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Fundamental study of localized atomically-flat Silicon Carbide surface reconstructions for novel, high-mobility and energy efficient, transistors

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Motivation

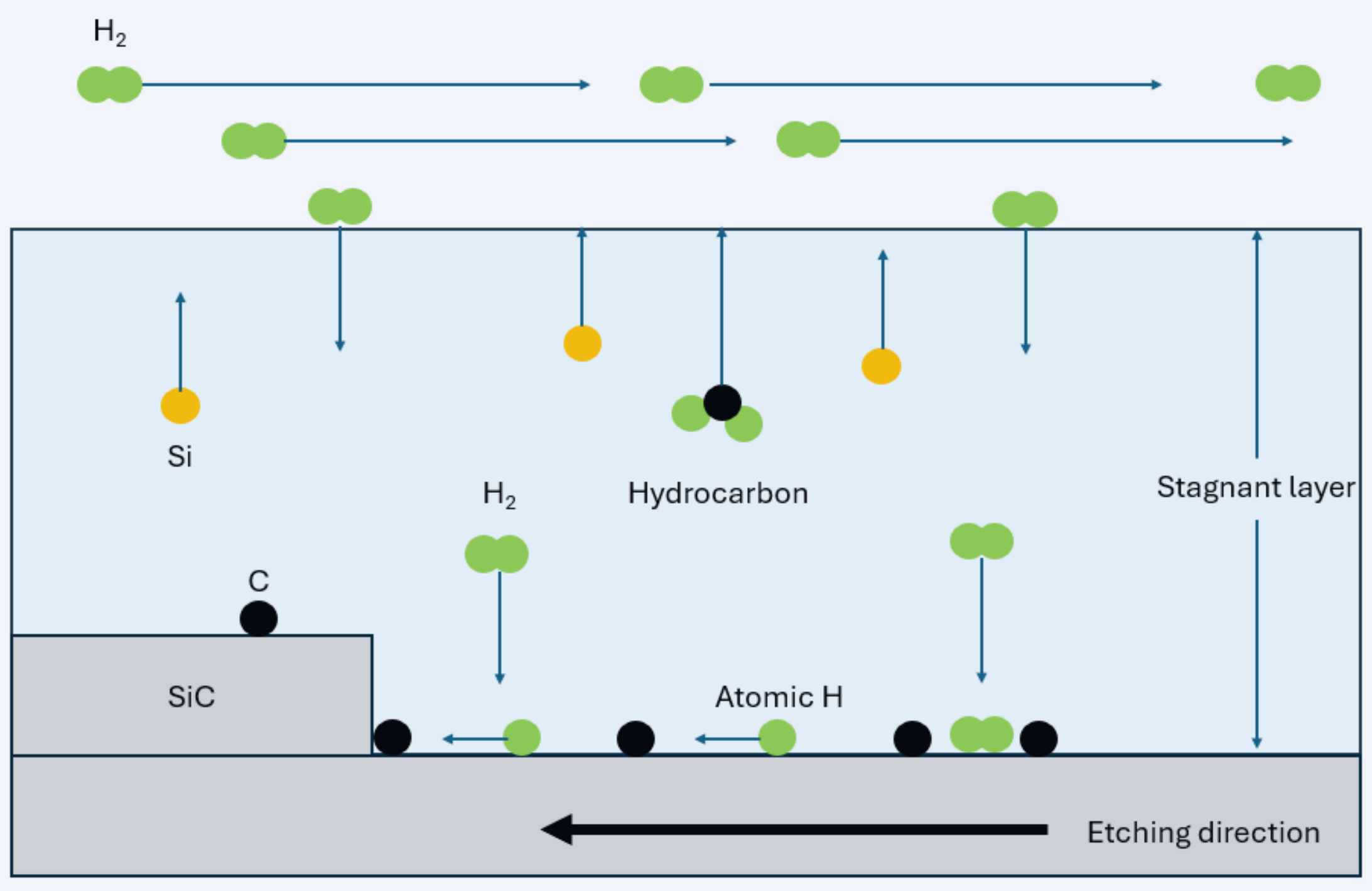
Despite major advances in processing technology, the performance of SiC power MOSFETs is still limited by high ON-state resistance (RON), mainly due to large channel resistance (RCH) [1]. A major cause is the surface morphology of SiC wafers: off-axis homoepitaxial growth produces sub-nanometer atomic steps on the surface [2]. During oxidation, these steps promote dangling bonds and a sub-stoichiometric interfacial layer, generating electrically active interface traps (DIT) at the SiO_2/4H-SiC interface.

