극한 환경 USN용 SAW 제작과 그 특성

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Fabrication of SAW for harsh environment USN and its characteristics

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Abstract : In this study, AlN thin films were deposited on a polycrystalline (poly) 3C-SiC buffer layer for surface acoustic wave (SAW) applications using a pulsed reactive magnetron sputtering system. AFM, XRD and FT-IR were used to analyze structural properties and preferred orientation of the AlN/3C-SiC thin film. Suitability of the film in SAW applications was investigated by comparing the SAW characteristics of an interdigital transducer (IDT)/AlN/3C-SiC structure with the IDT/AlN/Si structure at 160 MHz in the temperature range 30–150°C. These experimental results showed that AlN films on the poly 3C-SiC layer were highly (002) oriented. Furthermore, the film showed improved temperature stability for the SAW device, TCF = -18 ppm//°C. The change in resonance frequency according to temperature was nearly linear. The insertion loss decrease was about 0.033dB/°C. However, some defects existed in the film, which caused a slight reduction in SAW velocity.

key worlds : AlN thin film, polycrystalline 3C-SiC, two-portSAW resonator, SAW properties

I. INTRODUCTION

AlN as been widely used in thin film form for SAW applications because of its attractive material properties including: high electrical resistance, acoustic velocity, temperature and chemical stability and piezoelectric properties. Currently, AlN films grown on different substrates revealed many advantages such as high SAW velocity in AlN/diamond, AlN/sapphire, AlN/4H-SiC and AlN/6H-SiC embodiments [1-4], and low temperature coefficient of frequency (TCF) in AlN/Sapphire [2], AlN/Diamond [5] and AlN/6H-SiC [6] systems. Unfortunately, these structures still have some disadvantages. As-deposited poly diamond films exhibit poor surface roughness and high hardness. These disadvantages are improved by using a diamond (backside)/Si structure, or nanocrystalline diamond [5, 7], which is based on a complex process and therefore is relatively expensive. SiC wafers (4H- and 6H-bulk) fabricated by a sublimation method are commercially available, but these substrates have small areas and are very costly because it is difficult to obtain large area substrates by sublimation due to the high temperature (2,000°C) required. So, the main drawbacks of these substrates are that they are expensive and difficult to integrate into conventional Si manufacturing Technologies. Si substrates, on the other hand, are low cost but the difference in coefficient of thermal expansion (CTE) (17%) and the lattice mismatch (19%) between AlN and Si are large, which is a disadvantage for their SAW properties at high temperatures.

Recently, SiC-MEMS researchers have become interested in cubic 3C-SiC that can be grown on large Si wafers at relatively low cost. 3C-SiC is classified into single and polycrystalline types by its crystal structure. In comparison with poly 3C-SiC films, single 3C-SiC films require high growth temperatures, which cause problems such as a large residual stress, cracks, lattice mismatching (20%) and different CTE (8%) at the Si/single-SiC interface. Furthermore, The SiC's CTE is closely matched that of AlN, and the lattice mismatch is less than 1%. Therefore, both materials have been used in applications in high temperature packaging [9], and AlN thin films have been used as buffer layers for 3C-SiC grown on Si substrate [10].

Based on the discussion above, poly 3C-SiC is an ideal candidate for a buffer layer of poly AlN films grown on SiO2/Si substrate for SAW applications with variable temperature, which is the topic of this work. A pulsed magnetron reactive sputtering method was used to deposit AlN on 3C-SiC buffer layer. The structural properties of AlN/SiC were investigated by atomic force microscopy (AFM), X-ray diffraction (XRD), and Fourier transform infrared spectroscopy (FT-IR). The sample poly AlN (002) grown on Si (100) substrate was used. We fabricated an IDT/AlN/3C-SiC structure and an IDT/AlN/Si structure with the same wavelength (λ) and thickness (h), and investigated their SAW properties over the temperature range 30°C - 150°C.

