BNL-112675-2016-JA

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Submitted to the JOURNAL OF ELECTRONIC MATERIALS

April 2016

Center for Functional Nanomaterials

Brookhaven National Laboratory

**U.S. Department of Energy
USDOE Office of Science (SC),
Basic Energy Sciences (BES) (SC-22)**

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Study of defect structures in 6H-SiC a/m-plane pseudo fiber crystals grown by hot wall CVD epitaxy

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Abstract

Structural perfection of silicon carbide (SiC) single crystals is essential in achieving high-performance power devices. A new bulk growth process for SiC proposed by researchers at NASA Glenn Research Center, called large tapered

crystal (LTC) growth, based on axial fiber growth followed by lateral expansion could produce SiC boules with potentially as few as one threading screw dislocation (TSD) per wafer. In this study, the lateral expansion aspect of LTC growth is addressed through analysis of lateral growth of 6H-SiC a/m-plane seed crystals by hot wall chemical vapor deposition (HWCVD). Preliminary synchrotron white beam x-ray topography (SWBXT) indicate the as-grown boules match the polytype structure of the underlying seed, and have a faceted hexagonal morphology with a strain free surface marked by steps. SWBXT Laue diffraction patterns of transverse and axial slices of the boules reveal streaks suggesting the existence of stacking faults/polytypes and this is confirmed by micro-Raman spectroscopy. Transmission X-ray topography of both transverse and axial slices reveals inhomogeneous strains at the seed-epilayer interface and linear features propagating from the seed along the growth direction. Micro-Raman mapping of an axial slice reveals the seed contains a high stacking disorder, while contrast extinction analysis (g.b and g.bx1) of the linear features reveals these are mostly edge type basal plane dislocations (BPDs). Further high-resolution transmission electron microscopy (HRTEM) investigation of the seed-homoepilayer interface also reveals nanobands of different SiC polytypes. A model for their formation mechanism is proposed. Finally, the implication of these results for improving the LTC growth process is addressed.

Keywords: *Silicon Carbide, large tapered crystal, lateral expansion, Hot wall chemical vapor deposition, epitaxy, x-ray topography, stacking faults,*

Introduction

Silicon carbide is a wide-band gap compound semiconductor that possesses excellent electronic, thermal and mechanical properties, which make it suitable for a variety of applications [1, 2] such as high-power switching devices, light emitting diodes (LEDs) and junction field effect transistors (JFETs) [1-3]. Currently, commercial SiC single crystals are grown by the physical vapor transport (PVT) method [3].

Refinement and optimization of the PVT technique have enabled the production of large size SiC single crystal boules with improved quality. However, SiC technology still suffers from a high density of structural defects present in SiC single crystals [1-3]. Among these harmful structural defects are screw dislocations (SDs), micropipes (μ Ps), basal plane dislocations (BPDs) and stacking faults (SFs). Neudeck and coworkers have described the impact of screw dislocations on the reverse-bias current-voltage characteristic of 4H-SiC p^+n diodes [4]. While their study showed a reduction in breakdown voltage associated with SDs, i.e. an increase in leakage current, it revealed that SDs are less detrimental to SiC device performance compared to μ Ps. Similarly, R. E. Stahlbush et al. showed that under forward-biased mode, BPDs located in or at the interface of the active layer of PIN diode, a type of diode consisting of p- and n-doped semiconductor regions that are separated by an undoped intrinsic semiconductor region, generate SFs. These SFs expand during device operation, and cause a forward voltage drop [5]. Because of SiC's low SF energy, SiC is prone to polytypism, making polytype control a growth challenge. The factors affecting the control of the grown polytype have been studied [3, 6-8].

Various efforts have been carried out to reduce/eradicate these defects and mitigate their effect on SiC devices. These efforts aim at producing high quality silicon carbide single crystal boules for device application. In one case, growth of SiC boules is carried out on off-oriented seed crystal, usually 4° toward the [11-20] direction. In this approach, the off-oriented seed provides steps that contain information for polytype replication and removes the need for screw dislocation assisted growth. In another effort, the approach is more fundamental as it proposes growth on non-c oriented seed and in direction other than the c-axis [9-11]. If the former approach is considered a relative breakthrough, achieving a reduction in the density of structural defects is still a long way to go. On contrary, the latter has shown promises despite its level of difficulty and the density of SFs in the obtained crystals [10, 11]. Y. Urakami et al. demonstrated that SiC growth perpendicular to the c-axis produces higher quality bulk SiC [11]. Harnessing the potential of the latter approach, researchers at NASA Glenn Research Center (GRC) have proposed a new bulk growth process, large tapered crystal (LTC) growth, based on axial fiber growth (parallel to the c-axis) followed by lateral expansion (perpendicular to the c-axis) for producing SiC boules that can potentially produce wafers with as few as one SD per wafer [12]. In order to implement this novel growth technique, the lateral homoepitaxial growth expansion of a SiC fiber without introducing a significant number of additional defects is critical. Such lateral growth using hot wall chemical vapor deposition (HWCVD) is being carried out at NASA GRC on c-axis oriented ‘pseudo-fibers’ of 4H/6H-SiC cut from PVT-grown SiC boules. It is important to note that the development of a long seed single crystal fiber has been investigated, and the result published elsewhere [13, 14]. Thus, the successful implementation of the

