Vol 18 No 11, November 2009
1674-1056/2009/18(11)/4966-04

Chinese Physics B

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SiC based Si/SiC heterojunction and its rectifying characteristics*

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(Received 25 December 2008; revised manuscript received 5 March 2009)

The Si on SiC heterojunction is still poorly understood, although it has a number of potential applications in electronic and optoelectronic devices, for example, light-activated SiC power switches where Si may play the role of an light absorbing layer. This paper reports on Si films heteroepitaxially grown on the Si face of (0001) n-type 6H-SiC substrates and the use of B_2H_6 as a dopant for p-Si grown at temperatures in a range of 700–950 °C. X-ray diffraction (XRD) analysis and transmission electron microscopy (TEM) tests have demonstrated that the samples prepared at the temperatures ranged from 850 °C to 900 °C are characterized as monocrystalline silicon. The rocking XRD curves show a well symmetry with FWHM of 0.4339° Omega. Twin crystals and stacking faults observed in the epitaxial layers might be responsible for widening of the rocking curves. Dependence of the crystal structure and surface topography on growth temperature is discussed based on the experimental results. The energy band structure and rectifying characteristics of the Si/SiC heterojunctions are also preliminarily tested.

Keywords: Si/6H-SiC, heterojunction, heteroepitaxy SiC

PACC: 6150C, 6855, 7340L

1. Introduction

Silicon-based and III–V compound-based heterojunctions have been widely used in micro-electronic and optoelectronic devices for their prominent characteristics, but SiC-based heterojunctions have been less reported up to now because of their delayed development in material preparation technology, except GaN/SiC where SiC only plays the role of substrate. As for device-functional SiC-based heterojunctions, a few reports are concerned with SiCGe/SiC which is formed by either ion implantation of Ge into SiC[1] or heteroepitaxial SiCGe on SiC substrates.[2] Another device-functional SiC-based heterojunction is Si/SiC, in which the Si is mostly polycrystalline, however. In 1998, Henning *et al* reported the first Si/SiC heterojunction that used heavily doped polycrystalline silicon on a 4H-SiC epitaxial layer to develop an ohmic contact fabricating process on SiC substrates.[3] In 2004, Hayashi *et al* deposited p^+ polycrystalline silicon on SiC to make a heterojunction diode (HJD), which can block a voltage of 1600 V with low reverse leakage current.[4] In 2007, Chen *et al* reported their simulation work on a mono-Si/SiC heterojunction MOSFET.[5] This might be the first work on monocrystalline Si/SiC heterojunction, but there is no more information about their experiment. The most recent work on Si/SiC still focuses on depositing polycrystalline silicon films on 4H-SiC substrates by molecular beam epitaxy (MBE).[6]

SiC is a promising semiconductor material with a wide band gap (3.02 eV for 6H-SiC); however, it is insensitive to either visible or near-infrared light.[7] In order to develop SiC optoelectronic devices, we propose to make a monocrystalline Si/SiC heterojunction in which Si plays the role of light absorber in the visible and near-infrared regions. In realization of the idea, the quality of the Si epitaxial layer is a key point. Owing to a big mismatch in the thermal and lattice parameters, the Si layer grown on a SiC substrate is usually polycrystalline. However, strain growth or a buffer layer might be able to relax this difficulty and realize heteroepitaxial growth of monocrystalline Si on SiC.

2. Experiments

In this work, a hot-wall chemical vapour deposition system is employed to grow silicon layers on the Si face of (0001) n-type 6H-SiC substrates. Silane

*Project supported by the National Natural Science Foundation of China (Grant No 60576044).

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(SiH_4), diborane (B_2H_6) and hydrogen are used as a silicon source, a dopant source and a carrier, respectively. Most substrates used in this work are made in our lab itself, and are not intensely doped, but the resistivity is about a few tenths $\Omega \cdot$cm The substrates are cleaned in a standard RCA clean procedure.[8] After cleaning, the substrates are immediately loaded into the growth chamber. The background vacuum is about 1×10^{-3} Pa. Before growth, the substrates are treated in H_2 atmosphere at a high temperature of 1250 °C for 10 min. The growth pressure is maintained around 230 Pa by a rotary pump during the growth process. The gas flow-rates of SiH_4(10% in H_2), B_2H_6 (1% in H_2) and H_2 with high purity are optimized as 3, 0.2 and 300 SCCM, respectively. As substrate temperature is a very sensitive key point in the grown layers, the growth experiments were carried out at different temperatures in a range of 700–950 °C.

