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Performance Improvement by Carbon-Dioxide Supercritical Fluid Treatment for 4H-SiC Vertical Double Diffusion MOSFETs

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Abstract. This study examines the impact of supercritical fluid treatment on 1200V 4H-SiC vertical double diffusion MOSFETs (VD-MOSFETs). When exposed to pure carbon dioxide or carbon dioxide mixed with nitrous oxide, there is a significant increase in the improvement ratio of drain current, which is contingent upon channel mobility but has no effect on threshold voltage. Conversely, the degradation of drain current caused by ammonia gas treatment is attributed to a reduction in channel mobility. Furthermore, the treatment with pure carbon dioxide or carbon dioxide mixed with nitrous oxide effectively passivates shallow defects, while the presence of hydrogen atoms in ammonia gas leads to an increase in shallow defects.

Introduction

SiC MOSFETs play a crucial role in power applications such as dc-to-dc and ac-to-dc converters, where the power loss of the converter depends on the on-state resistance of the SiC MOSFETs. However, the on-state resistance of SiC MOSFETs is constrained by interface defects between SiC and SiO_2, which can reduce channel mobility to below 100 cm^2/ V·s. Traditional post-oxidation annealing methods using nitric oxide (NO), nitrous oxide (N_2O), or phosphorus oxide trichloride ($POCl_3$) gases at high temperatures exceeding 1000°C have been employed to passivate these defects and enhance device performance [1-2]. However, these methods require a substantial thermal budget, leading to complex processes [3-4]. In contrast, supercritical fluid processing offers a low thermal budget, with process temperatures below 400°C [5].

Experiment and Result

Figure 1(a) illustrates a schematic cross-sectional view of vertical double diffusion transistors. The device exhibits a threshold voltage of 0.35V and an on-state resistance of 81.5mΩ, with a breakdown voltage rating of 1200V in figures 1(b) and 1(c) respectively. Following supercritical fluid treatment with pure carbon dioxide gas, figure 2(a) depicts threshold voltages of 0.35V and 0.37V respectively, along with hysteresis voltages of 0.52V and 0.54V for pre- and post-treatment devices. Additionally, figure 2(b) demonstrates a 20% improvement in output current after supercritical fluid treatment with carbon dioxide, accompanied by an 11.1% enhancement in mobility for the post-treatment device, which is attributed to the passivation of shallow defects between SiO_2 and 4H-SiC [6].

Furthermore, figure 3(a) presents logarithmic-scaled transfer curves for pre- and post-supercritical fluid treatment with carbon dioxide and nitrous oxide, revealing no impact on threshold voltage and subthreshold swing for post-treatment devices. However, figure 3(b) indicates a 40% increase in output current.

Figure 4(a) displays linear-scaled transfer curves for the treatment gas transition from nitrous oxide to ammonia. It illustrates that the threshold voltage remains at 0.35V for the post-treatment device, comparable to the pre-treatment value of 0.34V. The subthreshold swing is recorded at 344mV/dec and 342mV/dec for pre-treatment and supercritical fluid treatment with carbon dioxide and ammonia respectively. Nonetheless, figure 4(b) reveals a 20% degradation in output current for treatment with carbon dioxide and ammonia, attributed to a 14% decrease in channel mobility. Additionally, hydrogen generates shallow defects from the conduction band, further reducing channel mobility [7].

From figure 4(c), a histogram illustrates the improvement ratio of output current by supercritical fluid treatment with pure carbon dioxide, carbon dioxide and nitrous oxide, and carbon dioxide and ammonia. Treatment with carbon dioxide and nitrous oxide yields the greatest improvement in output current, with no discernible impact on threshold voltage or subthreshold swing.

