Characteristics of 4H-SiC Dual-Metal and MOS Trench Schottky Rectifiers

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4H-SiC Schottky rectifiers have advantages of providing low forward voltage drops (V_F) and high breakdown voltages (V_{BD}) [1]. Among approaches of reducing reverse leakage current (I_R), the dual-metal trench Schottky barrier diodes (DM-TSBD) and the trench MOS barrier Schottky diodes (TMBS) are of interest because they don't need costly implantations. The improvements of I_R of DM-TSBD and TMBS as compared with parallel-plane SBD (PP-SBD) have been demonstrated at reverse bias up to 300V and 20V, respectively [2,3]. However, a systematic comparison of these two approaches is absent. Thus we used 2D numerical simulations to study characteristics of these two technologies as well as simple PP-SBD and single-metal TSBD (SM-TSBD) for control purpose. The structures used in simulations are shown in Fig.1, all with a drift region of 6×10^{15} cm^{-3} doping concentration and 10 μm thickness. The trench has a depth of 2 μm and a width of 3 μm, with a half-mesa width from 1 to 4 μm. Note that a rounded corner is critical to prevent premature breakdown caused by field crowding in trench rectifiers (as an example, a silicon TMBS with rounded bottoms shown in Fig.1 could support a reverse bias larger than 100V). Therefore all trench corners in simulations were processed to be with a radius of curvature of 1μm. The simulations results are summarized in Table 1 and the forward and reverse bias characteristics of high barrier PP-SBD-H (Φ=6.35eV) and low barrier PP-SBD-L (Φ=5eV) are shown in Fig.2. Fig.2 shows the trade-off between low V_F and low I_R of PP-SBD. The DM-TSBD solved this problem by providing a V_F close to that of PP-SBD-L and an I_R close to that of PP-SBD-H. The DM-TSBD with a wider mesa showed a lower V_F, and traded off some I_R. An even lower V_F could be achieved in TMBS by providing more effective zones for currents than in DM-TSBD, as can be seen from Fig. 3. The TMBS could also provide a higher V_{BD} than DM-TSBD because the avalanche of TMBS occurred in the edge of well-shielded mesa contacts, whereas the avalanche of DM-TSBD occurred on the field-crowding trench bottom (Fig.3). The TMBS also had the potential to provide a lower I_R than DM-TSBD. However, the trade-off between low V_F and low I_R is more significant in TMBS. The oxide thickness in TMBS should also be taken into account for determining the optimal mesa width because it affects the scale of reverse bias depletion region. The SiC TMBS was sometimes considered not viable because the high electric field in the oxide may easily exceed its breaking strength and lead to failure [4]. Our simulations, however, showed that by proper design (rounded corners with a oxide thickness of 0.25μm), the maximum electric field in the oxide when avalanche occurred was about 8×10^6 V/cm, which is a strength that average dielectrics should be able to endure. In summary, SiC TMBS has the potential to outperform DM-TSBD in terms of every aspect, but more efforts have to be made.

REFERENCES

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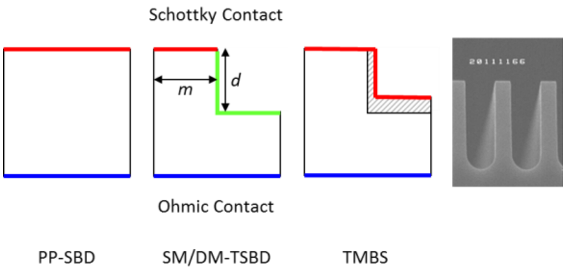

Figure 1. Simulation structures with a fixed trench depth (d) and varying half mesa widths (m); and the SEM picture of silicon TMBS trench

Table 1. Summary of simulation results

	PP-SBD-H	PP-SBD-L	SM-TSBD-H	SM-TSBD-L	DM-TSBD	TMBS
half mesa width (μm)	Breakdown Voltage (V)					
1	2307	2314	1825	1827	1826	2070
2			1740	1741	1739	2020
3			1668	1671	1670	1983
4			1642	1641	1632	1960
half mesa width (μm)	Reverse Leakage Current Density (A/cm2) @1500V					
1	6.25E-10	1.74E-06	5.15E-09	9.81E-03	4.84E-09	1.84E-10
2			8.55E-09	3.96E-02	7.16E-09	1.56E-09
3			1.50E-08	6.34E-02	6.79E-09	5.48E-07
4			3.00E-08	1.62E-01	8.92E-09	5.16E-07
half mesa width (μm)	Forward Current Density (A/cm2) @1.5V					
1	2.33E-10	387	2.19E-10	460	207	269
2			1.74E-10	446	282	312
3			1.57E-10	436	310	332
4			1.69E-10	428	328	343
half mesa width (μm)	Forward Voltage Drop (V) @200A/cm2					
1	2.5987	1.2417	2.5506	1.1627	1.4813	1.3649
2			2.5581	1.1701	1.3435	1.3068
3			2.5641	1.1800	1.3008	1.2859
4			2.5685	1.1855	1.2980	1.2852

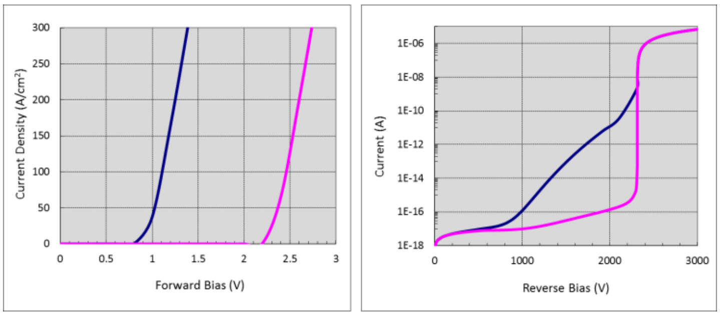

Figure 2. Forward and reverse characteristics of PP-SBD-H (pink line, Φ=6.35eV) and PP-SBD-L (blue line, Φ=5eV)

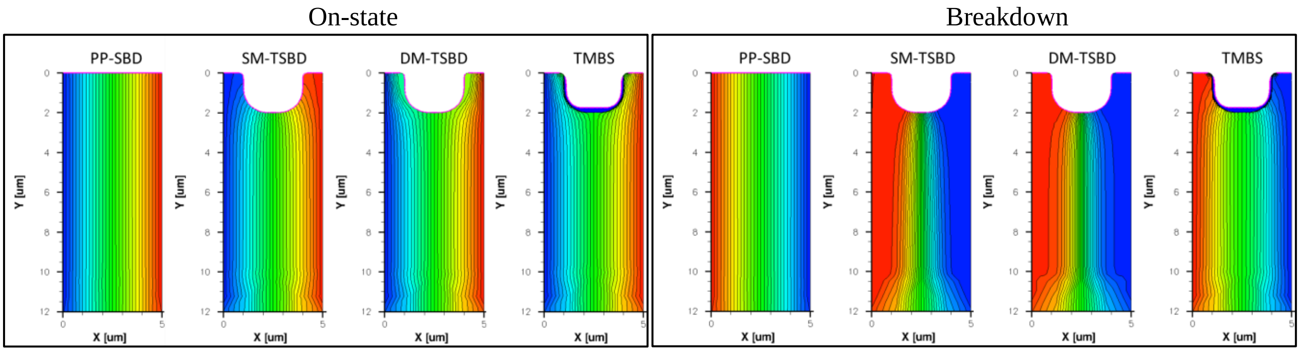

Figure 3. On-state and breakdown current distributions of studied structures