The Bragg Reflector Layer of Low Surface Roughness Based on Solidly Mounted Resonators

Wei-Che Shih^a, Ying-Chung Chen^a, Wei-Tsai Chang^a, Chien-Chuan Cheng^{b,*}, Kuo-Sheng Kao^c, Kuo-Hua Cheng^c, Chih-Ming Wang^d, Chih-Yu Wen^a, Jui-Yang Chang^a and Po-Wei Ting^a

^aDepartment of Electrical Engineering, National Sun Yat-Sen University, Kaohsiung, Taiwan

^bDepartment of Electronic Engineering, De Lin Institute of Technology, Taipei, Taiwan

^cDepartment of Computer and Communication, Shu-Te University, Kaohsiung, Taiwan

^dDepartment of Electrical Engineering, Cheng-Shiu University, Kaohsiung, Taiwan

*Corresponding Author: chengccc@dlit.edu.tw

Abstract

In this study, the solidly mounted resonator (SMR) device is composed of a piezoelectric layer sandwiched between two electrodes on a Bragg reflector attached to a silicon substrate. To obtain appropriate SMR characteristics for the new-generation communication applications, the surface roughness of Bragg reflector has been investigated thoroughly.

Manufacture parameters are adjusted in accordance with the results of atomic force microscopy (AFM) and scanning electron microscopy (SEM). The frequency response is measured using an HP8720 network analyzer and a CASCADE probe station.

Afterwards, a $\frac{1}{4}\lambda$ mode SMR is experimentally realized. The surface roughness of 6.442 nm and well return loss can be achieved for four-pair SiO₂/Mo Bragg reflector.

Keywords: SMR, Bragg reflector layer, SiO₂, Mo, AlN

1. Introduction

In recent year, the issue of the frequency bandwidth of wireless communication systems is being of great interest and attention. The global systems for mobile communication could be classified into four types of systems, GSM850/GSM900 band, DCS (GSM1800), WCDMA, and LTE. Thence, several acoustic devices were investigated for high frequency band such as nano-scaled surface acoustic wave (SAW) resonator⁽¹⁾, thin-film bulk acoustic resonator (TFBAR)^(2, 3) and SMR.

The high frequency SAW devices have some advantages, such as small size, simple structure and good reproducibility. However, it is difficult to manufacture nano-scale interdigital transducer electrodes (IDTs) through conventional methods. Nowadays, the nano-scale IDTs can be obtained using E-beam direct write lithography method, but its cost is expensive.

TFBAR and SMR devices have been widely investigated because they have many advantages such as low insertion loss, low cost, high power handling capability, and small size. There are two kinds of TFBAR structure to avoid acoustic energy dissipation in substrate, including air gap isolated resonator and via isolated resonator⁽⁴⁻¹⁰⁾, as shown in Fig. 1(a) and (b). The air gap isolated resonator and via isolated resonator were formed using etching process to obtain a cavity, but the cavity-based structure is easily destroyed in etching processes. On the other hand, the SMR structure is fabricated using planar processes. This better mechanical structure makes it easy to package and integrate with an IC⁽¹¹⁻¹³⁾, as shown in Fig. 1(c).

Despite the use of various piezoelectric films in transducer devices, including lead zirconate titanate (PZT), zinc oxide (ZnO), and aluminum nitride (AlN) thin films, most of the many studies of piezoelectric thin films have focused on ZnO and AlN thin films. This study concerns piezoelectric thin films of AlN, whose high quality factor make them suitable for using in the new-generation communication system.

Fig. 1. The three kinds of TFBAR structure, (a) air gap isolated resonator, (b) via isolated resonator and (c) SMR.

The SMR device is composed of a piezoelectric layer sandwiched between two electrodes on a Bragg reflector attached to a silicon substrate. In the Bragg reflector, high/low acoustic impedance materials in one quarter acoustic wavelength thin films are successively stacked onto the substrate to maintain the required resonant boundary conditions to avoid wave energy dissipation into the substrate. Hence, the surface roughness of the Bragg reflector layer is the key factor to avoid acoustic-energy scattering. It is believed that increasing the numbers of paired Bragg reflector layers will increase the reflection coefficient and yield better resonance property. Moreover, the surface roughness is varied with the numbers of paired Bragg reflector layers⁽¹⁴⁾. Therefore, the effect of SiO₂/Mo numbers on the frequency response will be discussed.

2. Experimental

Above all, the silicon wafers were cleaned using a normal process, as shown in Fig. 2. The SiO₂/Mo layer was deposited by DC and RF sputtering system to form a Bragg reflector layer. Sputtering pressure and sputtering power were modulated to obtain smooth surface structure. The

deposition parameters of Bragg reflector layer were described in Table I.

