High-Performance SAW Resonators at 3 GHz Using AlScN on a 4H-SiC Substrate

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***Abstract*— Surface Acoustic Wave (SAW) devices realized by the structure of Aluminum Scandium Nitride (AlScN) on a 4H-Silicon Carbide (SiC) substrate offer an advantageous combination of high sound velocity, low thermal resistance of the substrate, high electromechanical coupling (K^2), high Q factor, and low fabrication complexity. In this paper SAW resonators were fabricated with a resonance frequency at 3.1 GHz and sound velocity of 6900 m/s. The Q factor achieved of 650 was improved from a previous study [1]. SAW delay lines were also fabricated on the AlScN/SiC structure and a low propagation loss of 5.9 dB/mm was achieved.**

Keywords—Aluminum Scandium Nitride; Surface Acoustic Wave Resonator; Delay Line; Coupling Coefficient;

I. INTRODUCTION

Surface acoustic wave (SAW) resonators realized on piezoelectric substrates are widely used in filters and duplexers because of their small size, high performance, and low cost [2]. Previous studies have shown that by improving the piezoelectric material and the structure of the underling substrate that SAW resonator performance can be significantly enhanced [3, 4]. In this paper, Aluminum Scandium Nitride ($Al_{58}Sc_{42}N$) and 4H-silicon carbide (SiC) were chosen as the piezoelectric material and substrate. SiC, a wide bandgap semiconductor, is widely utilized in high voltage and high-power applications due to its high breakdown voltage [5]. It is particularly promising in high-heat-flux applications due to its low thermal expansion coefficient of 4~5 × 10^{-6}/K and high thermal conductivity of 490 W/mK [6,7]. In addition, the high acoustic velocity of SiC, that is more than 50% larger than silicon, serves to confine the acoustic wave in the piezoelectric materials, which increases the electromechanical coupling and decreases the propagation losses [8]. By alloying Sc with AlN, a previous study has shown the electromechanical coupling coefficient increased up to 4 times larger than for pure AlN [9]. The close lattice match of the SiC substrate to AlScN provides highly crystalline c-axis oriented growth of AlScN piezoelectric thin films [10].

A previous study has reported 340, 240, and 4.5% for the series resonance Q, anti-resonance Q, and K^2, respectively, for SAW resonators based on an AlScN/6H-SiC structure [1]. Here, we optimized the resonator design of an AlScN/4H-SiC structure with a similar resonance frequency around 3 GHz and achieved a higher Q. In addition, 4H-SiC offers the advantage for large-scale manufacturing since 6-inch 4H-SiC wafers are readily available due to the widespread use of the 4H poly type in power electronics.

II. METHODS

Previous research has found the electromechanical coupling coefficient reaches its maximum when the thickness of AlScN is 0.4 – 0.8 times the wavelength of the SAW device [1]. Thus, the AlScN thickness has been designed in this study as 1 μm for a resonance frequency near 3 GHz for the SAW resonators. The IDT has a periodicity of 1.11 μm with a line width of 650 nm and the aperture of 20 μm. The number of IDT finger pairs is 64, as shown in Fig. 1(a). The 1 μm thick AlScN layer was co-sputtered on high resistivity 4H-SiC wafers at 350 °C. After that, a Ti-Al (10 nm/100 nm) electrode layer was deposited via evaporation and patterned via lift-off.

III. RESULTS AND DISCUSSION

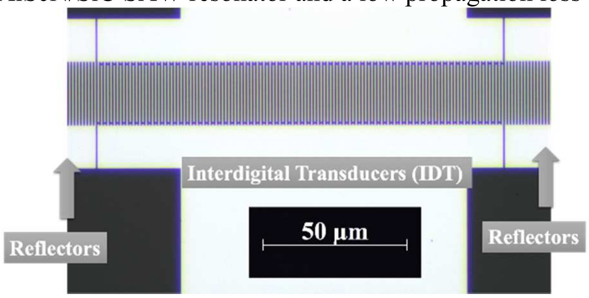
Fig. 1 (b) shows the surface profile of the deposited $Al_{58}Sc_{42}N$. The film exhibits a low surface roughness of 1.3 nm and is free of abnormally oriented grain (AOG) growth. A high surface roughness would attenuate the SAW wave [11] and lower the Q factor. Fig. 1 (a) and (c). show the optical and SEM images of the fabricated Interdigital Transducers (IDT) on $Al_{58}Sc_{42}N$.

