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A Study on Fabrication of Zinc Oxide thin Film Acoustic Sensors

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A STUDY ON FABRICATION OF ZINC OXIDE THIN FILM ACOUSTIC SENSORS

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ABSTRACT

In this study, acoustic sensors were formed by depositing a zinc oxide (ZnO) thin film on a silicon dioxide/silicon(SiO/Si) substrate using radio frequency (RF) planar-magnetron sputtering method. The results showed higher substrate temperatures and higher RF powers enhanced C-axis oriented structure of the ZnO thin film and optimized the ZnO thin film acoustic property. The frequency spectrum measurement on the acoustic sensor underwater involved three peaks at frequencies 640 KHz, 2.4 MHz and 2.9 MHz, respectively. Sensitivity reached to -132.02 dBrelv/ μpa. The results indicated that under the pressure of acoustic frequencies the sensor response was directly proportional to pressure and, therefore, can be actually utilized in underwater sounding tests.

INTRODUCTION

In zero or low visibility environments, acoustic devices are superior to optical devices in the detection of targets. Therefore, ultrasonic sensors and sonar are crucial to the development of submarine technologies. Since conventional acoustic sensors or transmitters are constructed of bulky ceramic materials, they have imposed severe restrictions on the development of acoustic systems. With the aid of integrated circuit (IC) technology to develop intelligent acoustic sensors, many researchers have recently begun to develop thin film acoustic sensors [1-3].

ZnO is a piezoelectric material that can be fabricated into thin film for intelligent acoustic sensor applications. The material can be deposited on various types of substrates[4,5]. The use of silicon materials as the substrate enables integration of intelligent acoustic systems onto a chip through IC techniques. In this study, ZnO served as the source material for the thin film acoustic sensor and was deposited on a SiO_2/(100) Si substrate, with aluminum(Al) utilized as the electrode. To improve sensitivity, the quality of the ZnO thin film used on acoustic sensors must be optimized. The optimization parameters included oxygen contents, RF power and substrate temperature[5], which were analyzed to study ZnO deposition conditions. Since the acoustic sensor was layered on a Si substrate, the placement of an IC on the same single chip to configure an intelligent sensor was not a difficult task.

EXPERIMENTAL PROCEDURES

Referring to the fabrication process of the ZnO thin film sensor in Figure 1, a Si(100) wafer was coated with SiO2 (Fig. 1a). A substrate window was created through the optical lithography(Fig. 1b) and after anisotropic etching the diaphragm was made in the Si substrate with EDP solution(Fig.1c, Fig. 1d) [6]. Furthermore, Al was utilized as the rear electrode material. With an Al deposition thickness of approximately 1,000Å, the electrode pattern was accomplished(Fig. 1e) through the same lithographic technique shown in Fig. 1b. The ZnO thin film material was then deposited on the Al/SiO_2/Si substrate with an RF planar magnetron sputter (Fig. 1f). Next, the Al front electrode and electrode pattern were also completed using the same lithographic technique(Fig. 1f). Following the etching of patterns(Fig. 1h) on the ZnO, the fabrication of the sensor was complete. Fig 1i was the top view of the ZnO thin film acoustic sensor. Since Al was utilized as the rear electrode in the experiment, ZnO thin film deposited on a SiO_2/Si substrate and Al electrode needed to be considered at the same time. In this paper, the experimental variables used are oxide contents of 0% to 50%, substrate temperatures of room temperature to 350°C and RF power from 80 watts to 200 watts. The quality of ZnO thin film

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structure was analyzed with XRD. Moreover, the characteristics of the acoustic sensor were measured in an underwater condition to find out its frequency spectrum and thereby determine the quality of the ZnO thin film acoustic sensor using reciprocity method.

