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Investigation of grinding or mechanical polishing surface of 4H-SiC substrate

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Abstract

We investigated the influence of mechanical grinding and polishing treatment on the surface of 4H-SiC(0001) substrate by mainly Scanning Probe Microscope (SPM) , Raman spectroscopy(Raman) and Transmission Electron Microscope(TEM). The processed surface morphology showing characters of the processing method and condition was observed by SPM. Especially, tunneling current measured by tunneling atomic force microscope (TUNA) mode was relatively larger at the scratches of the surface. This implies the localized defect energy states are created by mechanical damage of the crystal structure, which is induced in mid-gap energy region. FTO(2/4) peak in Raman spectrum of 4H-SiC is around 776cm-1 was used to monitor the residual stress in the processed surface, this zone folded TO phone peak originated 4H structure has Raman shift and stress ratio as 3.1cm-1/GPa according to reference [1]. As for polishing, the residual stress was relatively small in value and both compressive and extensive stress were distributed in the surface, but as to grinding surface, strong tensile stress, from 0.1 to 0.6GPa, was detected in entire surface. The focused ion beam etching (FIB) was used for cross section TEM sample fabrication. We obtained the surface damaged and defected lattice HR-TEM images. Atomic Scattering Spectroscopy (ASS) [2] with He atom flux in low kinetic energy was performed to estimate the atomic disordering of the processed surface. ASS was quite effective to monitor the crystalline surface disordering of processed 4H-SiC.

1. Introduction

4H-SiC which is typical poly type of SiC crystal has wide bandgap and widely used as electronic or optoelectronics device applications. Commercial 4H-SiC substrate include variety imperfections caused during the crystal growth process; threading screw dislocation (TSD), threading edge dislocation (TED) and point defects, but also subsequently induced defects in wafer fabrication with mechanical processes[3][4]。We studied such mechanically induced defect in grinding or polishing process of the 4H-SiC wafer by several methods as described above.

2. General Instructions

4H-SiC has the crystal structure with lattice constant; a=3.0851, c=10.0848, space group; P63mc, as shown in Fig.1(a). The electronic band structure of 4H-SiC is obtained by ab initio calculation based on DFT theorem and shown in Fig2(b). the mechanical processing destroy the crystal bonging and induce defects lead the electronic band modulation at the surface of 4H-SiC substrate.

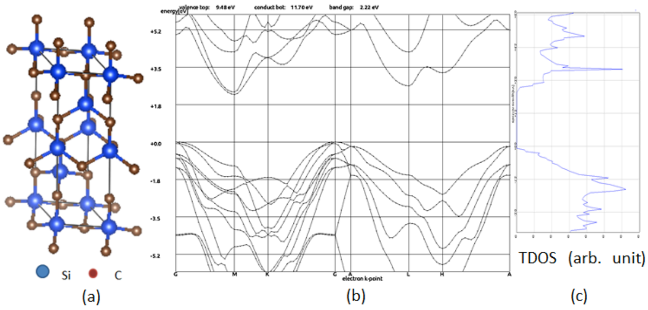


Fig.1 4H-SiC (a) crystal structure, (b) band diagram (C) TDOS

We used 4H-SiC(0001) wafer with 4 degree off angle from [0001] crystal axis. Grinding equipment is an air spindle type vertical grinding machine and single side polishing machine was used for polishing process, respectively. In grinding process, first used #400 vitrified grinding stone and followed by #8000 or #30000 vitrified stone treatment. In the mechanical polishing process, after the #400 stone grinding process, as same in grinding samples, followed by mechanical polishing with diamond slurry with 1μm or 3μm average diameter of diamond power.

In the SPM observation, we used Atomic Force Microscope (AFM) mode and TUNA mode for topological image and tunneling current image in the surface of processed samples, respectively. AFM topological images in Fig. 2(a),(b), which are observed on polished samples, shows the typical randomly scratched morphologies by free abrasive. On the other hand, Fig.2(c) and (d) shows aligned scratches, which are typical for grinding surface, caused by rotating fixed abrasive.

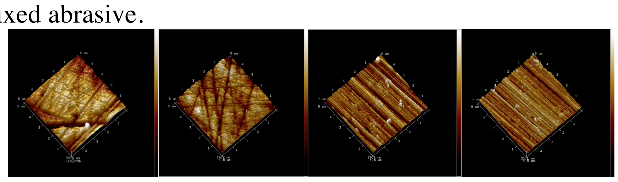

(a) (b) (c) (d)

Fig.2 AFM topographic images ; (a)3μm polish, (b)1μm polish, (c)#8000 grind、(d)#30000 grind

In TUNA mode observation, we obtained tunneling current images as shown in Fig. 3 (left) typically. Strong tunneling current image contrast was detected along scratches for all samples under relatively small applied voltage. Applied voltage vs. tunneling current curve at certain point on scratched (/flat) area was measured as shown in Fig.3 (right upper (/lower)). Large tunneling current was detected on the scratch at applied voltage corresponding mid-gap energy.

