NiO/Ga_2O_3 heterojunction power electronics devices

Researchers claim the highest Baliga figure of merit for high breakdown voltage balanced against on-resistance.

Hebei Semiconductor Research Institute and Nanjing University in China claim the highest Baliga figure of merit (FOM) achieved so far among all reported β-gallium oxide (Ga_2O_3) diodes [Yuangang Wang et al, IEEE Transactions on Power Electronics, v37, p3743, 2022].

The 5.18GW/cm^2 FOM comes in at about 15% of the theoretical limit for Ga_2O_3 of 34GW/cm^2, based on material properties. The device also surpassed reported silicon carbide (SiC) limits for diodes for the first time. The theoretical limit for SiC is 3.35GW/cm^2, calculated by the team, based on the references ([1] B. J. Baliga, Wide Bandgap Semiconductor Power Devices, Woodhead Publishing, 2019, p4; [2] Masataka Higashiwaki et al, Gallium Oxide Materials Properties, Crystal Growth, and Devices, Springer, 2020, p8).

The ultra-wide bandgap of Ga_2O_3 leads to expectations of a very high critical field for breakdown. Ga_2O_3 also has prospects arising from lower potential production costs, along with commercial availability of Ga_2O_3 in substrate form.

The devices (Figure 1) used a pn heterojunction structure of a thin p-type nickel oxide (p-NiO) layer on n-type Ga_2O_3. In addition, a junction termination extension (JTE) and a small-angle beveled field-plate (BFP) were used to control electric field crowding effects. Such structures reduce the peak field and allow higher breakdown voltages to be reached.