RESULTS AND DISCUSSION

Since the high degree of C-axis oriented or high degree of (002) preferred polycrystalline structure of ZnO thin film can enhance its piezoelectric properties [7-10]. The piezoelectric properties of high degree of C-axis oriented structure is similar to the piezoelectric properties of ZnO single crystal. How to enhance the degree of C-axis oriented is important for high sensitivity ZnO thin film acoustic sensor. In addition, the smaller full width at half maximum intensity (FWHM) also has better structure quality of ZnO thin film and can improve the quality of ZnO thin film acoustic sensor.It is very important to have higher degree of C-axis oriented structure and lower FWHM value of ZnO thin film for high senstivity ZnO thin film acoustic sensor.

The (002) peak FWHM of ZnO thin film which deposited at different temperatures on SiO_2/(100)Si substrate from X-ray diffraction patterns (XRD) are shown in Fig. 2. Higher deposition temperatures improved the crystallinity of ZnO thin film,since the FWHM value of the ZnO thin film is reduced. Different RF powers showed similar results. Therefore, higher deposition temperatures effectively improved the sensitivity of ZnO thin film acoustic sensors consisting of ZnO thin film layered on SiO_2/(100)Si substrates[5]. As indicated in Fig. 3, similar

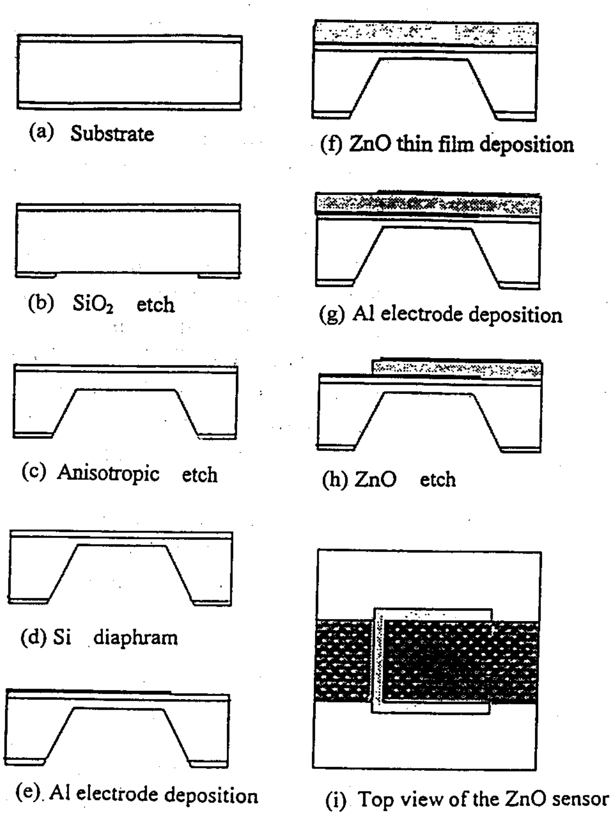

Fig. 1. Fabrication procedure of the ZnO thin film acoustic sensor.

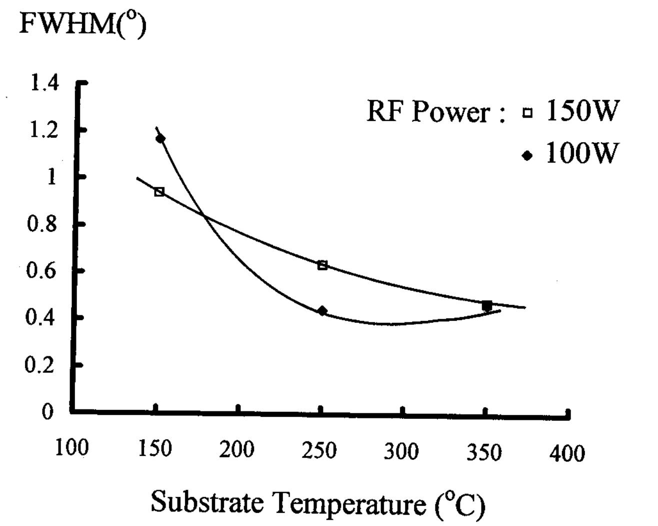

Fig. 2. The (002) peak FWHM of X-ray diffraction patterns of ZnO thin films on SiO_2/(100)Si substrate grown at 100 and 150 watts RF power with different substrate temperatures.

