2 kV, 0.7 mΩ·cm² Vertical Ga_2O_3 Superjunction Schottky Rectifier with Dynamic Robustness

We report the first experimental demonstration of a vertical superjunction device in ultra-wide bandgap (UWBG) Ga_2O_3. The device features 1.8 μm wide, 2×10^{17} cm^{-3} doped n-Ga_2O_3 pillars wrapped by the charge-balanced p-type nickel oxide (NiO). The sidewall NiO is sputtered through a novel self-align process. Benefitting from the high doping in Ga_2O_3, the superjunction Schottky barrier diode (SJ-SBD) achieves a ultra-low specific on-resistance ($R_{ON,SP}$) of 0.7 mΩ·cm² with a low turn-on voltage of 1 V and high breakdown voltage (*BV*) of 2000 V. In the unclamped inductive switching tests, the device shows a dynamic *BV* of 2.2 kV and no degradation under 1.7 kV repetitive switching, verifying the fast acceptor depletion in NiO under dynamic switching.

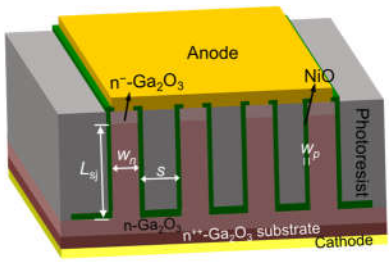

Fig.1. Schematic of vertical Ga_2O_3 superjunction Schottky barrier diode (SJ-SBD)

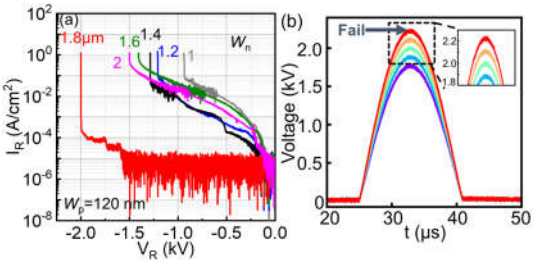

Fig. 2. (a) Reverse I-V characteristics of the Ga_2O_3 SJ-SBDs with w_n of 1-2 μm (b) Dynamic characteristics of the device in the UIS test

Fig. 1 shows the 3D schematic of our Ga_2O_3 SJ-SBD. The n-Ga_2O_3 pillars are wrapped around by p-NiO. The acceptor concentration (N_A) in NiO is designed to be larger than donor concentration (N_D) in Ga_2O_3. This makes the NiO thickness (w_p) much smaller than the Ga_2O_3 pillar width (w_n) at charge balance ($w_pN_A = w_nN_D/2$). This small w_p and a sufficient pillar spacing ($S > 2w_p$) can ease the NiO deposition into deep trenches and avoid the early coalescence at the top of the trench. In each Ga_2O_3 pillar, in addition to the n-Ga_2O_3 layer, a top n⁻-Ga_2O_3 layer is designed to boost *BV* by 1) lowering the tunneling leakage current of the Schottky contact and 2) moving the peak E-field from the Schottky contact into the bulk superjunction region.

Fig. 2 (a) shows the reverse I-V characteristics of Ga_2O_3 SJ-SBDs with w_n of 1~2 μm and an identical w_p of 120 nm. *BV* increases with the increasing w_n, reaching ~2 kV at w_n=1.8 μm, and starts to decrease at larger w_n. This behavior manifests the critical role of charge balance. Fig. 2 (b) shows the UIS waveforms of Ga_2O_3 SJ-SBDs (w_n=1.8 μm) under the increased inductive energy. The device survives the 2 kV UIS test and fails at a dynamic *BV* of 2.2 kV. This slightly higher dynamic *BV* than static *BV* is also reported in GaN HEMTs and may be due to the reduced trap ionization in short pulses (which may lead to the more precise charge balance if a slight mismatch exists in DC conditions). Practically, this suggests a higher device overvoltage margin in switching.

In summary, we demonstrate the first functional vertical superjunction device in Ga_2O_3. A bilayer epi enables the low Schottky leakage current and E-field migration into the bulk Ga_2O_3. A novel self-align process obviates the NiO etch and greatly simplifies the device fabrication. The device's $R_{ON,SP}$ *vs. BV* trade-off is among the best in all power SBDs. The hetero-superjunction retains high *BV* at high temperature and in dynamic switching. These results mark the arrival of UWBG superjunctions and show their promise for power electronics.