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Quality Improvement of SiC Substrate Surface with Using Non-Abrasive CMP Slurry

Seung Jun Lee[1,a], Byeong Hun Park[1,b], Cheol Ho Lee[1,c], In Kyu Lee[1,d], Jung Doo Seo[1,e], Kap Ryeol Ku[1,f], Bo Hyeok Choi[2,g], Eun Ock Kim[2,h], Na Ra Shin[2,i], Su Yeong Jung[2,j], Dong Wook Kim[2,k], Jun Hyuck Na[3,l] and Won Jae Lee[3,m*]

[1]Senic, 17-15, 4sandan 7-ro, Jiksan-eup, Seobuk-gu, Cheonan-si, Chuncheongnam-do, Korea

[2]KCTech, 50, Dongtancheomdansaneop 1-ro, Hwaseong-si, Gyeonggi-do, Korea

[3]Department of Advanced Materials Engineering, Dong-Eui University, 176, Eomgwang-ro, Busanjin-gu, Busan, Korea

[a]sjlee@senic.co.kr, [b]bhpark@senic.co.kr, [c]chlee@senic.co.kr, [d]iklee@senic.co.kr, [e]jdseo@senic.co.kr, [f]krku@senic.co.kr, [g]cbhyuk@kctech.co.kr, [h]zzangkeo@kctech.co.kr, [i]snr0316@kctech.co.kr, [j]sy1129@kctech.co.kr, [k]po99135@kctech.co.kr, [l]mjna21x@naver.com, [m]leewj@deu.ac.kr

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Abstract. Transition metal ion was added to CMP (chemical-mechanical polishing) slurry without abrasive particle to solve the problem of CMP. MRR (material removal rate) value of SiC substrate processed using non-abrasive slurry was comparable to MRR values of SiC substrates using abrasive slurries. The scratch formation was successfully suppressed in SiC substrate polished with using non-abrasive slurry and no residual particle resulting from agglomeration of abrasive particles could suppress scratches and forms a good quality of SiC substrate surface. Uniform and high-quality SiC substrates could be prepared through the non-abrasive CMP process.

Introduction

SiC single crystal is a power semiconductor material that has excellent properties such as high voltage strength, high thermal conductivity, and wide band gap, and is widely used for commercial and academical purposes. Ultra-flat and damage-free substrates are required for SiC substrates used in high-quality epi-layer or high-performance power devices such as MOSFETs and SBDs. For this purpose, CMP (chemical-mechanical polishing) process is generally performed with chemical reaction and physical polishing on SiC crystal surface. However, since SiC substrate has high hardness, brittleness, and inertness, CMP process basically has high cost and low efficiency. In the previous study, the physical polishing was carried out through the abrasive contained in the CMP slurry, but in this case, as the polishing progressed, second scratches could be formed on the surface of the SiC substrate due to aggregation of abrasive particles in the slurry, deteriorating the quality of the SiC substrate. Furthermore, the efficiency of polishing decreased rapidly as the process time passed due to residual particles [1,2]. Therefore, in this study, non-abrasive slurry containing some additives, not using the existing abrasive slurry that could cause the quality degradation was applied to improve the substrate surface quality and improve the cleaning ability of the slurry [3,4].

Experimental

Agglomerated particle generation factors. When the conventional abrasive slurry is applied to the CMP process, the temperature increases due to the frictional heat caused by the polishing pad and the reaction heat caused by the chemical reaction. Therefore, chemical interactions in the slurry become active, and collisions and bonding between abrasive particles could increase, resulting in aggregation between abrasive particles in the slurry. The aggregation of these abrasive particles causes secondary scratches on the SiC substrate and particle defects in the substrate (Fig. 1) [5].

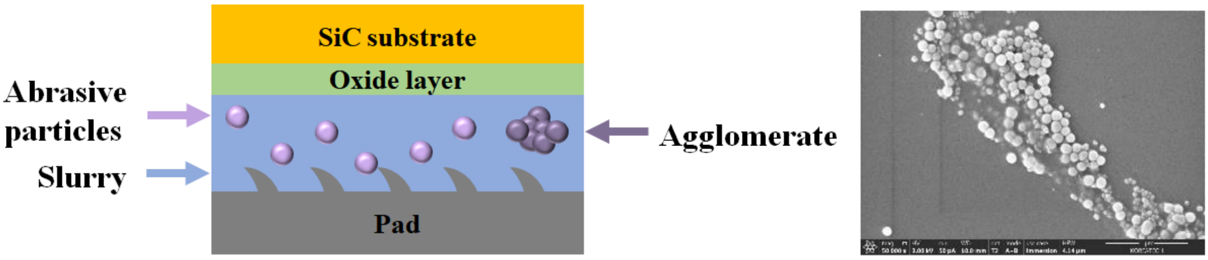
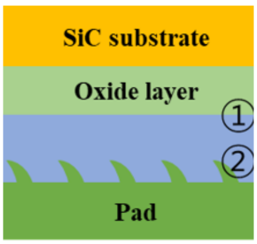


Fig. 1. Schematic diagram of aggregated particle formation and image of agglomerate.