Interface nitridation, typically via post-oxidation NO annealing, reduces carbon-related defects by incorporating nitrogen at the interface [3]. However, nitrogen incorporation saturates at ~10^{14} cm^{-2} (~10% of available carbon sites), limiting further improvement.

Developing more effective strategies to control surface steps and reduce interface traps remains a key challenge.

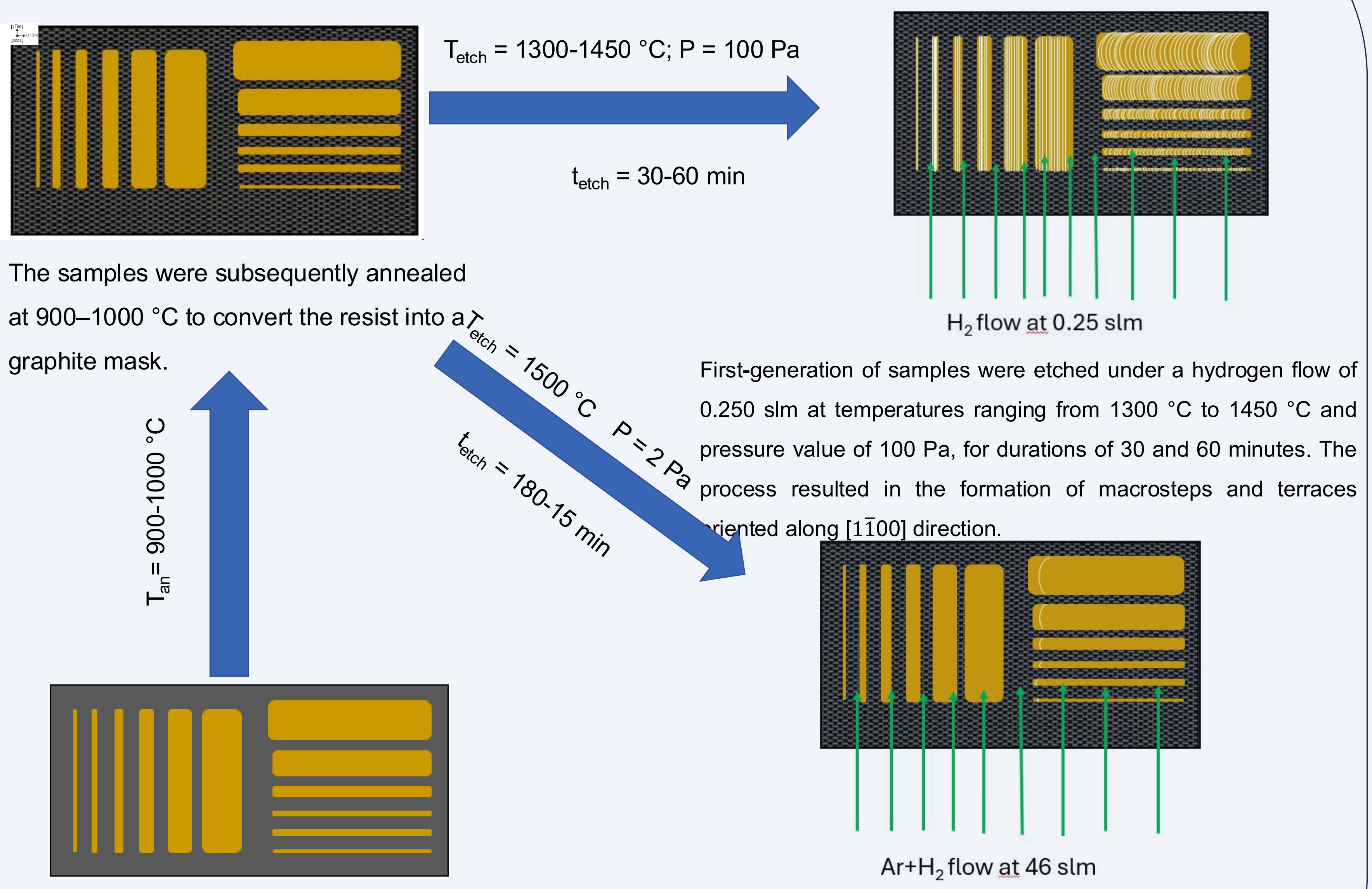
Why does hydrogen etching process at high temperatures result in steps reduction? Systematic studies of hydrogen etching on the surface morphology of on-axis 4H-SiC (0001) wafers have shown that the etching temperature and duration are key parameters governing terrace formation and morphology evolution [4]. However, hydrogen etching in spatially confined regions of off-axis 4H-SiC has not yet been systematically investigated. To the best of our knowledge, we reported the first study addressing hydrogen etching in lithographically defined restricted regions of 4° off-axis 4H-SiC substrates [5].

