Materials Science Forum
ISSN: 1662-9752, Vol. 1193, pp 41-45
doi:10.4028/p-BAyAw0

Submitted: 2025-09-12
Revised: 2025-12-23
Accepted: 2026-03-16
Online: 2026-05-21

Damage-Free Dicing of SiC Substrate Using High-Pressure SF6 Plasma: The Time Dependence of Processed Groove Profiles

Yuken Matsumura[1,a*], Shunto Iden[1,b], Daisetsu Toh[1,c], Jumpei Yamada[1,d] and Yasuhisa Sano[1,e]

[1]Department of Precision Engineering, Graduate School of Engineering, The University of Osaka, Osaka, Japan

[a*]y.matsumura@up.prec.eng.osaka-u.ac.jp, [b]iden@up.prec.eng.osaka-u.ac.jp, [c]toh@prec.eng.osaka-u.ac.jp, [d]yamada@prec.eng.osaka-u.ac.jp, [e]sano@prec.eng.osaka-u.ac.jp

Keywords: plasma chemical vaporization machining, atmospheric-pressure plasma, etching, dicing, SF_6, damage-free, time dependance.

Abstract. Plasma chemical vaporization machining (PCVM) is a high-rate etching method that uses atmospheric-pressure plasma. Its application to the plasma dicing of SiC wafers is anticipated. However, since the reaction is mainly driven by neutral radicals, it is difficult to maintain anisotropy, and issues such as side etching are of concern. In this study, PCVM processing was performed using SF_6 gas with a Ni mask to investigate vertical and lateral etching behaviors. We achieved vertical etching of 100 μm within approximately 35 minutes, and lateral side etching of about 50 μm. The lateral etch rate remained nearly constant, whereas the vertical etch rate was initially high but decreased as the etching progressed, approaching the lateral rate. Finite element-based electrostatic field analysis revealed that, as the etching depth increased, electric field shielding by the mask weakened the field at the bottom of the trench, leading to a transition toward neutral radical-dominated reactions.

Introduction

In semiconductor device manufacturing, wafer dicing is an indispensable process. SiC has attracted significant attention as a material for power devices; however, due to its high hardness and brittleness, conventional mechanical dicing using diamond blades often introduces defects and cracks, leading to reduced chip strength and yield. Laser-based dicing techniques, such as laser thermal dicing and stealth dicing, have also been explored as non-contact alternatives; however, they involve localized thermal modification or internal damage layers, which may induce residual stress and microcracks, thereby limiting the mechanical reliability of SiC chips. In contrast, plasma dicing—non-contact and damage-free processing using plasma—has already been put into practical use for silicon. Nevertheless, when applied to SiC, the removal rate is too slow for practical implementation. To address this issue, we propose the application of plasma chemical vaporization machining (PCVM) [1,2]—a high-pressure plasma process operating in the kPa-to-atmospheric-pressure range—to SiC dicing. PCVM removes material through chemical reactions using high-density radicals generated in atmospheric-pressure plasma. Owing to its non-contact nature, it suppresses cracks and chipping while enabling high-rate processing. It has previously been reported that a high etching rate of approximately 15 μm/min can be achieved on 2-inch SiC wafers [2]. In our previous work, we conducted etching experiments with varying metal mask widths and demonstrated that the etch rate decreases with narrower mask openings and deeper trenches. However, due to the limited durability of the masks, the etching depth was restricted to about 40 μm, which prevented sufficient evaluation of the time dependence of side etching or detailed electrostatic field analysis [3]. In this study, we applied PCVM to SiC wafers covered with a thick, durable Ni mask prepared by electroplating. By systematically measuring the trench depth and lateral progression as a function of processing time, we evaluated the development of side etching and the evolution of anisotropy. In addition, finite element analysis was employed to examine the electrostatic field distribution, and the observed decrease in the electric field at the trench bottom was interpreted as being attributable to mask-induced field shielding. Through this approach, we clarified the side etching behavior in SiC plasma dicing and provided a fundamental investigation toward its practical application.

