A Dual-Metal-Trench Schottky Pinch-Rectifier in 4H-SiC

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***Abstract*— Characteristics of high-voltage dual-metal-trench (DMT) SiC Schottky pinch-rectifiers are reported for the first time. At a reverse bias of 300 V, the reverse leakage current of the SiC DMT device is 75 times less than that of a planar device while the forward bias characteristics remain comparable to those of a planar device. In this work, 4H-SiC pinch-rectifiers have been fabricated using a small/large barrier height (Ti/Ni) DMT device structure. The DMT structure is specially designed to permit simple fabrication in SiC. The Ti Schottky contact metal serves as a self-aligned trench etch mask and only four basic fabrication steps are required.**

I. Introduction

Since they offer the potential for a low forward voltage drop, high breakdown voltage, and fast switching speed with no reverse recovery current, SiC Schottky rectifiers are a promising technology [1], [2]. However, the design of a power Schottky rectifier requires a tradeoff in selecting the optimal Schottky metal. The power dissipated by a Schottky rectifier depends on both the forward voltage drop and the reverse leakage current, both of which should be as low as possible. It is therefore desirable to have a small barrier height in the forward direction and a large barrier height in the reverse direction, however, these two requirements are in conflict and cannot be implemented in a planar Schottky rectifier. The situation is compounded by the fact that SiC Schottky rectifier reverse leakage currents have been observed to be larger than predicted by thermionic emission theory [3].

A potential solution to this problem is to use a Schottky pinch-rectifier. A pinch rectifier utilizes a high barrier region to pinchoff or electrically shield a low barrier region. Many different pinch-rectifier device structures have been implemented and proven in Si, including implanted/diffused P-N junction pinch rectifiers (junction barrier Schottky (JBS) rectifiers) [4], trench-JBS (TJBS) rectifiers [5], and trench-MOS-barrier-Schottky (TMBS) pinch rectifiers [6]. JBS and TMBS rectifiers have been recognized as evolutionary improvements of the planar power Schottky rectifier device structure [7].

II. Device Design, Simulation, and Fabrication

The implementation of a JBS or TJBS in SiC is difficult because at the temperatures required for diffusion of dopant impurities there is significant surface damage and no available dielectric masking layer. The usefulness of a SiC TMBS is somewhat limited because the oxide will breakdown before the critical field of SiC is reached. A structure has been proposed for a Schottky power pinch rectifier using regions of differing barrier heights [8]. Therefore, we have implemented a 4H-SiC pinch-rectifier with a small/large barrier height (Ti/Ni) dual-metal-trench (DMT) device structure. The device structure is given in Fig. 1. The Ti contact is the low barrier height interface and the Ni contact is the high barrier height interface. The dimensions of the mesa width (w_m) and the mesa thickness (t_m) are critical to effectively pinching off the mesa and electrically shielding the Ti interface. In forward bias, the mesa width, w_m, is not pinched off and the small barrier height Ti Schottky contact conducts current. In reverse bias, the mesa becomes fully pinched off, electrically shielding the Ti Schottky contact, and high electric fields are restricted to the large barrier height Ni Schottky contact. MEDICI simulations $(w_m = w_t = t_m = 2\ \mu\text{m})$ have been used to verify the mesa pinchoff and electric field shielding of the Ti interface. Simulation results plotted in Fig. 2(a) and (b) show that the electric field at the Ti interface is maintained at a low value compared to that of a planar structure. A tradeoff of the DMT design is the field crowding at the trench corner, which