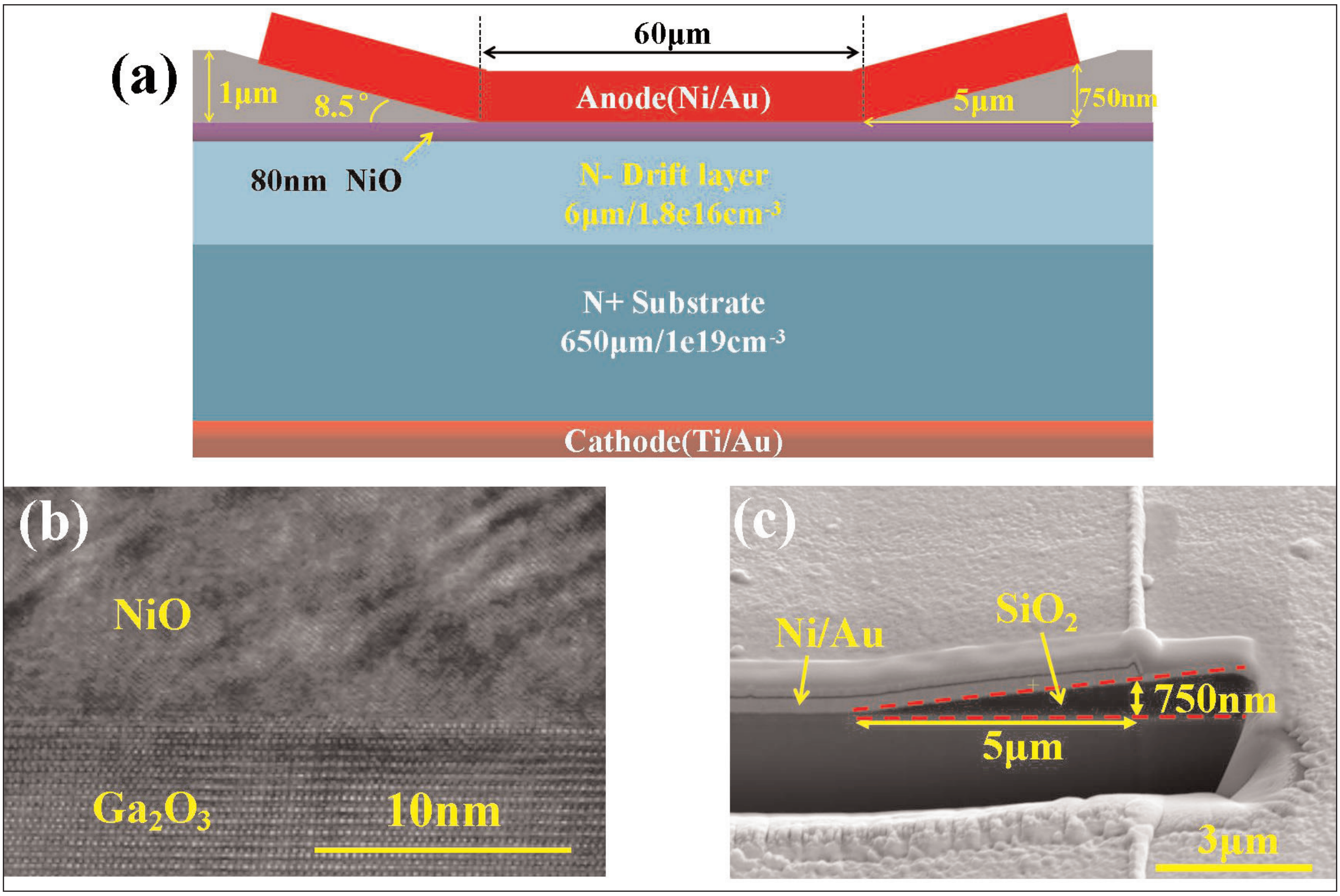

Figure 1. Schematic cross-section of (a) NiO/Ga_2O_3 HJD with JTE and small-angle BFP, (b) cross-sectional high-resolution transmission electron microscope images of NiO/Ga_2O_3 interface, and (c) cross-sectional scanning electron microscope images of BFP structure.