lateral growth expansion will enable single scale integration of the LTC growth process.

In this paper, we have carried out detailed characterization on the HWCVD-grown lateral enlargement of 6H-SiC a/m-plane seed crystals designed to replicate axially grown SiC single crystal fibers. As-grown crystals were analyzed by SEM and synchrotron white beam X-ray topography (SWBXT) followed by analysis of axial and transverse sections from the as-grown crystals using a combination of SWBXT, HRTEM and Raman scattering to map defect types and distribution. Further, the implication of these results for improving the LTC growth process is discussed.

Experiment

6H-SiC seed crystals (0.8 mm x 0.5 mm x 15 mm) with two m-plane faces and two a-plane faces were subjected to lateral growth by HWCVD between 8 -16 hours of growth over multiple growth runs at NASA GRC [15]. The as-grown crystals have evolved towards the hexagonal crystal symmetry (Fig. 1(a-b)) of the SiC crystal structure with the faces perpendicular to the $\langle 1-100 \rangle$ directions. SEM (Fig. 1(c-d)) and SWBXT (Fig. 1(e-f)) studies were carried out on the as-grown crystals to map the morphology and evaluate the general crystalline quality. The crystals were then sectioned into axial (m (1-100) and a-(11-20) plane) and transverse (c-plane (0001)) slices and mechanically polished with diamond abrasive films. The samples were then investigated using a combination of SWBXT, TEM and Raman scattering. Overall defect microstructures of the m/a-plane and c-plane slices were imaged using SWBXT in transmission geometry at the Stony Brook topography station, Beamline X19C, National Synchrotron Light Source (NSLS), Brookhaven National Laboratory (BNL) and at the Advanced

Photon Source (APS), Argonne National Laboratory (ANL). The images were recorded on Agfa Structurix D3-SC films. Second, micro-Raman scattering was measured for a region across the seed crystal for selected samples. This enabled determination of the inhomogeneity of the seed crystal and epitaxially grown layer. From the analysis of the recorded topographs and micro-Raman map, TEM specimens were prepared parallel to the [11-20] direction of both axial and transverse samples using focused ion beam (FIB). They were cut at the interface across the seed and the grown crystal. HRTEM experiments were conducted on a JEOL 2100F at the Center for Functional Nanomaterials (CFN) at BNL with an accelerating voltage of 200keV.

Results and discussion

SWBXT topographs of the as-grown crystals (Fig. 1(e-f)) reveal the hexagonal morphology and a strain-free surface characterized primarily by steps as observed in SEM micrographs. X-ray diffraction Laue patterns of axial slices from both boules 1 and 2 reveal that while the laterally grown material is only of 6H type, stacking faults are also present. Figure 2 shows an X-ray diffraction pattern and topographs of an axial-cut taken from the boule 2 (referred to as sample 2a).

While the streaking on the Laue pattern indicates the presence of stacking disorders, the SWBXT transmission topographs shows the sample is characterized by a band of linear defects propagating from the seed in the middle and running parallel to the basal planes. These are likely BPDs, but stacking faults can also be expected to be present, which has been reported [16]. These bands seem to correlate with microscopic steps observed on the surface of the as-grown boule under optical microscopy. Further, the seed-epilayer interface shows strain-induced distortion. Similarly, SWBXT Laue pattern of one of the transverse c-

plane slices (sample 2b) revealed a central seed region also characterized by streaking indicating the seed region itself is characterized by stacking disorders. Both axial and transverse slices from the boules 1 and 2 were further characterized using micro-Raman spectroscopy. Raman maps and spectra of regions encompassing the seed and grown epilayers were obtained. Raman intensity profile and frequency shift of SiC polytypes are well documented, and were employed to study polytypism and stacking disorder [17, 18]. Figure 3 shows optical micrographs of sample 2b along with its corresponding mapped region. Observation of Raman bands (Fig. 4) at 205cm^{-1} , 571cm^{-1} and 800cm^{-1} for spectra recorded at different positions on the sample indicates the presence of foreign polytypes in the 6H-SiC matrix. These bands correspond respectively to 4H, 15R and 3C-SiC polytypes. Red and turquoise spots in the seed and across the matrix (Fig. 4) indicate foreign phases that show the inhomogeneity of the starting seed, and sample. It is likely that the extremely poor quality of the seed material contributed to the presence of the observed foreign polytypes in the investigated samples. Besides the poor quality of the seed material, the use of uncoated graphite parts and a lack of control over the growth temperature are other contributing factors.

