

The Effect of Nitrogen Plasma Treatment Process on Ohmic Contact Formation to n-Type 4H-SiC

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Abstract: In this work, a nitrogen plasma treatment process was employed on n-type 4H-SiC. Both the Si- and C-face were studied and treated with N₂ plasma. The surface concentration of nitrogen increased from $5 \times 10^{18} \text{ cm}^{-3}$ to $5 \times 10^{21} \text{ cm}^{-3}$ in both the Si-face and C-face as analyzed by secondary ion mass spectroscopy (SIMS). This shows that a simple plasma treatment process was able to incorporate very high concentration of nitrogen dopants otherwise done using high temperature implanters. Titanium-based Ohmic contacts were formed at $\sim 800^\circ\text{C}$ thanks to the presence of high concentration nitrogen dopants. Specific contact resistance of ($\rho_c \sim 1.5 \times 10^{-6} \Omega \cdot \text{cm}^2$ and $\sim 1.9 \times 10^{-6} \Omega \cdot \text{cm}^2$) was obtained on Si-face and C-face, respectively.

Introduction

Ohmic contact formation are critical process steps to reduce ON-resistance as well as power losses in SiC MOSFETs. Commonly, Ni- and Ti-based metal contacts would require high temperature annealing ($> 950^\circ\text{C}$) to form Ohmic contacts on 4H-SiC [1-3]. Large thermal budget processes are unfavorable for integration of high- κ gate stacks and drain contacts.

High concentration of dopants is required for the formation of degenerate semiconductor to achieve good Ohmic contacts. The ion implantation process for n⁺⁺ doping generally done at high temperature ($\geq 500^\circ\text{C}$) and require annealing at elevated temperatures ($> 1650^\circ\text{C}$) for activation and surface recovery [4]. In this paper, we report a nitrogen plasma treatment process to realize the incorporation of n-type dopants and Ohmic contact formation at low temperatures ($\sim 800^\circ\text{C}$) on 4H-SiC.

Results and Discussion

4° off-cut N-type 4H-SiC substrates (0001), with a doping concentration of ($5 \times 10^{18} \text{ cm}^{-3}$) was used with the process flow as shown in Fig. 1(a-b). The 4H-SiC substrates were cleaned by SPM (3:1, H₂SO₄: H₂O₂) at 90°C for 10 mins followed by BOE (7:1) for one minute at room temperature. The cleaned samples were treated with different N₂ plasma conditions in an inductively coupled plasma (ICP) chamber.

