the thickness uniformity of the LZO films. Overall, the results show that the optimal microstructural and piezoelectric properties are obtained using a DC-bias voltage of 20 V.

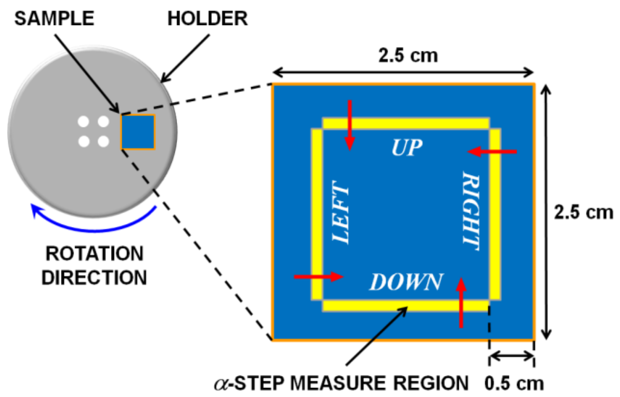


Figure 4. Schematic illustrations showing thickness measurement of LZO films. Note that each measured region has dimensions of 1.5 cm × 0.1 cm and yellow arrows indicate the direction of α-step measurement.

The feasibility of the LZO-based piezoelectric sensor fabricated using a 20-V DC-bias was evaluated by means of a simple experiment designed to emulate a touchscreen application. Fig. 5 shows the operating principle of the proposed sensor. As shown, the sensor generates an electrical signal when compressed, which is then processed by an operational amplifier (OP, UA741, ROHM Semiconductor). The amplified signal is then transferred to a micro-controller (AT89S51, Atmel Corporation) and used to drive a light-emitting diode (LED, Hatsushiba).

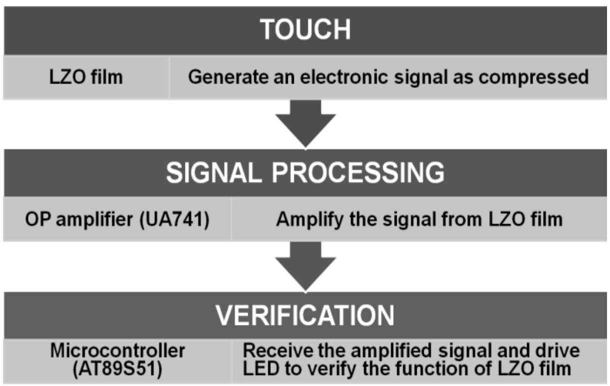
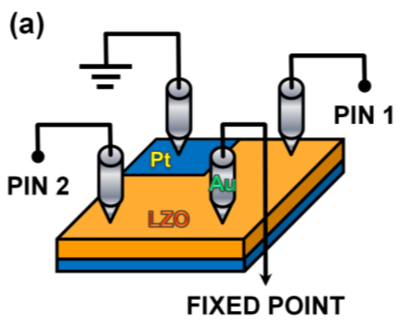


Figure 5. Flowchart and operating principle of LZO-based piezoelectric sensor for touchscreen applications.