Experimental Procedure

Figure 1 shows a schematic of the PCVM processing system. The sample was prepared by cutting a commercially available n-type 4H-SiC wafer into pieces of 10×20 mm^2; the (000$\bar{1}$) surface, corresponding to the back side of devices, was used as the processing surface. As the mask, a 100 nm-thick Ni metal layer was first deposited via vacuum evaporation, followed by electroplated Ni growth to a thickness of approximately 0.7 µm. To confine the plasma irradiation region, the mask was patterned with a cross-shaped slit opening about 50 µm wide. To prevent arc discharge during processing, the aluminum sample stage was coated with yttria via thermal spraying, to provide surface insulation and serve as a protective coating. The electrode was a water-cooled aluminum alloy plate with a diameter of approximately 2 inches in which numerous micro holes for gas injection were distributed on the surface facing the sample. A 13.56-MHz RF power supply was employed for plasma generation. The process gas was pure SF_6, supplied at a flow rate of 250 sccm. The chamber pressure was maintained at 2.5 kPa, with an electrode-to-sample distance of 1.7 mm and an applied RF power of 1200 W.

The experimental procedure was as follows: The chamber was first evacuated with a dry pump down to approximately 30 kPa, after which SF_6 was introduced to reach 2.5 kPa. The pressure was then kept at 2.5 kPa by adjusting the exhaust valve opening. RF voltage was applied between the plasma-generating electrode and the sample to ignite the plasma, and etching was carried out. Processing times were set to 5 or 10 minutes, and etching followed by evaluation was repeated multiple times. For post-process evaluation, the vertical etch depth was measured using a confocal laser scanning microscope (LEXT3000, Olympus). The lateral etch amount was determined using a scanning electron microscope (S-4800, Hitachi) to observe the cross-shaped mask opening from an oblique angle, as shown in Fig 2. To aid in the interpretation of the results, electrostatic field simulations were performed using the two-dimensional finite element analysis software E-STAT (Field Precision LLC) [4].

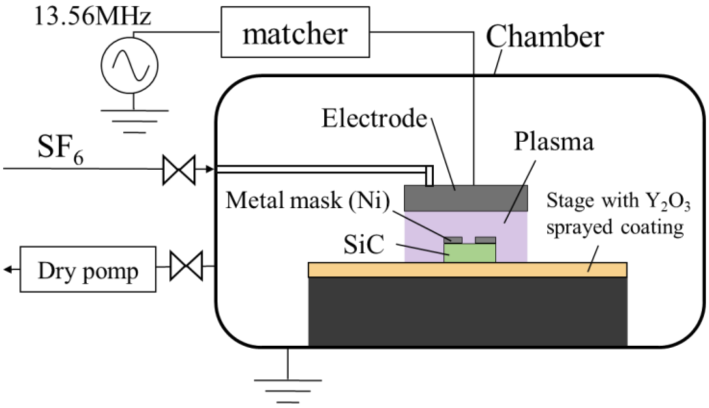

Fig. 1. PCVM experimental apparatus.

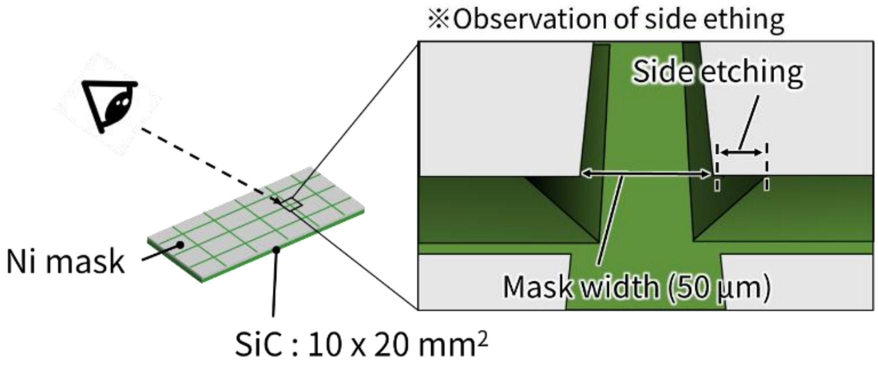

Fig. 2. Method for measuring side etching.

Results and Discussion

Removal rate.