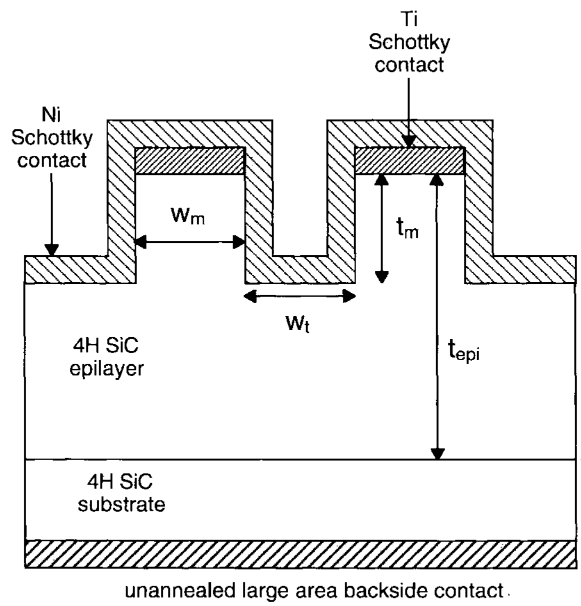

Fig. 1. Device structure of Ti/Ni dual-metal-trench pinch rectifier where w_m is the mesa width, w_t is the trench width, t_m is the mesa thickness, and $t_{\rm epi}$ is the epilayer thickness.

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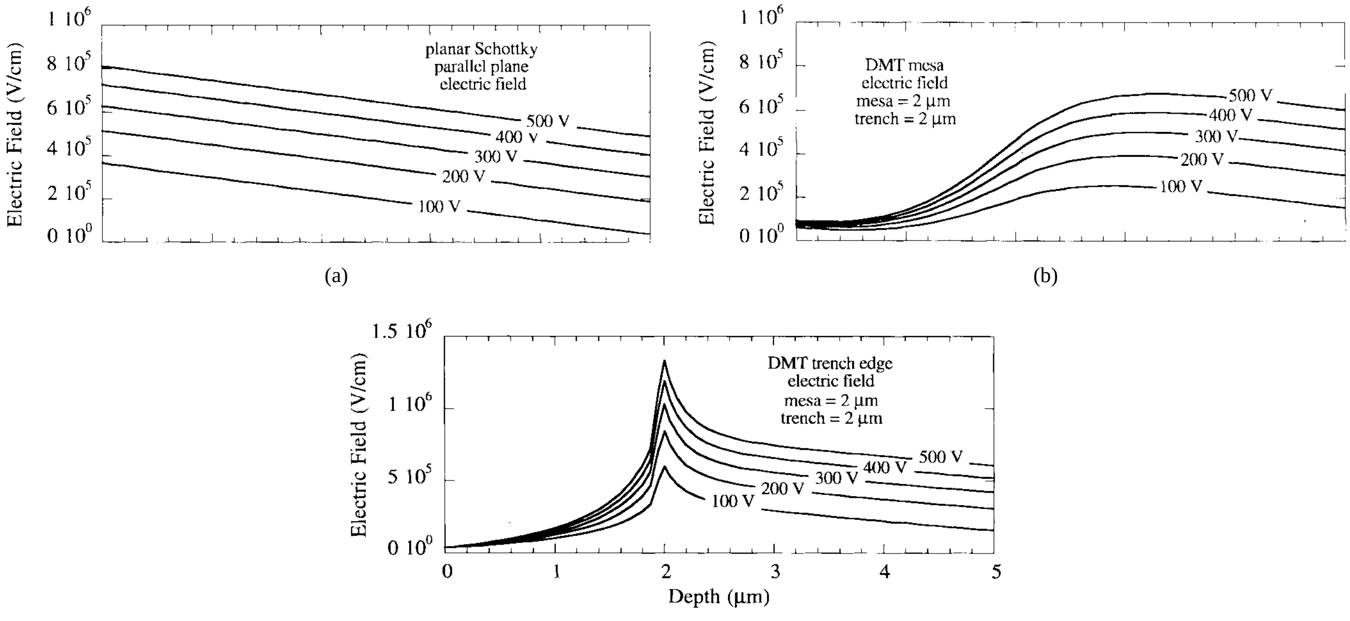

Fig. 2. Plots of electric field versus depth into for (a) a planar Schottky contact, (b) mesa center of a dual-metal trench rectifier, and (c) trench edge of a dual-metal-trench rectifier. The epilayer doping is $3.5 = 10^{15}$ cm^{-3} and the thickness is 13 μm. The dual-metal-trench rectifier has a w_m of 2 μm, a w_t of 2 μm, and a t_m of 2 μm.