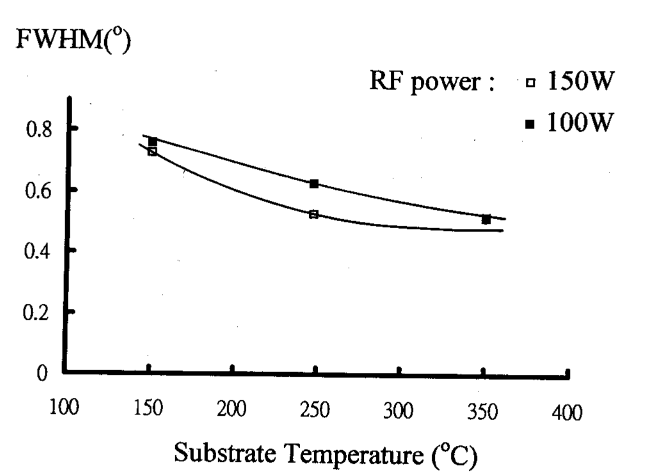

Fig. 3. The (002) peak FWHM of X-ray diffraction patterns of ZnO thin films on Al electrode grown at 100 and 150 watts RF power with different substrate temperatures.

findings were observed when ZnO thin film was deposited onto an Al electrode. In addition, Fig. 4 shows the relationship between the degree of (002) preferred orientation of ZnO thin film on SiO_2/(100)Si substrate and oxygen contents at different magnitudes of RF power, where the degree of the (002) preferred orientation structure was based on XRD data of the ZnO thin film. Sum of count values of peaks(002) and peaks (004) with respect to these of all diffraction peaks of ZnO thin film from XRD in the 2θ from 30° to 70° was used to determine the degree of (002) preferred orientation structure of ZnO thin film on Si substrate. According to this figure, the effect of the oxygen content on the degree of C-axis oriented structure of ZnO thin film was relatively small, and increase in RF power(more than 110 watts) achieved a superior C-axis oriented structure of ZnO thin film that is very beneficial to the sensitivity of acoustic sensor. Fig.5 is the relationship between (002) preferred orientation of ZnO thin film on SiO_2/(100)Si substrate and oxygen contents at different substrate temperatures. According to the figure,the effect of the oxygen content on the degree of (002) preferred polycrystalline structure of ZnO thin film was relatively small when the substrate temperature was higher than 200°C. Furthermore, the degree of (002) preferred structure of ZnO thin film was near 100% when the substrate temperature was at 200°C. The ZnO thin film on Al electrode had similar results. It seems that the higher deposition temperature and RF power at 110W or above are better to achieve higher sensitivity of ZnO thin film acoustic sensor. To optimize the ZnO thin film deposition on SiO_2/(100)Si substrate and Al electrode, the RF power applied in this experiment was 150 watts and the substrate temperature was 350°C.

The optimized ZnO thin film was then fabricated following the device processes illustrated in Fig. 1 to produce the ZnO thin film acoustic sensor. Fig. 6 shows the frequency spectrum of the ZnO acoustic sensor, which was fabricated according to the process illustrated in Fig. 1. These ZnO acoustic sensors were produced utilizing the optimal parameters of ZnO thin film deposition and their respective frequency spectrums were measured underwater. Four ZnO thin film acoustic sensors of different size were compared in this experiment. The dimensions are indicated in Table 1. Sensor A,B have larger film area than sensor C,D. On the other side, sensor B,D have thicker ZnO thin film than sensor A,C. From the frequency spectrum,it reveals a similarity in the respective spectrums. These samples have the same

