Ultraviolet sensing system using ZnO based surface acoustic wave oscillator

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Abstract

In accompany with the technique of semiconductor fabrication development, the ultraviolet (UV) sensor with specific wavelength absorption is worthy to investigate. This study realized a highly-sensitive UV sensing system based on a ZnO/LiNbO₃ hybrid surface-acoustic-wave (SAW) device, where ZnO is used as UV sensing material. The system includes a ZnO based SAW oscillator, a local oscillator, a Mixer, a frequency to voltage (F/V) converter, an analog to digital (A/D) converter, and a liquid crystal display interface. The ZnO UV sensor is characterized for its functional performance under different intensities of UV illumination. Experimental results show that the frequency shift of the SAW oscillator output exhibit a linear variation with UV light intensity. The low level UV intensity can be easily detected.

Keywords: ZnO, ultraviolet, surface-acoustic-wave.

1. Introduction

Detection of UV radiation is very important in a number of medical areas, such as biological fluorescence detection, UV disinfection, pollution monitoring, water purification, and resin curing of polymeric materials. Recently, UV light detection with ZnO has attracted much interest because of its excellent piezoelectric, optical, and semiconducting properties⁽¹⁻³⁾. ZnO is a direct band gap (3.3 eV) semiconductor material with hexagonal wurtzite structure and has potential applications for SAW devices,

transparent conducting layers, gas sensors, light-emitting diodes (LEDs) and especially the UV sensors. It has a larger exciton binding energy (60 meV) than other wide band-gap semiconductor materials (GaN, 25 meV). This may lower the threshold of UV excitonic lasers and be used in the integrated circuit system including and the tunable UV photodetectors.

Various methods have been used to achieve the UV sensor such as photoconducting effect⁽¹⁾, metal semiconductor Schottky barriers⁽²⁾, and the frequency response of SAW oscillator⁽³⁻⁴⁾. SAW devices are very sensitive to surface changes, because in SAW devices a high density of acoustic energy propagates in the near-surface region of a piezoelectric.

In this report, we deposited a ZnO layer on the piezoelectric material (LiNbO₃) to realize a UV sensor using SAW technology. The design and fabrication process of the UV sensor were described and the response for the frequency shift in the SAW device under UV illumination was discussed.

2. Experiment and discussion

2.1 Fabricated SAW device

A metallic zinc of 2-inch diameter and 0.25-inch thickness with 99.99 % purity was used as the target. After the vacuum chamber was evacuated below 10⁻⁵ Torr, argon (Ar) and oxygen (O₂) gases were introduced into the chamber as gas atmosphere during sputtering. The working pressure and rf power were 25 mTorr and 120 W,

respectively. The ratio of gas flow rate ($O_2/(Ar + O_2)$) was keep at 75%. The shutter was opened to sputter for 3 hours after 30 min of pre-sputtering. Table I presents the detailed sputtering parameters of ZnO piezoelectric layer.

Figure 1 shows full view of the hybrid SAW device. Thirty pairs of aluminum interdigital transducers were deposited on the ZnO layer surface of the hybrid SAW device, which the ZnO layer with the grain size of 100 nm and the thickness of 2.5 μm was grown by RF magnetron sputtering on LiNbO₃ substrates.

TABLE I Deposition parameters of ZnO thin films

Substrate	LiNbO ₃
Substrate to target distance	50 mm
rf power	120 W
Based vacuum	10 ⁻⁵ Torr
Sputtering pressure	25 mTorr
O₂ gas flos rate	5.6 sccm
Ar gas flow rate	1.9 sccm
Deposition time	3 hours

Fig. 1. Full view of the SAW device.

2.2 Detection circuit

The UV sensing system contains a detection circuit, a signal processing circuit and a readout circuit. Detection circuit includes a ZnO based SAW device and a LC circuit combined with a transistor for feedback to achieve a SAW oscillator as shown in Fig. 2. Figure 2 (a) illustrates the circuit of the SAW oscillator. The SAW oscillator consists of a high frequency amplifier, the match networks and a ZnO/LiNbO₃ layered SAW device. There are three kinds of preferred oscillated circuit for SAW: Colpitts, Clapp and Pierce. Because of the potential for high Q-value, low noise level and higher stability, we have selected Colpitts circuit to realize SAW oscillator. The Q1 is BFR505, R1 is 220 Ω , R2 is 12 k Ω , R3 is 91 Ω , L1 is 100

nH, L2 is 10 nH, L3 is 100 nH, L4 is 15 nH, L5 is 15 nH, C1 is 0.5 pF, C2 is 1000 pF, C3 is 330 pF, C4 is 270 pF, C5 is 68 pF, C6 is 3.3 pF, C7 is 33 pF. Frequency output of ZnO/LiNbO₃ hybrid SAW oscillator is about 107.98 MHz as shown in Fig. 2(c).

Fig. 2. (a) The electrical circuit design, (b) a practical device and (c) frequency response of the SAW oscillator.

2.3 Signal processing and readout circuit

To analyze the frequency shift, the output signals of the SAW oscillator and the local oscillator (LO) were fed to a frequency mixer as shown in Fig. 3. The local oscillator is a voltage-controlled circuit corresponding to a resonant frequency varied from 100 MHz to 120 MHz. SAW oscillator and local oscillator (LO) are using the same transistor and oscillation pattern.

Fig. 3. Signal processing diagram. (RF: Radio frequency, LO: Local oscillator, IF: Intermediate frequency)

Fig. 4. (a) The mixer of sensing circuit. (b) The S parameters of mixer.

Fig. 5. Signal process for the readout system. A/D converter: Analog to digital converter, PSoC: Programmable System-on-Chip.

Figure 4 is a mixer of signal processing circuit. The mixer is a branch-line coupler. The S parameters of mixer are shown in Fig. 4(b). Figure 5 illustrates the signal process for the readout system. The frequency to voltage converter is formed by a phase-locked loop (PLL) and a differential amplifier. PLL is a feedback loop, which contains a phase detector, a low pass filter and a voltage-controlled oscillator (VCO). The VCO and IF input are combined with a phase detector and any difference will result in a DC voltage output. The output voltage is accurately proportional to the input frequency to achieve a frequency to voltage convertor. Subsequently, the output voltage is converted to an 8-bit digital signals by ADC0804. Finally, UV intensity that is related to the frequency response is calculated by PSoC and readout by a liquid-crystal display (LCD).

Figure 5 shows full view of the practical UV sensing system. The present sensing system exhibits visible-blind characteristic when it was exposed to visible light. The values of the measurement without and with UV illumination on the ZnO/LiNbO₃ SAW oscillator are shown in Fig. 6(a) and 6(b) respectively. A linear frequency shift and voltage responses are clearly observed as shown in Fig. 7. The lowest sensitivity of the UV sensor in present work is about 1.8 $\mu\text{W}/\text{cm}^2$ with frequency shift of 5 KHz.

Fig. 5. UV sensing system

Fig. 6. (a) Without and (b) with UV illumination on UV sensing system.

Fig. 7. Frequency and voltage responses of the UV sensor

3. Conclusions

In conclusion, a high sensitive UV sensing system based on SAW oscillator has been realized. Results show its potential application in the measurement of low intensity of UV light ($1.8 \mu\text{W}/\text{cm}^2$). The device exhibits interesting characteristics and can be effectively utilized for the development of a biomedical detector for low level UV applications.

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