3C-SiC 버퍼층이 Si 기판위에 스퍼터링된 AlN 막의 특성에 미치는 영향

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Effect of 3C-SiC buffer layer on the characteristics of AlN films supttered on Si Substrates

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Abstract : Aluminum nitride (AlN) thin films were deposited on a polycrystalline 3C-SiC intermediate layer by a pulsed reactive magnetron sputtering system. Characteristics of the AlN/SiC heterostructures were investigated by field emission scanning electron microscopy (FE-SEM), atomic force microscopy (AFM), X-ray diffraction (XRD), and Fourier transform infrared spectroscopy (FT-IR). The columnar structure of AlN thin films was observed by FE-SEM. The surface roughness of AlN films on the 3C-SiC buffer layer was measured using AFM. The XRD pattern of AlN films on SiC buffer layers was highly oriented at (002). Full width at half maximum (FWHM) of the rocking curve near (002) reflections was 1.3°. The infrared absorbance spectrum indicated that the residual stress of AlN thin films grown on SiC buffer layers was nearly negligible. The 3C-SiC intermediate layers are promising for the realization of nitride based electronic and mechanical devices.

key worlds : AlN (aluminum nitride), 3C-SiC (Silicon carbide), Piezoelectric properties, buffer layer

I. INTRODUCTION

Aluminum nitride (AlN) is a III-V compound semiconductor with a wide band gap of 6.2 eV. AlN thin films have some attractive characteristics, such as high thermal conductivity, chemical stability, high electrical resistance, a high dielectric constant, high breakdown field, and high hardness. As a result, AlN films are widely used as buried insulators¬ in silicon-on-insulator (SOI) substrates instead of silicon dioxide (SiO_2) to reduce the self-heating effect (SHE) and gate dielectrics in high power devices [1]. Recently, piezoelectric properties of polycrystalline AlN thin films have been widely investigated. In spite of a smaller piezoelectric constant smaller than those of PbZrxTi1-xO3 (PZT) and zinc oxide (ZnO) films, AlN film is regarded as the most useful piezoelectric material due to the low deposition temperature and compatibility with the CMOS process. Due to the high surface velocity, AlN thin films are well suited for the fabrication of acoustic devices, such as surface acoustic wave (SAW) and bulk acoustic wave (BAW) filters and micro/nanoelectromechanical systems (M/NEMS)[2, 3, 4].

However, the when AlN film is deposited on a Si substrate, differences of the lattice mismatch (19%) and the difference of thermal expansion coefficients (17%) between Si and AlN are quite large, which can deteriorate the properties of AlN thin films. In order to reduce the degradation of properties of AlN films, 3C-SiC films have been used as a buffer layer because the lattice mismatch (1%) and the difference in the thermal expansion coefficients (7%) between 3C-SiC and AlN are considerably lower. 3C-SiC is also a wide band gap material and has high heat conductivity, thermal stability, and chemical inertness. Moreover, owing to its excellent mechanical properties, an especially high Young's modulus, the 3C-SiC thin films are applied as membranes in MEMS applications [5].

In this work, polycrystalline 3C-SiC thin films were grown on an oxidized Si substrate due to the low growth temperature, which causes less residual stress than that of single 3C-SiC and surface micromachining using an oxide layer. AlN thin films were deposited by pulsed magnetron reactive sputtering on the polycrystalline 3C-SiC intermediate layer. The structural properties of AlN/SiC were investigated using field emission scanning electron microscopy (FE-SEM), atomic force microscopy (AFM), X-ray diffraction (XRD), and Fourier transform infrared spectroscopy (FT-IR).

II. EXPERIMENTS

A p-type (100) oriented Si wafer was cut into a rectangular shape of 40×60 ㎟. After a 800 ㎚ SiO_2 layer was grown on the Si wafer using a wet thermal oxidization process, an intermediate layer of polycrystalline 3C-SiC thin film was grown on the oxidized Si (100) substrate via atmosphere pressure, chemical vapor deposition (APCVD) using $Ar+H_2$ mixtures as the carrier gas and hexamethyldisilane (HMDS: $(CH_3)_6Si_2$) as the precursor. Polycrystalline 3C-SiC thin film was grown at a 1100℃ deposition temperature without a carbonized layer [6]. Polycrystalline AlN thin film was deposited on the

polycrystalline 3C-SiC buffer layer by a 40-KHz pulsed magnetron reactive sputtering system. The distance between an aluminum target of 99.999% purity and the substrate was 80 ㎜. After the sputtering chamber was evacuated to a base pressure of 5×10^{-7} Torr, AlN films were deposited in an Ar (10%) / N2 (90%) atmosphere at a deposition pressure of 3.5×10^{-3} Torr. During the deposition, the applied power density was 12.5 W/㎠ ,and the substrate was kept at room temperature.