A two-dimensional COMSOL simulation was used to reveal the two propagating modes in the fabricated SAW resonators: a Rayleigh mode resonance around 1.9 GHz and a Sezawa mode resonance around 2.9 GHz, as shown in Fig. 2 (a) [1]. A vector network analyzer was used to measure the frequency response of the fabricated SAW devices. As shown in Fig. 2 (c)., the admittance plot shows two modes for the fabricated SAW resonator. Fig. 2 (b) reveals that the Q_s increases with increasing numbers of reflectors, achieving a maximum value of 650 which includes ohmic losses in the IDT traces and busing.

SAW delay lines based on the $Al_{0.58}Sc_{0.42}N$/4H-SiC structure were also designed and fabricated. The aperture width was 173.44 μm and the number of IDT finger pairs was 20, resulting in a delay line well matched to 50 Ω, as shown in Fig. 3 (b). The IDT width and periodicity of the SAW delay line transducers are the same as the SAW resonator. Fig. 3. shows the frequency response of the fabricated delay lines with different delay line lengths. The average propagation loss is 5.86 dB/mm. The ripples in the IDT passband are due to the reflection between the input IDT and the output IDT, and its magnitude becomes smaller with an increase of the delay line length.

IV. Conclusions

This paper described the increased Q factor of an AlScN/SiC SAW resonator and a low propagation loss SAW



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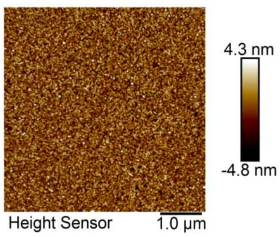

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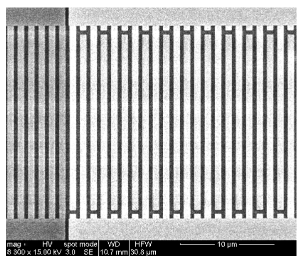

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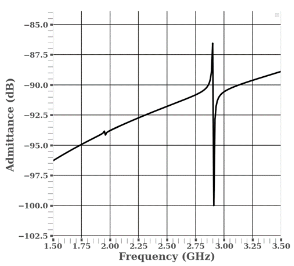
Fig. 1. (a) Optical microscope image of fabricated SAW resonators. (b) AFM image of deposited 1 μm thick $Al_{0.58}Sc_{0.42}N$ on 4H-SiC substrate. (c) Scanning Electron Microscope (SEM) image of fabricated SAW resonator.



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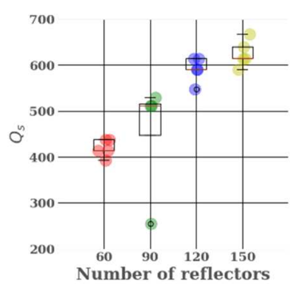

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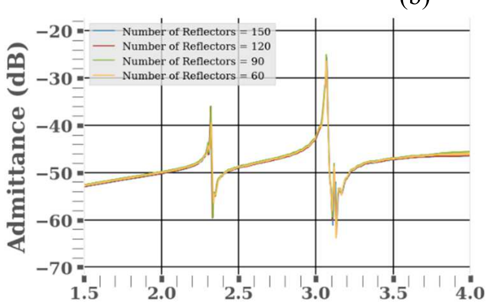
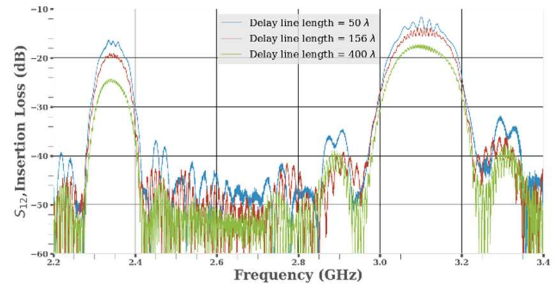


(c)

Fig. 2. (a) COMSOL simulation results of $Al_{58}Sc_{42}N$/4H-SiC SAW resonator. (b) Qs of the SAW resonators with respect to the number of reflectors. (c) Admittance, Y_{12}, characteristics of the fabricated SAW resonators.

delay line operating at 3.1 GHz. Further enhancement of Q and electromechanical coupling are the subject of ongoing research.



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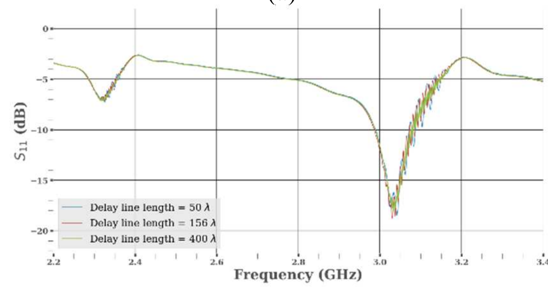

(b)

Fig. 3. Frequency response: (a) Insertion loss, S_{12}, and (b) S_{11} of SAW delay line fabricated on AlScN/4H-SiC structure.

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