Another sample taken from boule 1, referred to as sample 1, was also investigated. The sample contains a central seed region characterized by high defect densities from which bundles of dislocations emanate along the m-axis directions as seen in SWBXT images (Fig. 5). These dislocations appear to be mostly replicated from the seed although nucleation of new dislocations at the seed-epilayer interface cannot be ascertained due to the high dislocation densities involved. Any stacking disorders present in the seed will also likely be replicated into the epilayer, albeit at a possibly lower density. Analysis of these dislocation bundles by contrast

invisibility criteria (i.e. $\mathbf{g} \cdot \mathbf{b} = 0$ and $\mathbf{g} \cdot \mathbf{b} \times \mathbf{l} = 0$, where $\mathbf{g}$ is the reflection vector and $\mathbf{b}$ is the Burgers vector) reveals these are edge-type $1/3\langle 11-20 \rangle$ BPDs.

Similarly to sample 2b, micro-Raman study was performed on this sample. This allowed the determination of the inhomogeneity from the seed. Raman spectra and corresponding mapping are shown in figure 6. Analysis of the relative intensity for the folded transverse acoustic (FTA) and folded transverse optic (FTO) modes on the Raman spectra indicates a high stacking disorder in the seed region (Fig. 6b).

It is important to note that the observed Raman frequencies in our experiment are slightly larger than frequencies published for these polytypes [18], most likely due to strain. Xiang B. Li et al reported that doping-induced strain causes a shift toward higher frequency with increasing dopant concentration on the Raman spectra of 6H-SiC [19]. Similarly, the wavelength of the laser power source has been reported to affect the position and shape of Raman bands [20, 21]. It follows that the origin of the discrepancy between our frequencies and reported frequencies could be a combination of both strain in our sample and the wavelength of the laser power source we used.

Following the SWBXT and micro-Raman results, TEM cross-section specimens were prepared by focused ion beam (FIB) parallel to the $[11-20]$ direction for both samples 1 and 2a. Analysis of several bright field micrographs taken with $\mathbf{g}$ vector 0006 from the samples 1 and 2 reveals the presence of dislocations, SFs and an inclusion-like feature. The presence of the dislocations near the surface of the TEM specimen is consistent with electron beam induced damage from sample preparation [22]. Based on the bright field images, HRTEM of two stacking faults (SF_1 and SF_2) from sample 2a were recorded to determine their stacking sequence. The HRTEM image (Fig. 7a) of SF_2 shows lattice plane distortion and high

disordering in the stacking sequences of the 6H-SiC matrix. The observed lattice distortion could result from the misalignment of stacking sequences due to different attachment mechanism of atoms on each facet within the same interface as growth proceeds on many facets during lateral homo-epitaxial expansion [23, 24].

The other cause for the lattice distortion could be attributed to the propagation of partial dislocations (PDs) bounding stacking disorders during growth of the 6H matrix as observed in figure 7. Those PDs modify the stacking sequence of the 6H matrix, and result in the formation of high density of SFs. These SFs appeared as SiC nanobands of different polytypes and varying thickness. Furthermore, we observed a shift in the stacking sequence from left to right on Fig. 7, and lattice distortion along the c-axis. These observations are in agreement with results reported by Tsuchida et al. in their paper “Formation of extended defects in 4H-SiC epitaxial growth and development of a fast growth technique”, where they discussed the formation of prismatic stacking faults (PSFs) as a series of two-bilayer height distortions at intervals of two bilayers [25]. These lattice distortions and stacking faults most likely lead to polytype transformation. Thus growth along direction perpendicular to the c-plane axis appears to favor stacking fault formation and polytype transformation.

