A Study for the Homoepitaxial Growth of Single-crystalline 6H-SiCs.

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<Abstract> Silicon carbide(SiC) epilayers were grown by a thermal CVD(chemical vapor deposition) process, and their crystalline properties were investigated. Especially, the growth conditions of 6H-SiC homoepitaxial layers were obtained using a SiC-uncoated graphite susceptor that utilized Mo-plates. In order to investigate the crystallinity of grown layers, Nomarski photograph, transmittance, XRD, Raman, PL and TEM measurements were used. The best quality of 6H-SiC epilayers was obtained in conditions of growth temperature 1500℃ and C/Si ratio 2.0.

I . Introduction

A lot of electronic devices based on semiconductors have come into wide use in the world, and semiconductors have been indispensable to human beings in these days. Most of the present-day semiconductor devices utilize silicon, because of the availability of a very high-pure and high-quality crystal and excellent oxide. Si technology is now so mature that there remains a little prospect for revolutional improvement.

But, now that the performance of conventional semiconductor devices same as Si is approaching a certain ultimate due to the limitation of the material properties (Si devices cannot provide high-power, high-frequency, high-temperature, high-radiation energy due to the limitation of physical and chemical properties of Si) and the processing technology. Therfore, bringing up a new material may be the most effective way to satisfy the strong and increasing needs for high-power, high-temperature and radiation-resistant electronics.

As a semiconductor material for electronic devices, silicon carbide(SiC) has been intensively studied because of its execllent electronic, optoelectronic and other physical properties. The outstanding properties of SiC allow application to electronic devices that can be operated under extreme environmental conditions. SiC possesses excellent thermal and electrical properties for the application of the semiconducting and optoelectronic devices. The current interests in SiC for power device materials are based on its characteristics such as high breakdown voltage, high saturation velocity, high operation temperature, high thermal conductivity and high chemical stability. From a crystallographic point of view, SiC is well-known as a material showing polytypism.[1] The polytypism is a one-dimensional polymorphism which is the phenomenon of taking different crystal structures with the same chemical composition. SiC, however, crystallizes in surprisingly many (more than 200) polytypes.

In spite of the high potential for such device applications, the development of electronic devices using SiC has been delayed due to the difficulty in the steady supply of high quality crystals. However, significant advances have been achieved in the last several years in 6H-SiC crystal growth. Especially, homoepitaxial growth of device-quality 6H-SiC at low temperature has been achieved by step-controlled epitaxy utilizing off-oriented 6H-SiC(0001) substrates.[2] Step-controlled epitaxy is meaning that the polytypes of SiC epilayers can be controlled by the step density of substrates. In step-controlled epitaxy, crystal growth proceeds in a step-flow mode, which ensures the polytype replication in SiC epilayers by CVD even at relatively low temperature well bellow 1600℃. There exist two competitive processes on a growing surface: step-flow growth and two-dimensional nucleation. The supersaturation of chemical species on substrate terraces, which determines the growth mode, strongly depends on growth temperature, gas supply, C/Si ratio, and step structures. Besides, the nucleation rate and surface migration are different for substrate surface polarity(Si or C faces). It is, therefore, critical to control the supersaturation on a surface to get high-quality epilayers without any other polytype inclusions.

In this study, we report homoepitaxial growth of single-crystalline 6H-SiCs by a thermal CVD(chemical vapor deposition) process and their crystalline properties investigated. Especially, the growth conditions of 6H-SiC homoepitaxial layers were obtained using a SiC-uncoated graphite susceptor that utilized Mo-plates. The grown layers were characterized by Nomarski photograph, transmittance, XRD, Raman, PL and TEM measurements.

Ⅱ. Experiments

A. CVD (chemical vapor deposition) System

CVD methods have merits of high quality, high purity, large area crystal growth and precise impurity doping, in spite of non-equilibrium growth. In the homoepitaxial CVD growth of 6H-SiC, there had been a serious problem that high temperatures over 1800℃ had been required to grow homoepitaxial 6H-SiC layers on well-oriented(0001) substrates reproducibly.[3-6] In recent years, one can grow single-crystalline 6H-SiC with very smooth surfaces on off-oriented 6H-SiC(0001) substrates at 1500℃, using so called "step-controlled epitaxy" technique.[2]

Figure 1 shows a photograph of the thermal CVD growth system and a schematic diagram of the CVD process used in this study. The epitaxial growth of 6H-SiC by thermal CVD was carried out in a horizontally set fused quartz reaction-tube at atmospheric pressure. Substrates were put on a graphite susceptor and they were heated by RF induction using a 400㎑, 25㎾ RF generator. Especially, the susceptors used in this study were SiC-uncoated graphite susceptors that utilized Mo-plates instead of a SiC-coated susceptor used in the growth of SiC epilayers generally. The susceptor was inclined at an angle of 10° toward the upper stream of gas flow to improve the uniformity in epilayer thickness.[8] The substrate temperature was monitored by an optical pyrometer.