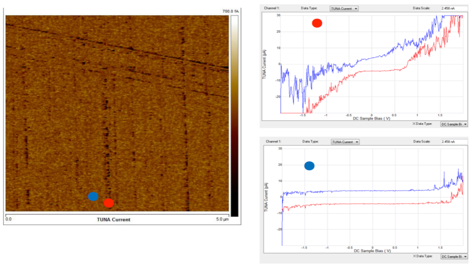


Fig.3 TUNA Current image and TUNA current measurement graph

In Raman 2D mapping data, FTO(2/4) peak Raman shift wavenumber distributions were observed as shown in Fig.4. Polished sample surface was not so strongly stressed in average, but grinding one sustained strong tensile stress in its surface. Especially very strong residual tensile stress, 0.6MPa in average, observed grinding with #30000 grinding stone.

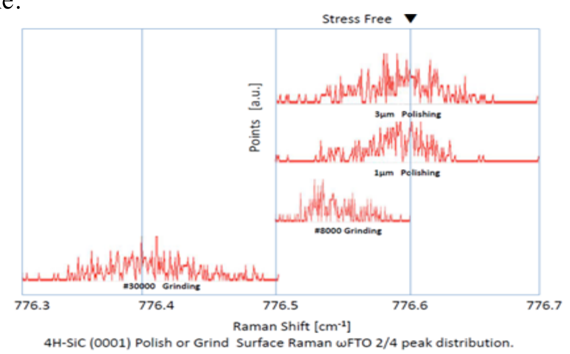
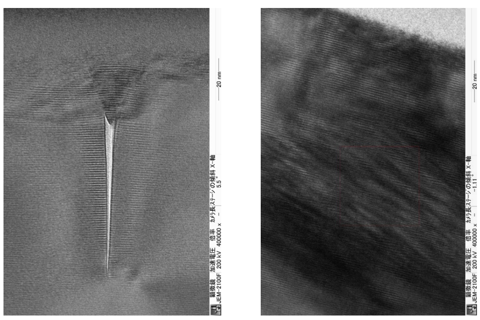


Fig.4 4H-SiC(0001)Polish or Grind Surface Raman ωFTO 2/4 peak distribution.

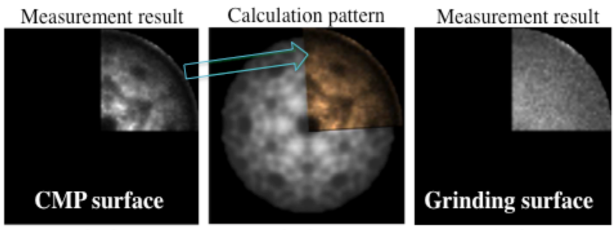
In FIB-TEM observation, as shown in Fig. 5(a), median crack was typically observed in a grinding sample, on the other hand as shown in Fig 5(b), corn crack was typical in polished surface. Also poor crystallinity thin layer was observed in both grinding and polishing surfaces.



(a) (b)

Fig.5 FIB-TEM (a)median crack in grinding surface (b)corn cracks in polished surface.

As described in section 2.3, all mechanically treated samples had damaged surface thin layer on top surface. ASS is one of the best ways to characterize atomic disordering in mm scale area. As a reference data, a Chemical Mechanical Polishing (CMP) treated 4H-SiC (000-1) surface was measured as shown in Fig. 6(a) this is quite in high contrast and good agreement with simulation pole figure data in Fig. 6(b). But grinded samples was quite in dull contrast, this implies thin damaged layer exist at top surface. CMP treatment is quite effective to improve surface crystallinity of 4H-SiC after mechanical processing.



Pole figure (a) Pole figure (b) Pole figure (c)

Fig. 6: ASS pole figure (a),(c) measurement, (b)simulation

3. Conclusions

In conclusion, mechanically processed 4H-SiC(0001) surface was investigated by SPM, Raman, FIB-TEM and ASS. Under the Scratch, median or cone cracks were observed for grinding and polishing samples, respectively. At the scratched area, strong tunneling current was observed. This tunneling current might be caused by mid-gap defect energy states. Both mechanical processing cause surface damage tin layer on the top surface, detected by TEM and ASS. The CMP treatment is quite useful to remove the top surface thin damage layer. Large residual tensile stress was detected for grinding samples by Raman estimation.

We will study electronic states modification at the samples surface induced by mechanically introduced damage or defects in advance, and wish to find advanced process to improve surface quality and to achieve less emission processes.

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