Low Q_CV_F Trench β-Ga_2O_3 Schottky Barrier Diode with Extreme-k Dielectric RESURF using Low Work-function Anode Contact

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We report the combination of high-k dielectric RESURF with trench geometry to realize large area ($1mm^2$ and $4mm^2$) β-Ga_2O_3 Schottky Barrier Diodes with low turn-on voltage (V_{on}=0.5V) and high current values (20 A pulsed). This work presents a novel approach to engineer the tradeoff between the on-state and the reverse blocking characteristics of a diode. Vertical trench Schottky Barrier Diodes (SBDs) using β-Ga_2O_3 first reported by Li *et al.* [1] have been shown to exhibit excellent reverse leakage characteristics due to the RESURF effect which leads to the reduction in parallel plane field at the metal-semiconductor junctions. Improved RESURF effects using high-k dielectrics have also been demonstrated in [2, 3] due to dielectric polarization mediated field screening.

1 µm deep trenches are etched on HVPE-grown 11 µm epilayer with 8×10^{15} cm^{-3} apparent charge density concentration using dry etching and 180 nm $BaTiO_3$ (BTO) is then sputter deposited which is followed by annealing at 700 °C to enhance the dielectric constant. A 20 nm of atomic layer deposited (ALD) Al_2O_3 was used as an interlayer dielectric to reduce sputter induced damage on the fin sidewalls. The fins are then opened using dry etching. **Ru/Au Schottky contacts with work function of 4.6 eV** are deposited using **ALD** for conformal deposition. The schematic and the cross-sectional SEM image of the fabricated device is shown in Fig. 1. The on resistance ($R_{on,sp}$ normalized to the device footprint) trench SBD with Ru contact is extracted to be 8.9 mΩ-cm^2 for small area SBDs (Fig. 2). The large area **1 mm^2 trench** SBD exhibits a current of **6A(Pulsed)** and the **4mm^2** trench SBD exhibits **a current of 20A(Pulsed) at 4.5V** (Fig. 3). The breakdown voltage of the small area (200×200 $µm^2$) trench SBD with Ru contact is measured to be higher than 3kV (Fig. 4(a)). The leakage current of the trench SBD with Ru contact increases beyond 2kV reverse bias compared to the trench SBD with Pt contact but negligible at voltages lower than 2kV. The breakdown (catastrophic) voltage of the $1mm^2$ and $4mm^2$ trench SBDs are measured to be **1.4 and 1.8kV** (Fig. 4(b)). The leakage currents at 1.2kV are significantly lower compared to other high current SBDs reported in the literature despite the large area of the device, due to the much-reduced parallel field at the metal/semiconductor interface (simulations not shown). The measured capacitance, stored charge and switching energies at 1kV for the high current SBDs are found to be lower than commercial bare die SiC SBDs (Fig. 5). The large area high-k RESURF trench SBDs also have **the lowest $V_{on}I_{leakage}$ product** for any β-Ga_2O_3 SBDs with more than 1kV breakdown voltage and 1A current, which is important to reduce both the on and off-state power dissipation. The demonstrated SBDs also have **lowest Q_CV_F product** for any β-Ga_2O_3 SBDs with more than 1kV breakdown voltage and 1A current and also comparable to the commercial SiC SBDs, which is important to reduce both the conduction and switching power dissipation. Further improvement in the process and design of such devices can push the performance limits even further, fundamentally improving the trade-off between the forward and reverse characteristics of a diode.

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References: [1] Li *et al.*, *IEEE EDL*, vol. 41, p107 (2020) [2] Z. Xia *et al.*, *IEEE-TED*, vol. 66, p. 896, (2019). [3] Roy *et al.*, *IEEE EDL*, vol. 43, p2037 (2022)

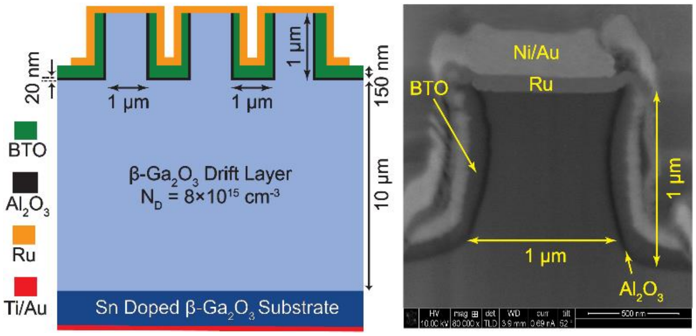

Fig. 1 Schematic diagram of the trench SBD and cross-sectional SEM image.