II. EXPERIMENTS

The (100) oriented Si wafer was cut into a rectangular shape of 4×6 cm^2. After an 800 nm SiO$_2$ layer was grown on the Si wafer using a wet thermal oxidization process, poly 3C-SiC thin film (used as a buffer layer) was deposited on the oxidized Si (100) substrate by atmospheric pressure chemical vapor deposition (APCVD) using $Ar+H^2$ mixtures as a carrier gas and Hexamethyldisilane (HMDS: (CH3)6Si$_2$) as a precursor. Poly 3C-SiC thin film with 0.5μm thickness was grown at a deposition temperature of 1100℃ [8]. Poly AlN thin film with 2 μm thickness was deposited on the poly 3C-SiC buffer layer by a 40 kHz pulsed magnetron reactive sputtering system. The distance between the aluminum (Al) target (99.999 % purity) and the substrate was 8 cm. After the sputtering chamber was evacuated to a base pressure of 5x10-7 Torr, AlN films were deposited at a deposition pressure of 3.5 x 10^{-3} Torr with gas flow ratio (Ar:N$_2$) of 10:1. Deposition rate was 800-850 Å/min. During the deposition, the applied power density was 12.5 W/cm^2 and substrate was at room temperature. XRD and FT-IR was performed to check textures of the AlN/SiC structure. An AFM was employed to observe the surface morphology.

Two-port SAW resonators were fabricated by conventional photolithography technology and wet etching. Inter-digital transducers (IDT) and reflectors (Aluminum) were 100 nm thick. IDTs of 50 finger pairs having an electrode period (d) of 8 μm were used. The grating width and a gap of reflector was 8 μm, the aperture was W=60λ, and the wavelength (λ=4d) was 32 μm. The length from center to center was 2240 μm, and the spacing between the IDT and the reflector was 170 μm. Transmission characteristics of the two-port SAW resonators were measured using an Agilent 8802A Network Analyzer in the temperature range of 30 – 150℃

IV. RESULTS AND DISCUSSION

Fig. 1. shows the XRD pattern of a poly 3C-SiC film grown on oxidized Si (100) substrate. Among the two peaks, the stronger one appeared at 2Θ = 35.54°, which is characteristic of the SiC (111) plane. The other peak presented at 2Θ = 60.24°, characteristic of the SiC (220) plane. From XRD results, then, it is clear that poly 3C-SiC films grown on the oxidized Si substrate had a (111) preferred orientation.

In Fig. 2, the XRD spectrum of the AlN/SiC structure shows that the peak with the highest intensity is observed at 2Θ = 36.05°, indicating the (002) oriented plane. The full width of half maximum (FWHM) of the AlN(002) peak was approximately 1.3°. However, other non-(002) peaks appeared at 2Θ = 49.85 and 66.08° indicating (102) and (103) planes, which are related with some defects that degrade the piezoelectric properties of the thin films [11]. The existence of these defects was confirmed by FT-IR analysis. The effect of these defects was investigated by measuring the SAW velocity of the film. The reason for this is that the difference between the 3C-SiC (111) plane peak and the AlN (002) plane peak is only 2Θ ×0.6° according to the data in Joint Committee on Powder Diffraction Standards (JCPDS). The existence of SiC layer was verified in the FT-IR absorption spectra.

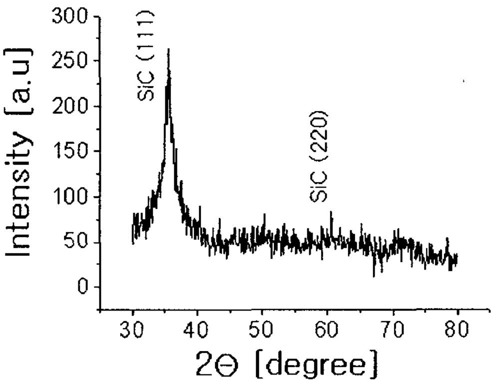

Fig. 1. XRD spectrum of poly 3C-SiC thin films deposited on an oxidized Si(100) substrate.