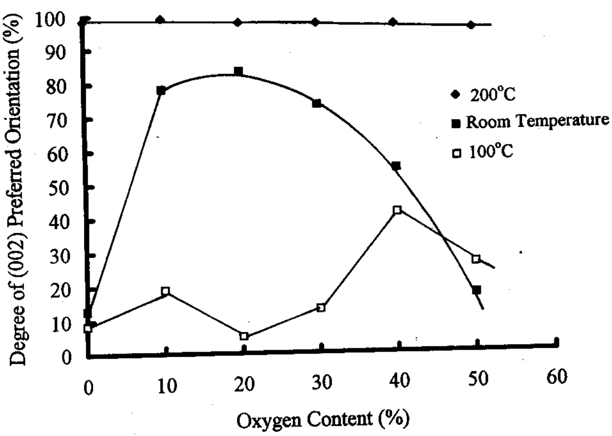

Fig. 5. Degree of (002) preferred orientation as a function of oxygen content with different deposition temperatures.

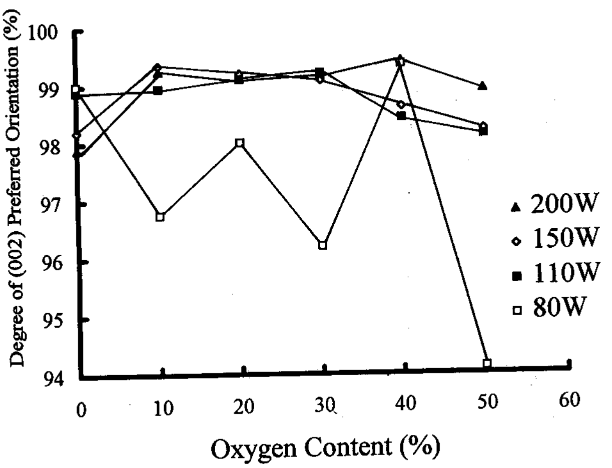

Fig. 4. Degree of (002) prefered orientation as a function of oxygen content different RF powers.

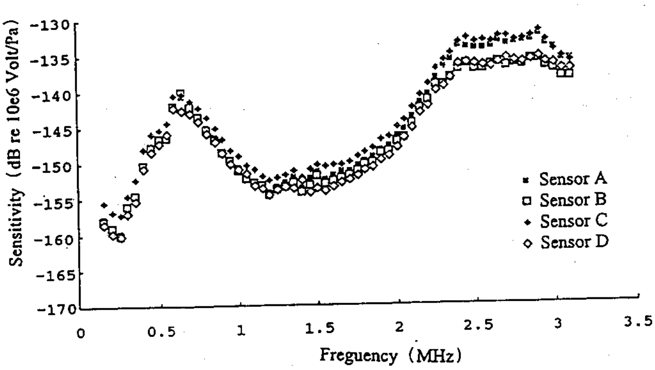

Fig. 6. Frequency spectrum of the ZnO thin film acoustic sensors at different structural scales.

Table 1 The respective geometrical dimension of film layers for sensors A, B, C and D.

	Sensor A	Sensor B	Sensor C	Sensor D
ZnO film thickness ($\mu m)^2$	8.6	12.2	8.6	12.2
SiO_2 film thickness ($\mu m)^2$	0.5	0.5	0.5	0.5
Si diaphram thickness ($\mu m)^2$	9.5	9.5	9.5	9.5
film area ($\mu m)^2$	$(980)^2$	$(980)^2$	$(580)^2$	$(580)^2$