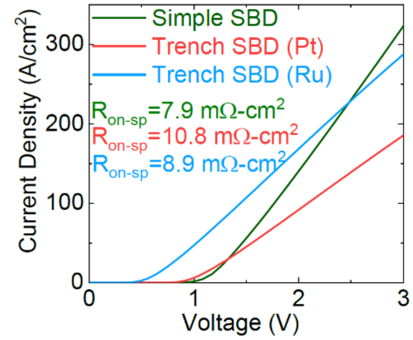

Fig. 2 IV characteristics of three types of SBDs (small area ~ 200x 200 μm^2)

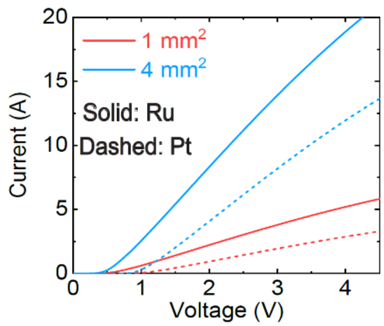

Fig. 3 DC and pulsed IV characteristics of (a) $1mm^2$ and (b) 4 mm^2 large area SBD.

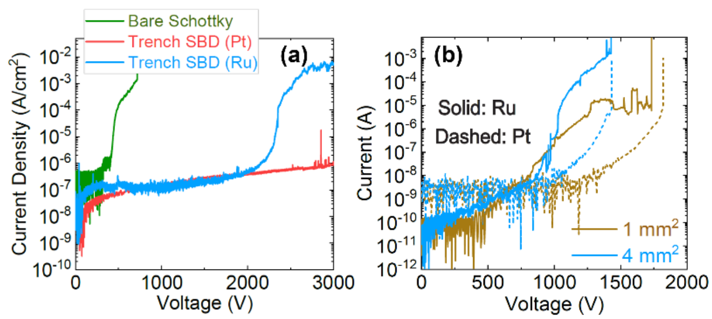

Fig. 4 Reverse IV and breakdown characteristics of the **(a)** small area and **(b)** large area SBDs.

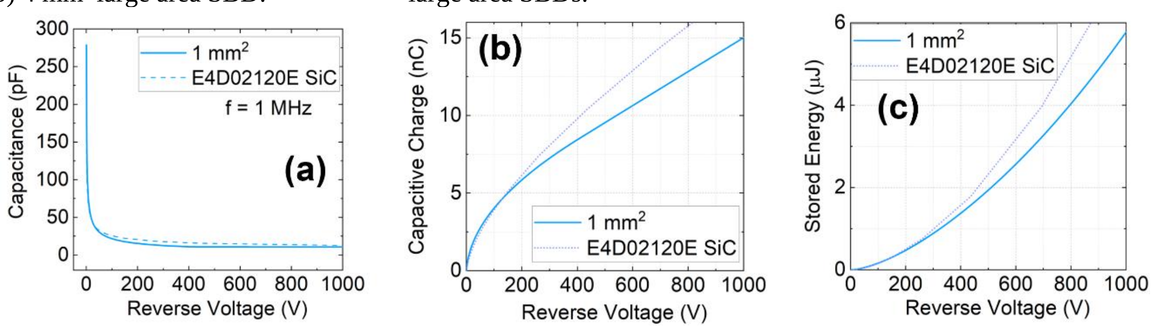

Fig. 5 Measured **(a)** Capacitance, **(b)** stored charge, **(c)** stored energy for 1 mm^2 trench SBD

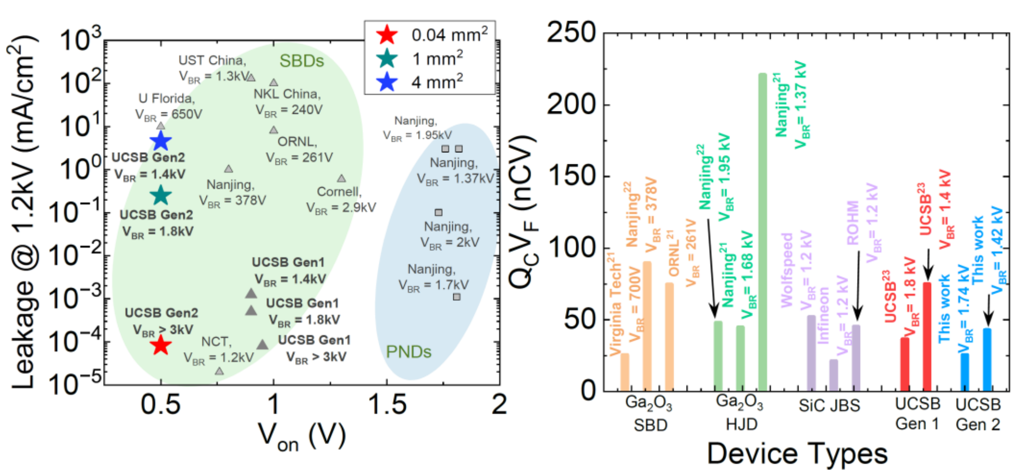

Fig. 6 Benchmark plot showing **(a)** leakage @ 1.2kV vs. the turn-on voltage and **(b)** $Q_C V_F$ for the state-of-the-art β-Ga_2O_3 based diodes.