SCIENCE CHINA
Information Sciences

• Supplementary File •

High-voltage quasi-vertical GaN-on-Si Schottky barrier diode with edge termination structure of optimized multi-level N ion implantation

Qingyuan CHANG[1], Bin HOU[1*], Ling YANG[1], Mei WU[1], Meng ZHANG[1], Hao LU[1], Fuchun JIA[2], Xuerui NIU[1], Chunzhou SHI[3], Jiale DU[1], Mao JIA[1], Qian YU[1], Shiming LI[1], Youjun ZHU[1], Xiaohua Ma[1] & Yue HAO[1]

[1]*School of Microelectronics, Xidian University, Xi'an* 710071*, China;*
[2]*The 29th Research Institute of China Electronics Technology Group Corporation, Chengdu* 610036*, China;*
[3]*School of advanced materials and nanotechnology, Xidian University, Xi'an* 710071*, China*

Appendix A Optimization of the high-resistance region depth

In this experiment, we investigated the impact of the depth of the high-resistance region on the electric field at the edge of the Schottky contact in the GaN SBD with NET. The three-dimensional cross-sectional structure diagram of quasi-vertical GaN-on-Si SBD with NET is shown in Figure A1 (a). Due to the disruptive effect of nitrogen atoms on the lattice structure of GaN through ion implantation, deep level traps are created, leading to high electrical resistivity [1]. In this study, the high-resistance region is simulated by employing acceptor trap doping. Additionally, through simulation experiments, we analyzed the variations in the peak electric field at the Schottky contact edge and the corresponding changes in the electric field distribution below. Figure 1 (a) highlights the points of interest, namely point A and cutline A-B, for further analysis. Figure A1 (b) illustrates the analysis of the electric field distribution along cutline A-B. It is observed that the introduction of a high-resistance region effectively reduces the peak electric field at the Schottky contact edge, while simultaneously generating a weaker peak electric field below the high-resistance region within the GaN material. This allows for effective regulation of the electric field. By extracting the peak electric field at the Schottky contact edge (i.e. point A), we obtained the relationship between the peak electric field and the thickness of the high-resistance region, as shown in the insertion diagram of Figure 1 (b). The peak electric field exhibits a linear decreasing trend and reaches saturation after 400 nm as the depth of the high-resistance region increases. Taking into consideration the potential surface cracking caused by ultra-high energy ion bombardment, a high-resistance region of 300-400 nm was ultimately chosen for the quasi-vertical GaN-on-Si SBD with NET fabrication.

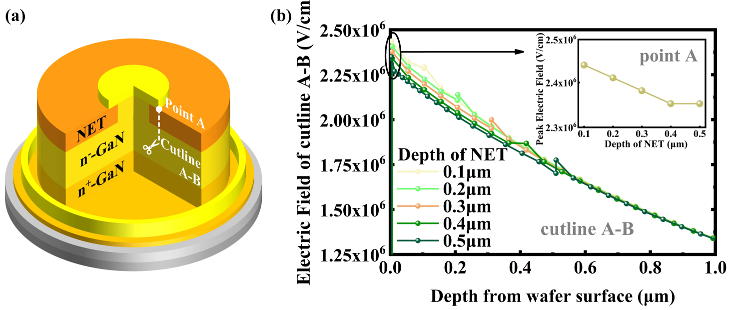

Figure A1 (a) Three-dimensional cross-sectional structure diagram for quasi-vertical GaN-on-Si SBD with NET. (b) Simulation results of the relationship between the electric field of cutline A-B at the Schottky contact edge and the depth of high-resistance region. Inset: Peak Electric Field vs. Depth of NET.

In the Figure A2, we present the electric field distribution simulated by Silvaco for the SBD (a) without and (b) with the NET. It can be clearly seen that the peak electric field position is at point A. Figure 2 (c) compares the peak electric field changes before and after using the NET, showing that the peak electric field decreases after adopting the NET.

After confirming the depth of the high-resistance region, we optimized the ion implantation energy and dose using SRIM software, and ultimately decided to use quadruple energy NII. The simulation distribution diagram of NII using quadruple energy is shown in the Figure A3. According to the simulation results, at the N ion densities of 1×10^{19} cm^{-3}, 1×10^{18} cm^{-3}, and 1×10^{17} cm^{-3}, the injection depths reached 325 nm, 375 nm, and 400 nm, respectively, meeting the design requirements.