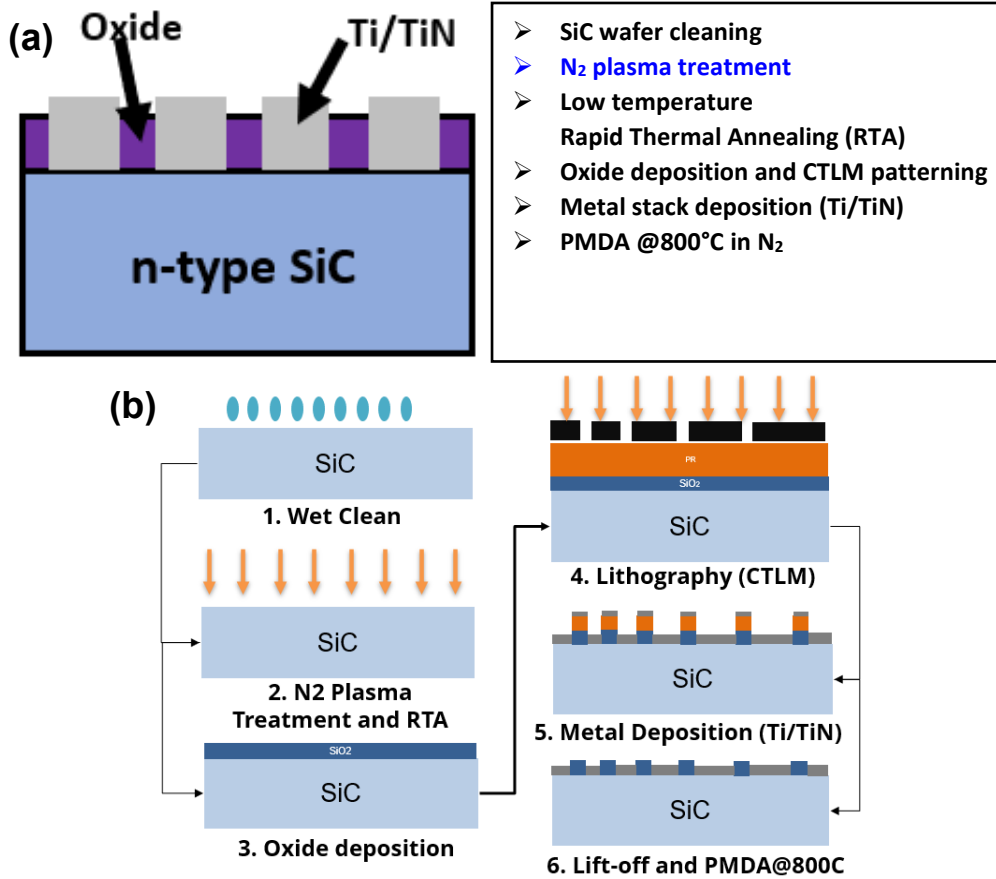


Fig. 1. (a) CTLM structures fabricated on n-type SiC (Si-face and C-face) and (b) Process steps and fabrication process flow via lift-off method

The nitrogen doping profiles were analysed by SIMS as shown in Fig. 2(a). It was observed that the N₂ plasma treatment helps to enhance the n-dopant concentration by 3 orders of magnitude (10^{18} cm^{-3} to 10^{21} cm^{-3}). However, the depth of dopant distribution at SiC surface is $\sim 20\text{-}30 \text{ nm}$. This shallow surface doping is probably due to the limitations of our plasma system [5]. We studied the Ohmic contact after plasma doping on both surfaces. Circular Transmission Line Measurement (CTLM) structures for contact resistance measurement were fabricated on both Si-face and C-face 4H-SiC (0001). A Ti-based metal stack (Ti/TiN) was selected for this Ohmic contact study.

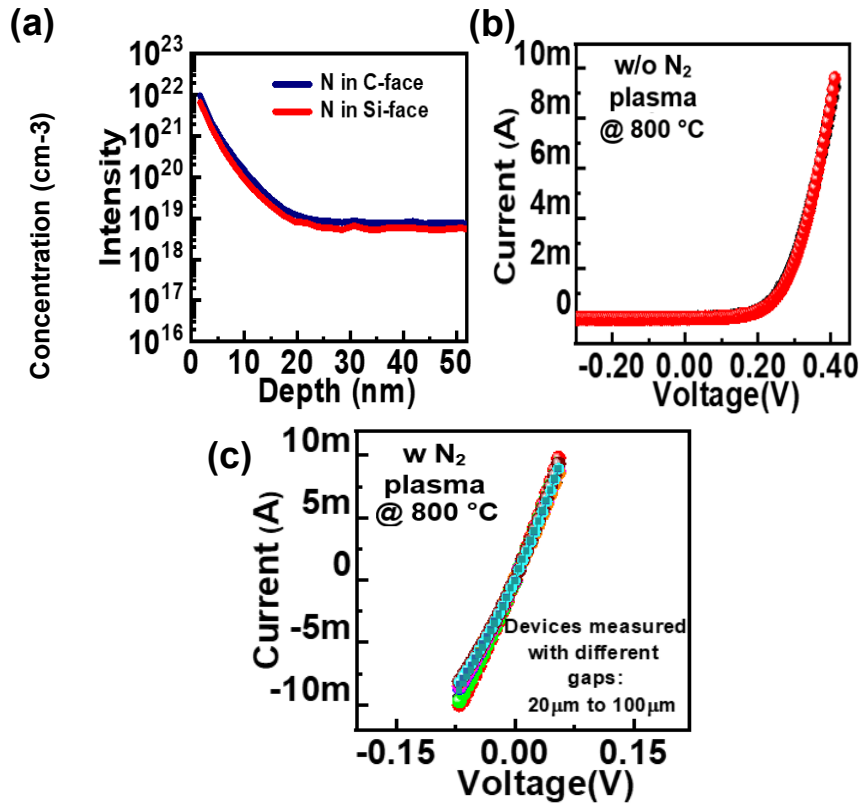


Fig. 2. (a) SIMS analysis on N₂ concentration after plasma treatment on C-face and Si-face (b) IV graph of untreated sample showing Schottky-characteristics (c) IV Graphs of N₂ plasma treated samples on Si-face with gaps of 20-100 μm with Ohmic characteristics

