SMaterial and SAW properties of AlN thin film deposited by reactive RF magnetron sputtering method on various substrates

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ABSTRACT

AlN thin film for SAW filter application was deposited on various substrates such as (100) silicon, sapphire, Si_3N_4/Si subatrates by reactive magnetron sputtering method. The structural property was dependent on the deposition conditions such as sputtering pressure, RF power, substrate temperature, and nitrogen partial pressure. Scanning Electron Microscope(SEM), X-ray diffraction(XRD), and Atomic Force Microscope(AFM) have been used to find out structural properties and preferred orientations of AlN thin films. Preferred orientation and SAW characteristic of AlN were improved by insertion of Al_2O_3 buffer layer. Insertion loss of SAW devices using AlN/Si and AlN/Al_2O_3/Si were about 33.27[dB] and 30.20[dB] individually.

Keywords: SAW, AlN thin film, Al_2O_3 buffer layer.

1. INTRODUCTION

ZnO and AlN have been extensively studied as thin film SAW (Surface Acoustic Wave) material[1]. Thin film SAW devices have an advantage to be integrated with acoustic devices or other electronic devices on the same substrate. Compared to ZnO thin film deposited on the GaAs substrate, AlN thin film deposited on the Si substrate has higher SAW velocity by 2000m/s in spite of its low piezoelectric constant. AlN has also characteristics such as its good chemical stability, high mechanical strength, high thermal conductivity, and good dielectric property. To obtain good SAW characteristics, we have to deposit AlN thin film with good preferred orientation, small surface roughness, high surface resistivity, and high electro-mechanical coupling coefficient, etc. Since all these properties of single layer thin film are not good enough, buffer layers such as SiO_3[2], Si_3N_4[3], DLC (Diamond-like carbon)[4,5], AlN[6], Al_2O_3[7], diamond[8,9,10] are being investigated by several groups.

Thin film AlN with good preferred orientation can be grown with CVD (Chemical Vapor Deposition)[11,12], pulse laser deposition method[13], or sputtering method[14,15]. CVD method needs high temperature process at higher than 1000°C and thus leads to high grain growth rate, which results in high surface roughness, high lattice mismatch, and increasing stress due to the difference of coefficient of thermal expansion. Sputtering method can be used to deposit AlN with good SAW properties at low temperature.

For this study, RF(Radio Frequency) reactive sputtering method was used to fabricate AlN/Si_3N_4/Si, AlN/Al_2O_3/Si, AlN/Si, and AlN/Sapphire structure, respectively. We investigated substrate structure and buffer layer to obtain improved SAW properties.

2. EXPERIMENTAL

RF magnetron sputtering system has been used to deposit AlN thin film on the (100) Si wafer. Rotary pump and cryo pump lowered

pressure down to 3.0×10^{-6} torr. RF power was set to 200 Watt, and distance between substrate and target was 8 cm. Nitrogen partial pressure was 0.5 and operating pressure was 5 mtorr. No intentional heat was applied to the substrate. Table 1 shows various deposition conditions. AlN thin film was deposited for 10 hours on various substrates such as sapphire, Si_3N_4/Si, Al_2O_3/Si, and Si wafer. AlN thin film properties were investigated by SEM, AFM, and XRD.
Aluminum was deposited on AlN thin film with vacuum evaporator and lithography process was used to fabricate IDT(Interdigital transducer). Network Analyser E8802A (Agilent, USA) was used to analyze SAW characteristics.

Table 1. Deposition conditions of Al_2O_3 and AlN thin films.]

Deposition conditions	AlN thin film	Al_2O_3 thin film
RF POWER	200,300 W	300 W
Deposition pressure	5 mTorr	8 mTorr
Substrate temperature	Room temperature	Room temperature
Gas partial pressure	$N_2/(N_2+Ar)=0.5$	$O_2/(O_2+Ar)=0.1$
Deposition duration	10, 5 hours	45 min
Base pressure	3×10^{-6} torr	3×10^{-6} torr
Distance between substrate and target	8 cm	8 cm
Gas	Ar, N_2(10[sccm])	Ar, O_2(30[sccm])