X-ray diffraction (XRD), transmission electron microscopy (TEM) and selected area electron diffraction (SAED) were employed to understand the microstructural features of the heterostructures, while the electrical properties were investigated by an Agilent 4155C semiconductor parameter analyser at room temperature.

3. Results and discussion

XRD analysis was carried out to study the microstructure of the Si epilayers grown at different temperatures, as shown in Fig.1. It can be found that the XRD spectra of the samples grown at different temperatures have the same peaks but different relative strengths, which are located at $2\theta = 28.46°$, 35.5° and 75.5°, respectively. The peaks centred at $2\theta = 35.5°$ and 75.5° are in accord with (0006) and (00012) faces of 6H-SiC, respectively, while the peak centred at $2\theta = 28.46°$ comes from the Si epilayers. However, the samples only grown at 850 °C and 900 °C have a more evident Si(111) peak. This implies that the optimum substrate temperature for best crystalline quality might be in this range.

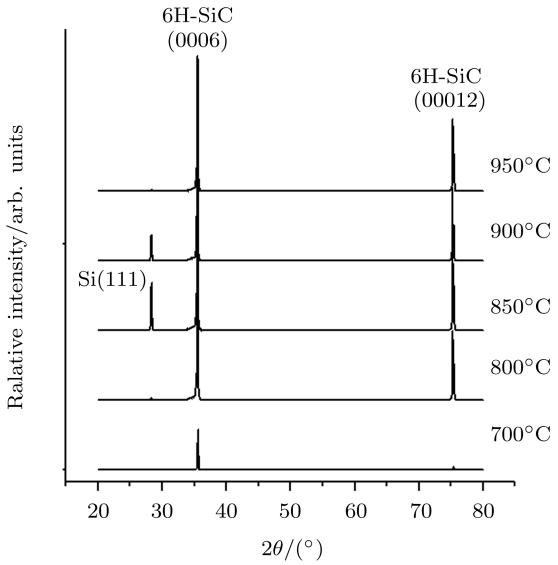


Fig.1. XRD spectra of Si films grown on 6H-SiC at different temperatures.

Figure 2(a) shows an XRD rocking curve of the Si film grown at 850 °C. The peak is completely symmetrical with an FWHM (full-width-at-half-maximum) of 0.4339°. Compared to the 0.06° FWHM of a standard epitaxial Si sample shown in Fig.2(b), the FWHM broadens significantly. As is well known, the thermal mismatch and lattice mismatch introduce a high density of twins and stacking faults in the heteroepitaxial Si layer, especially far from the Si/SiC interface, and the defects are responsible for the FWHM broadening. Furthermore, the defects in the SiC substrate, the high impurity concentration in the Si epitaxial layer and the imperfect process may also result in the FWHM broadening.

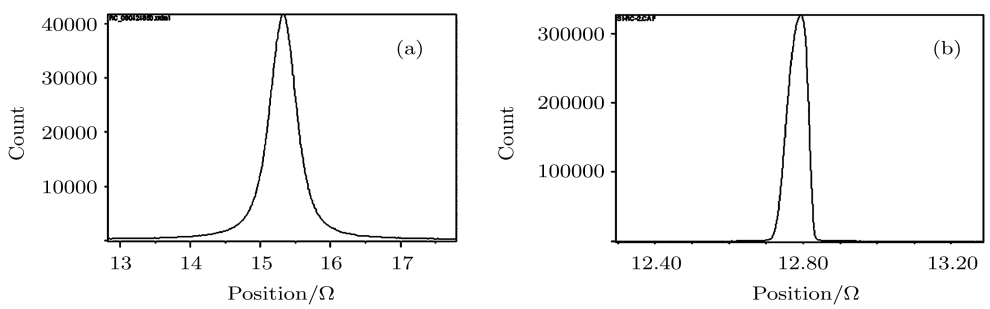


Fig.2. XRD rocking curves of (a) the Si film grown at 850 °C and (b) a standard epitaxial Si sample.