Intermetallic diffusion and silicide formation at the metal-semiconductor interface after low temperature annealing was observed with TEM-EDX colour mapping as shown in Fig. 3(a-e). We observed the formation of Ti₂Si phase in both treated and untreated samples at 800 °C. In the untreated sample, an accumulation of Si atoms and a combination of Ti₃Si and Ti₂Si phases were present at the metal-semiconductor interface. On the other hand, in the nitrogen plasma treated sample, a higher carbon content was observed at the interface from the colour map as shown in Fig. 3(a). These carbon atoms at the interface could be due to the displacement of carbon during the high energy nitrogen plasma treatment.

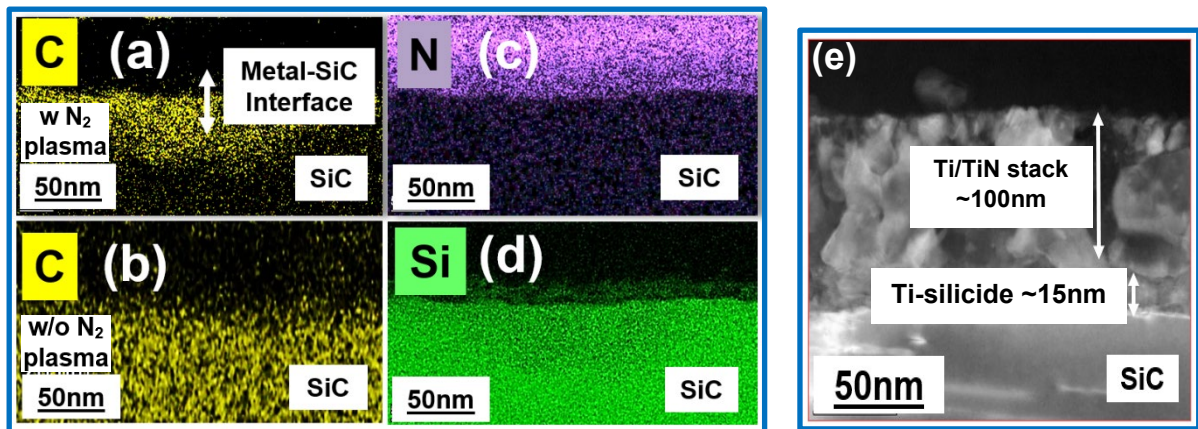


Fig. 3. TEM-EDX with elemental colour mapping on C-face: (a) Carbon accumulation observed at the Metal-SiC interface with N₂ plasma treatment (b) Carbon atoms at the interface without N₂ plasma treatment (c) Nitrogen in SiC and in Ti/TiN metal stack, (d) Silicon atoms in silicide formation, (e) cross-section TEM image of N₂ plasma treated Ohmic contacts with Ti-silicide formed on n-type SiC

Electrical measurements on the CTLM structures of both treated and untreated samples were conducted by measuring current as a function of voltage (I vs V) in Fig. 2(b-c). The untreated sample displayed a Schottky-type contact as shown in Fig. 2(b) on both faces. The Ohmic IV characteristics in the treated samples in Fig. 2 (c) could be due to the displacement of some of the carbon atoms by nitrogen atoms in the lattice. This promoted the low temperature Ohmic contact formation on the C-face and Si-face. The specific contact resistance of $\rho_c \sim 10^{-6} \Omega \cdot \text{cm}^2$ was extracted from different gap spacings of 20-100 μm as shown in Fig. 4(a-b) for both C-face and Si-face [7]. These results are close to standard Ohmic contact formation at high temperatures as benchmarked in Fig. 4.

