

Research on the LGS SAW sensor coated with AlN film

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Abstract- In this work, SAW resonators with high temperature piezoelectric LGS substrate have been studied. A layer of AlN piezoelectric film is deposited on the SAW devices. The influences of the AlN film on the characteristics of the SAW device have been explored. The simulation results show that the resonance frequency and the quality factor of the SAW device with AlN film is larger than that of the SAW device without AlN film. The experimental results agree well with the simulation results. The increase of the resonance frequency is interpreted by the coupling effect between acoustic waves propagating in AlN film and LGS substrate.

Keywords- SAW sensor, FEM, LGS, AlN film.

1. INTRODUCTION

Nowadays, passive and wireless sensors based on surface acoustic waves (SAW) resonator are widely concerned. The SAW sensors have been developed to measure torque[1], mass[2], strain[3] and temperature [4]. In a typical SAW device, a surface mechanical wave is generated and propagates in the substrate due to the electro-mechanical coupling effect. The Rayleigh SAW propagates along the interdigital transducers (IDTs) within 3λ in depth, where λ is the wavelength of the acoustic wave. The characteristics of the SAW sensors are strongly dependent on the piezoelectric substrate.

To operate at high temperature, SAW sensors must be deposited on high temperature piezoelectric substrates. Among various piezoelectric materials, langasite (LGS) has been thought as one of the most attractive material in high temperature due to its good temperature stability and large coupling constant K^2 (0.34%), which is two times larger than that of ST-quartz (0.14%) [5]. Haifeng Zhang [6] reported the force-frequency effect of LGS resonators.

Peng[7] and Thiele[8] fabricated the high temperature SAW gas sensor with LGS materials. And another LGS SAW gas sensor for hash environment had been reported by David et al.[9]. However, an obviously signal attenuation or an unexpected shift of the resonance frequency of the SAW sensor appear [10] after a long-term measurement in high temperature. This is not only caused by the degradation of the metal electrodes, but also the surface contamination in hash environment. So a protective layer is required to improve the stability of the SAW sensor. AlN film was selected as the protective layer on LGS SAW devices [11] due to its good resistant to chemic corrosion and good high-temperature stability. At the same time, AlN film is a good piezoelectric materials with high SAW velocity. Then the AlN film may affect the propagation of the acoustic wave, thereby the characteristics of the SAW resonator.

In this work, the LGS SAW resonator coated with AlN film was simulated and prepared. The influences of the AlN film on the propagation of acoustic wave were studied.

2. MODELING AND SIMULATION

Fig. 1 shows a schematic diagram of the SAW resonator coated with AlN thin film layer. The SAW resonator includes an inter-digital transducers (IDTs) and reflectors which were deposited on LGS substrate.

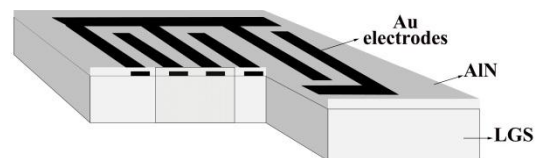


Fig. 1. A section of SAW device.

Usually, the IDTs of SAW resonator consists of hundreds of electrodes, and the electrodes are periodic in nature consisting of positive and negative potentials

alternately. Thus, one period of the electrodes is sufficient to model the SAW resonator. A 2D simulation model as shown in Fig. 2 was used [12, 13]. SAW resonators with and without AlN coating layer are simulated by the COMSOL software. The simulation parameters such as elastic properties of LGS and AlN are summarized in Table 1 [14],[15]. The boundary conditions in simulation are presented in Table 2.

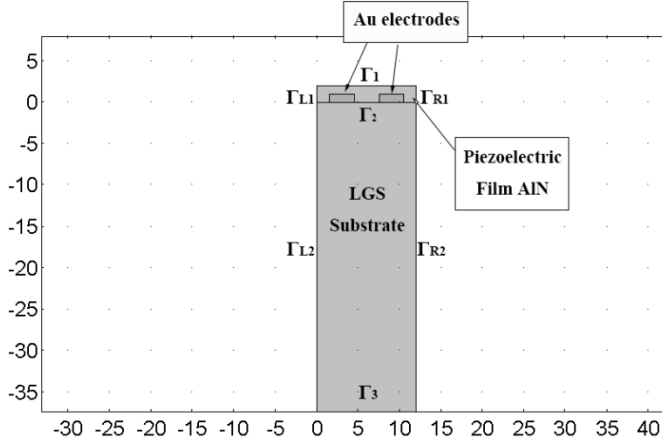


Fig. 2. The simulation structure of the model.

Table 1. The material parameters used in the FEM simulation.

