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Characteristics of polycrystalline 3C-SiC thin films grown on Si wafers for harsh environment microdevices

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Abstract

This paper presents the growth conditions and characteristics of polycrystalline (poly) 3C-SiC thin films for applications related to harsh environments. The growth of the poly 3C-SiC thin film on the oxided Si wafer was carried out by (atmospheric pressure chemical vapor deposition) APCVD using hexamethyildisilane (HMDS, $Si_2(CH_3)_6$) precursor. To obtain an optimized growth condition, we have performed depositions under various conditions that temperature adjusted from 1000 to 1200 °C, the HMDS flow rate changed from 5 to 9 sccm, and carrier gas (Ar) kept up 500 sccm. Each sample was analyzed by XRD (X-ray diffraction), XPS (X-ray photoelectron spectroscopy) and GDS (glow discharge spectrometer). SEM (scanning electron microscope) was utilized to determine layer density, voids and dislocations of the cross-section. From the results of experiment, we have obtained that temperature and HMDS flow rates of the optimized polycrystalline 3C-SiC thin films growth condition were 1100 °C and 8 sccm, respectively.

Keywords: Carbides; SiC; Grown growth; Gas phase reaction

1. Introduction

In recent years, many electronic and mechanical microdevices that can apply to high temperature and corrosive environments have particularly demanded by fields involved in automotive, aerospace, ships, nuclear power instrumentation, satellites, space exploration and geothermal wells [1]. Therefore, many researchers have concentrated on development of small, light and fast microdevices. Silicon carbide (SiC), among semiconductor materials, is a suitable material for these applications because it has many merits, which are wide bandgap energy, high-power, -voltage, -frequency, -temperature, -thermal conductivity, -break down field and -saturation velocity properties [2,3]. Thus, the polycrystalline (poly) 3C-SiC thin film is very useful to fabricate extreme environment micro-sensors and -actuators applied to vehicle, RF, bio, space and environment fields. The 3C-SiC is classified into single and poly types by crystal directions. Since the growth temperature of the single 3C-SiC is higher than that of the poly 3C-SiC, the single crystalline 3C-SiC has the problems which are residual stress, cracks and lattice mismatching of interfacial Si/SiC caused by high growth temperature and different thermal expansion coefficients. These problems are serious factors to microdevices fabrication and other technology applications [4]. However, since the growth temperature of poly is lower than that of single crystal, these problems can reduce.

In general, one may use, chemical vapor deposition (CVD) to grow heteroepitaxial SiC thin films with two precursors such as SiH_4 (or $SiHCL_3$) and C_3H_8. However, it is difficult to control Si and C ratio and silane gas explosive nature, flammability and toxicity. To overcome these serious problems, a single organo-silane precursor such as tetramethyldisilane (TMS, $Si(CH_3)_4$) or hexamethyildisilane (HMDS, $Si_2(CH_3)_6$) gas has been used to grow 3C-SiC thin films for safety, ease of handling, low growth temperature and accurate stoichiometry recently.

In this work, heteroepitaxial polycrystalline 3C-SiC thin films grown on the oxided Si wafers with the single precursor HMDS. Then, the grown 3C-SiC films were analyzed by XRD (X-ray diffraction), GDS (glow discharge spectrometer), XPS (X-ray photoelectron spectroscopy). Finally, the layer density, voids and dislocations of the cross-section of the deposited 3C-SiC films were also evaluated by SEM (scanning electron microscope).