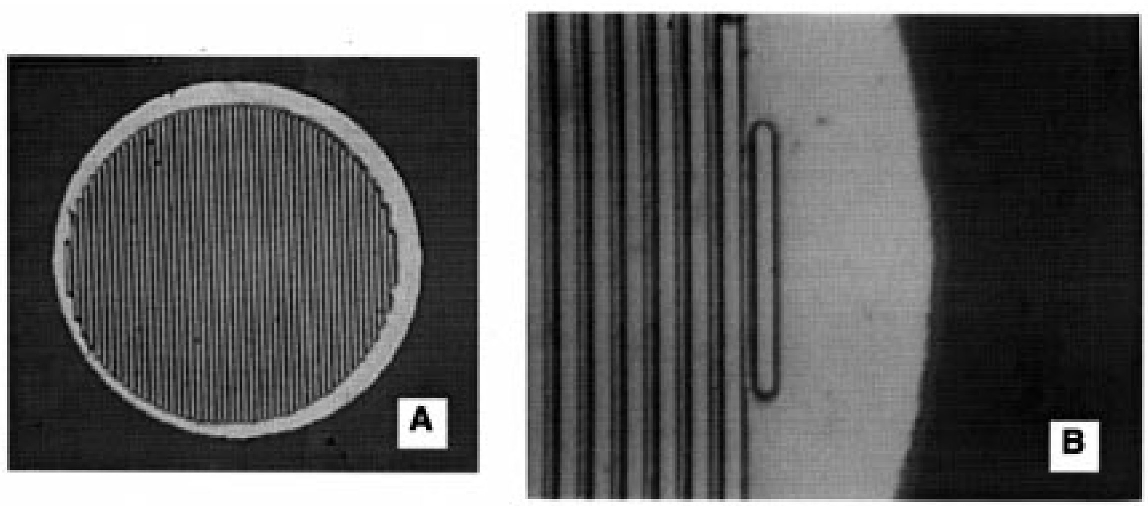

Fig. 3. Photographs of a Ti/Ni dual-metal-trench pinch rectifier with a w_m of 3 μm, a w_t of 3 μm, and a t_m of 2 μm. (a) Photo of entire device. (b) Close-up photo of mesas and device edge.

causes a premature increase in the reverse leakage current of the Ni Schottky contact and reduces the breakdown voltage. Fig. 2(c) shows the electric field at the edge of the trench, with the corner being at a depth of 2 μm. It may be possibly to partially mitigate the field crowding at the trench corner by etching the bottom of the trenches and rounding the corners.

Ti/Ni DMT Schottky rectifiers were fabricated on a 3×10^{15} cm^{-3} doped 13-μm thick n-type 4H Si-face SiC sample obtained from Cree Research, Inc. The Ti Schottky contact metal served as a self-aligned trench etch mask and only four basic fabrication steps were required (Ti deposition, trench etch, Ni deposition, large area backside contact deposition). The w_m and w_t are either 2 or 3 μm and equal. Trenches with a t_m of 2 μm were formed by reactive-ion-etching. A photo of a fabricated DMT device and a close-up photo of the device structure are shown in Fig. 3.

