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2.5 kV/674 MW/cm^2 or 100 A/2 kV β-Ga_2O_3 heterojunction diodes with large surge current and small recovery time

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The ultra-wide bandgap semiconductor β-Ga_2O_3 exhibits excellent material properties and availability of large-area (6-inch) substrates, showing great potential for next-generation power diodes requiring high current, high breakdown voltage (BV), low on-resistance (R_{on}), and low loss. Thus, developing β-Ga_2O_3 diodes capable of handling hundreds of amperes and kilovolts is crucial [1–5].

This work demonstrates two vertical β-Ga_2O_3 diodes with different active areas featuring a magnetron-sputtered 20-nm p-Cr_2O_3 film and a semi-insulating beveled edge termination (ET). The 4-mm^2 device achieves a record 2530 V BV and 9.5 mΩ·cm^2 specific on-resistance ($R_{on,sp}$) for a power figure of merit (PFOM) of 674 MW/cm^2—the highest among Ga_2O_3 diodes >1 mm^2. The 25-mm^2 device maintains 2000 V BV while delivering 100 A at 10 V and 68 A surge capability. Both devices exhibit negligible reverse recovery loss.

Experiments. The schematic cross-section of the p-Cr_2O_3/n-β-Ga_2O_3 heterojunction diode (HJD) with a semi-insulating beveled ET is shown in Figure 1(a), using epitaxial wafers (NCT Corp., Japan) with parameters as listed. The *C-V* characteristics in Figure 1(b) yield a carrier concentration of 8×10^{15} cm^{-3} for the p-Cr_2O_3 layer.

Device fabrication began with electron-beam evaporation of a Ti/Au (80/200 nm) bilayer, followed by annealing at 475°C for 1 min in N_2 for Ohmic contact formation. A 20-nm p-Cr_2O_3 layer was then sputtered (160 W RF, 5 mTorr Ar). A Ni/Au/Ni (50/150/50 nm) anode stack was deposited, which also functioned as a self-aligned etch and implantation mask. The beveled mesa (∼77°) was defined by ICP etching (BCl_3/Ar, 7:1; 300 W ICP/50 W RF; 5 mTorr) to a depth of 500 nm. Nitrogen ion implantation (∼100 nm depth) created the semi-insulating region, and both electrodes were thickened to >1 µm for high forward current (I_F).

Results and discussion. Figures 1(c) and (d) show forward characteristics of 4-mm^2 and 25-mm^2 HJDs. For the device with 4-mm^2 active area, I_F reaches 12 A at 5 V and 28.5 A at 10 V, with a maximum I_F of approximately 40 A. The minimum R_{on} is 237 mΩ. For the 25-mm^2 active area device, it delivers 32 A at 5 V and 100 A at 10 V, exhibiting a minimum R_{on} of 66 mΩ. The lowest $R_{on,sp}$ is 9.5 mΩ·cm^2 for the 4-mm^2 device and 16.5 mΩ·cm^2 for the 25-mm^2 device.

Figures 1(e) and (f) present the log-scale BV characteristics of HJDs with and without ET across different active areas. The 4-mm^2 HJDs with ET show a BV of 2435–2535 V. The calculated PFOM is 674 MW/cm^2, which is the highest reported among large-area (>1 mm^2) β-Ga_2O_3 diodes. The 25-mm^2 HJDs with ET achieve a BV of 1810–2000 V and yield a calculated PFOM of 242 MW/cm^2.

Figures 1(g) and (h) compare the minimum $R_{on,sp}$ versus BV and the maximum I_F versus PFOM of our HJDs against other state-of-the-art, large-area (>1 mm^2) β-Ga_2O_3 diodes, respectively. The 4-mm^2 HJD achieves a BV of 2535 V and a PFOM of 674 MW/cm^2, which is the highest among all β-Ga_2O_3 diodes over 1 mm^2. Furthermore, our 25-mm^2 HJD delivers I_F ∼100 A at 10 V, a first for β-Ga_2O_3, and maintains a high BV of 2000 V. These results confirm the strong potential of high-I_F, high-BV, and high-PFOM diodes for next-generation power applications.

