Impact of Device Parameters on Performance of SAW Resonators on AlN/Sapphire

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Abstract

In this paper, highly c-axis-oriented AlN films with an AlN (0002) peak Full Width at Half Maximum (FWHM) value of 0.2° were prepared by RF reactive sputtering on a 2 inch Sapphire substrate. One-port Rayleigh wave Surface Acoustic Wave (SAW) resonators were fabricated by lift-off photolithography techniques. The influence of Inter Digital Transducer (IDT) finger width and IDT aperture on the resonant characteristics (resonant frequency f_r, electromechanical coupling coefficient K_t^2, and S_{11} magnitude difference at resonant and anti-resonant frequency (ΔS_{11})) of the SAW devices were experimentally investigated. The results show: 1) the acoustic velocity for the AlN/Sapphire can be improved by 60% over that of $LiNbO_3$ with the same IDT finger width of 2 μm, 2) the maximum K_t^2 value of 0.168% and f_r of 692 MHz are achieved when the IDT finger width is 2 μm, and 3) K_t^2 and ΔS_{11} increase with increasing IDT finger aperture.

INTRODUCTION

Today bulk piezoelectric materials such as $LiNbO_3$ and $LiTaO_3$ are commercially available for SAW filter fabrication. However, the low acoustic velocity of those materials limits their operating frequency to below 2.5 GHz [1]. This limitation makes AlN an alternative solution for high frequency SAW devices due to its high acoustic velocity (5600 m/s - 6000m/s). This allows the fabrication of high frequency devices up to 5 GHz when combined with high velocity materials such as diamond or Sapphire [2, 3].

In the past decades, multiple research efforts in materials and device structures have been carried out to obtain well-performing AlN-based SAW devices. Hashimoto et al. [4] have reported on new ScAlN films for fabricating high K_t^2 SAW devices. Fu et al. [5] reported high quality AlN material grown on sapphire with a ZnO buffer layer. Kaya, et al. [6] studied the effect of AlN film thickness on K_t^2. Malocha et al. [7] have investigated the evolution of several SAW interdigital transducer (IDT). However, the impact of device parameters such as the IDT finger width (W_{IDT}) and IDT aperture (L_{IDT}) on SAW resonators on AlN/Sapphire structures is rarely studied. In this paper, the impact of device structures on the performance of one-port Rayleigh wave SAW resonators on that material will be investigated experimentally.

EXPERIMENTS AND RESULTS

AlN films with thicknesses of 1 μm were deposited on 2 inch (0001) sapphire wafers by RF reactive sputtering with a high purity Al target in an Ar and N_2 gas mixture. Then, one-port SAW resonators with Ti/Al electrodes were fabricated by electron beam evaporation and lift-off photolithography. The metal thickness of Ti and Al was 10 nm and 150 nm, respectively.

Figure 1(a) shows the 2 - X-ray Diffraction (XRD) scan pattern of those films. The diffraction peaks at 2 = 36.1°, and 41.78° correspond to the (0002) plane of the hexagonal AlN phase and the (0002) plane of the hexagonal Al_2O_3, which means a highly c-axis textured AlN thin film was successfully grown on the sapphire substrates. Figure 1(b) shows the XRD rocking curve of AlN films, indicating that the full width at half maximum (FWHM) value of AlN films is as low as 0.2°.

The surface morphology of these AlN films was characterized using Atomic Force Microscopy (AFM). As shown in figure 2, the AFM image of AlN film reveals a homogeneous surface without abnormally grown grains. The root mean square (rms) roughness value of AlN film is 1.37 nm.

Figure 3(a) shows the fabricated one-port SAW resonators on this AlN/sapphire bilayer. The SAW devices include IDTs and a pair of reflectors. The IDTs contain 100 pairs of equally spaced fingers and100 reflector gratings. Figure 3(b) shows a SEM picture of IDTs with a metallization ratio of 50%.

Figure 4 presents the measured frequency responses (S_{11}) of the $LiNbO_3$ and AlN SAW resonators with the same wavelength ($\lambda = 4\ W_{IDT}$) of 8 μm and fabrication process. The resonant frequency (f_r) of the $LiNbO_3$ and AlN SAW resonators are 427 and 692 MHz, respectively. The sound velocity (υ_{SAW}) is 3416 m/s for the $LiNbO_3$ bulk substrate and 5536 m/s for the AlN/Sapphire, which can be calculated according to Eq. (1). The experimental results of acoustic velocity for AlN /Sapphire can be improved by 60% than that of $LiNbO_3$.