Figure 3(a) shows a low magnitude TEM bright-field image of the Si film grown at 850 °C. In this image, the left grey region belongs to the 6H-SiC substrate, while the area with a different diffraction contrast belongs to the Si thin film. The Si film is 1.2 μm thick and has a good crystal quality. The high-resolution TEM image shows that the epilayer close to the Si/SiC interface is predominantly defect-free, as shown in Fig.3(b). The inset in Fig.3(b) is an image of the SAED pattern of the same sample. The diffraction spot diameter is about 200 nm. The pattern shows that the Si epilayer has a face centred cubic structure, and the growing orientation follows ⟨111⟩. The SAED pattern of the thin film gives a lattice constant of 5.416 Å, which is in accord with the corresponding lattice constant of Si (5.43 Å), suggesting that the epilayer is monocrystalline Si.

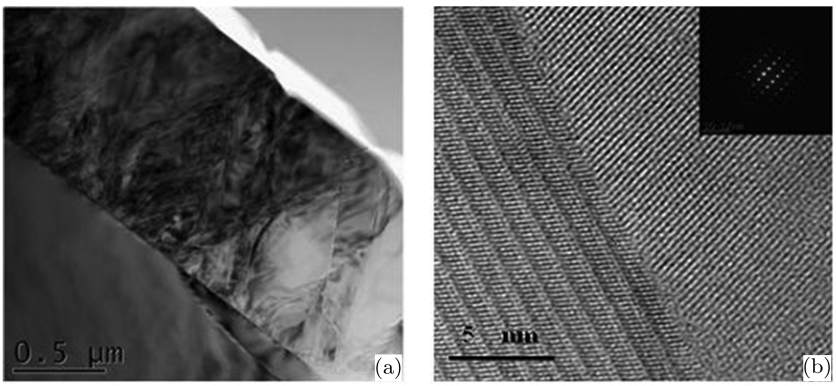


Fig.3. TEM image and SAED pattern of Si film grown at 850 °C. (a) Low magnitude TEM bright-field image, (b) high-resolution TEM image and SAED pattern.

Although the epilayer near the Si/SiC interface is predominantly defect-free, defects such as stacking faults and twins are present in the epilayers due to the cumulative misfit strain, as shown in Fig.4. The cumulative strain is relieved somewhat in these defects, thus the upper portion of the film above the defect regions is also defect-free.

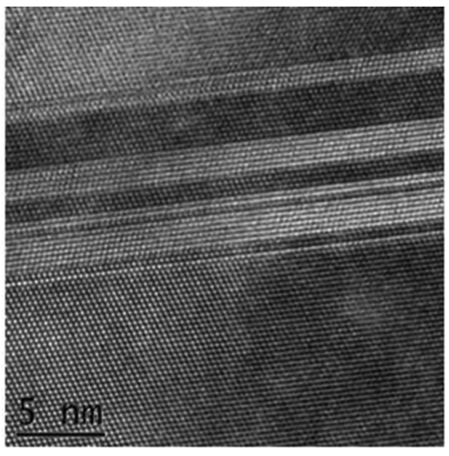


Fig.4. HRTEM image of stacking faults and twins in Si film grown at 850 °C.

Heteroepitaxial growth of Si on a SiC substrate is expected to develop a new application of SiC in optoelectronics. Therefore, we tested the I–V characteristics of the p-Si/n-6H-SiC heterojunction sample grown at 850 °C. The ohmic contact on 6H-SiC is made of Ni with 950 °C annealing for 2.5 minutes, while the other on the silicon layer is made of ITO for light absorption, because ITO is transmitting in the wavelength range from visible to near-infrared and can form an ohmic contact with silicon. But the contact properties of the electrodes are unstable because of their sensitivity to the fabrication process and annealing process. Now, the contact resistance of the electrodes is still large.