Figures 1(i) and (k) show the reverse recovery characteristics of the 4-mm^2 and 25-mm^2 diodes at different I_F levels. For the 4-mm^2 device at I_F of 10, 20, and 30 A, reverse recovery time (T_{rr}) is stable at ∼25 ns, with reverse recovery current (I_{rr}) at ∼3.2 A and reverse recovery charge (Q_{rr}) at ∼50 nC. For the 25-mm^2 device at I_F of 10, 30, and 50 A, T_{rr} is 40–50 ns, with I_{rr} at 2.0–2.2 A and Q_{rr} at 50–60 nC. Figures 1(j) and (l) compare our diodes with commercial SiC JBS devices (CRXU30D065G2). At 30 A, the 4-mm^2 HJD outperforms SiC ($T_{rr} \approx 31$ ns, $I_{rr} \approx$ 3.9 A, $Q_{rr} \approx 65$ nC) in all parameters. At 50 A, the 25-mm^2 HJD matches SiC performance ($T_{rr} \approx 44$ ns, $I_{rr} \approx 2$ A, $Q_{rr} \approx 57$ nC). The test circuit details can be found in Appendix A.

Figure 1(m) presents the *I/V* waveforms for various surge current tests of the 4-mm^2 β-Ga_2O_3 HJD under an 8.3 ms-wide half-

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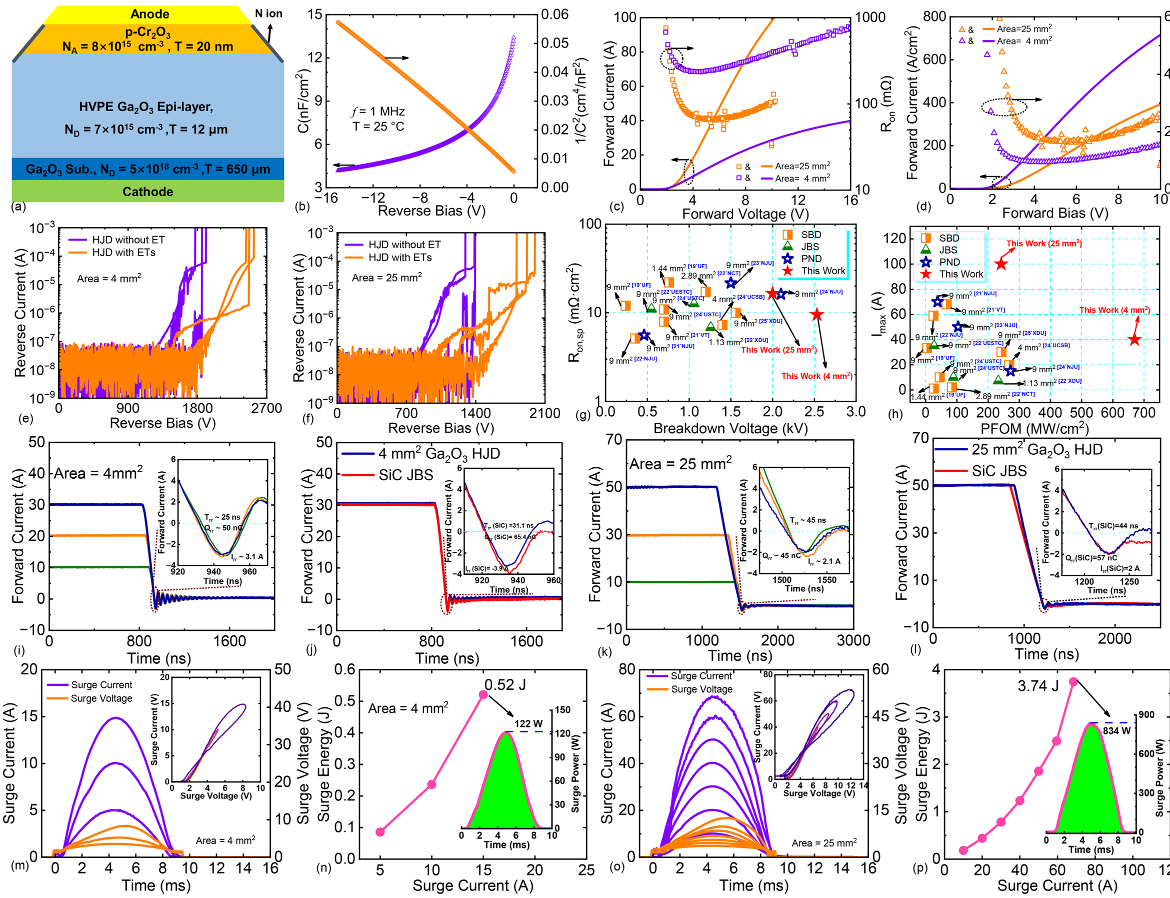