Material		AlN	LGS
Density(kg/m ³)		3260	5743
Elastic constant (Gpa)	C11	345	189.8
	C12	125	105.8
	C13	120	102.2
	C14		14.4
	C33	395	263.5
	C44	118	54.16
	C66	110	42.02
Piezoelectric constant (C/m ²)	e11		-0.44
	e14		0.08
	e15	-0.48	
	e31	-0.45	
	e33	1.55	
Relative permittivity	ε11	9	19.2
	ε33	11	50.7

In our simulation model, the wavelength of the SAW

device is 12 μm and the pitch is 3 μm. The metallization ratio is 0.5. The Au electrodes are used and its thickness is 400nm. The thickness of the AlN film is 1μm. The thickness of the LGS is 40 μm which is greater than three times wavelength and enough to simulate the SAW resonator without large error because the surface acoustic wave propagates only in the surface of the piezoelectric substrate. Eigen-frequency analysis is done to determine the eigen-frequency and the acoustic propagation modes in the structures.

Table 2. Boundary conditions of the model.

Boundary	Mechanical boundary condition	Electrical boundary condition
ΓL1, ΓR1 ΓL2, ΓR2	Periodical boundary	
Γ1 Γ2 Γ3	Free Free Fixed Ground	Zero Charge continuity

The typical simulation displacement mode of the SAW resonator with and without AlN coating layer is shown in Fig. 3. The eigen-mode can be divided into two resonant modes, i.e. symmetric mode and anti-symmetric mode, which are shown in Fig. 3. The resonant frequency of anti-symmetric mode and symmetric mode can be written as [16]

$$f_{M+} = (1 + \frac{\kappa p}{\pi})f_0 \quad (1),$$

$$\text{and } f_{M-} = (1 - \frac{\kappa p}{\pi})f_0 \quad (2),$$

where f_{M+} and f_{M-} are the resonant frequency of anti-symmetric mode and symmetric mode, correspondingly. p is the pitch and f_0 is the center frequency which is defined as $f_0 = v/\lambda$ and v is the acoustic velocity. The symmetric resonance frequency and anti-symmetric resonance frequency correspond to the stopband edges of the surface wave. As shown in (1) and (2), the width of the stopband depends on the reflection coefficient κ . Therefore, we can conclude that the larger κ , the bigger the width of stopband.

To increase κ , it is necessary to design reflectors with large number of gratings.

From the simulation results as shown in Fig.3, the symmetric resonance frequency f_{M+} is 220.5691 MHz, and the anti-symmetric frequency f_{M-} is 211.5145 MHz for the LGS SAW resonator with AlN film. By solving equations (1) and (2), the f_0 is 216.0418 MHz and the Rayleigh wave velocity is 2593 m/s. For the SAW device without AlN film, the f_{M+} is 197.2042 MHz and f_{M-} is 197.1585 MHz. The f_0 is 197.1813 MHz. It can be seen that the resonance frequency of the SAW device with AlN film is larger than that of the SAW device without AlN film. Generally, the resonance frequency of a SAW resonator would be decreased if a layer of materials deposited on the IDTs and the substrate due to the mass effect [2]. However, we can find the deposition of AlN film on the SAW device increases the resonance frequency of the SAW resonator. This may be caused by the coupling effect between acoustic waves propagating in AlN film and LGS substrate [17].

From the frequency response analysis, the admittance (Y) of the device can be calculated by

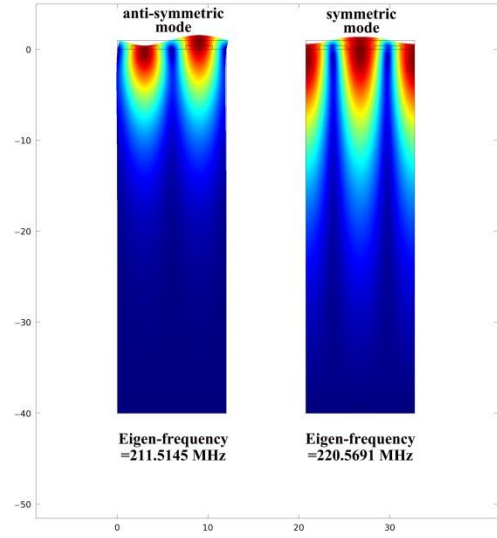
$$Y = j\omega_r Q/V \quad (3),$$

where ω_r is the angular frequency, Q is the complex charge (or current in the electrode), V is the electric potential. The computational frequency responses of the SAW devices are shown in Fig. 4.

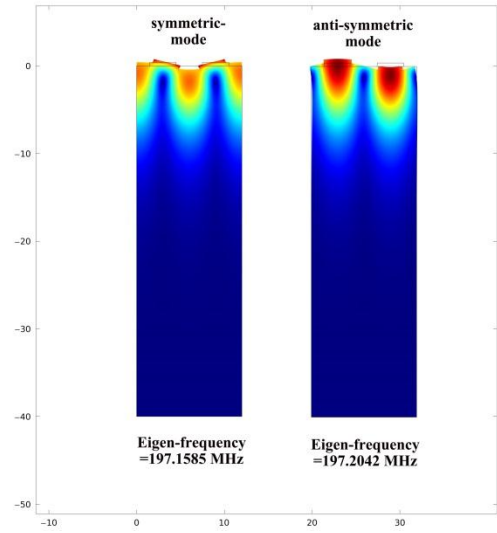
The quality factor Q_r could be calculated by

$$Q_r = \omega_r / FWHM \quad (4),$$

where FWHM is half width of the resonant peak of the admittance. With (4), the Q_r are 42743 and 38533 for the LGS SAW device with and without AlN film, correspondingly. We can see that the quality factor of the SAW resonator can be increased by depositing a layer of AlN piezoelectric film.