(a) (b) (c)

Fig.1 (a)Photograph of CVD growth system. (b)Reaction-tube for CVD growth. (c)CVD process.

B. CVD Growth.

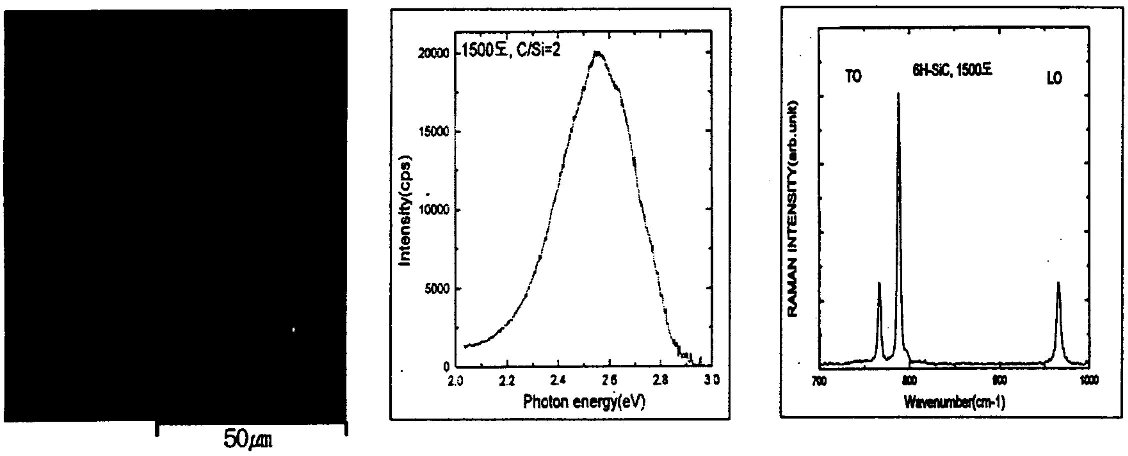
Substrates used in this study were n-type 6H-SiC (0001)Si face grown by a modified Lely methods. The off-orientation of 6H-SiC substrates was 3.5° toward [11$\bar{2}$0]. Undoped 6H-SiC layers were homoepitaxially grown by step-controlled epitaxy, using a SiH_4-C_3H_8-H_2 system. SiH_4 (1% diluted in H_2) and C_3H_8 (1% diluted in H_2) were used as source gases, and carrier gas was H_2 purified with a Ag-Pd purifier. The growth temperature was varied in the range of 1200~1500℃. Substrates were treatmented with cleaning and chemical etching sources before growth. And prior to the CVD growth, the susceptor, susceptor holder and reactor were baked out at 1500℃ for 20~30minutes in H_2 ambient at 1 atm. The typical growth temperature and the flow ratio of C/Si were 1500℃ and 2.0, respctively. The H_2 flow rate was fixed at 3.0slm, which provides a linear gas velocity above the substrates.

Ⅲ. Results

Homoepitaxial growth of single-crystalline 6H-SiC was carried out by step-controlled epitaxy which has been applied to 1200~1500℃. In order to investigate the crystallinity of grown layers, Nomarski photograph, transmittance, XRD, Raman, PL and TEM measurements were used. Single-crystalline 6H-SiC epilayers could be grown at temperature as low as 1300℃ utilizing step-controlled epitaxy.

