Extended Abstracts of the 2009 International Conference on Solid State Devices and Materials, Sendai, 2009, pp1250-1251

Polytype-Stabilized Solution Growth of 3C-SiC

Toru Ujihara, Kazuaki Seki, Ryo Tanaka and Yoshikazu Takeda

Department of Crystalline Materials Science, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan
Phone: +81-52-789-3368 E-mail: ujihara@numse.nagoya-u.ac.jp

1. Introduction

Silicon carbide (SiC), which have wide band gaps, high thermal conductivities, and high electrical break-down field strengths, can be utilized for power devices. SiC exists in a large number of polytypes due to the different stacking sequences of Si-C double atomic planes. 3C-SiC, the target of the present study, is a promising polytype for MOSFETs with a higher channel mobility since the electron trapping by "near-interface-traps" in the SiO_2/3C-SiC system can be much suppressed [1, 2]. Nevertheless, few device studies on 3C-SiC have been reported because no high-quality substrates exist. In our previous study [3], we grew a high quality needle-like 3C-SiC crystal by using a low-temperature solution growth technique. Then, to obtain a larger crystal, the top-seeded solution growth was performed on a (111) surface of the high quality needle-like 3C-SiC. However, the polytype of the grown crystal changed to 6H-SiC. The polytype transformation from 3C-SiC to 6H-SiC is considered to occur easily on the (111) surface due to the stacking errors since the (111) 3C-SiC is equivalent to the (0001) 6H-SiC. In this study, we grew stably large-scale 3C-SiC crystals by the following two approaches: (1) One is the homogeneous growth of 3C-SiC on (001) 3C-SiC thick epilayer. The concept of this approach is similar to the polytype stabilization in the step-controlled epitaxy on CVD method by utilizing the step-flow growth on off-oriented SiC substrates. (2) The other is a different approach that we intentionally induce the stacking error just at the surface of the 6H-SiC seed crystal and grow the crystal under the growth condition that 3C-SiC was thermodynamically stable. Consequently, the growth of a large-scale 3C-SiC crystal on the 6H-SiC substrate was achieved.

2. Experimental

A top-seeded dipping method was performed in a carbon crucible. For homogeneous growth, a seed crystal was a thick free-standing (001) 3C-SiC epilayer grown on an undulated Si substrate [4]. For heterogeneous growth, a seed was a (0001) 6H-SiC substrate. The seed crystal was mounted on the top of graphite rod and dipped to a Si solvent or Si-Sc solvent. The growth temperature was ranged from 1300 to 1700 ºC.

3. Results and Discussion

Homogeneous growth of 3C-SiC on (001) 3C-SiC

Figure 1 shows the cross-sectional optical-microscope image of the SiC crystal grown on the free-standing (001) 3C-SiC epilayer at 1700 ºC for 4 h. The surface of the grown layer partially consists of {111} facet planes. The thickness of the grown layer ranged from 80 to 180 μm corresponding to the growth rate of 22-49 μm/h. The polytypes of both the seed crystal and the grown crystal were identified to be 3C-SiC from a transmission electron diffraction patterns. Thus, the use of (001) 3C-SiC seed made it possible to grow 3C-SiC crystals stably avoiding the polytype transformation.

However, some problems are still present. The stripes parallel to {111} planes are clearly observed in the optical microscopic image. The typical micro-Raman spectra obtained from the dark and light stripe regions are shown in Fig. 1 (b). In the micro-Raman spectrum at the dark region, the transverse optical (TO) mode of the 3C-SiC appears at 796 cm^{-1}. On the other hand, in the spectrum at the light region, the measured Raman spectrum is similar to the spectrum of 6H-SiC although the electron diffraction pattern indicates 3C-SiC. This discrepancy means that the high-density stacking faults with the density of $\sim 10^6$ cm^{-1} exist in the crystal [5]. We also observed the high-density stacking faults with TEM. The (001) 3C-SiC epilayers used as seeds slightly include stacking faults of the density of 5×10^3 cm^{-1} due to the lattice mismatch between SiC and Si [6]. These stacking faults drastically increased and extended to the grown crystals during the high temperature growth process.

Heterogeneous growth of 3C-SiC on (0001) 6H-SiC

For the "heterogeneous" growth, the following three points were considered: (1) A 4H- or 6H-SiC on-axis

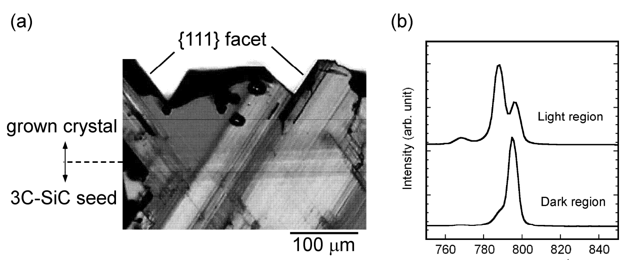

Fig. 1 (a) Cross-sectional optical microscopic image near the interface between the grown and seed crystal of SiC, (b) typical micro-Raman spectra obtained from the light region and the dark region. 3C-SiC grew on the seed crystal homogeneously. However, high-density stacking faults existed in the light region.