Summary

This study explores the impact of supercritical fluid treatment on 1200V 4H-SiC VD-MOSFETs. When exposed to pure carbon dioxide or a mixture of carbon dioxide and nitrous oxide, the improvement ratio of drain current effectively increases by approximately 20% and 40% respectively, correlating with an 11.1% enhancement in channel mobility. Conversely, the degradation of drain current by about 20% is observed following treatment with ammonia gas, attributed to a reduction in channel mobility by 14%. Notably, the treatment gas does not influence threshold voltage.

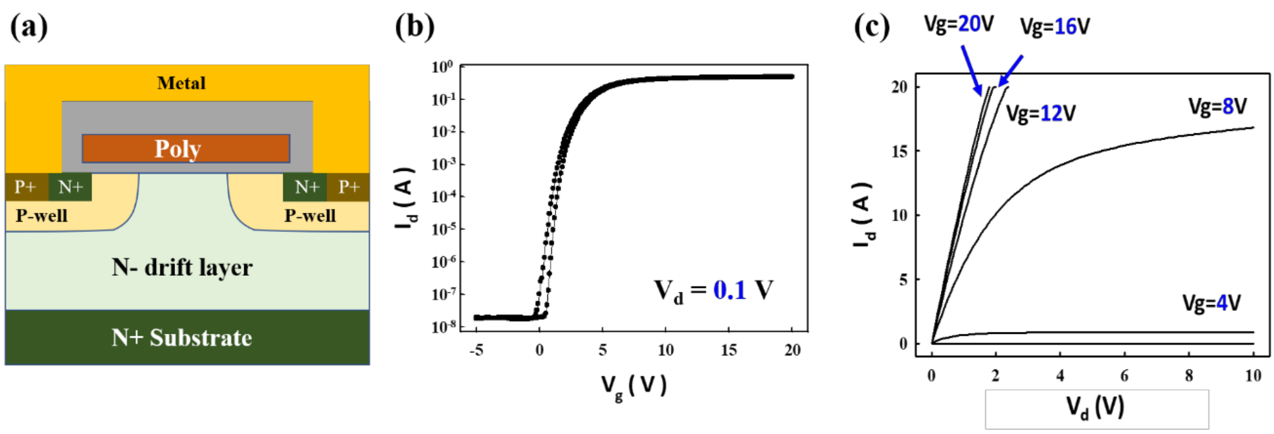

Fig. 1. (a) Schematic cross-section of vertical double diffusion transistors, (b) Logarithmic-scale transfer curve with a drain voltage of 0.1 V, and (c) Output curve of the 1200V device.