Non-abrasive CMP mechanism. In order to solve the problems from the existing abrasive slurry described above, the non-abrasive slurry that does not contain abrasive has been proposed. In the non-abrasive slurry, a transition metal ion is used as another additive. Fig. 2 shows the chemical reaction between the transition metal ion and the SiC substrate in the non-abrasive slurry. MnO_4^- can be produced through the addition of transition metal. Firstly, at the reduction reaction of the acidic region of MnO_4^-, MnO_4^- reacts with acid to separate into Mn^{2+} and $4H_2O$. Here, $4H_2O$ is separated into $8H^+$ and $4O^{2-}$ simultaneously with heat generation through chemical interaction. Then, the separated $4O^{2-}$ reacts with SiC to produce soluble SiO_3^{2-} and CO on the surface of the SiC substrate, indicating that SiC surface can be polished by the only dissolution. Mn^{2+} ion that did not participate in the dissolution reaction produces MnO_4^- again through a reaction with the transition metal ion in the slurry. With this polishing mechanism by the dissolution on the SiC substrate, the risk of scratching the SiC substrate could be effectively removed. Furthermore, since residual Mn^{2+} ion participates in the reaction again, the risk of aggregation is also kept to be low, and the lifetime of the slurry is getting longer. In this study, the surface quality of SiC crystal substrate after the CMP process was investigated with varying abrasive content in the modified SiC slurry added transition metal ion for CMP process.



①SiC Surface Oxidation: $4O^{2-}$ separated from MnO_4^- formed SiO_3^{2-} on SiC surface,

Equation: $MnO_4^- \rightarrow Mn^{2+} + 4O^{2-}$ / $SiC + 4O^{2-} \rightarrow SiO_3^{2-}$ (Soluble) + CO

②Oxidant Regeneration: MnO_4^- oxidant regeneration by additive transition metal Ion

Equation: $Mn^{2+} + 5Me^{3+}$(Metal ion) + $4H_2O \rightarrow MnO_4^- + 5Me^{2+} + 8H^+$

[Me^{3+}(Metal ion) + $e^- \rightarrow Me^{2+}$]

Fig. 2. Reduction reaction of MnO_4^- on acid region and surface reaction of SiC substrate.

CMP process conditions. Table 1 exhibited the CMP conditions to which three types of slurry are applied. The abrasive content decreased from 5% to 0% in the modified SiC slurry added transition metal ion for CMP process and the surface quality of SiC substrate after the CMP process was systematically investigated. Non-abrasive slurry was manufactured by KC Tech co ltd. Fig. 3 shows the concentration distribution of additives contained in each slurry detected by an inductively coupled plasma-optical emission spectrometer (ICP-OES) analysis. While high concentration of Si was observed in the abrasive slurry, non-abrasive slurry did not contain Si. And Mn, K were detected in all slurries. Table 2 exhibited physical properties of slurries with abrasive 5%, 3.5% and non-abrasive slurry. All slurries had similar pH values and the particle size of abrasives was 250 nm.

Table 1. CMP process conditions

Conditions	Degree
Plate RPM	105 rpm
Head RPM	95 rpm
Membrane pressure	4.5 psi
Inner pressure	3.5 psi
Retainer pressure	6.5 psi
Slurry flow	150ml/min.

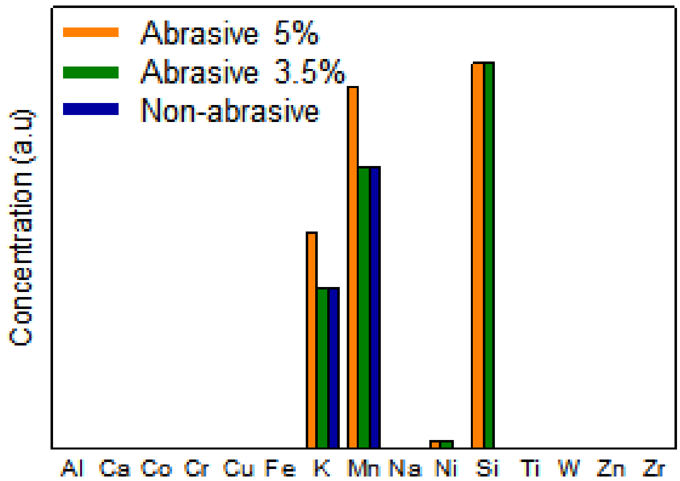


Fig. 3. ICP-OES analysis data of slurries with abrasive 5%, 3.5% and non-abrasive slurry