Hydrogen Etching Mechanism



- ❑ Thermal decomposition of SiC occurs at the surface.
- ❑ Si atoms desorb rapidly, whereas carbon atoms remain on the surface and diffuse along the terraces.
- ❑ Carbon atoms subsequently aggregate to form carbon clusters, which preferentially accumulate on terrace regions and at step edges.
- ❑ H_2 molecules impinging on the hot SiC surface dissociate into highly reactive atomic hydrogen.
- ❑ The generated atomic hydrogen readily reacts with surface carbon atoms and carbon clusters, particularly at terrace edges, forming volatile hydrocarbon species that desorb from the surface.

Experimental Procedure



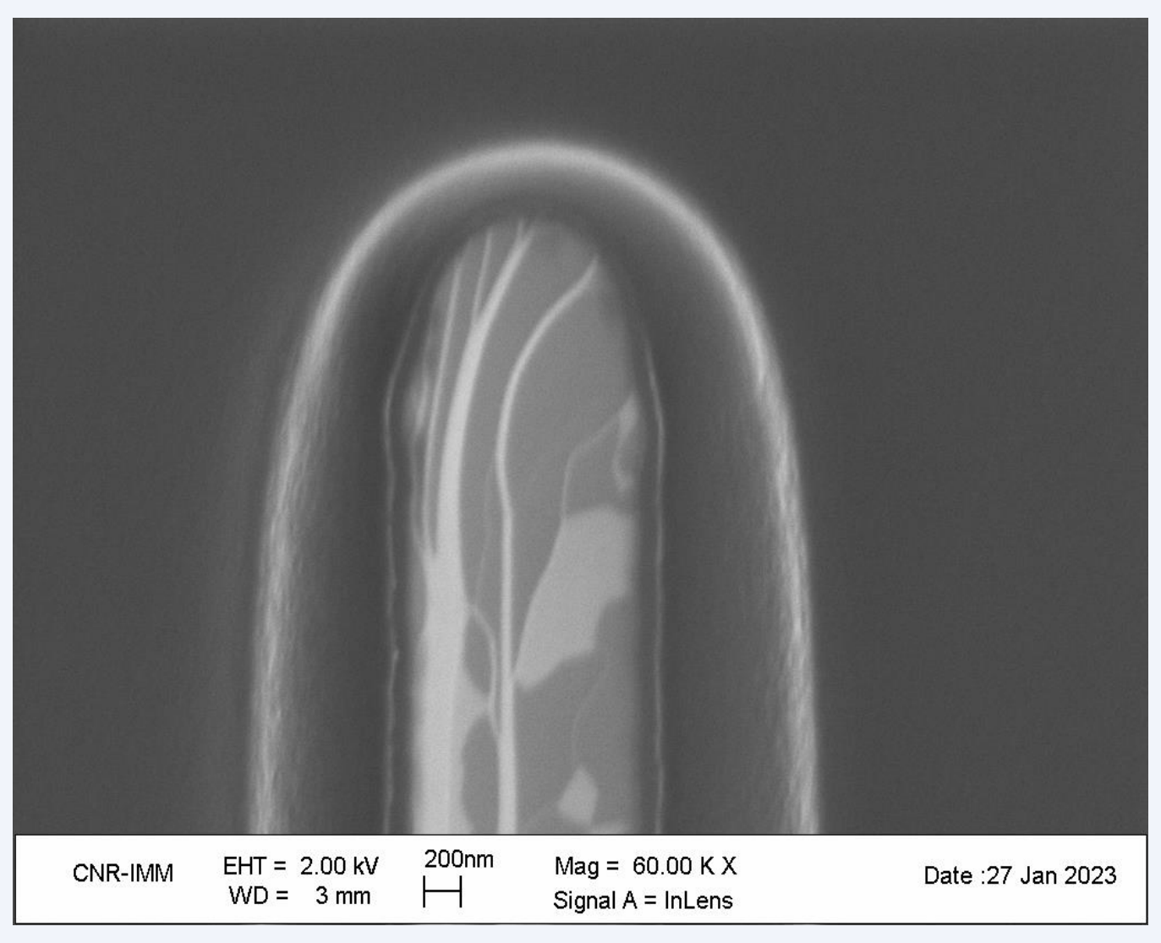
Micrometer-wide confined regions were patterned in a resist layer along deposited on the 4H-SiC (0001) surface.