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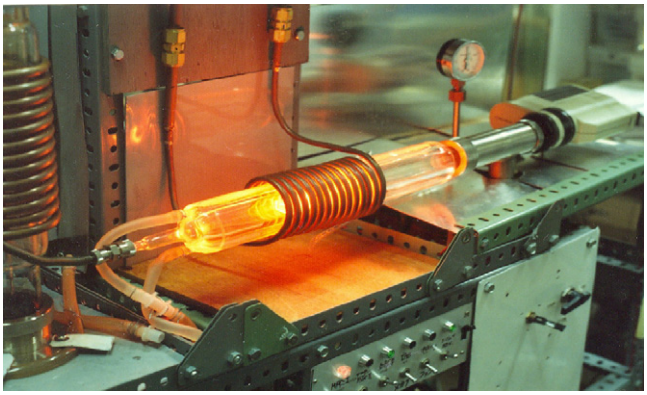

Fig. 1. The reactor tube image of APCVD for the deposition of poly 3C-SiC thin film.

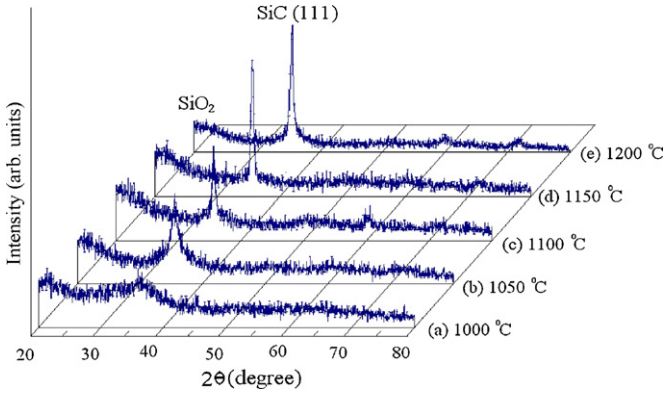

Fig. 2. The XRD spectra of the poly 3C-SiC thin films grown on the oxided Si substrate according to temperature.

2. Experimental procedure

Fig. 1 shows the schematic diagram of APCVD used in this work. The oxide Si substrate is horizontally parallel to gas flow of the center of the reactor tube. For cleaning the reactor tube, Ar purging cycle was performed three times. The graphite susceptor heated by high frequency and ramping up the time (from room temperature to growth temperature) was less than 2 min. The HMDS flow rate was kept up 7 sccm and growth temperature was varied from 1000 to 1200 °C to find an optimal growth temperature. After the optimal growth temperature was defined, the HMDS flow rate was changed from 5 to 9 sccm to investigate the effect of flow rate on SiC film density. Various conditions employed to investigate the effect of growth temperature on the film compositions, bonding structure and crystallinity of 3C-SiC thin film.

XRD patterns were recorded using X'pert APD operated in θ–2θ geometry to determine the crystal structure of the deposited SiC films. Wavenumber has chosen 400–1000 cm^{-1} range to avoid the Si–O (1100 cm^{-1}) bonding peak float. Crystallinity of the polycrystalline 3C-SiC was characterized by XRD measurements. XPS used to determine the chemical nature and elemental compositions of the deposit films. The XPS analyses were performed using ESCALAB 250 XPS spectrometer. Surface and cross-section observed by SEM (Jeol JSM-820). GDS investigates the depth profiling for component analysis by thickness change.

3. Results and discussion

Fig. 2 shows the crystallinities of the polycrystalline 3C-SiC deposited on the oxided Si substrates. By scattering effect of crystal structure, the polycrystalline 3C-SiC and the Si peaks were corresponding to $2\theta = 36^\circ$ and 69°, respectively. In this figure, the Si peak corresponding to $2\theta = 69^\circ$ was removed for reducing the errors caused by the difference of the intensity peaks. The SiC (1 1 1) peak was observed at $2\theta = 35.6^\circ$. This result was consistent with previously reported data [5]. This peak shows the polycrystalline SiC (1 11) thin films were heteroepitaxially grown on the oxided Si (1 0 0) substrate with the single HMDS precursor. By increasing growth temperature, shape and intensity of peaks were sharper and higher, respectively. These results clearly indicated that the SiC crystal structure had improved as increasing temperature.