Table 2. Physical properties of slurries with abrasive 5%, 3.5% and non-abrasive slurry

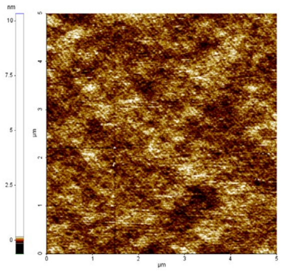
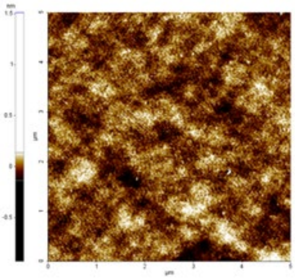
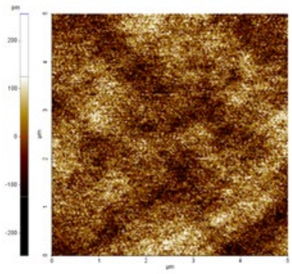
	Abrasive 5%	Abrasive 3.5%	Non-abrasive
Abrasive type	Silica	Silica	-
pH	2.0~4.0	2.0~4.0	2.0~4.0
Abrasive Size(nm)	250	250	-

Result and Discussions

AFM (Atomic Force Microscope) analysis of SiC substrate. SiC substrate surfaces after the CMP process were analyzed by AFM (Parksystems' XE-150 equipment) in order to check secondary scratches and to evaluate surface roughness. Table 3 shows the AFM image and averaged roughness data of CMP-processed SiC substrates with 5%, 3.5% and non-abrasive content. The root mean square (rms) roughness value of SiC surface processed by using non-abrasive slurry was observed to be slightly lower than those of SiC surface by slurries with 5%, 3.5%.

MRR (Material Removal Rate) analysis of SiC substrate. MRR as an important factor to determine a polishing efficiency was measured on Si-face and C-face of SiC substrate. MRR was calculated by measuring the SiC wafer thickness before and after the CMP process. Fig. 4 shows MRR data of CMP-processed SiC substrates with 5%, 3.5% and non-abrasive content. The MRR value of CMP-processed SiC substrate with all slurries on C-face was definitely higher(~3X) than on Si-face. It is interesting point that MRR value of SiC substrate using non-abrasive slurry was comparable to MRR values of SiC substrates using abrasive slurries. Polishing could be achieved by only dissolution without any abrasive materials. In addition, there was no significant difference in MRR value and measured temperature increase due to chemical reaction and friction, which indicating the comparable lifetime of the pad and slurry. In conclusion, the MRR values of the abrasive slurry and the non-abrasive slurry did not show a significant difference, confirming the suitable function of the non-abrasive slurry for polishing of SiC substrate.

Table 3. AFM image data and roughness of CMP-processed SiC substrates with 5%, 3.5%, and non-abrasive content.

	Abrasive 5%	**Abrasive 3.5%**	**Non-abrasive**
AFM Image			
Roughness	0.054 nm	0.056 nm	**0.050 nm**

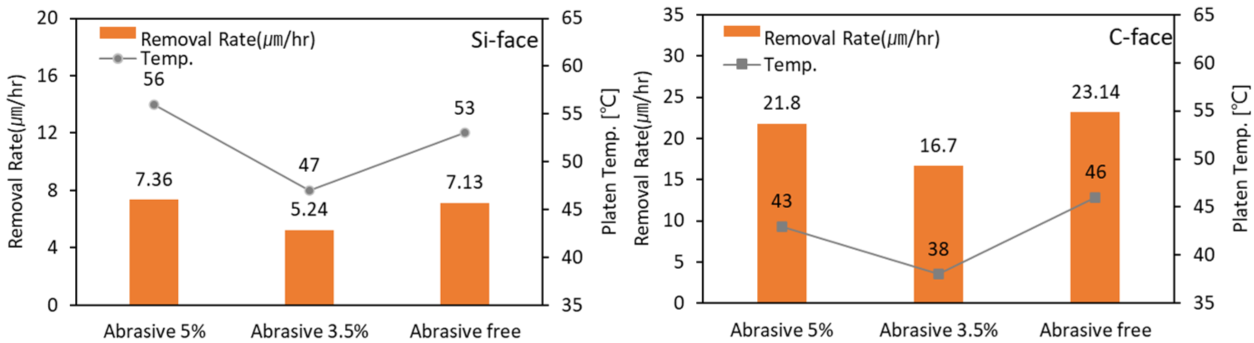


Fig. 4. MRR data of CMP-processed SiC substrates with 5%, 3.5% and non-abrasive content.