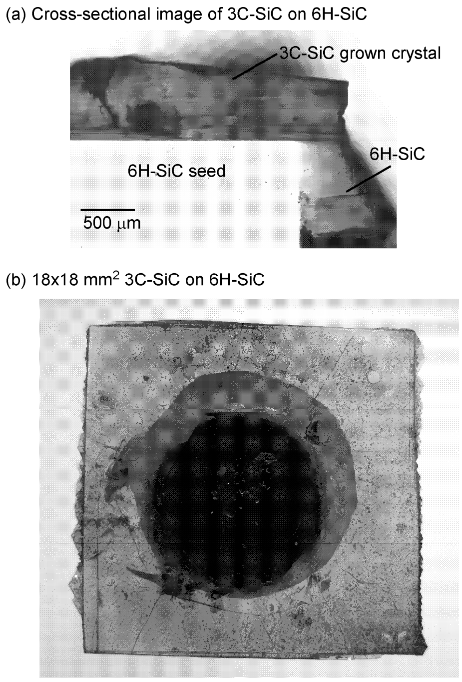

Fig. 2. (a) Cross-sectional optical-microscope image of the crystal grown on the 6H-SiC (000-1) C-face for 50 hours at 1300 °C. The grown crystal on the 6H-SiC was identified as 3C-SiC. The green 6H-SiC crystal was grown from the edge of the seed. (b) Optical-microscope images of 18×18 mm^2 3C-SiC on 6H-SiC seed crystals. In the center black area, the carbon rods mounting seed crystals are seen through the transparent wafers.

(0001) substrate was used as a seed to avoid the continuity of the polytype of the seed crystal; (2) low-temperature growth was performed by using a Si-Sc solvent of the eutectic composition; (3) growth was carried out on the (000-1) C-face. Figure 2 shows the optical-microscope image of 3C-SiC with the area of 18×18 mm^2 grown on 6H-SiC (000-1) C-face for 50 hours at 1300 °C. The grown crystal on the 6H-SiC was transparent yellow, and this crystal was identified as 3C-SiC with Raman spectrum measurement. The green 6H-SiC crystal grew from the edge of the seed. This indicates the use of (000-1) was important to induce intentionally the stacking error. Under the various growth conditions without the successful example of Fig. 2, 3C-SiC did not stably grow or the other polytype grew. In other words, it is possible to grow the 3C-SiC and the 6H-SiC selectively on 6H-SiC substrate by optimizing the growth condition. This developed technique can grow large-area 3C-SiC crystals using commercial 2 or 3 inch 6H-SiC substrates made by the sublimation method. Moreover, the crystal quality is expected to be better since the stacking fault density in 6H-SiC substrate is very low.

4. Conclusions

We grew the large-area 3C-SiC crystals by the two approaches. In the case of growth on (001) 3C-SiC epilayer, the 3C-SiC could grow stably. However, the high density stacking faults were induced in the grown crystal at 1700 °C by the extension of the stacking faults originally included in the seed crystal. In the growth on (000-1) 6H-SiC substrate, the 18×18 mm^2 3C-SiC could grow heterogeneously under the specific growth condition. We consider that the former technique is better since it is easy to grow large-area 3C-SiC crystals using commercial 2 or 3 inch 6H-SiC substrates without stacking fault. The surface morphology of the crystal on (000-1) 6H-SiC is smoother than that on (001) 3C-SiC. In addition, it is possible to grow the various polytype selectively by optimizing the growth condition.

Acknowledgements

The authors acknowledge Dr. H. Nagasawa for supplying 3C-SiC specimens, Prof. M. Morinaga, Dr. H. Yukawa and I. Nakaya for their assistance in Raman spectroscopy measurements and Prof. K. Kotara, Prof. K. Sasaki, Dr. T. Tokunaga and K. Morimoto for their assistance in TEM observations. This study was supported by Industrial Technology Research Grant Program in 2007 from NEDO, and KAKENHI (20686003).

References

[1] G. Pensl, M. Bassler, F. Ciobanu, V. Afanas'ev, H. Yano, T. Kimoto and H. Matsunami, *Mat. Res. Soc. Symp. Proc*. **640** (2001) H3.2.

[2] V. V. Afanas'ev, F. Ciobanu, G. Pensl and A. Stesmans, in: *Silicon Carbide, Recent Major Results* (Eds: W. J. Choyke, H. Matsunami, G. Pensl), Springer, Berlin (2004) 343.

[3] T. Ujihara, R. Maekawa, R. Tanaka, K. Sasaki, K. Kuroda and Y. Takeda, J. Crystal Growth **310** (2008) 1438.

[4] H. Nagasawa, K. Yagi and T. Kawahara, J. Crystal Growth **237** (2002) 1244.

[5] T. Mitani, S. Nakashima, H. Okumura and H. Nagasawa, Mater. Sci. Forum. **527-529** (2006) 343.

[6] H. Nagasawa, K. Yagi, T. Kawahara, N. Hatta and M. Abe, Microelectron. Eng. **83** (2006) 185.