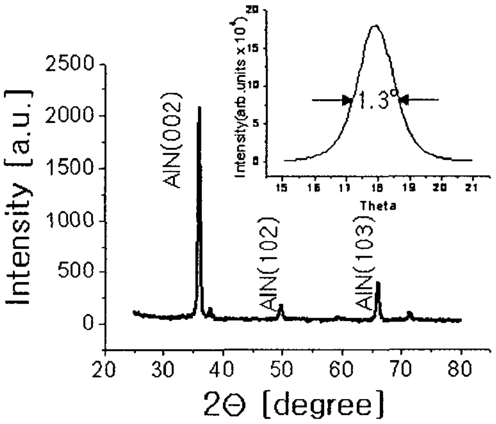

Fig. 2. XRD spectra of AlN/SiC structure and the rocking curve (inset) around the (002) reflection.

Four kinds of stretching vibrations are observed in Fig. 3. The peak at around 810.1cm^{-1} indicates that SiC exists in the films. The SiO$_2$ peak appeared at approximately 1095.6 cm^{-1}, while peaks at 613.4 and 671.2 cm^{-1} correspond to the A1(TO) and E1(TO) vibrational modes of wurtzite AlN [12], respectively. The A1(TO) mode of AlN is related to the existence of grains of mixed orientations in the films while the E1(TO) absorption bands are related to the preferred orientation of the films. The energy of E1(TO) and A1(TO) peaks were intense and weak, respectively, which confirm the high crystal quality of the (002) plane. Lattice mismatch between AlN films and 3C-SiC buffer layer was approximately 1 %. The as-grown AlN thin films on 3C-SiC buffer layer had a low root mean square (RMS) roughness of about 9.3 nm, as shown in Fig. 4.

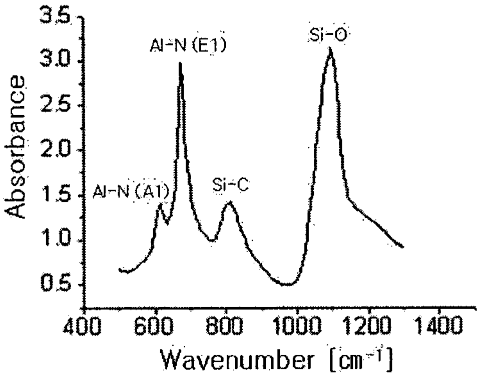

Fig. 3. FT-IR absorption spectra of the AlN/SiC structure.

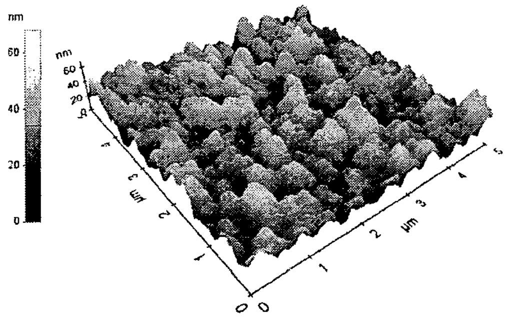

Fig. 4. AFM image of the AlN/SiC structure.

Figure 5 shows the frequency responses of two-port SAW resonators fabricated on AlN/3C-SiC/SiO$_2$/Si and AlN/Si samples at room temperature. The SAW velocity of the AlN/3C-SiC SAW resonator was 5020.8 m/s at $h/\lambda = 0.0625$ (h= 2 µm, λ = 32 µm), with a corresponding resonance frequency of 156.9 MHz as shown Fig. 5(a). This SAW velocity was 153.6 m/s lower than the SAW velocity (5174.4 m/s) of an AlN/Si sample (Fig. 5(b)) with the same h and λ. These results can be caused by the appearance of some non-(002) peaks in the XRD spectrum of the AlN/SiC structure, which was explained above. Nevertheless, with λ = 32 µm, the SAW velocity of the AlN/3C-SiC SAW resonator is high and can be made higher by reducing the resolution of the IDTs and reflector gratings by e-beam lithography [3].

Figure 6 shows the change in insertion loss of SAW resonators in the temperature range of 30°C–50°C. In the range of 30 – 80°C, delta IL (ΔIL) changes are similar in both an IDT/AlN/3C-SiC and IDT/AlN/Si structures. The change in ΔIL for AlN/Si sample is irregular when compared with that of AlN/3C-SiC in range of 80 – 150°C. In addition, the insertion loss of the IDT/AlN/3C-SiC structure was - 21.92 dB with 9.3 nm RMS roughness at room temperature; the change in insertion loss is approximately linear and decreases by 0.033 dB//°C in the temperature range from 30°C to 150°C. This insertion loss is significant when the temperature increase is high.