---

[*] Corresponding author (email: houbinme@163.com)

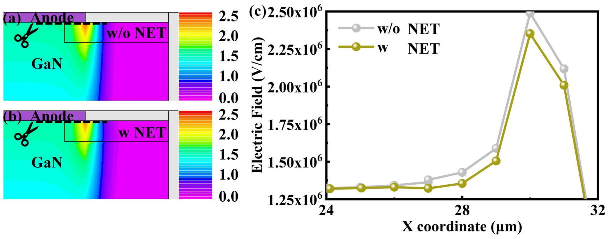

Figure A2 Schematic diagram of electric field distribution for SBD (a) without and (b) with NET; (c) Electric field intensity variation curve along the transverse tangent direction below the anode metal of SBDs without and with NET.

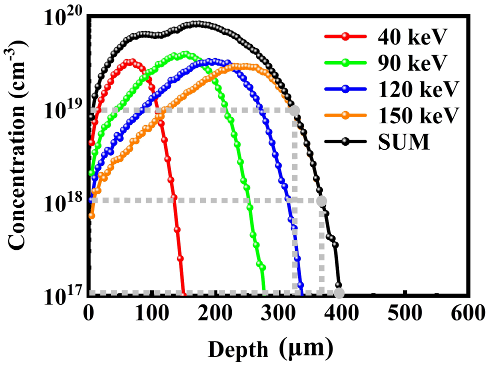

Figure A3 Simulated N ion profiles at 40, 90, 120, and 150 keV by the SRIM software.

Appendix B Device fabrication process

The epitaxial wafer was grown on Si substrate, consisting of buffer layer, 1 μm n^+-GaN conducting layer (N_D:5 × 10^{18} cm^{-3}), and 4.5 μm n^--GaN drift layer (N_D:1 × 10^{16} cm^{-3}). The fabrication process of the quasi-vertical GaN-on-Si SBD with NET is shown in Figure B1. Firstly, a quadruple-energy NII was performed to form a uniform and effective high resistance annular region, with an energy level/dose of 40 keV/2.5 × 10^{14} cm^{-2}, 90 keV/5 × 10^{14} cm^{-2}, 120 keV/5 × 10^{14} cm^{-2}, and 150 keV/5 × 10^{14} cm^{-2}. Secondly, the photoresist is used as a mask to selectively etch n^--GaN to form the first mesa and expose n^+-GaN for subsequent cathode metal fabrication. Thirdly, n^+-GaN is cut off to achieve electrical isolation between devices for the fabrication of the second MESA. Fourthly, the cathode metal of multi-metal (Ti/Al/Ni/Au) layers was deposited on the n^+-GaN layer by electronic beam evaporation, and annealed at 450 ℃ in nitrogen atmosphere for 5 min to form an ohmic contact. Before the fabrication of anode metal, in order to ensure high contact quality between metal and semiconductor, the sample surface is treated with hydrochloric acid solution to remove the autoxidation layer on the surface. Finally, circular anode metal was formed with Ni/Au on n^--GaN layer. So far, the fabrication of quasi-vertical GaN-on-Si SBD with NET has been completed.

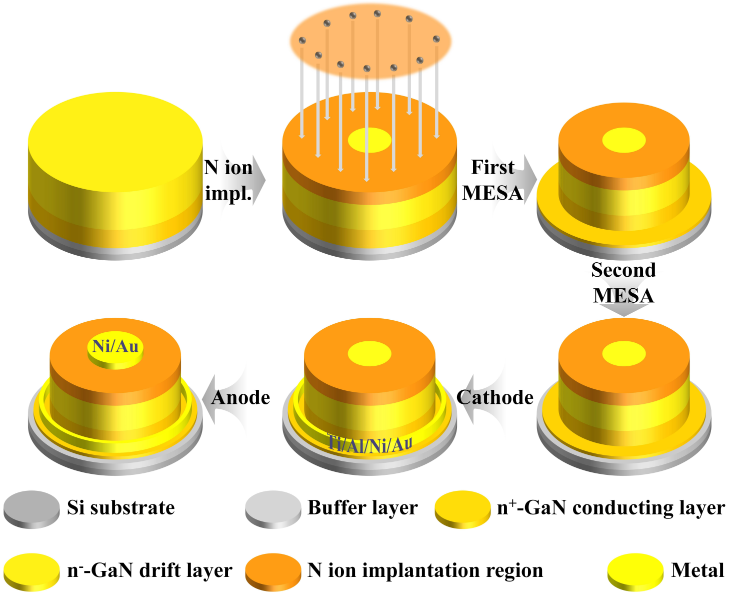

Figure B1 Schematic diagram of the fabrication process of the quasi-vertical GaN-on-Si SBD with NET.

References

1 Haase D, Schmid M, Kürner W, et al. Deep-level defects and n-type-carrier concentration in nitrogen implanted GaN[J]. Applied physics letters, 1996, 69(17): 2525-2527.