Field-plated Ga_2O_3 Trench Schottky Barrier Diodes with a Record High Figure-of-merit of 0.78 GW/cm^2

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Introduction

The availability of melt-growth techniques for high quality substrates and the high critical electric field of 6-8 MV/cm makes β-Ga_2O_3 an attractive material for power electronic devices [1]. To enable high field operation in Schottky barrier diodes (SBDs) without incurring excessive leakage current, reduced surface field (RESURF) techniques are generally needed [2]. With the adoption of the trench Schottky barrier diode structure, we have demonstrated an effective reduction of the leakage current in Ga_2O_3 trench SBDs and a high breakdown voltage (BV) of 2.44 kV [3]. While the BV in the devices with large fin channel widths can be limited by the field crowding at trench corners [3], devices with a 1-µm fin width appear to be limited by the field crowding at the device edge [4]. In this work, we employed field plating in the Ga_2O_3 trench SBDs to reduce the edge field crowding. The field plate (FP) boosts the BV of the trench SBDs, which show a record high Baliga's figure-of-merit of 0.78 GW/cm^2 from pulsed measurements.

Experimental Process

The trench SBDs have a fin channel width of 1-µm and a fin height of 1.1 µm, as shown in Fig. 1(a). The epitaxial wafer and the fabrication process before the addition of the field plate are similar with those shown in our previous work [3]. The field-plate process started with the deposition of a second Al_2O_3 dielectric layer (125 nm) by atomic layer deposition (ALD), followed by the dry etching of Al_2O_3 for contact holes exposing the anode metal. Finally, metal layers (Ti/Al/Au) for the field plate were deposited and patterned by lift-off. Fig. 1(b) shows the optical image of a fabricated device. All measurements were performed at room temperature (25 °C).

Results and Discussion

As shown in Fig. 2, the extracted net doping concentration of the 10-µm drift layer is ~1.47×10^{16} cm^{-3} from *C-V* measurements. Fig. 3 shows the forward *I-V* characteristics of a field-plated trench SBD, which exhibits an extracted barrier height of ~1.5 eV and an ideality factor of 1.08. In comparison with DC measurements, pulsed measurements show a higher on-current, likely due to the reduction of self-heating and sidewall trapping effects [4][5]. The differential specific R_{on} is 7.0 mΩ·cm^2 from pulsed measurements and 9.1 mΩ·cm^2 from DC measurements. Fig. 4(a) shows the reverse *I-V* characteristics of the trench SBDs. In comparison with the regular SBDs, much lower leakage current and a much higher BV (2.33 kV) is observed in trench SBDs. To investigate the effectiveness of the field plates, MOS-capacitors with and without FP were fabricated on the same wafer. The MOS-capacitors have the same structure as the edge part of the trench SBDs (see Fig. 1(a)), thus can reflect the effectiveness of the field-plated edge termination in trench SBDs. As shown in Fig. 4(b), the BV of the MOS-capacitors is increased from ~2.0 kV to 2.48 kV with the addition of the FP. The BV of field-plated trench SBDs (2.33 kV) is slightly lower than the BV of the MOS-capacitors with FP, but much higher than the MOS-capacitors without FP, indicating that the increase of the BV is due the FP. To understand the mechanisms of the FP, the electric field profile of the MOS-capacitors without and with FP is simulated at their respective highest BVs, as shown in Fig. 5. The field plate largely eliminates the field-crowding at the anode edge, and moves the field-crowding location to the outer edge of the FP. Due the thicker total dielectric layer thickness under the FP metal (230 nm) than under the anode edge (105 nm), both the electric field in Ga_2O_3 (Fig. 5(b)) as well as the average electric field in the dielectric layer is reduced, leading to a higher BV. Note that the actual electric field is likely lower than the simulated values due to the dielectric charging effect. Fig. 6 shows the benchmark plot of Ga_2O_3 SBDs. The field-plated trench SBDs in this work exhibit the highest Baliga's figure-of-merits (BV^2/R_{on}) from both DC (0.60 GW/cm^2) and pulsed (0.78 GW/cm^2) measurements among all reported devices.

Conclusion

The breakdown voltage of the Ga_2O_3 trench SBDs is successfully improved by the incorporation of a field plate at the device edge. This work highlights the importance of edge termination in Ga_2O_3 vertical power devices.

Acknowledgement

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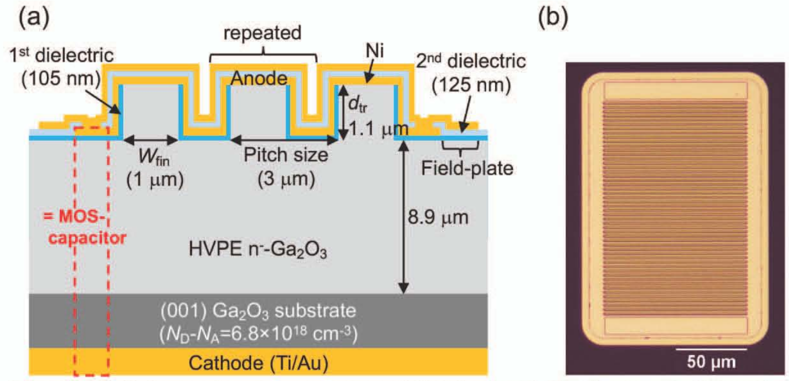

Fig. 1. (a) Schematic cross-section of field-plated Ga_2O_3 trench Schottky barrier diodes (SBDs). (b) Optical top-view image of a fabricated device with a central anode area of 100×150 μm^2.