Figure 5 shows I–V characteristics of the p-Si/n-6H-SiC heterojunction. Figure 5(a) is an experimental result, and Fig.5(b) shows a curve obtained from the simulation according to the experimental parameter. It can be seen that the heterojuntion demonstrates good rectification characteristics with a forward transfer voltage of about 1.4 V from the experimental result and about 0.9 V from the simulation result, respectively. The reverse current density is not very high. The experimental value is 3.9×10^{-5} A/cm^2 and 2.3×10^{-3} A/cm^2 at 10 V and 20 V, respectively. The series resistance of the primary samples is larger than the ideal case because of the high contact resistance, so the I–V characteristic is linear when the forward voltage exceeds 10 V.

Figure 5(b) is a simulated curve of I–V characteristics for the p-Si/n-6H-SiC heterojunction. The sim-

ulation parameters are as follows: the energy gaps are 1.12 eV and 3.0 eV for silicon and 6H-SiC, respectively. The steps of the conduction band and the valence band in the heterojuntion are 0.2 eV and 1.68 eV, respectively. Because the potential barrier of the hole is much larger than that of the electron, the forward current is mainly carried by electrons. Comparing the experimental results with the simulation, we find that the difference is in two orders of magnitude for the forward current density between experiment and simulation due to the large contact resistance of the experimental samples.

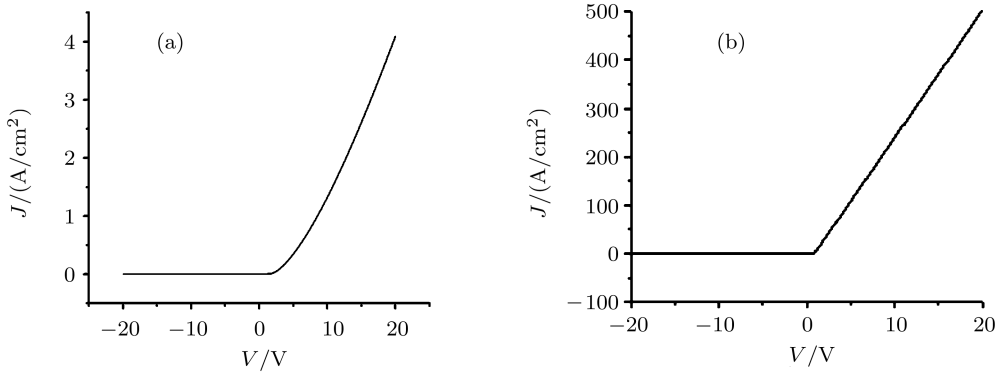


Fig.5. I–V characteristics of the p-Si/n-6H-SiC heterojunction. (a) measured curve, (b) simulated curve.

4. Conclusions

A (111) oriented monocrystalline p-Si thin layer has been heteroepitaxially grown on the Si face of (0001) n-type 6H-SiC substrate in a low-pressure chemical vapour (LPCVD) deposition system. XRD and TEM analyses show that a monocrystalline silicon layer with good quality can be obtained in a temperature range from 850 °C to 900 °C when the reaction pressure is below 230 Pa and an appropriate proportion of the mixed gases is used. Defects such as stacking faults and twinned crystals exist in the near-surface layer of the epitaxial silicon, which are caused by the thermal and lattice mismatches between silicon and SiC. This is responsible for the widened FWHM of the XRD rocking curves. The measured I–V curve experimentally shows that the heterojunction has good rectifying characteristics.

References

[1] Roe K J, Katulka G, Kolodzey J, Saddow S E and Jacobson D 2001 *Appl. Phys. Lett.* **78** 2073

[2] Chen Z M, Pu H B and Beyette Jr F R 2003 *Chin. Phys. Lett.* **20** 430

[3] Henning J P, Schoen K J and Melloch M R 1998 *J. Electron. Mater.* **27**(4) 296

[4] Hayashi T, Tanaka H and Shimoida Y 2005 *Materials Science Forum* **483-485** 953

[5] Chen L, Guy O J, Jennings M R, Igic P, Wilks S P and Mawby P A 2007 *Solid-State Electronics* **51**(5) 662

[6] Pérez-Tomás A, Jennings M R and Davis M 2007 *J. Appl. Phys.* **102**(1) 14505

[7] Li L B, Chen Z M, Lin T, Pu H B, Li Q M and Li J 2007 *Chin. Phys.* **16** 3470

[8] Kern W and Vossen J 1978 *Thin Film Processes* (New York: Academic Press)