(a)



(b)

Fig. 3 Deformed shape plot of the Rayleigh SAW mode. (a) with AlN film and (b) without AlN film.

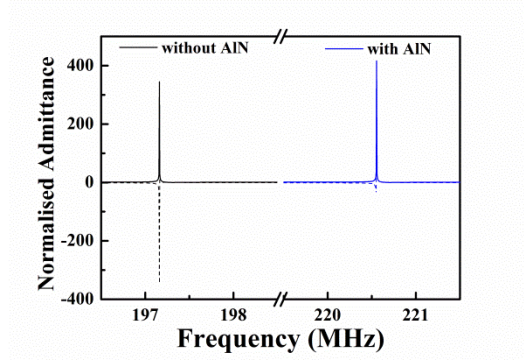


Fig. 4. The normalized admittance of the SAW resonators.

3. FABRICATION AND MEASUREMENTS

According to the designed LGS SAW resonator, a one-port SAW resonator has been fabricated using LGS substrate. There are 150 pairs IDTs and 400 grating reflector at each side of the IDTs. The thickness of the Au electrodes is 380nm. The IDTs and reflector were fabricated on LGS substrate using lift-off photolithography technique. A layer of AlN films with thickness of about 1 μm was sputtered on the top of Au/LGS substrate using middle frequency magnetron sputtering. The sputtering pressure is 0.94 Pa. The flow of N_2 and Ar are 58 sccm and 72 sccm, correspondingly. The sputtering power was 2000 W. The fabricated SAW device was annealed in pure nitrogen at 500 $^\circ\text{C}$ for 10 min. The characteristics of the prepared SAW resonator are measured using a network vector analyzer (Agilent N5234A).

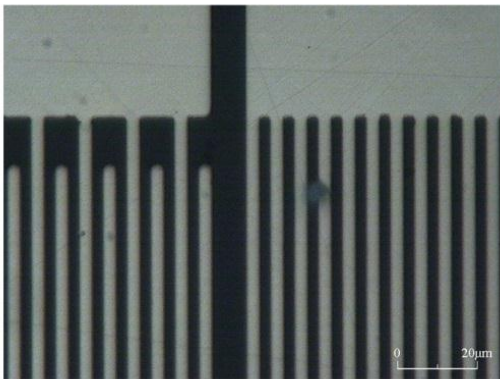


Fig. 5. The photo of the fabricated SAW resonator.

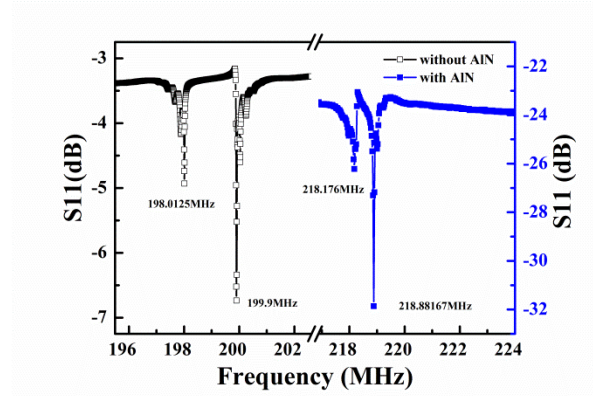


Fig. 6 The frequency response of the SAW resonators with and without AlN top layer.

Fig. 6 shows the experimental results of the prepared SAW resonators with and without AlN top layer. From Fig.6, we can find that the resonance frequency of the LGS SAW resonators with and without AlN coating layer are 218.882MHz and 199.9 MHz, correspondingly. The experimental result is very close to the simulation results. The little differences are caused by the fabrication error, which results in the thicknesses of the electrodes and AlN films are not fully same as the simulation model. We can find that the measurement results verify our simulation results, i.e., the AlN coating layer increases the resonance frequency of the SAW resonator due to the coupling effect[17].

4. CONCLUSIONS

In this work, the LGS SAW resonator coated with AlN piezoelectric film was simulated and prepared. We investigated the influences of the AlN film on the characteristics of the SAW resonator. The simulation shows that the SAW resonator has a higher resonance frequency and larger quality factor with AlN film coated, than that without AlN film. And according to the experimental results which verify the simulation, it can be concluded that it is feasible to use AlN film as a protective layer on LGS SAW sensor. Furthermore, the depositing AlN film could even improve the performance of the SAW device.

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