Fig. 2. The silicon wafers were cleaned using a normal process

Table I. The sputtering parameters of SiO₂/Mo layer

	Mo	SiO ₂
Base pressure (mTorr)	3×10^{-3}	3×10^{-3}
Sputtering pressure (mTorr)	1~9	10~20
Sputtering power (W)	1~9	100~150
Substrate temperature (°C)	R. T.	350
Ar flow (sccm)	10	10

The Ti and Pt thin films were adopted as bottom and top electrodes for SMR devices because of its high electrical conductivity and chemical stable. The Pt/Ti thin films were deposited using DC sputtering system and the AlN piezoelectric thin films were deposited using reactive radio-frequency (RF) magnetron sputtering system. Next, the Ti and Pt thin films were deposited on AlN thin films as top electrodes. The sputtering parameters of Ti, Pt, and AlN thin films were presented in Table II and III, respectively.

Table II. The sputtering parameters of Pt/Ti layer

	Ti	Pt
Base pressure (mTorr)	3×10^{-3}	
Sputtering pressure (mTorr)	3	1
Sputtering power (W)	75	175
Substrate temperature (°C)	R.T.	
Ar flow (sccm)	10	

Table III. The sputtering parameters of AlN thin films

	Al (99.9995%)
Base pressure (mTorr)	5×10^{-4}
Sputtering pressure (mTorr)	5
Sputtering power (W)	230
Substrate temperature ($^{\circ}\text{C}$)	300
$\text{N}_2/\text{N}_2+\text{Ar}$ flow (%)	60

3. Results and Discussion

3.1 Structural and morphological properties of Bragg reflector layer

3.1.1 Analysis of Mo thin films

The deposition parameters were modulated to obtain smooth surface structure of SiO_2/Mo thin films. Firstly, five sputtering pressures with RF power of 100 W were used to study the phenomenon of Mo thin films. As shown in Fig. 3, a sputtering pressure of 7 mTorr resulted in the low surface roughness. Therefore, the sputtering pressure was fixed at 7 mTorr to produce a smooth surface structure of Mo thin films.

Then, the sputtering power was controlled to investigate the influence of surface roughness. Figure 4 presents the surface roughness of the Mo thin film deposited on the Si substrates with various sputtering powers. The optimize low surface roughness of Mo thin films can be obtained through sputtering pressure of 7 mTorr and the sputtering power of 100 W.

Fig. 3. The surface roughness of Mo thin films with various sputtering pressure.

Fig. 4. The surface roughness of Mo thin films with various sputtering power.

3.1.2 Analysis of SiO_2 thin films

Secondly, the SiO_2 thin films were deposited on the Mo thin films using RF sputtering systems. The sputtering pressure and sputtering power were controlled to improve the surface roughness of SiO_2 thin films. The sputtering pressure was controlled from 10 mTorr to 30 mTorr and the sputtering power was set at 150 W to investigate the effect of the sputtering pressure on SiO_2 thin films. Fig. 5 shows the lower surface roughness can be obtained using sputtering pressure of 20 mTorr. Next, the sputtering pressure was set at 20 mTorr and sputtering power was controlled from 100 W to 150 W to investigate the influence of sputtering power on SiO_2 thin films. From the Fig. 6, the sputtering power of 150 W exhibited the lower surface roughness than other sputtering power. Therefore, the optimize low surface roughness of SiO_2 thin films can be obtained through sputtering pressure of 20 mTorr and the sputtering power of 150 W.

Fig. 5. The surface roughness of SiO_2 thin films with various sputtering pressure.

Fig. 6. The surface roughness of SiO₂ thin films with various sputtering power.

3.2 Frequency response of SMR with 3 and 4 pairs SiO₂/Mo

As shown in Fig. 7 and Fig. 8, the 3-pair and 4-pair of SiO₂/Mo layer exhibit smooth and clear interfaces morphology.

Figure. 9 shows the frequency responses of SMR device with 3-pair and 4-pair SiO₂/Mo. The smooth and low surface roughness can be obtained by SiO₂/Mo consisting Bragg reflector layer, and the 4-pair of SiO₂/Mo layer of root mean square (R_{ms}) was 6.442 nm, as shown in Fig. 9 (a). The well return loss can be obtained -21.5 dB through SiO₂/Mo constructed Bragg reflector layer.

Fig. 7. The cross-sectional SEM image of Bragg reflector layer with (a) 3-pair and (b) 4-pair SiO₂/Mo

Fig. 8. The AFM image of Bragg reflector layer with (a) 3-pair and (b) 4-pair SiO₂/Mo

Fig. 9. The frequency response with (a) 3-pair and (b) 4-pair SiO_2/Mo

4. Conclusions

In this study, the SMR devices were composed of Pt/Ti/AlN/Pt/Ti and combined with Bragg reflector layer. The low surface roughness of Bragg reflector layer was consisted using 3-pair and 4-pair SiO_2/Mo and the AFM image presents surface roughness of 4.72 nm and 6.442 nm, respectively. The SMR devices of surface roughness and well return loss can be obtain 6.442 nm and -21.5 dB through 4-pair Bragg reflector layer.

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