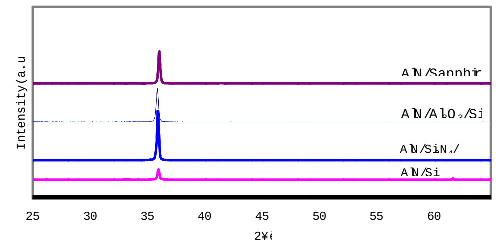
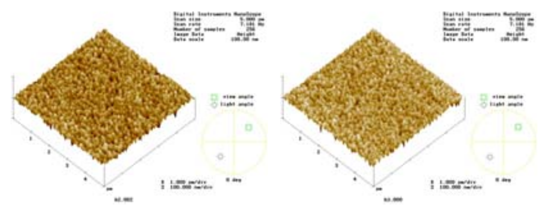
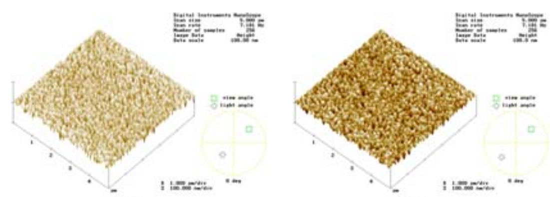


Fig. 1. XRD results of AlN thin film fabricated on the various substrates.



(a) AlN/Si_3N_4/Si, RMS=6.27 nm (b)AlN/Sapphire, RMS=5.83nm



(b) AlN/Al_2O_3/Si, RMS=9.345 nm (d)AlN/Si, RMS=5.55 nm

Fig. 2. Surface roughness and images of AlN thin film deposited on the various substrates.

3. RESULTS

Figure 1 shows HR-XRD results of AlN thin film deposited on Si_3N_4/Si, Al_2O_3/Si, Si, and sapphire substrates. Preferred orientation of AlN deposited on the crystalline sapphire substrate is about 98.1% and that of AlN deposited on Si_3N_4/Si, Al_2O_3/Si, and Si substrate is almost 100%.

Figure 2 shows surface roughness measured with AFM. Roughness of AlN/Al_2O_3/Si structure was measured to be 9.34 nm and other structures have lower values. Surface roughness of AlN/ Si_3N_4/Si was 5.83 nm and that of AlN/Si was 5.55 nm.

90 pairs of IDT were fabricated on AlN thin film as SAW electrodes. Finger overlap is 1.6 mm and the width of busbar is 0.8 mm. Distance between input IDT and output IDT was 1.2 mm to obtain two-port SAW filter. Figure 3 shows SAW characteristics of these two-port SAW filters fabricated on various substrates. Insertion loss of SAW filter with AlN/Sapphire structure was 44.83 dB and its center frequency was 137.9 MHz. Insertion loss of SAW filter with AlN/ Al_2O_3/Si structure was 30.20 dB and its center frequency was 126.1 MHz. Insertion loss of SAW filter with AlN/Si_3N_4/Si structure was 40.52dB and its center frequency was 125.7 MHz. Insertion loss of SAW filter with AlN/Si structure was 33.27 dB and its center frequency was 125.3 MHz. Center frequency of

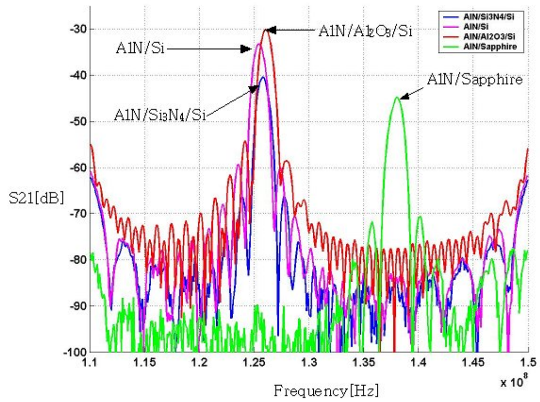


Fig. 3. Characteristics of two-port SAW filter fabricated on various substrates.

AlN/Sapphire SAW filter is about 12 MHz higher than that of other structure due to higher Young's modulus of sapphire substrate and thus faster SAW velocity. It is estimated that AlN/Si structure has the lowest insertion loss.

Electromechanical coefficients K^2 were calculated and shown in Figure 4. Electromechanical coefficient for AlN/sapphire structure is the lowest of 0.022 %, for the AlN/ Si_3N_4/Si structure 0.028 %, for the AlN/Si structure 0.15 %, and for the AlN/Al_2O_3/Si structure 0.175 %, the highest value. These values explain the results shown in the Figure 3. Substrate does not seem to affect the structural properties of AlN thin film deposited on it, but does affect the value of electromechanical coefficient K^2. From these results, AlN/Al_2O_3/Si structure can be used to reduce insertion loss and AlN/Sapphire structure may be used to fabricate high frequency device.