Other groups have carried out growth on (1-100) and (11-20) seeds and directions [9, 26]. It has been reported that growth along these directions are prone to stacking fault formation. Takahashi et al have proposed the reason for this. They have suggested that when disregistry at the boundaries between (1-102) and (1-10-2) subsurfaces of (1-100) surface is relaxed, SFs are generated. The generation of stacking faults, which relaxes the disregistry at the boundaries, also relieves the large localized strain at the boundaries most likely in the form of partial

dislocations. The model proposed by Takahashi et al. appears to be in agreement with our results [9]. Figure 8 shows the stacking sequence of a (1-100) surface taken along the [11-20] direction. It is important to note that the SiC nanobands observed in the HRTEM images correspond to macrosteps observed on the surface of the as-grown laterally expanded boules, in agreement with observations made by Takahashi for growth of 4H and 6H-SiC on (1-100) seed.

The above results confirm the potential of the large tapered crystal (LTC) growth technique as it relates to enlargement of SiC pseudo fiber by lateral expansion in HWCVD. The lateral expansion is epitaxial and replicates the defects already present in the seed while the nucleation of new defects is not apparent. However, the seeds used in these experiments are of low quality with high defect densities and stacking disorders and therefore the use a high quality single crystal as seed would be more helpful. It is thus very likely that the defective quality of the seed crystal played a role in the formation/generation of stacking faults and polytypes. This could also explain the inhomogeneous strain observed at the seed-epilayer interface observed in figure 2. In order to mitigate the formation of stacking faults/polytypes and ensure growth of crystal of higher quality, the use of high quality single crystal seed will be necessary. Additionally, certain growth parameters will have to be optimized.

Conclusions

HWCVD homoepitaxial lateral expansion of 6H-SiC a/m-plane oriented pseudo fibers has been demonstrated. SEM revealed the hexagonal tapered morphology of the grown boules, indicating the presence of steps on the as-grown surface. SWBXT confirmed growth was homoepitaxial. Analysis of axial and transverse slice showed bands of edge type dislocations that propagated from the seed

crystal, with significant strain at the seed/epilayer interface. μ RS and HRTEM revealed the existence of several SiC polytypes in the 6H-SiC matrix and the nature of their stacking sequences. These polytypes form nanobands of various thicknesses and correspond to microscopic steps visible on the surface of the as-grown laterally expanded epilayer. Further experiments using pre-screened high quality seeds and optimized growth conditions will allow the realization of the lateral growth aspect of the LTC growth process.

Acknowledgements

Work supported by NASA Glenn Research Center and the US Department of Energy (DOE) Vehicle Technology Program via Space Act Agreement (SAA3-1048) (DOE IA # DE-EE0001093/ 001) monitored by Susan Rogers (DOE). NASA Postdoctoral Program Fellowship supported by NASA Vehicle Systems Safety Technologies Project in the Aviation Safety Program. SWBXT work was carried out at Stony Brook Topography Facility (Beamline X19C) at the NSLS, Brookhaven National Laboratory, which is supported by the U.S. DOE. under Grant No. DE-AC02-76CH00016. HRTEM work carried out at the Center for Functional Nanomaterials, Brookhaven National Laboratory, which is supported by the U.S. DOE, Office of Basic Energy Sciences, under Contract No. DE-AC02-98CH10886. Raman scattering performed by Nicholas Heller.

References

- [1] A. Grekov, Q. Zhang, H. Fatima, A. Agarwal and T.S Sudarshan, *Microelectron. Reliab.* 48, 1664 (2008).
- [2] H. Fujiwara, T. Kimoto, T. Tojo and G. Matsunami, *Appl. Phys. Lett* 87, 51912 (2005).

- [3] K. Semmelroth, N. Schulze and G. Pensl, *J. Phys.: Condens. Matter* 16, 1597 (2004)
- [4] P.G. Neudeck, W. Huang and M. Dudley, *Sol. State electronic* 42, (1998)
- [5] R. E. Stahlbush, K. X. Liu and M. E. Twigg, IEEE 06CH37728, 44th Annual International Reliability, Physics Symposium, San Jose (2006)
- [6] S. Harada, K. Seki, Y. Yamamoto, C. Zhu, S. Arai, J. Yamsaki, N. Tanak and T. Ujihara, *Cryst. Growth Des.* 12, 3209 (2012).
- [7] C. Liu, X. Chen, T. Peng, B. Wang, W. Wang and G. Wang, *J. Cryst. Growth* 394, 126 (2014).
- [8] Daisuke Nakamura, *Mater. Sci. Forum* 527-529, 3 (2005).
- [9] J. Takahashi, N. Ohtani M. Katsuno and S. Shinoyama, *J. Cryst. Growth* 181, 229-240 (1997)
- [11] Y. Urakami et al. Proceeding of ISCRM, (2011)
- [12] US Patent 7,449,065
- [13] A. A. Woodworth, P. G Neudeck, A. Sayir, F. Solá, M. Dudley and B. Raghothamachar, *J. Cryst. Growth* 392, 34-40 (2014)
- [14] A. A. Woodworth, P. G. Neudeck, A. Sayir, D. J. Spry, A. J. Trunek and J. A. Powell, *Mat. Sci. Forum* 717-720, 49-52 (2012)
- [15] A.J. Trunek, P.G Neudeck, A.A Woodworth, J.A Powell, D.J Spry, B. Raghothamachar and M. Dudley, *Mater. Sci. Forum* 717-720, 33 (2012).
- [16] H.J. Rost, M. Schmidbauer, D. Siche and R. Fornari, *J. Cryst. Growth* 290, 137 (2006).
- [17] S. Rohmfeld, M. Hundhausen and L. Ley, *Phys. Rev. B* 58, 9858 (1998)
- [18] S. Nakashima and H. Harima, *Phys. Stat. Soli (a)* 162(1), 36-64 (1997)
- [18] T. Werninghaus, PhD Thesis (1997)
- [19] Xiang-Biao Li, Zhi-Zhan Chen and Er-wei Shi, *Physica B Cond. Matter*