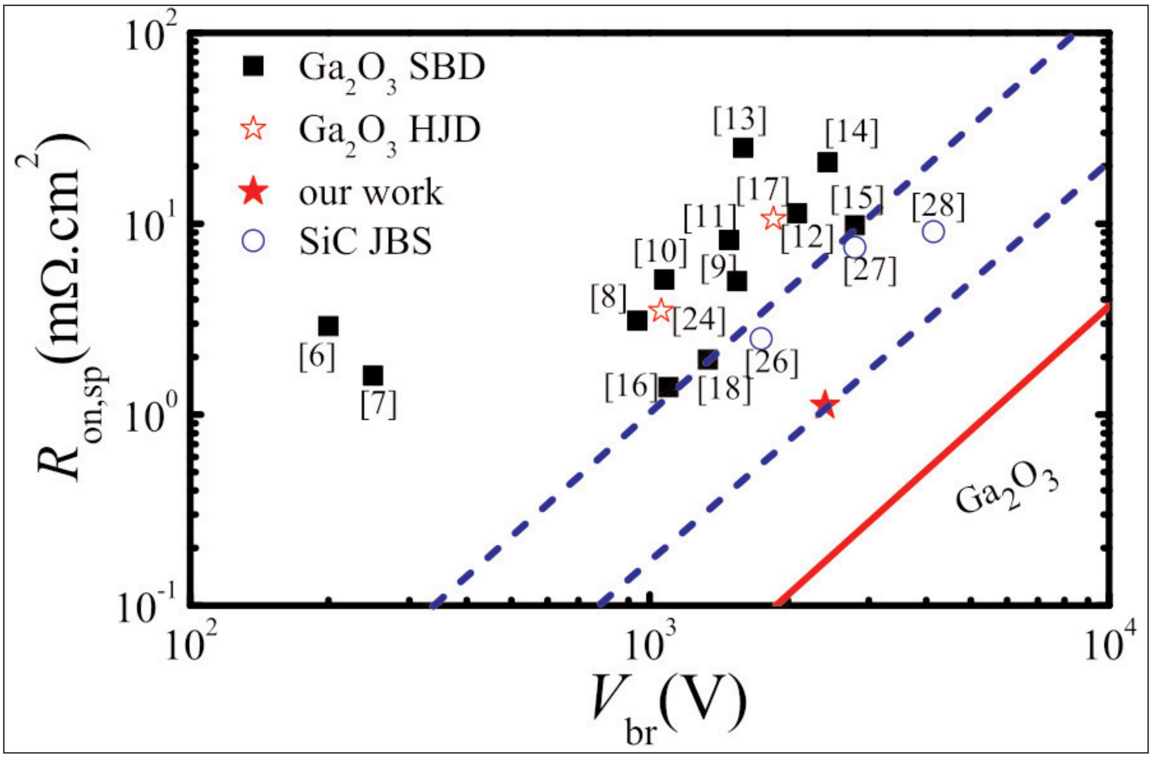

Figure 2. Plot of Ron,sp versus V_{br} for reported vertical β-Ga_2O_3 and SiC diodes. Red solid star represents Hebei/Nanjing record. Diagonal lines represent equal Baliga figures of merit, including the Ga_2O_3 theoretical limit.

The Baliga FOM represents the leading trade-off between breakdown voltage and specific on resistance in the combination $V_{br}^2/R_{on,sp}$.

The drift layer of the device was grown on heavily n-type Ga_2O_3 substrate using halide vapor phase epitaxy (HVPE). The electron concentration from tin doping of the substrate was $1x10^{19}/cm^3$. The 6μm drift layer had a much lower electron concentration of $1.8x10^{16}/cm^3$.

The 80nm polycrystalline NiO layer was applied by 150W radio frequency (RF) magnetron sputtering in argon/oxygen atmosphere at room temperature. Hall measurements showed the layer to be p-type with a hole concentration of $2.5x10^{18}/cm^3$ with $0.53cm^2/V$-s mobility. The NiO layer was covered with silicon dioxide (SiO_2) from plasma-enhanced chemical vapor deposition (PECVD).

The beveled field-plate was formed from variable-temperature (90–145°C) photoresist reflow and inductively coupled plasma etch of the SiO_2 layer. The bevel angle was about 8.5°.

The back ohmic contact came from electron-beam evaporation and rapid thermal annealing (RTA) in nitrogen of titanium/gold (Ti/Au). The Ni/Au anode was formed in a lift-off process. The field-plate was around 5μm thick. The anode area was 60μmx60μm.

The researchers are still working on challenges for the delivery of large-size devices with controllable performance and robust reliability. These challenges concern the uniformity of the Ga_2O_3 epitaxial wafer and sputtered NiO layer, especially in terms of thickness, concentration, and defect density.

Despite the challenges, the Baliga figure of merit of the JTE/BFP HJD reached a record $5.18GW/cm^2$

The researchers also produced Ga_2O_3Shottky barrier diodes (SBDs) and heterojunction diodes (HJDs) without JTE and/or beveled field-plate.

The SBD had the lowest $R_{on,sp}$ of 1.09mΩ-cm^2, while it was 1.23mΩ-cm^2 for an HJD without junction termination extension or beveled field-plate. The JTE and BFP reduced $R_{on,sp}$ for HJDs to 1.12mΩ-cm^2. The turn-on voltage of the HJDs was around 1.6V (giving $1A/cm^2$ current density), higher than for the SBD. Also, the ideality of the HJDs was higher at 1.38/1.20 without/with JTE and BFP, compared with 1.08 for the Schottky barrier diode.

Although the SBD seems preferable so far, the HJD, with its higher barrier and deeper depletion junction depth, is likely to be more resilient under ultra-high voltage stress. Without JTE/BFP the reverse-bias breakdown for the HJD came in at 955V, relative to 460V for SBDs. Adding a JTE increases this to 1945V. The full JTE/BFP package gave a further boost to 2410V.

The researchers are still working on challenges for the delivery of large-size devices with controllable performance and robust reliability. These challenges concern the uniformity of the Ga_2O_3 epitaxial wafer and sputtered NiO layer, especially in terms of thickness, concentration, and defect density.

Despite the challenges, the Baliga figure of merit of the JTE/BFP HJD reached a record $5.18GW/cm^2$ (Figure 2). ■

https://doi.org/10.1109/TPEL.2021.3123940

Author: Mike Cooke