The samples were subsequently annealed at 900–1000 °C to convert the resist into a graphite mask.

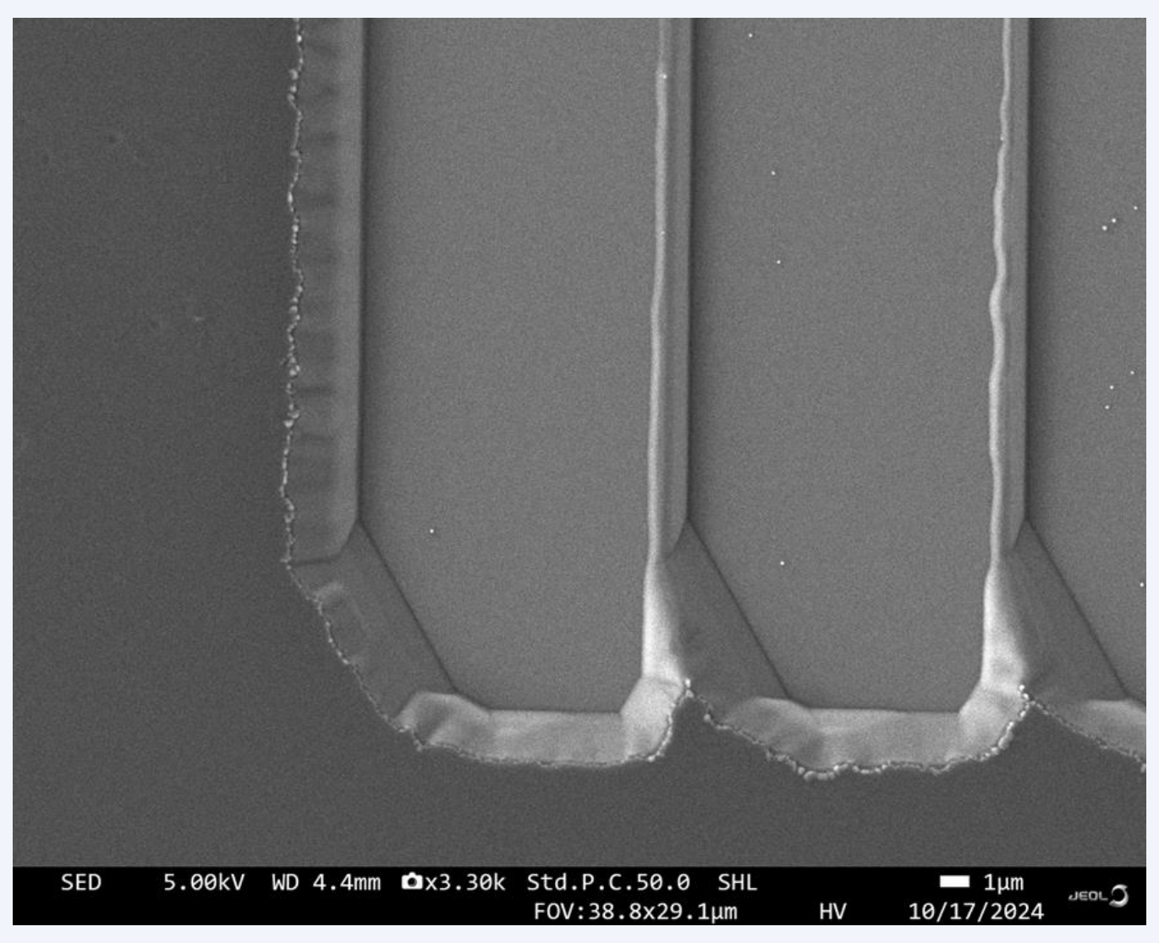
First-generation of samples were etched under a hydrogen flow of 0.250 slm at temperatures ranging from 1300 °C to 1450 °C and pressure value of 100 Pa, for durations of 30 and 60 minutes. The process resulted in the formation of macrosteps and terraces oriented along [1$\bar{1}$00] direction.

Second-generation of samples were etched under Ar/H_2 mixture with total flow rate 46 slm at 1500 °C and pressure value of 2 Pa for durations of 180 and 15 minutes. The process resulted in the formation of “giant” macrosteps along [1$\bar{1}$00] direction.