Particle mapping analysis of SiC substrate. Residual particles in the SiC substrate, which could cause secondary scratches and particle defects in the SiC substrate and lower the polishing quality, were investigated. CMP-processed SiC substrates using three different slurry types were examined for exited particles after typical RCA cleaning. Table 4 exhibited particle mapping analysis data of SiC substrates with abrasive 5%, 3.5%, and non-abrasive content after the RCA cleaning. It was found that SiC substrates with abrasive 5%, 3.5% contained much higher particle content. The formation of residual particles was rapidly suppressed in the SiC substrate using non-abrasive slurry because there was no abrasive on CMP process. Table 5 showed scratch mapping analysis data of SiC substrates with 5%, 3.5%, and non-abrasive content after RCA cleaning. The scratch formation was successfully suppressed in SiC substrate using non-abrasive slurry. No residual particles resulting from agglomeration of abrasive particles could suppress scratches and form good quality of SiC substrate surface. In terms of surface roughness, MRR value and slurry lifetime, non-abrasive slurry was definitely comparable to abrasive slurry. Furthermore, non-abrasive slurry used in this study had much better advantage in suppressed formation of residual particles/scratch.

Table 4. Particle mapping analysis data of SiC substrates with 5%, 3.5%, and non-abrasive content after RCA cleaning.

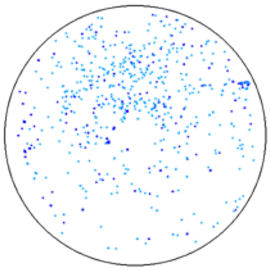
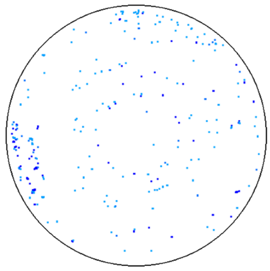
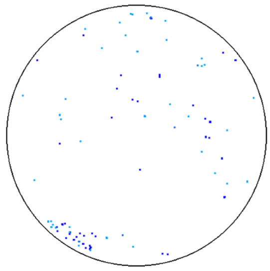
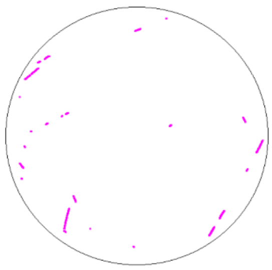
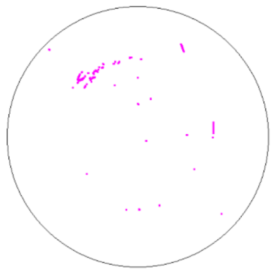
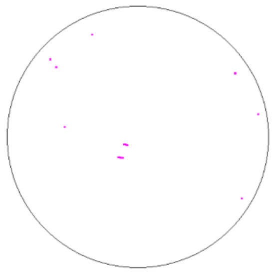
	Abrasive 5%	Abrasive 3.5%	Non-abrasive
Particle map			
Counts	575 ea	247 ea	**87 ea**

Table 5. Scratch mapping analysis data of SiC substrates with 5%, 3.5%, and non-abrasive content after RCA cleaning.

	Abrasive 5%	Abrasive 3.5%	Non-abrasive
Scratch map			
Total Length	102 mm	49 mm	**10 mm**

Summary

The non-abrasive slurry was proposed to prevent agglomeration occurring in the abrasive type of CMP process and particle defects resulting in secondary scratches. MRR value of SiC substrate using non-abrasive slurry was comparable to MRR values of SiC substrates using abrasive slurries. The scratch formation was successfully suppressed in SiC substrate using non-abrasive slurry. No residual particles resulting from agglomeration of abrasive particles could suppress scratches and form good quality of SiC substrate surface. In conclusion, it was demonstrated that uniform and high-quality SiC substrates could be processed through the non-abrasive CMP process.

Acknowledgements

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References

[1] B.C Peethala, H.P. Amanapu, U.R.K. Lagudu, S.C. Babu: Journal of the electrochemical society Vol. 159, Number 6, p. H582

[2] R. Chen: Applied Surface Science Vol. 264 (2013), p. 148

[3] Y. Zhou: Applied Surface Science Vol. 316 (2014), p. 643

[4] G. Cehn: Russian Journal of Applied Chemistry Vol. 93, No. 6 (2020), p. 832

[5] R. Wang: Appl. Phys. Lett. Vol. 122 (2023), p. 180501