405(10), 2423-2426 (2010)

[20] Ru Han and Xiaoya Fan, Mod. Phys. Letters B 27(5), 50035 (2013)

[21] Y. Ward, R. J. Young and R. A. Shatwell, J. Appl. Phys 102(2), 023512-023512-7 (2007)

[22] J. Ayache, L. Beaunier, J. Boumendil, G. Ehret and D. Laub, Sample preparation handbook for transmission electron microscopy, Springer 2010

[23] E. N. Mokhov, M. G. Ramm et al., Mat. Sci. Forum 433-436, 29 (2003)

[24] N. Sugiyama, A. Okamoto and T. Tani, Inst. Phys. Conf. Ser. 142, 489 (1996)

[25] H. Tsuchida, M. Ito, I. Kamata and M. Nagano, Phys. Stat. Soli (b) 246(7), 1553-1568 (2009)

[26] T. Furusho et al., Mat. Sci. Forum 527-529, 35-38 (2005)

(a) boule 1

(b) boule 2

(c) boule 1

(d) boule 2

(e) boule 1

(f) boule 2

Fig 1. As-grown laterally expanded 6H-SiC crystals(a-b) Optical photographs (yellow crystallites are of 3C-SiC polytype) and (c-d) SEM micrographs showing the hexagonal morphology; (e-f) Reflection X-ray topographs showing the strain-free as-grown surfaces of the single crystals and light bands running parallel to the basal planes.

(a) Experimental Laue pattern

(b) Simulated Laue pattern

(c) Transmission topograph with $g = -1-120$

(d) Transmission topograph with $g = -1010$

Fig 2. Experimental and simulated X-ray diffraction pattern (a-b) (m-plane orientation rotated 10° about vertical a-axis) and transmission topographs with different g-vectors (c-d) recorded from sample 2a. Note the streaking of diffraction spots in (a) indicative of stacking disorders. The seed-epilayer interface in (c) and (d) is distorted.

(a)

(b)

Fig 3. Optical micrographs of (a) transverse-sectioned sample 2b, and (b) Raman mapped region.

(a)

(b)

(c)

(d)

Fig 4. Raman map of selected region (a), Raman spectra of spot 1 (b), spot 2 (c) and spot 3 (d). Note that spots 1, 2 and 3 correspond respectively to $x=84.4\mu\text{m}$, $x=-375.1\mu\text{m}$ and $x=372.1\mu\text{m}$.

Fig 5. Transmission X-ray topographs of sample 1 for (a) $g = -1-120$ and (b) $g = -3300$ along with a schematic showing the crystallographic directions. Note the bundles of dislocations running along the $\langle 1-100 \rangle$ directions, and absence of contrast for some dislocation bundles on reflection vector $3-300$.

Fig 6. Raman spectra from selected regions 1-6 of sample 1 as shown in schematic and (b) color Raman map of the seed region showing stacking disorders.

Fig 7. (a) Bright field TEM image of sample 1 showing an inclusion-like feature and dislocations due to electron beam induced damage and (b) HRTEM image of region of interest showing stacking disorders corresponding to 15R-SiC stacking (SF_2).

Fig 8. Illustration of $[11-20]$ projection of atomic configuration of Si and C atoms for 6H-SiC (1-100) surface. Note the (1-102) and (1-10-2) subsurface of the (1-100) surface have identical bond configurations to (0001)Si and (000-1)C, respectively. The 19.5° is the angle between the $[111]$ axis of 3C-SiC and $[1-100]$ axis of 6H-SiC [9].