A cross sectional image of the AlN/SiC hetrostructures was observed by FE-SEM (JEOL JSM 6500F). XRD using a high resolution, triple axis X-ray diffractometer (HRXRD: Philips X'Pert Pro-MRD) was performed to verify the textures of the AlN and SiC layers before and after AlN thin films were deposited on the 3C-SiC buffer layer. Based on data in the Joint Committee on Powder Diffraction Standards (JCPDS), the (002) oriented plane's peak of AlN and (111) the oriented plane's peak of 3C-SiC are very close, differing by only 0.6×2θ°. In order to identify the chemical composition and structure of AlN/SiC films grown on an oxidized Si substrate, the infrared absorption spectrum was measured at room temperature with the FTS-2000 Scimitar spectrometer.

IV. RESULTS AND DISCUSSION

Figure 1 shows the XRD pattern of polycrystalline 3C-SiC film grown on an oxidized Si (100) substrate. Two peaks appeared in the pattern. The angle of the strong peak was 2 Θ=35.54°, which represents the SiC (111) plane. The other peak presented at 2Θ =60.24° was characteristic of the SiC (220) plane. From the results of the XRD pattern, the poly 3C-SiC film grown on the oxidized Si substrate had a (111) preferred orientation. Generally, the (111) plane in a face-centered cubic (FCC) structure is well matched with the (002) plane in a hexagonal structure. Therefore, in the fabrication of resonators using AlN thin films, (111) oriented Pt thin films were often used as bottom electrodes. However, a 12% lattice mismatch between AlN and Pt caused compressive stress [7].

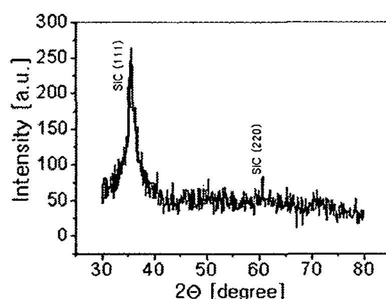

Fig. 1. XRD spectrum of polycrystalline 3C-SiC thin film grown on an oxidzed SI (100) substrate.

Figure 2 shows the cross sectional FE-SEM image of the AlN/SiC heterostructure. The two layers were easily distinguished due to the different structures. Poly AlN films with 400-㎚ thicknesses were grown perpendicular to the surface, but round polycrystalline 3C-SiC grains were stacked on each other. Figure 3 shows that the AlN thin film roughness had an RMS value of 9.3 ㎚.

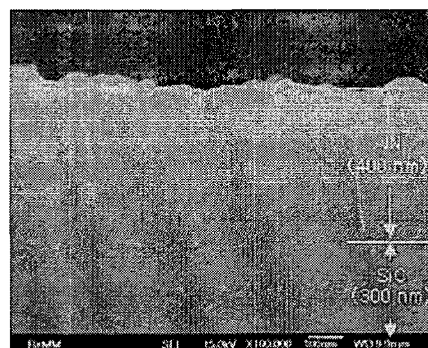

Fig. 2. Cross sectional FE-SEM image of AlN/SiC heterostructures

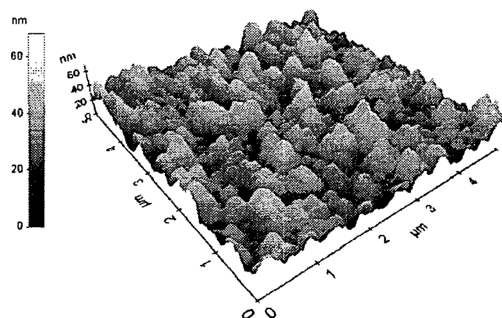

Fig. 3. AFM image of polycrystalline AlN thin film deposited on the SiC buffer layer

Figure 4 (a) shows the XRD spectrum of the AlN/SiC heterostructure. Three peaks were observed at 2Θ=36.05, 49.85, and 66.08°, which indicated the (002), (102), and (103) planes of AlN, respectively. Among the peaks, 2Θ =36.05° is a very important component for evaluating the piezoelectric properties of AlN thin films. Non-(002) reflections in the XRD pattern are related to some defects in the films [8]. Figure 4 (b) shows the rocking curve near the (002) reflection, and the full width at half maximum (FWHM) was 1.3°, which is lower than AlN on poly-Si [9]. The FWHM of AlN thin films is inversely proportional to piezoelectric coefficients (d33) and the electromechanical coupling factor (k) [3, 7].

The SiC (111) peak did not appear in Fig. 4 because the peak degree was similar to AlN (002). The FT-IR analysis in Figure 5 verifies the existence of the SiC layer. The two FT-IR peaks at approximately 613.4 and 671.2 cm^{-1} correspond to the A1(TO) and E1(TO) modes of AlN,

respectively. Peaks appearing near 810.1 and 1095.6 cm^{-1} were ascribed to the Si-C and Si-O-Si stretching vibrations, respectively.

