INDUCTIVELY COUPLED PLASMA FOR SILICON CARBIDE(SIC) HIGH ASPECT RATIO ETCHING

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This study highlights recent advancements in high-aspect-ratio (HAR) deep reactive ion etching (DRIE) of 4H-Silicon Carbide microelectronics nanofabrication using inductively coupled plasma (ICP) of SF_6, O_2 and Ar. Detailed etching recipes characterizations, and systematically etching investigations are demonstrated. As a result, ultra-high aspect ratios of 1:20 with critical dimensions around ~3.5 µm is achieved. These advancements provide a robust foundation for advancing SiC MEMS device fabrication and represent a critical step towards the integration of silicon carbide as a replacement for silicon in the semiconductor industry. Even with outstanding material properties [1], high-precision nanofabrication, especially the HAR-DRIE of SiC microelectronic devices remains relatively nascent and limits its widespread development to replace Si. Previous research pointed out the rough etching profiles, and lack of optimized recipe explorations and comprehensive investigations into the etching process. This work presents a meticulously ICP etching process using SF_6, O_2 and Ar with best values' range, etching profiles with high yields across a 6 inch SiC wafer is demonstrated in Fig. 1, as well as the etching profiles on small pieces with 1:20 ultra HAR.

SiC DRIE is a relatively 'dirty' process due to the formation of non-volatile byproducts that adhere to the inner walls of the etching chamber [2]. While the etcher's processing time increases, the influence of electrode temperature on etching yields gradually becomes more pronounced, following a normal distribution trend with electrode temperature at 0°C as the optimal point (Fig. 2a). Moreover, experimental results indicate that the O_2 and SF_6 flow rate significantly influences etching yields and depth, while the Ar flow primarily affects mask selectivity (Fig. 2b-d). Additionally, Ni is selected as the hard etching mask due to its higher mask selectivity [3]. However, etching gases react with Ni will form a stressed passivation layer on trench sidewalls. Delamination and rupture of this layer can cause irregular plasma reflection, leading to sidewall bombardment and a knifing effect that observed from both peer's and our studies (Fig. 3). In addition to excessive Ni thickness, electrode temperature and O_2 flow rate also influence the delamination and rupture of the passivation layer. Given the complexity of the passivation layer, more explorations of its formation principle and the elimination methods will be carried out in future.

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[1] Long, Y., Liu, Z., & Ayazi, F. (2023). 4H-silicon carbide as an acoustic material for MEMS. IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, 70(10), 1189-1200.
[2] Hamelin, B., et al., Precision deep reactive ion etching of monocrystalline 4H-SiCOI for bulk acoustic wave resonators with ultra-low dissipation. Journal of the Electrochemical Society, 2021. 168(1): p. 017512.
[3] Li, Ningxin, et al. "Advances in High-Aspect-Ratio Deep Reactive Ion Etching of 4H-Silicon Carbide Wafers." Journal of Microelectromechanical Systems (2024).

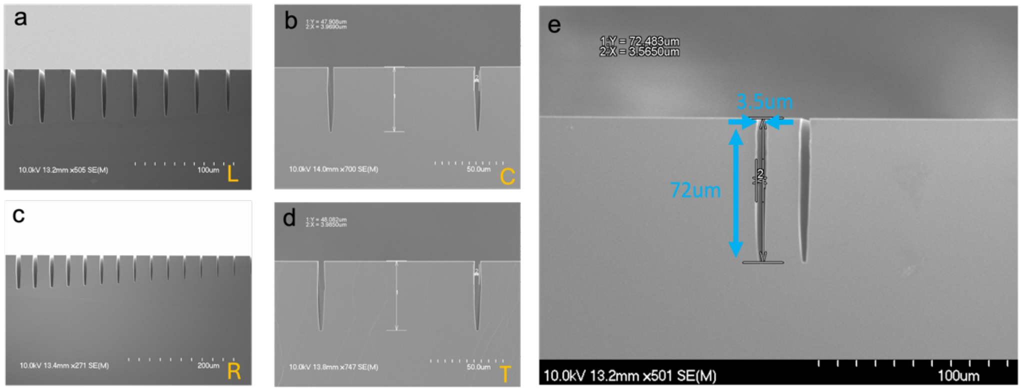
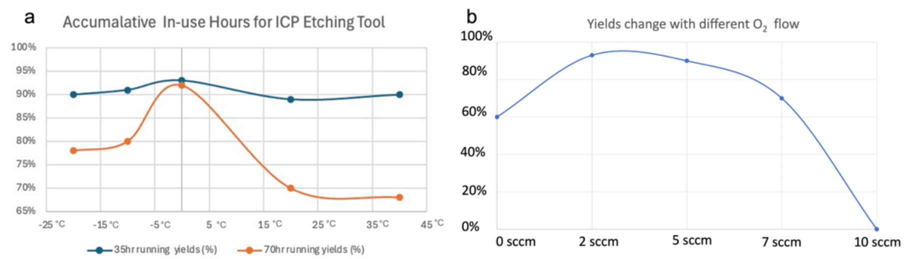
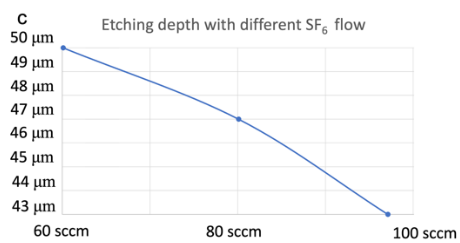


Figure 1: (a)-(d) Etching profiles from different locations of 6inch SiC wafers to demonstrate the whole wafer etching high yield. (e) 1:20 Ultra high aspect ratio of 4H-SiC DRIE achieved in ICP etching.





d

Mask selectivity with different SF_6 flow.

60 sccm	16: 1
80 sccm	11: 1
97 sccm	10: 1

Mask selectivity with different Ar flow.

3 sccm	15: 1
7 sccm	16: 1
10 sccm	25: 1
15 sccm	20: 1
20 sccm	9: 1

Figure 2: (a)-(d) Etching parameters' characterizations.

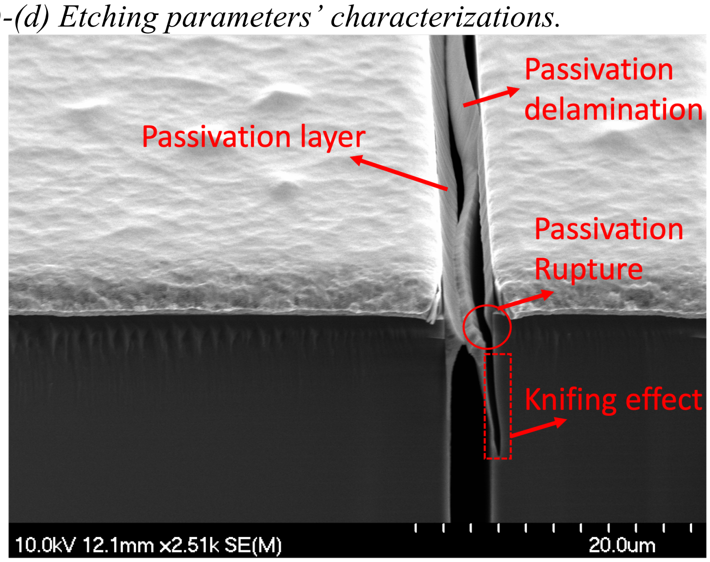


Figure 3: Sidewall knifing effect caused by passivation layer delamination and rupture.