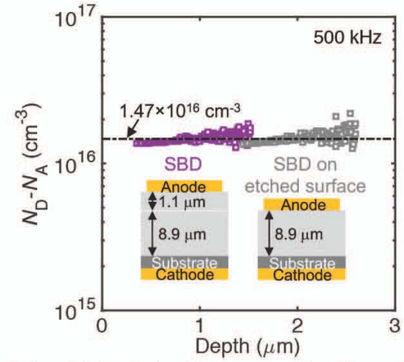

Fig. 2. Net doping concentration of the drift layer extracted by *C-V* measurements on regular SBDs.

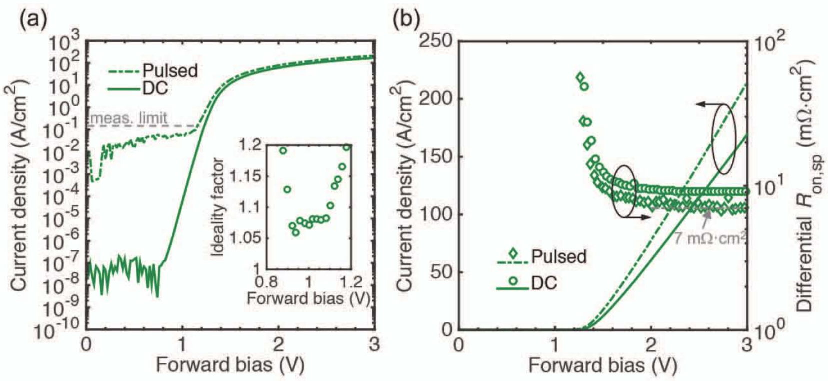

Fig. 3. Forward *I-V* characteristics of a trench SBD (a) in log scale and (b) in linear scale. The device area is 70×40 μm^2. In comparison with DC measurements, pulsed measurements exhibit slightly higher on-current, likely due to the reduction of self-heating as well as sidewall trapping effects [4][5]. A pulse width of 1 μs, a duty cycle of 0.1% and a base voltage of 0 V were used for the pulsed measurements.

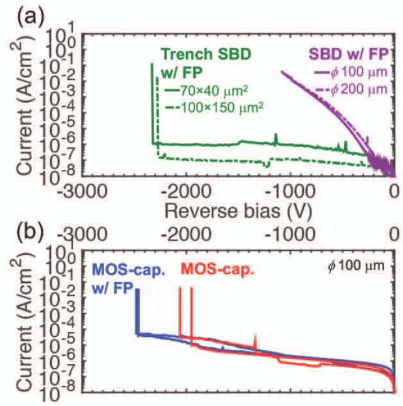

Fig. 4. Revere *I-V* characteristics of (a) field-plated trench SBDs and (b) MOS-capacitors. The breakdown voltage (BV) of the MOS-capacitors is increased by the addition of the field-plate, indicating its effectiveness. The highest BV of the trench SBD is 2330 V.

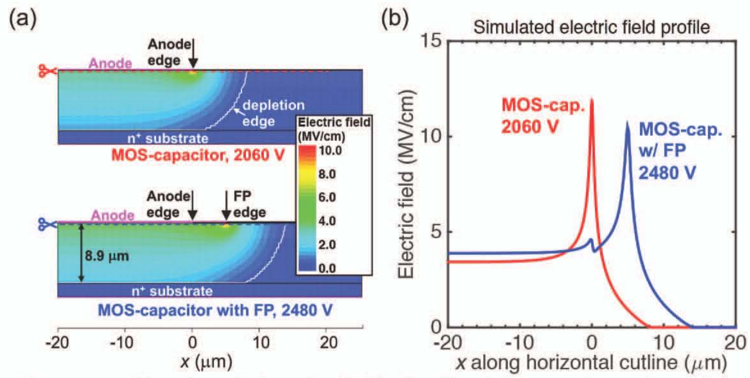

Fig. 5. (a) Simulated electric field distribution near the edge of the MOS-capacitors without and with the field plate at their respective highest BV. With the addition of the field-plate, the field crowding at the anode edge is largely eliminated, and the field crowding is moved to the field-plate edge. (b) Electric-field profile along horizontal cut-lines (dashed lines in (a)) taken 0.1 μm below the Ga_2O_3 surface. With the field plate, the peak electric field is lower even at a higher voltage.

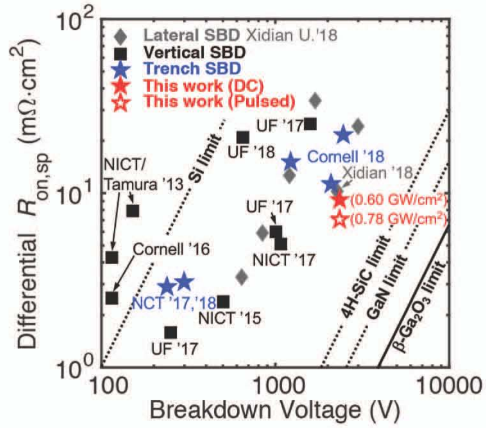

Fig. 6. Benchmark plot of Ga_2O_3 Schottky barrier diodes. The trench SBDs in this work achieve the highest Baliga's figure-of-merits from both DC and pulsed measurements.