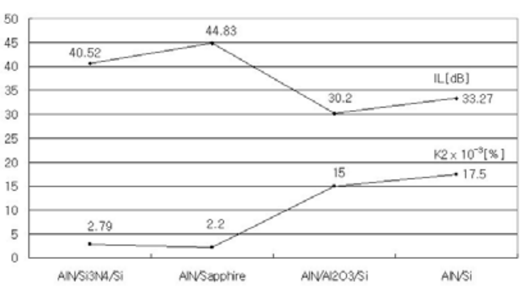


Fig. 4. Insertion loss and electromechanical coupling coefficients of two-port SAW filters fabricated on various substrates.

RF power was increased to 300 W to improve the growth rate of AlN thin film on the Al_2O_3/Si substrate. Thickness of Al_2O_3 buffer layer was about 100 nm and operating pressure was 8 mtorr. AlN deposition has been done for 5 hours at room temperature. Nitrogen partial pressure was 0.5. As can be seen in Figure 5, (101) peak appeared in AlN/Si structure but AlN/Al_2O_3/Si structure maintains good preferred orientation without any other peak.

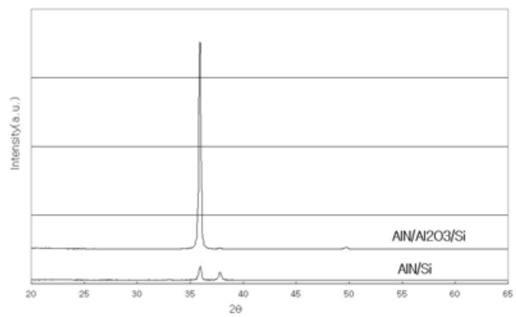


Fig. 5. XRD results of AlN thin film deposited on the Al_2O_3/Si structure.

Figure 6 shows SEM cross section view of AlN/Al_2O_3/Si structure and AlN/Si structure. The thickness of AlN of the structure with buffer layer is about 3.03 μm and that of the structure without buffer layer is about 2.87 μm. It seems that Al_2O_3 buffer layer improves preferred orientation and also thin film growth rate. Two-port SAW devices were fabricated with these structures and their SAW characteristics were measured as shown in Figure 7. Insertion loss of AlN/Al_2O_3/Si structure was 28.75 dB and that of AlN/Si structure was 34.64 dB. Insertion loss has been increased by 5.89 dB with the help of Al_2O_3 buffer layer

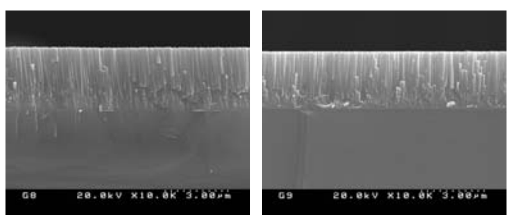
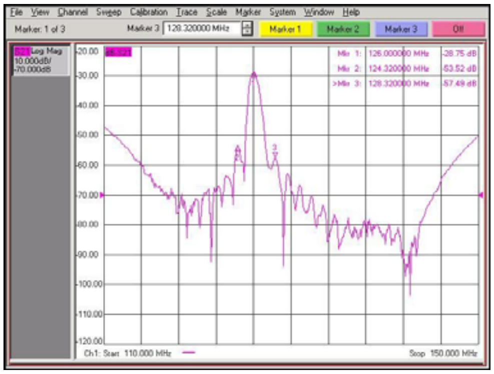
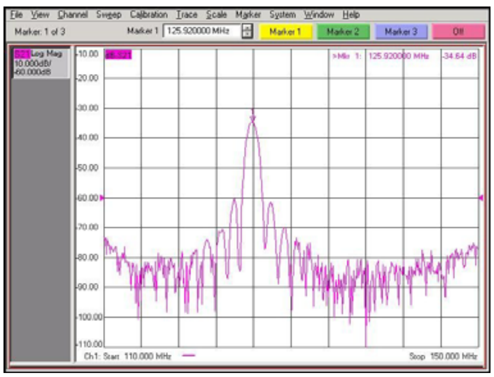


Fig. 6. Sectional images of AlN thin film deposited on the Al_2O_3 buffer layer.



(a) $AlN/Al_2O_3/Si$, IL=28.75[dB]



. (b) AlN/Si, IL=34.64[dB]

Fig. 7. Insertion losses of two-port SAW filter with $AlN/Al_2O_3/Si$ and AlN/Si structures.

4. CONCLUSION

It was shown that Al_2O_3 buffer layer improves electromechanical coefficient and preferred orientation of AlN thin film. Also, Al_2O_3 buffer layer increases the growth rate of AlN thin film without deterioration of structural properties. To fabricate high frequency SAW device, sapphire substrate may be used instead of Si substrate. SAW velocity of AlN/sapphire structure was 5516 m/s and that of AlN/Si was 5012 m/s.

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