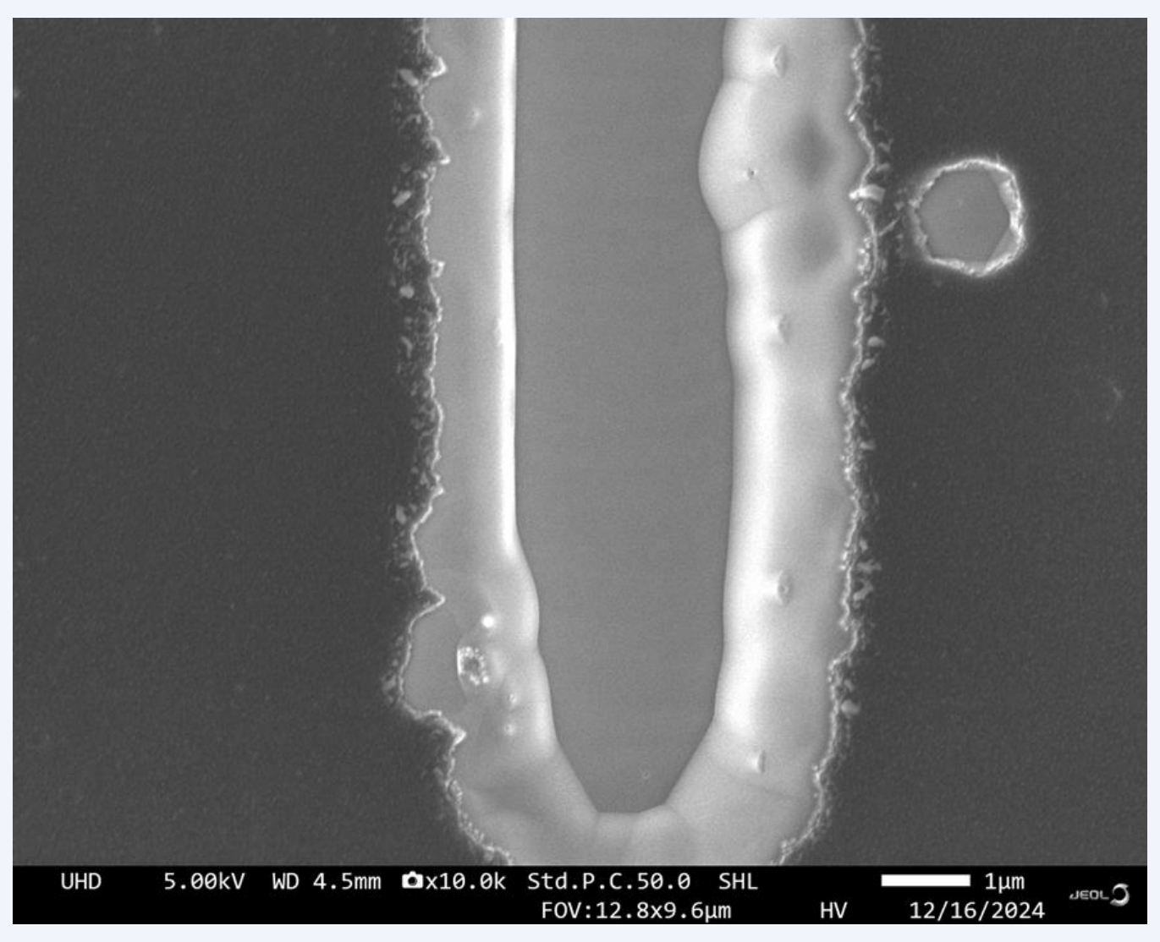
Morphological Analysis



Under H_2 etching process at 1450 ° C for 30 minutes, SiC sample exhibited a measurable surface roughness characterized by terraces preferentially oriented along the [1$\bar{1}$ 00] direction within 5 µm-wide line.



Lowering the pressure to 2 Pa and rising the etching temperature at 1500°C over an extended time of 180 minutes, The morphology of the 4H-SiC surface shows that etching process can effectively improve the elimination of terraces and formation of macrostep in all limited region, but the long etching times can exacerbate the aggressiveness of the process, leading to the formation of deeper giant macrosteps.



Under identical etching conditions, reducing the etching time to 15 minutes still led to terrace elimination, but shallower macrostep was observed within the 1 µm-wide line..

Conclusions

In this work we demonstrate that the implementation of optimized etching conditions led to a nearly complete suppression of step bunching. These results represent a significant advancement in SiC MOSFET fabrication technology. By effectively suppressing step bunching and increasing macrostep width, our method addresses one of the primary factors limiting channel mobility, thereby paving the way for high-performance devices with reduced on-state resistance.

References

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