

# Improving the Polishing Speed and Surface Quality of 4H-SiC Wafers with an MnO<sub>2</sub>-Based Slurry

Takuma Nakamura<sup>1,a\*</sup>, Akinori Kumagai<sup>1,b</sup>, Yasunobu Saruwatari<sup>1,c</sup>,  
Syuhei Hara<sup>1,d</sup>

<sup>1</sup>Mitsui Mining & Smelting Co., Ltd. Tosen, Omuta, Fukuoka, 836-0003, Japan

<sup>a</sup>taku\_nakamura@mitsui-kinzoku.com, <sup>b</sup>aki\_kumagai@mitsui-kinzoku.com,  
<sup>c</sup>y\_saruwatari@mitsui-kinzoku.com, <sup>d</sup>s\_hara@mitsui-kinzoku.com

**Keywords:** CMP, MnO<sub>2</sub> abrasive, latent scratch, high speed, high quality, short-time process, Mirror Projection Electron Microscopy

**Abstract** We carried out chemical mechanical polishing (CMP) on commercially available 6 inch SiC wafers (epi-ready products) with slurries containing different abrasive types and evaluated the latent scratch density from the mapping measurement of the wafers using mirror projection electron microscope (MPJ). Comparing to the wafer before polishing, the latent scratch density decreased on the wafer polished with MnO<sub>2</sub>+KMnO<sub>4</sub>, while that increased by polishing with Al<sub>2</sub>O<sub>3</sub>+KMnO<sub>4</sub>. The two-step polishing using first Al<sub>2</sub>O<sub>3</sub>+KMnO<sub>4</sub> and then SiO<sub>2</sub>+H<sub>2</sub>O<sub>2</sub> can reduce the latent scratch density to the same level as that with MnO<sub>2</sub>+KMnO<sub>4</sub>, but long polishing time is required because of the low polishing rate in the process with SiO<sub>2</sub>+H<sub>2</sub>O<sub>2</sub>. We investigated the reason why MnO<sub>2</sub> slurry can suppress the occurrence of latent scratches by a polishing test on a wafer with an SiO<sub>2</sub> film on its (0001)Si surface. The results suggest the oxidation of the SiC surface is rate-determining step for polishing with MnO<sub>2</sub>+KMnO<sub>4</sub>. It was also found that wafers without an SiO<sub>2</sub> film could not be polished with only MnO<sub>2</sub> abrasives. Thus the mechanical contribution to polishing by MnO<sub>2</sub> abrasives in KMnO<sub>4</sub>-based slurry is smaller than the chemical contribution, which can suppress the occurrence of latent scratches. KMnO<sub>4</sub>-based slurry containing MnO<sub>2</sub> abrasives performs the CMP process with low latent scratch density in a time shorter than that containing Al<sub>2</sub>O<sub>3</sub> or SiO<sub>2</sub> abrasives.

## Introduction

Silicon carbide (SiC) is expected to be a next-generation material for power devices demanding reduced energy consumption and device miniaturization, and so on. [1]. However, since SiC has a high hardness and is chemically and thermally stable, wafer processing takes a long time. In particular, the finishing process chemical mechanical polishing (CMP) requires a high surface accuracy, low surface, scratch-free, a low latent scratch density as finished surface conditions, which is difficult to achieve with high speed polishing. In fact, linear latent scratches and dent-like latent scratches are generally observed in commercially available post-CMP wafers (epi-ready wafers) using Mirror Projection Electron Microscopy (MPJ) [2]. These latent scratches induce step bunching and epitaxial defect generation after epitaxial growth [3,4], which are also believed to impact device performance [5]. In this study, we focused on MnO<sub>2</sub> abrasives, which have a low hardness among abrasives, and investigated a slurry for CMP that can be used to achieve a low latent scratch density in a short period of time.

## Experimental

We used three commercially available n-type 4H SiC(0001) bulk wafers with an offcut angle of 4 deg (6 inch epi-ready products) (A, B, C). Two of the wafers' (A and B) Si face (0001) were polished till approximately 1 μm with two types of KMnO<sub>4</sub>-based slurries containing different types of abrasives (wafer A: MnO<sub>2</sub>+KMnO<sub>4</sub> (NANOBI<sup>TM</sup> manufactured by Mitsui Mining & Smelting Co., Ltd), wafer B: Al<sub>2</sub>O<sub>3</sub>+KMnO<sub>4</sub>), whereas the third wafer (C) Si face (0001) was polished first with Al<sub>2</sub>O<sub>3</sub>+KMnO<sub>4</sub> and then with SiO<sub>2</sub> (colloidal silica)+H<sub>2</sub>O<sub>2</sub> up to around 0.1 μm. Tables 1 shows the