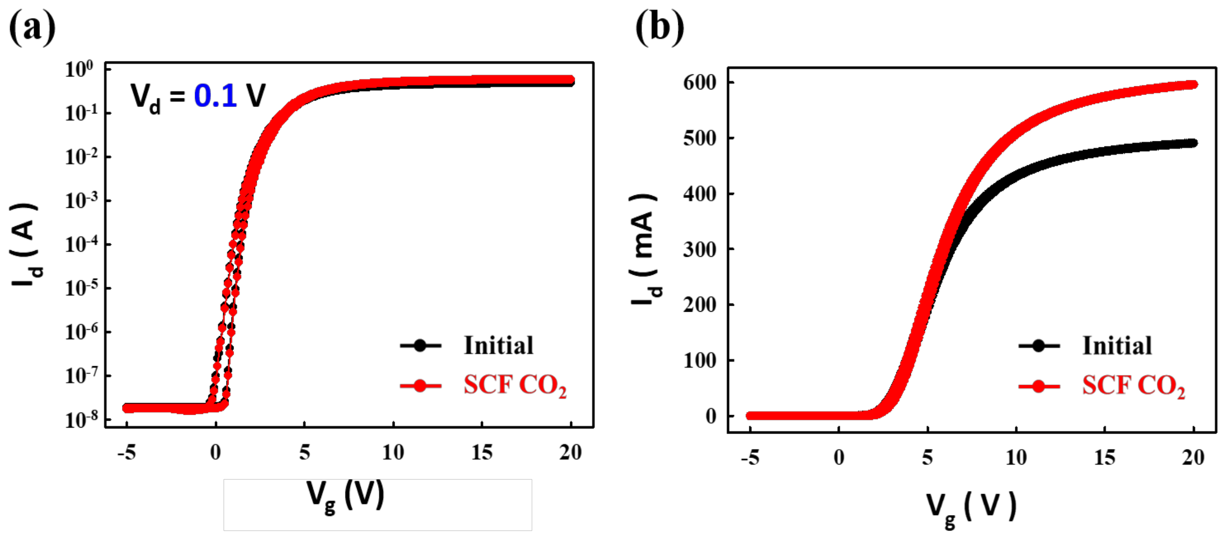

Fig. 2. Drain current-gate voltage curve (IDS-VGS) for pre- and post-super-critical fluid treatment with carbon dioxide, shown in (a) logarithmic scale and (b) linear scale.

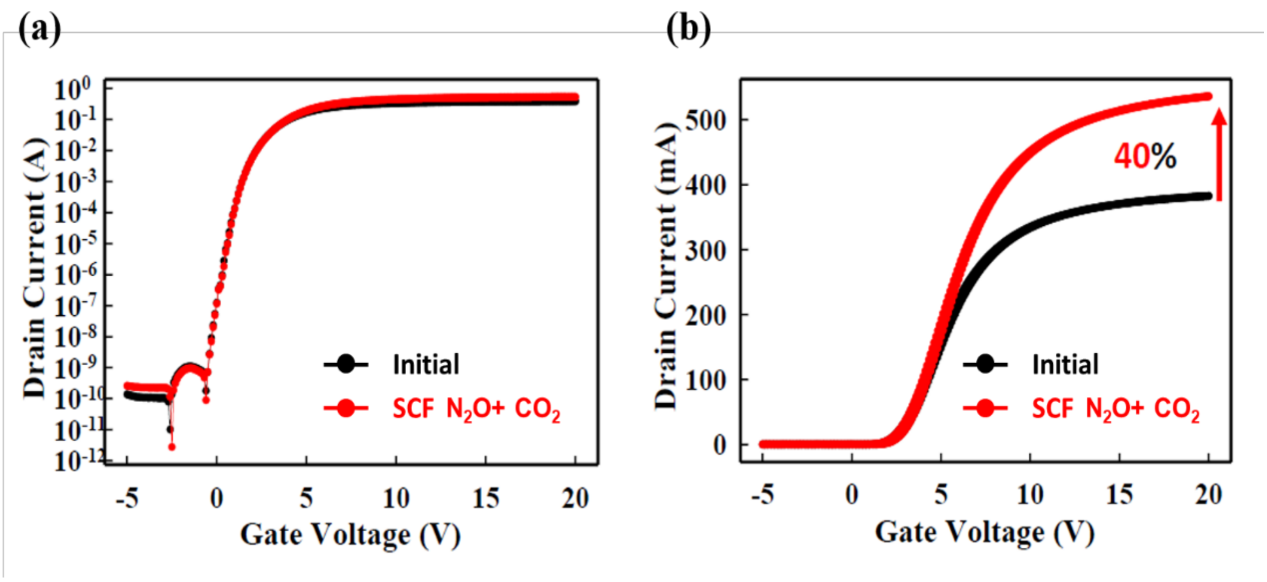

Fig. 3. Drain current-gate voltage curve (I_{DS}-V_{GS}) for pre- and post-supercritical fluid treatment with carbon dioxide and nitrous oxide, depicted in (a) logarithmic scale and (b) linear scale.