Fig. 3(a) and (b) shows the SEM images of the crystalline 3C-SiC grown at 1100 °C, in which the HMDS flow rate was 5 and 8 sccm, respectively. The HMDS flow rate was adjusted for confiding in 3C-SiC film quality. In Fig. 3(a), there are some voids in polycrystalline 3C-SiC film, but not appears in Fig. 3(b). These results may be considered that 5 sccm flow rate

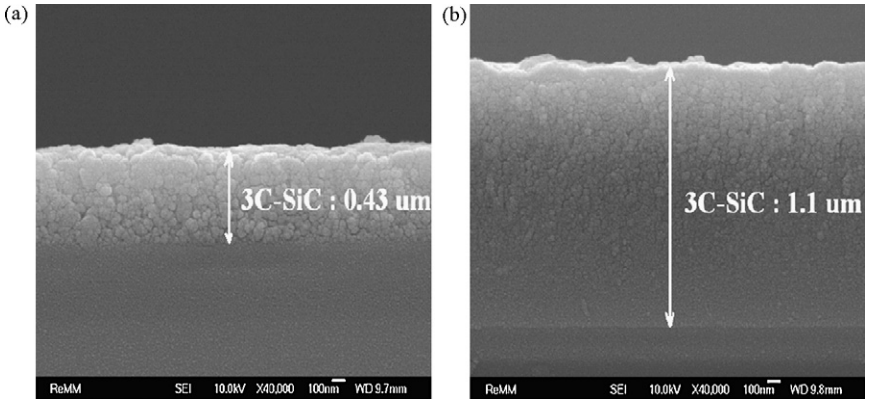

Fig. 3. SEM images of the grown poly 3C-SiC in different flow rates. Cross-section: (a) 5 sccm, (b) 8 sccm.

is not satisfied with the requirement for crystalline formation. Thus, the grains in Fig. 3(a) could not combine with other grains. However, the condition of the 8 sccm flow rate is satisfied with the requirement for crystalline formation and the growth rate is 36.67 nm/min.

Fig. 4 shows the XPS spectra of Si 2p and C 1s. The XPS used to investigate confirmation of the content ratio of atoms in SiC films. Temperature and the HMDS flow rate were 1100 °C and 8 sccm, respectively. Ar ion etching performed for 30 s to clean the surface of the polycrystalline 3C-SiC thin film and the XPS spectra on the bonding energies of Si 2p and C 1s atoms obtained at room temperature. Fig. 4 shows high resolution scan of Si 2p and C 1s, respectively. The peaks of Si 2p and C 1s binding energies were 283.25 and 100.15 eV, respectively. Content ratios of the atoms were 45.796% (Si 2p), 45.487% (C 1s), and 8.717% (O 1s). Here, the O 1s considered cause by nature oxidation layer. However, since the ratio of Si/C is 1:1, it can deduce that the polycrystalline 3C-SiC film is composed of Si and C with the composition to stoichiometric SiC.

To confirm the component ratios with thickness change, the depth profiling investigated. Fig. 5 shows the depth profiling of the polycrystalline 3C-SiC thin film on the oxided Si substrate. Its growth conditions were 1100 °C, and 8 sccm and deposition time was 60 min. The thickness of SiC and SiO_2 is 2.0 and 0.4 μm, respectively. In the layer of SiC, Si and C graphs show same shape and ratio. The element ratio on Si and C maintained equally from surface to interface of SiC and SiO_2.

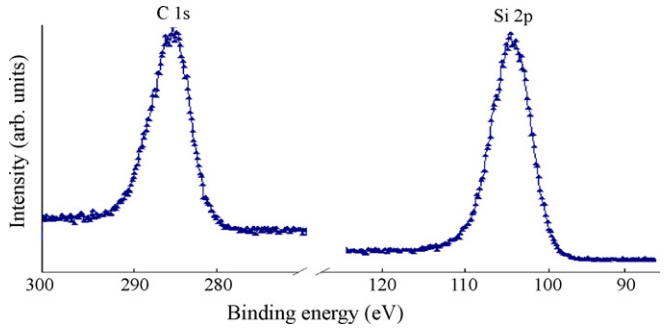

Fig. 4. XPS spectrum of poly 3C-SiC; high resolution scans of Si 2p and C 1s.