polishing conditions. The wafer evaluation was performed in the following two parts: First, a scratch mapping measurement of the entire wafer was done using a differential interference microscope (Lasertec Co. SICA6X). Next, latent scratch mapping measurements of the entire wafer was conducted using MPJ (Hitachi High-Tech Co. Mirror Electron Inspection System Mirelis VM1000). Mapping measurement was conducted by arranging a 5 mm  $\times$  5 mm chip in a region excluding the outer 5-mm periphery of the wafer and setting 64 imaging points with a field of view of 80  $\mu\text{m}$   $\times$  80  $\mu\text{m}$  in each chip. MPJ evaluation involved comparing each wafer before and after polishing and investigating the effect of polishing.

Table 1. Polishing Conditions.

SiC wafer	n-type 4H(4° off)
Wafer size	6 inch
Polishing face	Si-face
Polisher	$\Phi$ 610mm SSP
Pressure	300gf/cm <sup>2</sup>
Rotation speed (platen/head)	41rpm/40rpm
Polishing amount	1 $\mu\text{m}$

## Results and Discussion

Table 2 shows the results of scratch mapping measurements of the polished wafers. No scratches were detected on any of the wafers. Upon performing the latent scratch mapping measurement of the entire wafer using MPJ, the latent scratch density of the polished wafer A was observed to be lower than that before polishing (Fig. 1(a)), whereas the same of the polished wafer B was higher than that before polishing (Fig. 1(b)). Furthermore, comparisons of the latent scratch images between wafers A and B showed that the contrast of wafer A was relatively low, suggesting little damage under the wafer surface (Fig. 2(a)), whereas thick dent-like latent scratches were observed in wafer B, which could impact the epitaxial film such as step bunching and formation of stacking faults [4] (Fig. 2(b)). Wafer C had the same latent scratch density as wafer A (Fig. 1(b)), and the latent scratch contrast was lower as well (Fig. 2(c)). However, since the polishing speed with  $\text{SiO}_2 + \text{H}_2\text{O}_2$  is slow, the polishing process takes longer to reach the same level of latent scratch density as that with  $\text{MnO}_2 + \text{KMnO}_4$  (Table 2). These results show that the  $\text{KMnO}_4$ -based slurry containing  $\text{MnO}_2$  abrasives results in a low latent scratch density in a shorter time than when using  $\text{Al}_2\text{O}_3$  or  $\text{SiO}_2$  abrasives.

Table 2. Test content / results (Zygo field of view: 0.14 mm x 0.11 mm).

Wafer	Polishing Conditions			Polishing Results					
	Slurry		Pad	Polishing amount ( $\mu\text{m}$ )	Polishing time (min)	Rate (nm/min)	Zygo Ra(nm)	SICA Scratch density ( $\text{cm}^{-2}$ )	MPJ Latent scratch density ( $\text{cm}^{-2}$ )
	Components	Particle size D50( $\mu\text{m}$ )							
A	$\text{MnO}_2 + \text{KMnO}_4$	0.40	IC1000 <sup>TM</sup> XY Grv.	1.04	60	17	0.138	0	131
B	$\text{Al}_2\text{O}_3 + \text{KMnO}_4$	1.00		1.04	55	19	0.138	0	1346
C	1P $\rightarrow$ 2P		-	1.12	93	-	0.136	0	258
	1P	$\text{Al}_2\text{O}_3 + \text{KMnO}_4$	IC1000 <sup>TM</sup> XY Grv.	1.04	55	19	0.143	0	-
	2P	$\text{SiO}_2 + \text{H}_2\text{O}_2$	Supreme <sup>TM</sup> RN-H	0.08	38	2	0.136	0	258