Figure 1 (Color online) (a) Cross-sectional diagram of the β-Ga_2O_3 HJD; (b) C-V characteristic of the β-Ga_2O_3 HJD; forward characteristics of (c) 4-mm^2 and (d) 25-mm^2 HJDs; comparison of breakdown characteristics with and without ET for (e) 4-mm^2 and (f) 25-mm^2 β-Ga_2O_3 HJDs in log scale; key relationships for representative state-of-the-art large area (>1 mm^2) β-Ga_2O_3 diodes: (g) BV vs. minimal $R_{\rm on,sp}$ and (h) PFOM vs. $I_{\max}$; (i)–(l) reverse recovery characteristics of the 4-mm^2 and 25-mm^2 diodes at varied forward currents, and their performance comparison versus a commercial SiC JBS diode; (m)–(p) surge current/voltage waveforms (insets: I-V loops) for the 4-mm^2 and 25-mm^2 β-Ga_2O_3 HJDs under a half-sine pulse, and their corresponding surge energy and power at various currents.

sinusoidal current waveform, achieving a maximum surge current of 15 A, with the inset showing loops derived from time-resolved data. Figure 1(n) illustrates the surge energy versus surge current for the 4-mm^2 HJD, with extracted values of 0.52 J and 122 W, respectively, and with its inset displaying the surge power versus time at the peak surge current of 15 A. Figure 1(o) shows the I/V waveforms for surge current tests of the 25-mm^2 β-Ga_2O_3 HJD, reaching a maximum surge current of 68 A, with its inset displaying the corresponding surge current I-V loops. Figure 1(p) demonstrates the surge energy versus current characteristics for the 25-mm^2 HJD, with the inset depicting the surge power versus time curve at the peak surge current of 68 A. The corresponding surge energy and power are measured to be 3.74 J and 834 W, respectively.

The higher voltage required during surge testing compared to DC measurements at identical currents stems from significant Joule heating induced by transient stresses. This thermal accumulation also governs the evolution of surge I-V loops, primarily due to the lack of thermal management in our simple packaging.

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Supporting information Appendix A. The supporting information is available online at info.scichina.com and link.springer.com. The supporting materials are published as submitted, without typesetting or editing. The responsibility for scientific accuracy and content remains entirely with the authors.

References

1 Feng Y, Zhou H, Alghamdi S, et al. 1.5 kV β-Ga_2O_3 vertical Schottky diodes with 58 A surge current and off-state stressing study. Appl Phys Lett, 2025, 126: 182101
2 Roy S, Kostroun B, Liu Y, et al. Low QCVF 20 A/1.4 kV β-Ga_2O_3 vertical trench high-k RESURF Schottky barrier diode with turn-on voltage of 0.5 V. IEEE Electron Device Lett, 2024, 45: 2487–2490
3 Feng Y T, Zhou H, Alghamdi S, et al. 1.56 kV/30 A vertical β-Ga_2O_3 Schottky barrier diodes with composite edge terminations. Sci China Inf Sci, 2025, 68: 129401
4 Gong H, Zhou F, Xiao M, et al. Enhanced avalanche (2.1 kV, 83 A) in NiO/Ga_2O_3 heterojunction by edge termination optimization. IEEE Electron Device Lett, 2024, 45: 1421–1424
5 Feng Y, Zhou H, Ma J, et al. 120 A/1.78 kV p-Cr_2O_3/n-β-Ga_2O_3 heterojunction PN diodes with slanted mesa edge termination. IEEE Electron Device Lett, 2025, 46: 1705–1708