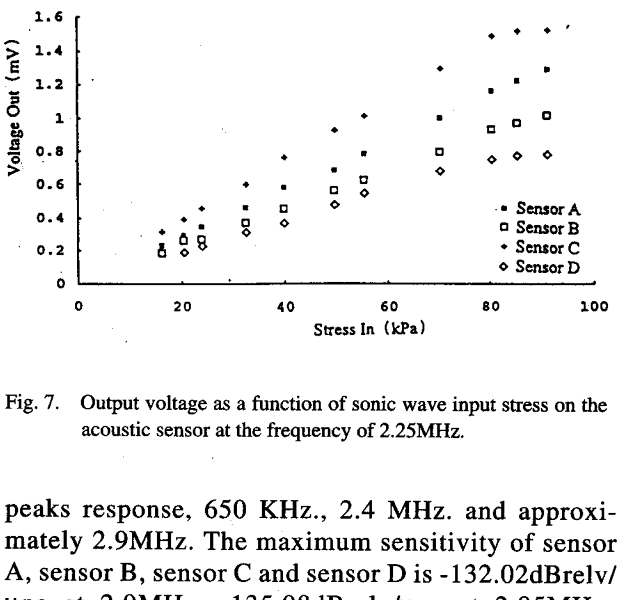

Fig. 7. Output voltage as a function of sonic wave input stress on the acoustic sensor at the frequency of 2.25MHz.

peaks response, 650 KHz., 2.4 MHz. and approximately 2.9MHz. The maximum sensitivity of sensor A, sensor B, sensor C and sensor D is -132.02dBrelv/µpa at 2.9MHz, -135.98dBrelv/µpa at 2.85MHz, -132.03 dBrelv/µpa at 2.9Mhz and -135.62 dBrelv/µpa at 2.9MHz, respectively, with a reference level of 0 dBrelv/µpa. Based on the figure, the thinner film had a higher sensitivity. In addition, a smaller film area yielded a higher sensitivity in the high frequency range also that may be related to the mechanical vibration characteristics of ZnO thin film. Fig. 7 shows the sensor output voltages as function of input sonic pressure at the frequency of 2.25MHz. The voltage output showed a linear variation with the sonic pressure when the pressure was less than 80 Kpa. It seems that the sensor sensitivity is correlated to input sonic pressure. However, when the sonic pressure exceeds 80 Kpa, sensitivity decreased due to the thin film vibration saturation. The findings reveal that under an appropriate range of pressure applied, the thin film acoustic sensors fabricated in this study will not pose any difficulties in practical applications.

CONCLUSIONS

Semiconductor fabrication process and the Si micromachining techniques were utilized to fabricate the thin film acoustic sensor in this study, wherein a ZnO thin film was deposited on SiO_2/(100)Si substrate and an Al electrode by RF planar-magnetron sputtering method. The optimal prefered(002) orientation of the ZnO thin film was achieved under the condition, substrate temperature 350°C, RF power 150W. The frequency spectrum of the ZnO thin film acoustic sensors in this experiment have three peaks of approximate 650 KHz, 2.4MHz and 2.9MHz with the optimal sensitivity of -132.03dBrelv/µpa. Moreover, the results revealed the effects of film geometrical dimension on sensor sensitivity.The sensitivity increased as the ZnO thin film thickness was reduced and as the film area was decreased. In addition, when subjected to an appropriate magnitude of sonic pressure(<80Kpa) the sensitivity of the thin film sensor was proportional to the sonic pressure.

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氧化鋅薄膜音波元件製作研究

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摘 要

本論文以射頻磁控濺射系統於SiO_2/(100)Si基板上沈積氧化鋅薄膜，配合蝕刻技術製作氧化鋅薄膜音波感測。由實驗結果可知，較高的射頻功率和較高的氧化鋅薄膜沈積溫度可提昇氧化鋅薄膜之C軸配向性，也因此可得到高靈敏度之氧化鋅薄膜水下音波感測元件。由頻譜之測量可知，以不同薄膜厚度及薄膜面積所製作之元件在640KHz, 2.4MHz和2.9MHz皆有峰值響應，而較薄及較小面積之薄膜靈敏度較高，元件靈敏度可達-132.02 dBrelv/μpa，另外由於元件之響應和音波壓力成正比，因此實驗所製作之元件可實際應用於水下音波之偵測。