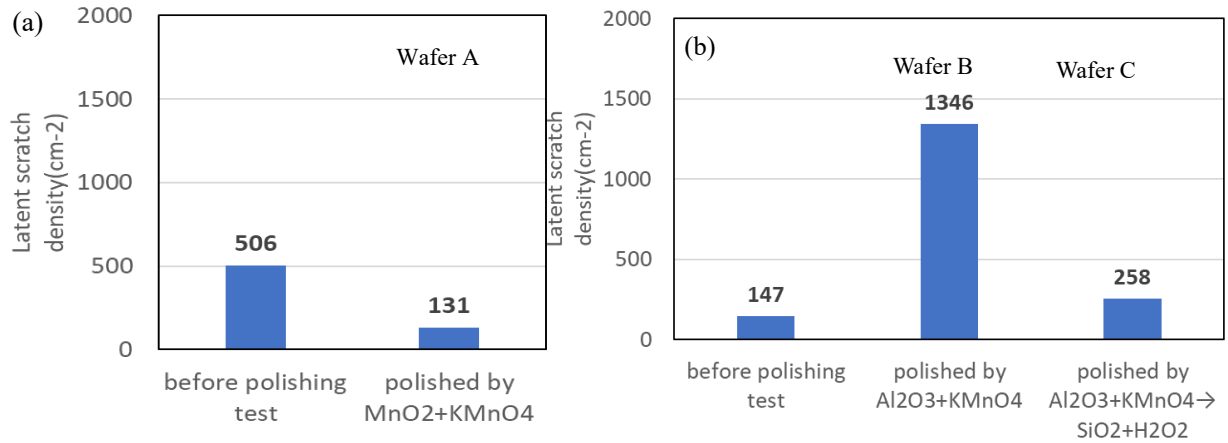
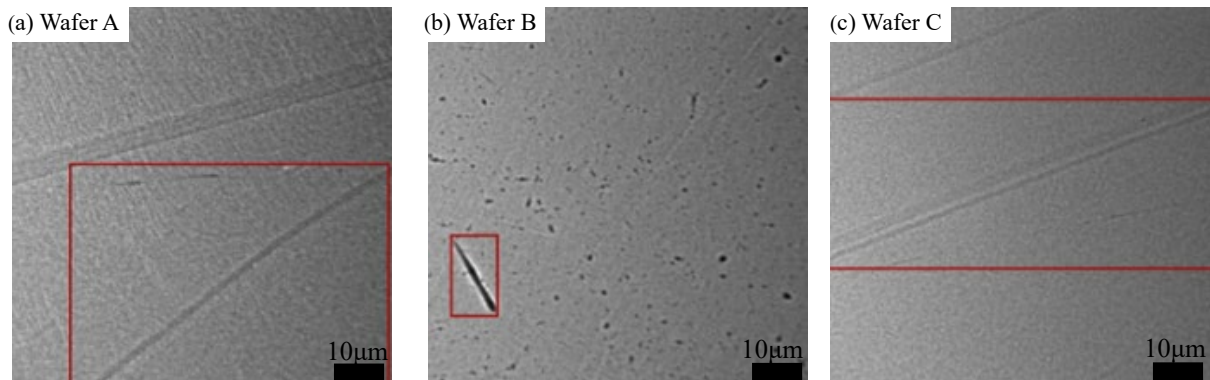


Fig.1. Wafer latent scratch density detected by MPJ (by automatic detection function).

((a): Wafer A: polished by  $\text{MnO}_2 + \text{KMnO}_4$ , (b): Wafer B: polished by  $\text{Al}_2\text{O}_3 + \text{KMnO}_4$ , Wafer C: polished by  $\text{Al}_2\text{O}_3 + \text{KMnO}_4 \rightarrow \text{SiO}_2 + \text{H}_2\text{O}_2$ )

Fig.2. A MPJ image of the polished wafer including the latent scratch (field of view:  $80\mu\text{m} \times 80\mu\text{m}$ ).

((a): Wafer A: polished by  $\text{MnO}_2 + \text{KMnO}_4$ , (b): Wafer B: polished by  $\text{Al}_2\text{O}_3 + \text{KMnO}_4$ , (c) Wafer C: polished by  $\text{Al}_2\text{O}_3 + \text{KMnO}_4 \rightarrow \text{SiO}_2 + \text{H}_2\text{O}_2$ )

We also studied the polishing mechanism to investigate the reason behind low latent scratches when polishing with  $\text{MnO}_2$  abrasives. First, a SiC wafer was heated at 1,000  $^{\circ}\text{C}$  for 20 hours in atmosphere to form an  $\text{SiO}_2$  film of approximately 40 nm on its Si face (0001). Next, the wafer was