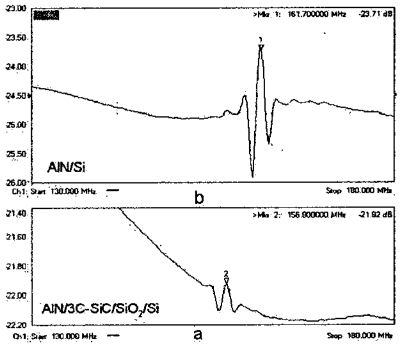

Fig. 5. Frequency response of two-port SAW resonators
(a) AlN on 3C-SiC/SiO$_2$/Sisubstrate,
(b) AlN on Si substrate.

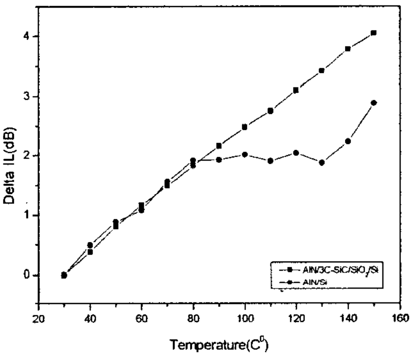

Fig. 6. The change of insertion loss of two-port SAW resonators using AlN/3C-SiC and AlN/Si structures as a function of temperature.

Figure 7 shows the fractional change in the resonance frequency ((f – fo)/fo) of SAW resonators as a function of temperature in the range of 30 – 150°C, where fo was selected as the frequency at 30°C (room temperature). The TCF was calculated from the following equation: TCF= (df/dT) x 1/fo. The TCF of AlN/3C-SiC sample was about -18 ppm/°C with $h/\lambda = 0.0625$. This value is better than the value of -30.8 ppm/°C obtained for AlN/Si as in Fig. 7, which is comparable with that of materials often used in SAW devices: 13.4 ppm/°C in AlN/Diamond [5] and -19 ppm/°C in bulk AlN single crystal [13] and -28.21 ppm/°C in AlN/Y-1280 LiNbO3 [14]. Our -18 ppm/°C result is smaller than the -20.5 ppm/°C for AlN grown on 6H-SiC(0001) substrate [6]. This difference in TCF may be caused by the restricted temperature [6] or SiO$_2$ buffer layer.

IV. CONCLUSION

Poly AlN thin films were deposited on a poly 3C-SiC buffer layer by pulsed reactive magnetron sputtering. The XRD spectra of 3C-SiC films showed a (111) preferred orientation. From the results of both XRD and FT-IR analysis, highly (002) oriented AlN thin films were achieved using a poly 3C-SiC buffer layer. Some defects existing in the poly AlN thin films grown on the 3C-SiC buffer layer caused a light decrease in SAW velocity. The results indicate that the change in resonance frequency is nearly linear with changes in temperature, and that of the TCF of device is small (about 18 ppm/°C). The decrease of the insertion loss is about 0.033 dB/°C. The temperature-basis frequency response of the two-port SAW resonator of AlN films deposited on 3C-SiC buffer layers are enhanced significantly when compared with the resonator of AlN film grown on Si substrate. Therefore, the poly AlN grown on the poly 3C-SiC buffer layer can be used for SAW applications with various temperatures, which is the basis for study of SAW applications in harsh temperature environments with low cost.

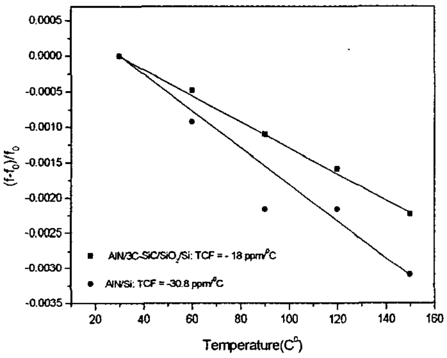

Fig. 7. Temperature dependence of the center frequency of two-port SAW resonators using AlN/3C-SiC and AlN/Si structures.

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