Figures 3 and 4 show the time evolution of etch depth and etch rate. In this experiment, vertical etching to a depth of 100 µm—comparable to the thickness of thinned wafers after backside thinning—was successfully achieved within approximately 35 minutes. As for the amount of side etching accompanying the vertical etch, cross-sectional SEM images (Fig. 5) revealed that, after 35 minutes, lateral etching beneath the mask reached up to approximately 50 µm. Focusing on the time dependence of the etch rates, the lateral etch rate remained almost constant regardless of etching duration, whereas the vertical etch rate exhibited a pronounced time variation. Specifically, the vertical etch rate was initially very high, but gradually decreased as etching proceeded, eventually converging to a value comparable to that of the lateral etch rate.

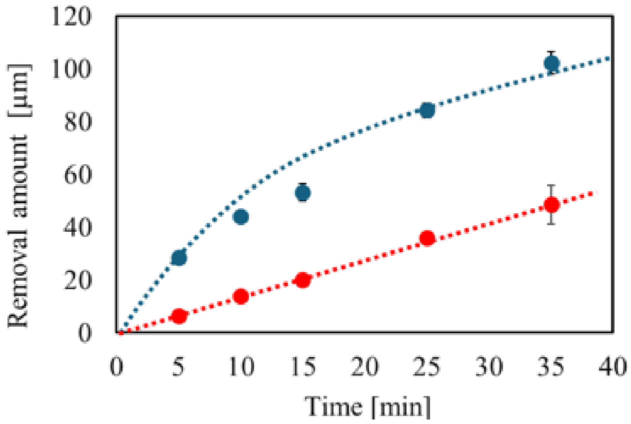

Fig. 3. Time evolution of removal amount (red: lateral, blue: vertical).

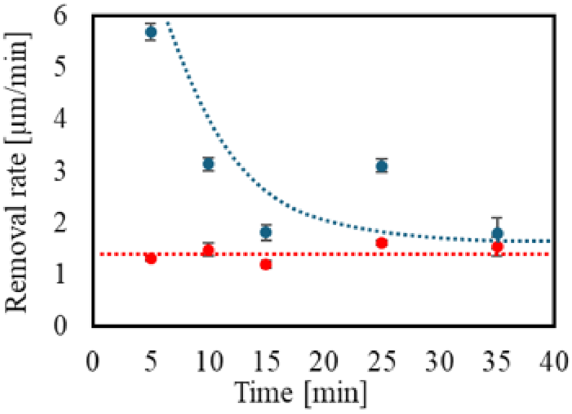

Fig. 4. Time evolution of removal rate (red: lateral, blue: vertical).

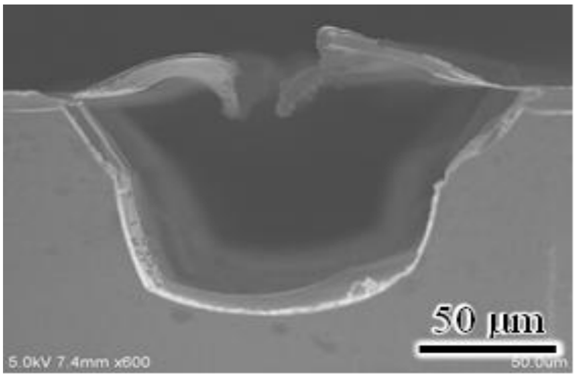

Fig. 5. Cross-sectional SEM image of the processed sample (600 × magnification).

Electrostatic field analysis.

To elucidate the physical factors underlying this behavior, two-dimensional finite element-based electrostatic field analyses were performed to calculate the field distribution within the etched trench. Fig. 6 shows an example of the calculated distribution at a trench depth of 100 µm. The trench depth varied from 0 to 100 µm, in 10-µm increments, and the electric field intensity at the trench bottom was extracted; the results are summarized in Fig. 7, illustrating the quantitative relationship between trench depth and bottom field intensity. At the early stage of etching, the high vertical etch rate can be attributed to the strong electric field formed between the electrode and the sample when the trench was shallow and close to the surface. In this region, ions were slightly accelerated by the near-surface electric field and bombarded the sample surface, thereby promoting material removal reactions and resulting in rapid vertical etching. It has been reported elsewhere that, in SiC, even slightly accelerated ions can enhance the etching reaction [5]. In our experiment, the estimated ion energy, derived from the field strength and mean free path, was below 2 eV, suggesting that physical damage to the sample was negligible. As the etching progressed and the trench deepened, however, the electric field intensity at the trench bottom was found to decrease, due to the shielding effect of the mask structure. Consequently, ions were less able to reach and be accelerated at the bottom, and the dominant reactive species gradually shifted to neutral radicals. Unlike ions, neutral radicals are unaffected by electric fields; therefore, the etching proceeded isotopically. This explains the observed trend in which the vertical etch rate approached the lateral etch rate over time. From these results, we could demonstrate that, in the plasma etching of SiC using the PCVM method, the strong electric field present in the initial stage plays a crucial role in achieving high vertical etch rates. As etching proceeds and the bottom field intensity diminishes, the etching mechanism transitions to radical-dominated isotropic etching. Future studies should focus on optimizing processing conditions to maintain higher anisotropy while achieving fast and precise SiC dicing.