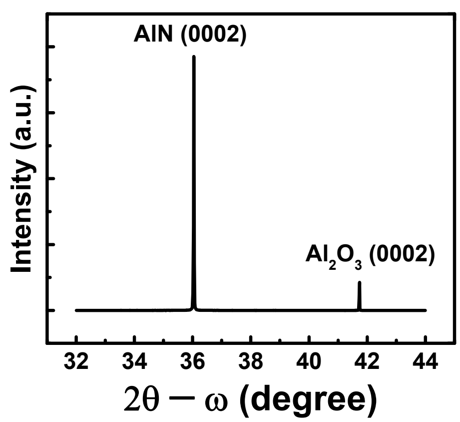
$$v_{SAW} = \lambda \cdot f_r \quad (1)$$

Figure 5 exhibits the frequency response of the AlN/Sapphire SAW devices with different IDT finger widths W_{IDT}. We can observe clearly that f_r decreases from 692 MHz to 347 MHz. The magnitude of S_{11} is also attenuated when W_{IDT} increases from 2 μm to 4μm.

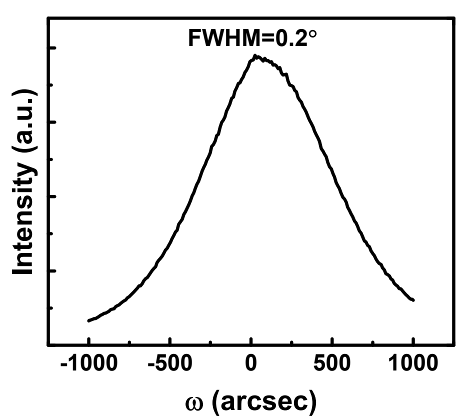
Figure 6 shows the dependence of ΔS_{11} and K_t^2 on W_{IDT}. The maximum values of $\Delta S_{11} = 0.42$ dB and $K_t^2 = 0.168\%$ are achieved when W_{IDT} is 2 μm, corresponding to a normalized AlN thickness h/λ (h is the thickness of AlN thin films) of 0.125. Reducing h/λ will degrade ΔS_{11} and K_t^2 because less electron energy can be transferred to the Rayleigh wave mode for smaller values of h/λ.

Figure 7 exhibits the frequency response of different IDT finger apertures, L_{IDT}. It is obvious that S_{11} magnitude is attenuated when L_{IDT} decreases from 240 to 80 μm.

Figure 8 shows the dependence of the ΔS_{11} and K_t^2 on the IDT finger aperture. ΔS_{11} increases from 0.17 dB to 0.42 dB with increasing IDT finger aperture, and K_t^2 shifts from 0.067% to 0.168% with the increase of L_{IDT}, a 150% K_t^2 improvement. The improvement can be attributed to increasing L_{IDT} increasing the active area of the resonators, which can excite surface acoustic waves more effectively.



(a)



(b)

Fig. 1. (a) The 2 - XRD scan pattern of AlN thin films. (b) The XRD rocking curve of AlN films.

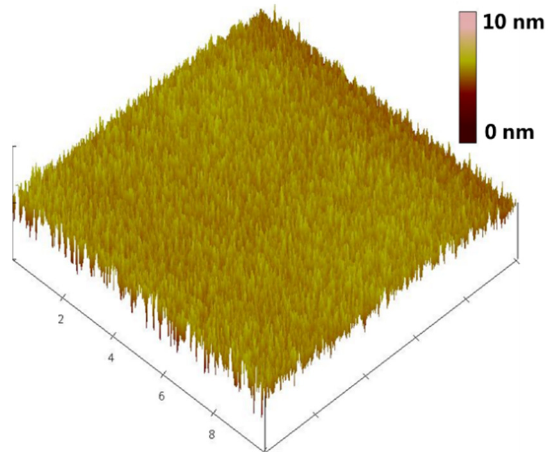


Fig. 2. 3D AFM image of AlN films in a range of 10 × 10 μm.

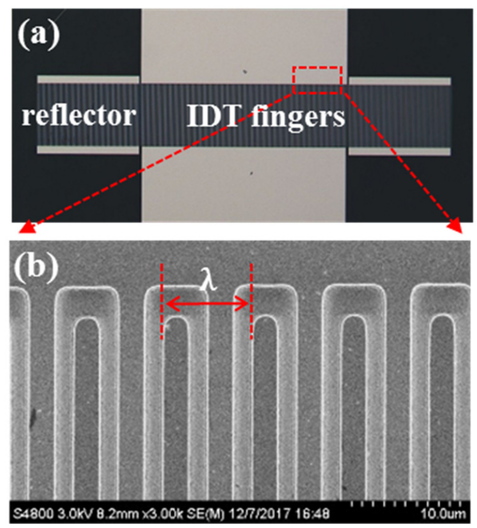


Fig. 3. (a) Microscope picture of a one-port SAW resonator (b) SEM picture of IDT fingers.