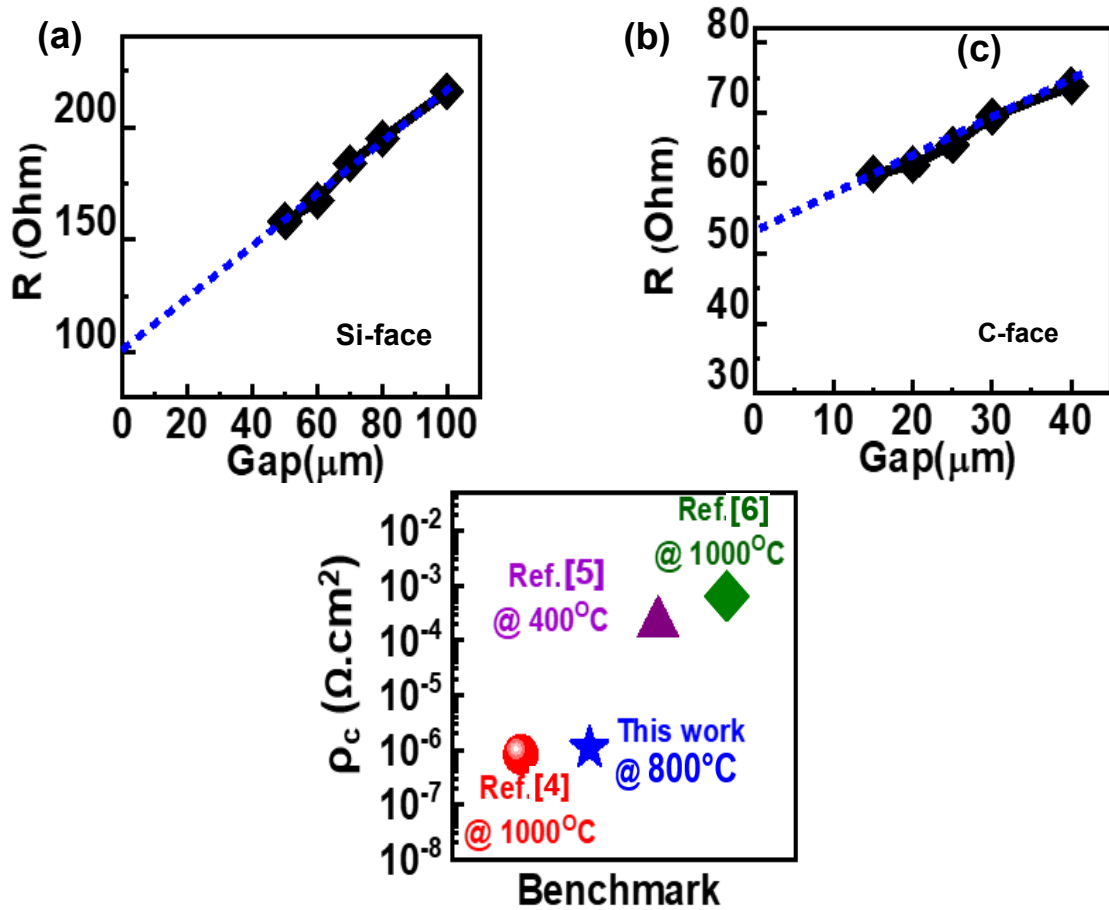


Fig. 4. Average R vs Gap plotted for ρ_c extraction based on 3 sets of CTLM structures on: (a) Si-face and (b) C-face, (c) Benchmarking of our extracted specific contact resistance with other studies, with N_2 plasma ($\rho_c \sim 10^{-6} \Omega \cdot \text{cm}^2$) at low temperature ($\sim 800^\circ\text{C}$) on n-type SiC

Conclusion

In this work, we have shown that nitrogen plasma treatment on n-type SiC is able to provide very high nitrogen concentration without high temperature implant process. This high concentration of nitrogen (n-type dopants) allowed the realization of low temperature Ohmic contact formation at $\sim 800^\circ\text{C}$. The specific contact resistance value $\rho_c \sim 10^{-6} \Omega \cdot \text{cm}^2$ obtained was benchmarked with high temperature process. This novel approach would enable integration of high- κ materials for Ohmic contact formation at lower thermal budget for 4H-SiC. In future work, low temperature Ohmic contacts obtained at room temperature would allow more processing flexibility in SiC.

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