repeatedly polished five times with  $\text{MnO}_2 + \text{KMnO}_4$  for one minute. Fig. 3(a) shows the variation of polishing rate with polishing time. Fig. 3(b) shows the Fourier transform infrared attenuated total reflection (FTIR-ATR) spectrum of the wafer before polishing and after every minute during polishing. FTIR-ATR measures the total internal reflection of the irradiated infrared light penetrating the sample, which is then used to obtain the absorption spectrum of the surface layer of the sample. Referring to Fig. 3(b), the peaks near 1,070  $\text{cm}^{-1}$  and 1,220  $\text{cm}^{-1}$  corresponding to the wafer before polishing are the absorption peaks related to the transverse optical (TO) mode and the longitudinal optical (LO) mode respectively due to the asymmetric stretching vibration of Si-O-Si of  $\text{SiO}_2$  [6]. In the TO and LO modes, adjacent atoms of Si-O-Si vibrate in opposite phases along the perpendicular and parallel directions, respectively, with respect to the phonon propagation direction. The polishing rate for the first one minute, when the TO and LO peaks were observed was approximately 34  $\text{nm/min}$ , which was high when compared to the polishing rate for a SiC wafer without an  $\text{SiO}_2$  film (red dotted line). After that polishing, since the  $\text{SiO}_2$  film was scraped off by polishing, and its thickness was not sufficient for detection, TO and LO peaks disappeared, and then the polishing rate was similar to that of a normal wafer (two minutes after start). Based on these results, (1) oxidation of the SiC surface by  $\text{KMnO}_4$  and (2) removal of the  $\text{SiO}_2$  film by  $\text{MnO}_2$  abrasives are believed to be the processes comprising the polishing mechanism of  $\text{MnO}_2 + \text{KMnO}_4$ . Moreover, it is believed that the oxidation reaction (1) (Eqs. (1) and (2)) is the rate-determining factor for this polishing method.



Next, the above study was repeated with  $\text{MnO}_2$  abrasives (Fig. 4). Here too, in a manner similar to that with  $\text{MnO}_2 + \text{KMnO}_4$ , (a) the polishing rate was higher and (b) the  $\text{SiO}_2$ -derived TO and LO peaks were present after one minute of polishing, as shown in Fig. 3(a). However, in this case, the polishing rate approached zero after disappearance of the peaks, which implies that polishing was not possible three minutes after the start. These results thus suggest that a SiC wafer without a  $\text{SiO}_2$  film cannot be polished with only  $\text{MnO}_2$  abrasives, which may be due to the fact that  $\text{MnO}_2$  abrasives are softer than  $\text{Al}_2\text{O}_3$  abrasives.

The above results also suggest that the mechanical contribution of  $\text{KMnO}_4$ -based slurry containing  $\text{MnO}_2$  abrasives to polishing is smaller than the chemical contribution, which is believed to be advantageous in suppressing the occurrence of latent scratches.

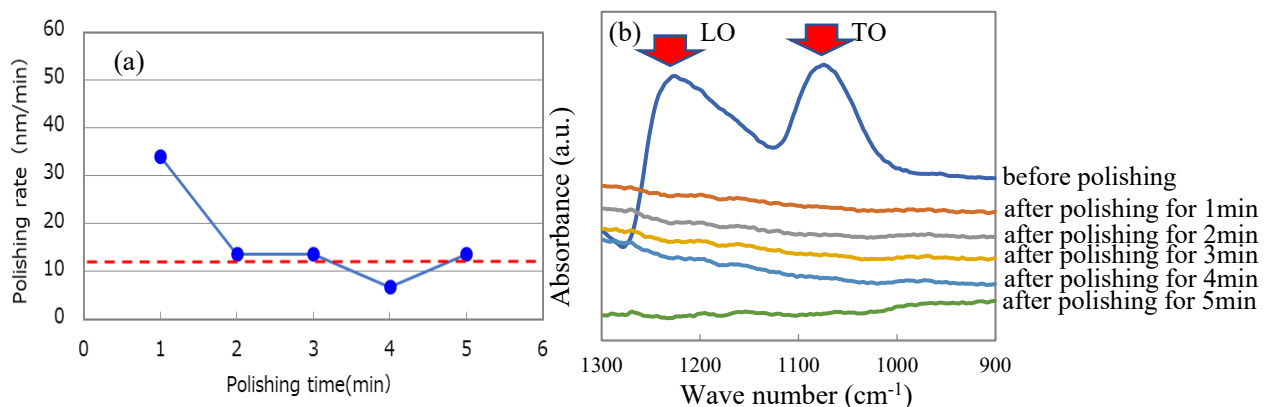


Fig.3. Results of polishing SiC wafer containing a  $\text{SiO}_2$  film with  $\text{MnO}_2 + \text{KMnO}_4$ :  
 (a) Variation in polishing rate with polishing time (red dashed line represents the polishing rate of SiC wafer without a  $\text{SiO}_2$  layer).  
 (b) Absorption spectrum of SiC wafer by FTIR-ATR.