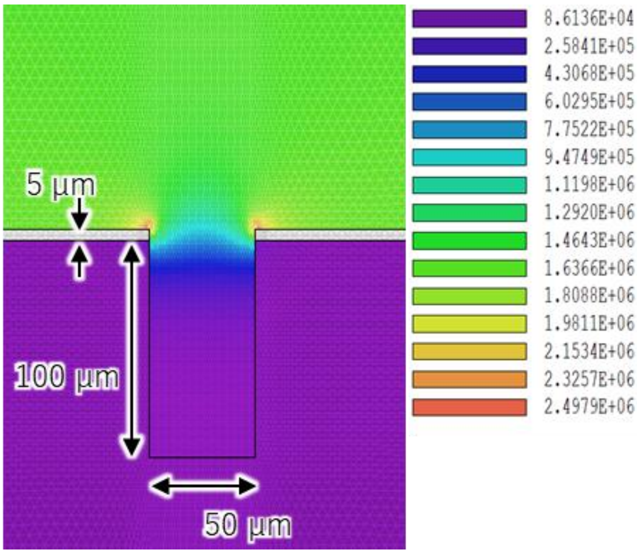

Fig. 6. Electrostatic field analysis example (trench depth: 100 µm).

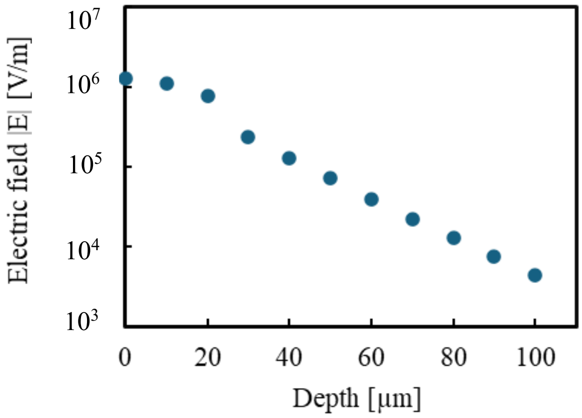

Fig. 7. Electric field distribution at each etch depth.

Summary

In this study, PCVM was applied to SiC wafers with patterned mask openings, and damage-free dicing with a vertical etch depth of 100 μm was successfully demonstrated within approximately 35 minutes. We observed a decrease in the vertical etch rate accompanied by an increasing depth. which was mainly attributable to the reduction of ion contributions caused by electric field attenuation. Future work will systematically investigate the effects of plasma generation conditions - such as pressure, electrode configuration, and RF power - on both vertical and lateral etch rates, with the aim of optimizing dicing conditions to achieve greater anisotropy in SiC etching.

References

[1] Y. Mori, K. Yamauchi, K. Yamamura, and Y. Sano. *Rev. Sci. Instrum*. 71, 4627–4632 (2000).

[2] Y. Sano et al. ECS J. Solid State Sci. Technol. 10, 014005 (2021).

[3] Y. Sano et al. Mater. Sci. Forum 1124, 51–55 (2024).

[4] E-Stat: Electric Field Distribution Simulation Tool, Field Precision LLC. [Online]. Available: https://www.fieldp.com/estat.html.

[5] S. Iden, Y. Matsumura, J. Yamada, D. Toh, K. Yamauchi, and Y. Sano. "Basic study of plasma dicing for SiC wafer using high-pressure plasma," presented at the 20th International Conference on Precision Engineering (ICPE2024), Oral, GS17-05, Tohoku University Aobayama Campus, Miyagi, Japan, Oct. 23–26, 2024.