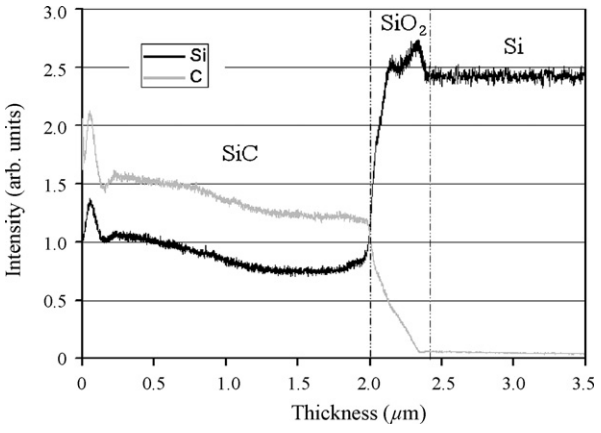

Fig. 5. Depth profiling of poly 3C-SiC thin films by GDS.

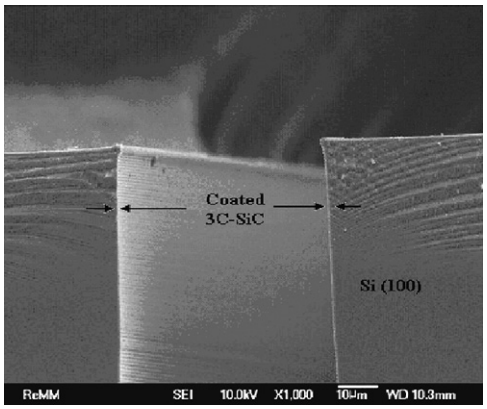

Fig. 6. SEM image of Si microstructure coated poly 3C-SiC film.

The wear property is one of the 3C-SiC benefits and the hardness of 3C-SiC is 2.5–4 times stronger than that of any semiconductors. Because of remarkably physical and mechanical properties of 3C-SiC thin films, it can apply to a coating material for MEMS made by Si base. Moreover, since 3C-SiC has no side effects to the human body, it can be used to coating material for directed contact with skins. RIE etching performed for forming the trench. Deposition time was 20 min and the thickness of 3C-SiC is 0.8 μm. Fig. 6 shows the SEM image of Si microstructure coated polycrystalline 3C-SiC film and performed linearly without any crookedness.

4. Conclusions

Characteristics of the polycrystalline 3C-SiC thin films grown on the oxided Si substrate by APCVD using single precursor HMDS analyzed. When the crystallinity of the 3C-SiC film was investigated with XRD, SiC crystalline was formed well at 1100 °C and the crystallinity of the film was improved as increasing temperature. However, since high temperature for the depositions of 3C-SiC caused the high residual stress, we obtained the optimized temperature 1100 °C. Moreover, the results of the XPS and GDS analyses explain that the chemical contents and compositions are stoichiometric SiC. From the SEM images, we have not observed defects and dislocations when the optimal HMDS flow rate was 8 sccm. Therefore, from our experiment results, the optimal conditions temperature and HMDS flow rate on polycrystalline 3C-SiC thin firm were 1100 °C and 8 sccm, respectively. This as a SiC coating can be applied to machinery technique and biotechnology fields. Further more, the 3C-SiC membrane can be used to applications related to high-pressure and -thermal micro-devices by Si anisotropic etching technique, and extreme environment microdevices due to heteroepitaxial structure. Because the SiO_2 layer is prevent the electrical connection with SiC and Si, there is no leakage current. The 3C-SiC films grown on the oxided Si substrate have potential applications as mechanical, electrical materials and biological fields for next generation.

Acknowledgements

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