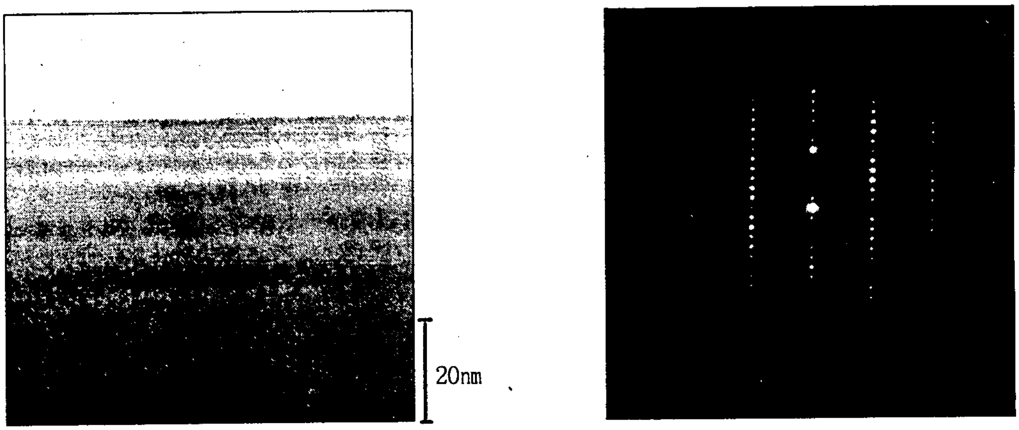
Figure 2(a) shows the surface morphology of epilayers grown on off-oriented (0001)Si face at 1500℃ under the typical gas flow condition (SiH_4:0.3sccm, C_3H_8:0.2sccm). In this conditions, the grown layers showed specular smooth surfaces, and significant differences in surface morphology were not observed between using a SiC-coated susceptor and using an uncoated susceptor. Typical surface morphologies characteristic to 6H-SiC growth on off-oriented substrates were shown like triangle-shaped shadows and line-shaped shadows etc. at some defect sites.[9]

Photoluminescence (PL) measurement was performed to elucidate the polytype of epilayers. A suitably filtered 200㎽ He-Cd laser with a wavelength of 325㎚ was used as an excitation source. Figure 2(b) shows the wide range PL spectra at 11K obtained from the above sample. PL is explained as a phenemenon of light emission due to recombination of a D-A(donor-acceptor) pair or excitons in crystals when the crystals are excited by a light source of higher energies than the bandgap of crystals. In the present samples, the result shows the typical PL spectra of the unintentionally doped 6H-SiC epilayers due to donor - acceptor pair recombination appeared at 440~550nm. The spectra from the epilayer are composed of several overlapping signals, but peaks are not clearly distinguished. Figure 2(c) shows the Raman scattering spectra obtained from the layers grown on off-oriented 6H-SiC (0001)Si face at 1500℃. Raman spectra cleared up the difference of the 3C-SiC in 6H-SiC. Only the peaks characteristic to 6H-SiC are observed and no incorporation of other polytypes is detected. It was identified that the epilayer on 6H-SiC had grown to be homoepilayer by CVD. Based on these results, the grown layers are identified as single-crystalline 6H-SiC epilayers. Also, the polytype of grown layers was verified by transmission electron microscope (TEM) observation. High quality of 6H-SiC grown layers was demonstrated through cross-sectional TEM image and diffraction pattern analysis. Figure 3(a) and (b) show the cross-sectional TEM image and diffraction pattern for surface of 6H-SiC epilayers grown on (0001)Si face 3.5° off-oriented toward [$11\bar{2}0$], respectively.



(a) (b) (c)

Fig.2 (a)Surface morphology of layers grown on 3.5° off-oriented 6H-SiC(0001)Si face. (b)The photoluminescence spectra obtained from the grown layer at 11K. (c)Raman spectra obtained from the grown layer. The growth temperature and the flow ratio of C/Si were 1500℃ and 2.0, respectively.



(a) (b)

Fig.3 (a)A cross-sectional TEM image and (b)a TEM diffraction pattern for surface of 6H-SiC epilayers grown on (0001)Si face 3.5° off-oriented toward [$11\bar{2}0$]. The growth temperature and the flow ratio of C/Si were 1500℃ and 2.0, respectively.

Ⅳ. Conclusions

In this study, silicon carbide(SiC) epilayers were grown by a thermal CVD process, and their crystalline properties were investigated. Especially, the growth conditions of 6H-SiC homoepitaxial layers were obtained using a SiC-uncoated graphite susceptor that utilized Mo-plates instead of a SiC-coated susceptor. In order to investigate the crystallinity of grown layers, Nomarski photograph, transmittance, XRD, Raman, PL and TEM measurements were used. Single-crystalline 6H-SiC epilayers could be grown at temperature as low as 1300℃ utilizing step-controlled epitaxy. The best quality of 6H-SiC epilayers was obtained in conditions of growth temperature 1500℃ and C/Si ratio 2.0, and significant differences in surface morphology were not observed between using a SiC-coated susceptor and using an uncoated one. Consequently, the grown layers were identified as single-crystalline 6H-SiC epilayers, and the optimum growth condition of homoepitaxial 6H-SiC was growth temperature 1500℃ and C/Si flow ratio 2.0 in this study.

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