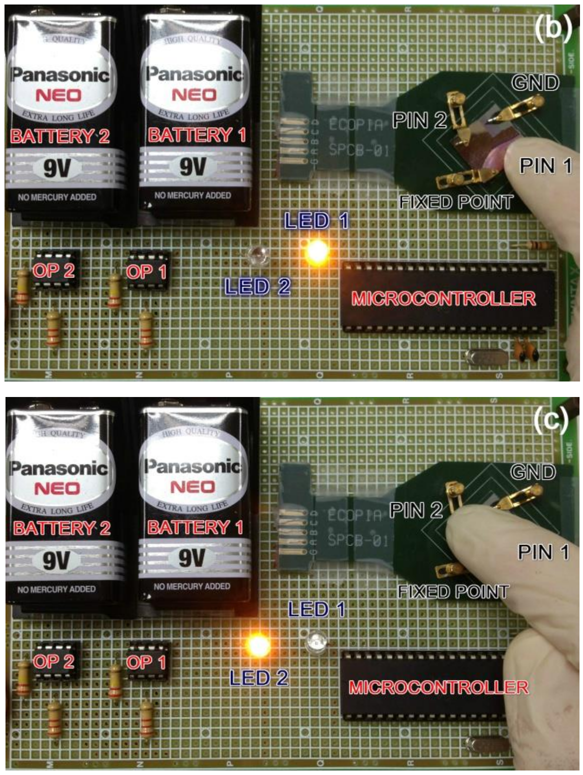


Figure 6. (a) Schematic illustration of LZO-based piezoelectric sensor. Photographs of prototype piezoelectric sensor when pressing (b) PIN 1 and (c) PIN 2.

TABLE I. AVERAGE THICKNESS OF LZO FILMS VERSUS DC-BIAS VOLTAGE FOR FOUR MEASURED REGIONS (UP, DOWN, RIGHT, AND LEFT IN FIG. 4). NOTE THAT $\bar{X}$ INDICATES THE AVERAGE OF FIVE MEASURED RESULTS FOR EACH REGION AND $\bar{X}_{udrl}$ INDICATES THE AVERAGE OF $\bar{X}_{up}$, $\bar{X}_{down}$, $\bar{X}_{right}$, AND $\bar{X}_{left}$.

Bias (V)	$\bar{X}_{up}$ (nm)	$\bar{X}_{down}$ (nm)	$\bar{X}_{right}$ (nm)	$\bar{X}_{left}$ (nm)	$\bar{X}_{udrl}$ (nm)
0	185	206	181	208	194.9
10	216	219	190	215	210.0
20	228	223	201	227	219.7
25	233	226	208	230	224.3

TABLE II. STANDARD DEVIATION (SD) OF $\bar{X}_{up}$, $\bar{X}_{down}$, $\bar{X}_{right}$, AND $\bar{X}_{left}$ IN TABLE I VERSUS DC-BIAS VOLTAGE. NOTE THAT σ_{UDRL} INDICATES THE SD OF σ_{UP}, σ_{DOWN}, σ_{RIGHT}, AND σ_{LEFT}.

Bias (V)	σ_{up} (nm)	σ_{down} (nm)	σ_{right} (nm)	σ_{left} (nm)	σ_{udrl} (nm)
0	12.45	11.76	5.34	6.55	3.12
10	11.49	9.39	4.03	5.78	2.93
20	10.06	8.26	2.93	4.96	2.78
25	9.21	7.46	2.87	4.75	2.44

As shown in Fig. 6(a), the LZO-based sensor was attached to a printed circuit board by means of four Au

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pins (i.e., PINs 1 and 2, fixed and ground points). Fig. 6(b) and (c) present photographs of the piezoelectric sensor during the experimental process. As shown, the microcontroller and amplifiers are powered by 9 V batteries, and the user is wearing a plastic glove in order to reduce the capacitive effect. As the finger touches PIN 1, the piezoelectric effect causes LED 1 to light. Similarly, LED 2 is lit when the finger touches PIN 2. Pins 1 and 2 are located in different regions of the LZO film surface. Thus, the experimental results confirm the local touch-sensitive nature of the proposed piezoelectric sensor.

IV. Summary

This study has investigated the microstructure and piezoelectric properties of LZO thin films deposited on $Pt/Ti/SiO_2/Si$ substrates via a RF magnetron sputtering technique with DC-bias voltages ranging from 0 ~ 25 V. It has been shown that the optimal value of the piezoelectric coefficient is obtained in the sample synthesized using a DC-bias of 20 V. Moreover, the results have shown that the microstructure of the LZO film has a greater effect on the piezoelectric property than the thickness uniformity. The feasibility of the proposed LZO-based piezoelectric sensors has been demonstrated by means of a simple experiment. In general, the results have shown that the piezoelectric sensor provide a promising solution for touchscreen applications.

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