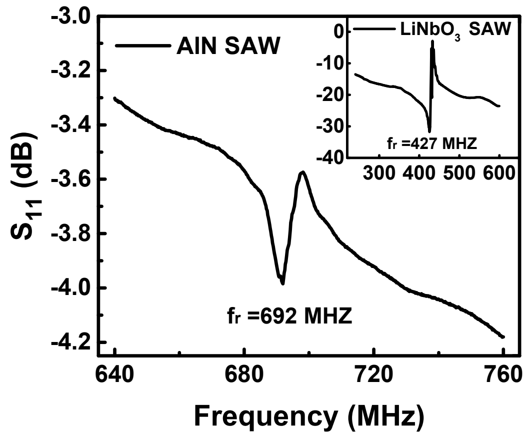


Fig. 4. Frequency response (S_{11}) of $LiNbO_3$ and AlN SAW resonators

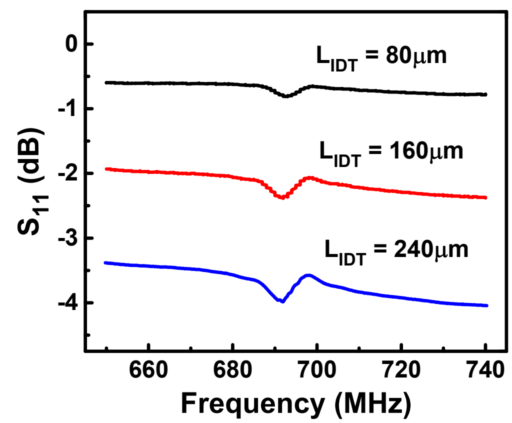


Fig. 7. Frequency response (S_{11}) of a one-port SAW resonator with increasing IDT finger aperture

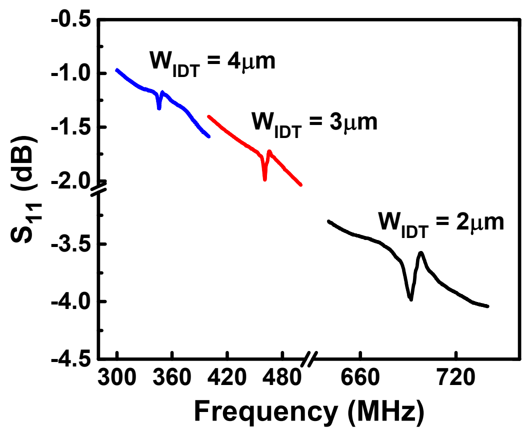


Fig. 5. Frequency response (S_{11}) of a one-port SAW resonator with different IDT finger widths

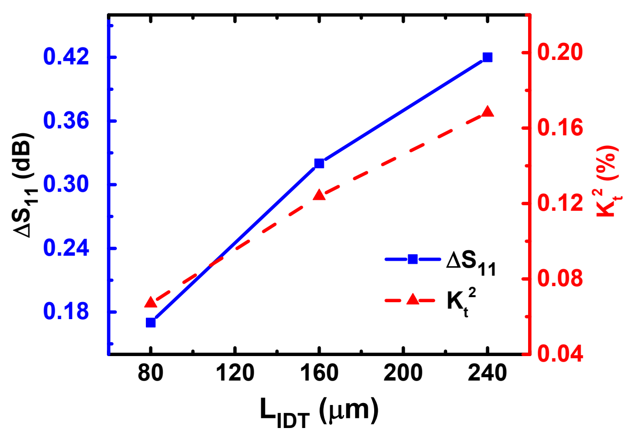


Fig. 8. Dependence of ΔS_{11} and K_t^2 on IDT finger aperture

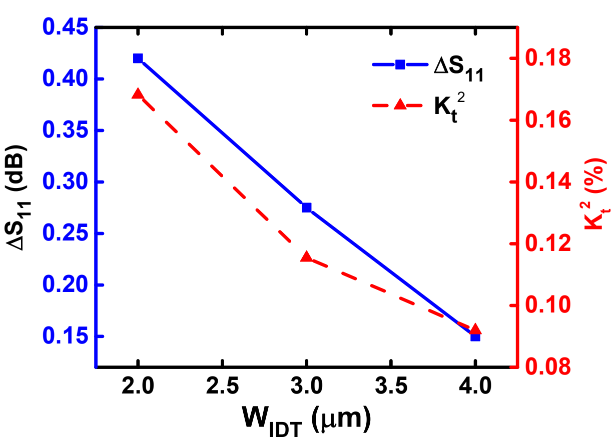


Fig. 6. Dependence of ΔS_{11} and K_t^2 on IDT finger width

CONCLUSIONS

In conclusion, highly c-axis-oriented AlN films were sputtered on (0001) sapphire substrates with a FWHM of 0.2° by reactive magnetron sputtering. Then, SAW resonators on that Al/AlN/sapphire structure fabricated by lift-off photolithography with different device parameters were investigated. The experimental results showed that the acoustic wave velocity of AlN/sapphire is almost 1.6 times that of $LiNbO_3$. The K_t^2 coefficient increased from 0.092% to 0.168% when the IDT finger width was decreased from 4 μm to 2 μm and the K_t^2 coefficient increased from 0.067% to 0.168% when the IDT finger aperture was increased from 80 μm to 240 μm.

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Acronyms

SAW: Surface Acoustic Wave
IDT: Interdigital Transducer
AlN/Sapphire: AlN films on Sapphire substrate
XRD: X-ray diffraction
AFM: Atomic force microscopy
FWHM: Full Width at Half Maximum
K_t^2: Electromechanical Coupling Coefficient