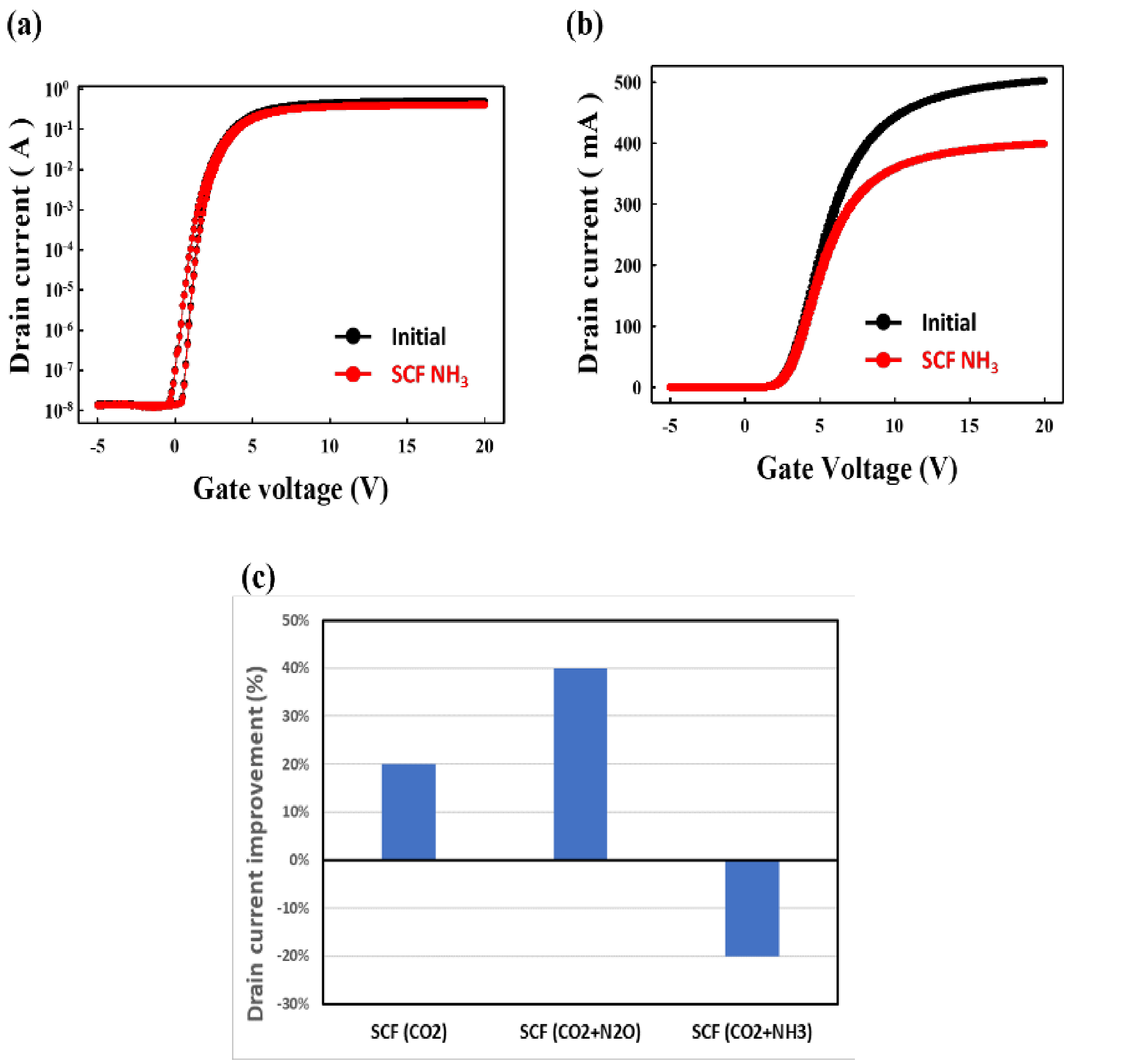

Fig.4. (a) Logarithmic-scale and (b) linear-scale drain current-gate voltage curve (I_{DS}-V_{GS}) for pre- and post-supercritical fluid treatment with carbon dioxide and ammonia. (c) Histogram illustrating the improvement ratio of drain current by supercritical fluid treatment with pure carbon dioxide, carbon dioxide and nitrous oxide, and carbon dioxide and ammonia.

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