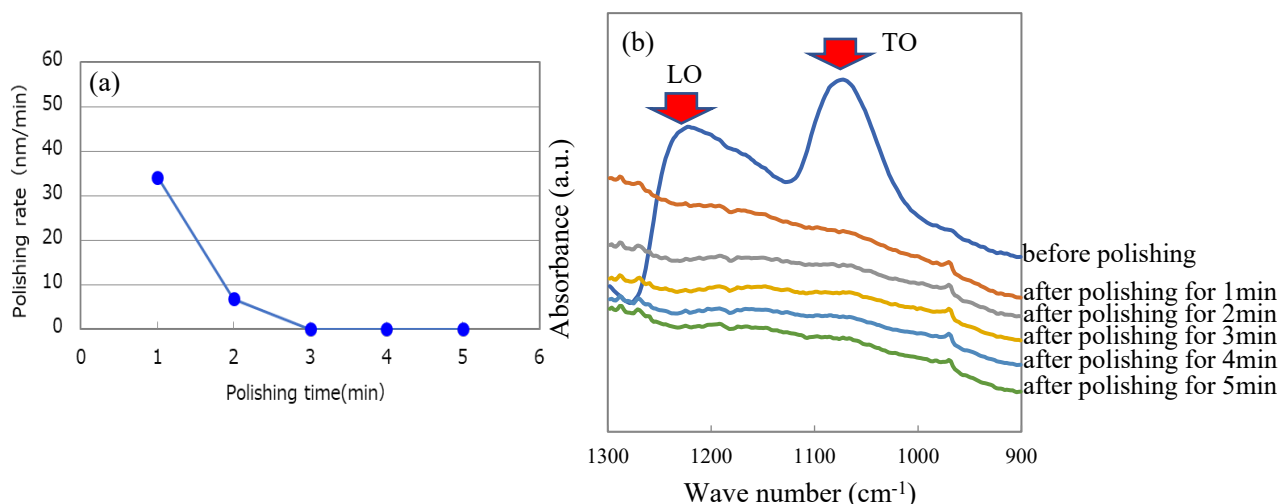


Fig. 4. Results of polishing SiC wafer containing a SiO<sub>2</sub> film with MnO<sub>2</sub> abrasives:

- (a) Variation in polishing rate with polishing time.  
 (b) Absorption spectrum of SiC wafer by FTIR-ATR.

## Summary

The present results indicate that polishing SiC wafers with a KMnO<sub>4</sub>-based slurry containing MnO<sub>2</sub> abrasives can result in a low latent scratch density in a shorter period of time than when using Al<sub>2</sub>O<sub>3</sub> or SiO<sub>2</sub> abrasives. This means that by using the above slurry, the process time can be shortened, and the wafer yield can be improved, both of which, contribute to reduce the process cost.

## Acknowledgement

We would like to thank Mr. Kenji Kobayashi and Mr. Kentaro Ohira of Hitachi High-Tech Co. for conducting wafer measurements using Mirelis VM1000. We would also like to thank Prof. Toshiyuki Isshiki of Kyoto Institute of Technology for the valuable advice given during the preparation of this paper. Lastly, We would like to thank Editage ([www.editage.com](http://www.editage.com)) for English language editing.

## References

- [1] Roccaforte, F., Fiorenza, P., Greco, G., Vivona, M., Nigro, R. L., et al., Appl. Surf. Sci 301, 9-18 (2014)
- [2] T. Isshiki, M. Hasegawa, T. Sato, K. Kobayashi, A. Miyaki, M. Iyoki, T. Yamaoka, K. Onuki, Mater. Sci. Forum 924, 543-546 (2018)
- [3] M. Sasaki, K. Tamura, H. Yamaguchi, H. Matsuhata, K. Kojima, M. Kitabatake, Mater. Sci. Forum 821-823, 285-288 (2015)
- [4] I. Kamata, K. Ohira, K. Kobayashi, M. Hasegawa, M. Miyata, N. Noguchi, S. Takami, H. Tsuchida, Mater. Sci. Forum 963, 255-258 (2019)
- [5] J. Sameshima, O. Ishiyama, A. Shimozato, K. Tamura, H. Oshima, T. Yamashita, T. Tanaka, N. Sugiyama, H. Sako, J. Senzaki, H. Matsuhata, M. Kitabatake, Mater. Sci. Forum 740-742, 745-748 (2013)
- [6] B. C. Trasferetti and C. U. Davanzo, Appl. Spectroscopy 54, 502 (2000)