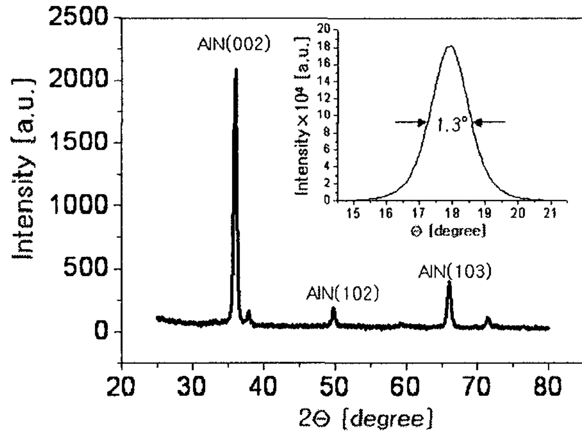

Fig. 4. XRD spectrum of AlN/SiC heterostructure and the rocking curve (inset near the (002) reflection

The A1(TO) mode of AlN is associated with the existence of mixed grain orientations in the films. The intensity of the E1(TO) absorption band is related to (002) oriented crystallites. The reference [10] used two peaks, A1(TO) and E1(TO), to evaluate residual stress in the film. It was reported that the AlN film free of stress had two absorption bands: 612 cm^{-1} for the Al(TO) mode and 672 cm^{-1} for the E1(TO) mode. Compared to their data of stress free AlN film, the AlN film deposited on a 3C-SiC buffer layer had a greater wavenumber for the A1(TO) mode by 1.4 cm^{-1} and a smaller wavenumber for E1(TO) mode by 0.8 cm^{-1}. Therefore, the AlN film deposited on the 3C-SiC buffer layer had a smaller compressive stress. *Figure 1 shows the* XRD pattern of polycrystalline 3C-SiC film grown on an oxidized Si (100) substrate. Two peaks appeared in the pattern. The angle of the strong peak was 2Θ=35.54°, which represents the SiC (111) plane. The other peak presented at 2Θ = 60.24° was characteristic of the SiC (220) plane. From the results of the XRD pattern, the poly 3C-SiC film grown on the oxidized Si substrate had a (111) preferred *orientation. Generally, the (111) plane in a face-centered* cubic (FCC) structure is well matched with the (002) plane in a hexagonal structure. Therefore, in the fabrication of resonators using AlN thin films, (111) oriented Pt thin films were often used as bottom electrodes. However, a 12% lattice mismatch between AlN and Pt caused compressive stress [7].

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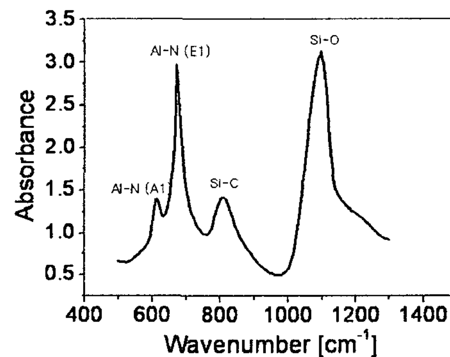

Fig. 5. FT-IR absorbance spectrum of AlN/SiC heteros

The two FT-IR peaks at approximately 613.4 and 671.2 cm^{-1} correspond to the A1(TO) and E1(TO) modes of AlN, respectively. Peaks appearing near 810.1 and 1095.6 cm^{-1} were ascribed to the Si-C and Si-O-Si stretching vibrations, respectively. The A1(TO) mode of AlN is associated with the existence of mixed grain orientations in the films. The intensity of the E1(TO) absorption band is related to (002) oriented crystallites. The reference [10] used two peaks, A1(TO) and E1(TO), to evaluate residual stress in the film. It was reported that the AlN film free of stress had two absorption bands: 612 cm^{-1} for the Al(TO) mode and 672 cm^{-1} for the E1(TO) mode. Compared to their data of stress free AlN film, the AlN film deposited on a 3C-SiC buffer layer had a greater wavenumber for the A1(TO) mode by 1.4 cm^{-1} and a smaller wavenumber for E1(TO) mode by 0.8 cm^{-1}. Therefore, the AlN film deposited on the 3C-SiC buffer layer had a smaller compressive stress.

IV. CONCLUSION

Highly c-axis // [002] oriented poly AlN thin film on a polycrystalline 3C-SiC buffer layer with (111) orientation was deposited by pulsed reactive magnetron sputtering. The columnar structure of polycrystalline AlN thin films was observed with FE-SEM. The roughness of AlN thin films was 9.3 nm. Highly (002) oriented growth was exhibited, but non-(002) reflections were also observed. A very narrow FWHM of 1.3° was achieved from the rocking curve near (002) reflection. The FT-IR absorbance spectrum indicated that AlN thin films grown on the 3C-SiC buffer layer were nearly free of residual stress. Therefore, polycrystalline AlN thin films deposited on a polycrystalline 3C-SiC intermediate layer can be applied to the realization of nitride based electronic and mechanical devices using piezoelectric properties.

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