III. Experimental Results

A comparison of planar and DMT device forward bias current–voltage $(I - V)$ characteristics is shown in Fig. 4. Current densities for the DMT devices were calculated using the area of the Ni metallization [the light area shown in Fig. 3(a)]. Both the 2- and 3-μm Ti/Ni DMT devices show forward bias characteristics that are comparable to the planar Ti Schottky rectifier. The barrier height and the ideality factor of the Ti/Ni DMT devices are 0.8 eV and 1.09. The barrier height and ideality factor of the planar Ti devices are 0.84 eV

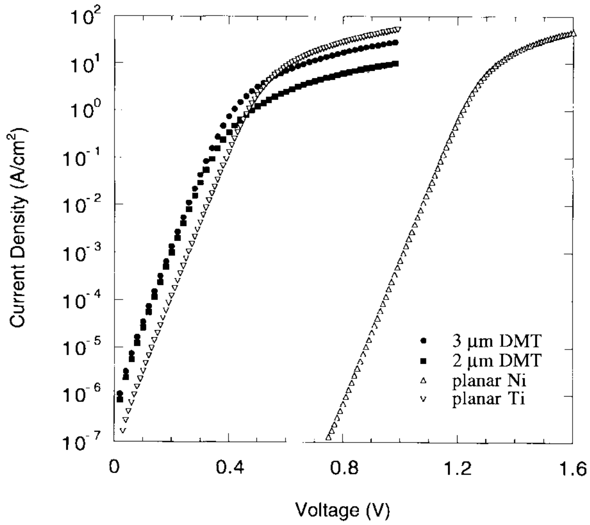

Fig. 4. Forward bias current–voltage characteristics of Ti/Ni dual-metal-trench (DMT) and planar Schottky rectifiers (3-μm DMT devices have a w_m and w_t of 3 and 2 μm, DMT devices have a w_m and w_t of 2 μm, and both have a t_m of 2 μm).

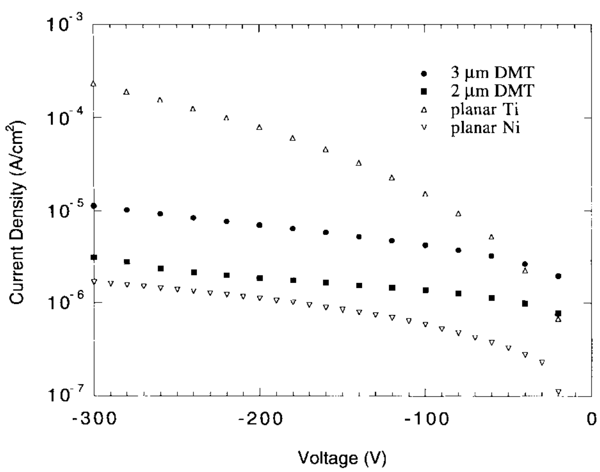

Fig. 5. Reverse bias current–voltage characteristics of Ti/Ni dual-metal-trench (DMT) and planar Schottky rectifiers (3-μm DMT devices have a w_m and w_t of 3 μm, 2-μm DMT devices have a w_m and w_t of 2 μm, and both have a t_m of 2 μm).

and 1.09 and the barrier height and ideality factor of the planar Ni devices are 1.51 eV and 1.11. The differences in barrier height between the Ti/Ni DMT devices and the planar Ti devices is likely due to differences in surface treatment and metallization of the two device structures. The 2-μm device structure shows a larger series resistance than the 3-μm device structure. This is expected since the percentage of the mesa that is not laterally depleted by the Ni contact at zero bias is smaller for the 2-μm sample than for the 3-μm sample.

A comparison of planar and DMT device reverse bias I–V characteristics is shown in Fig. 5. The planar device structures include a boron implant edge termination. Previous work has shown that the boron implant edge terminated planar devices have a reverse leakage current which depends on the device area, schottky barrier height, and parallel plane electric field at the metal semiconductor interface [9]. The reverse I–V characteristics of both the 2- and the 3-μm Ti/Ni DMT Schottky rectifiers show a reduction in reverse leakage current when compared with the planar Ti Schottky rectifier. The reverse leakage currents of the 2- and 3-μm Ti/Ni DMT structures are approximately 75 times and 20 times less than the reverse leakage current of the planar Ti Schottky rectifier, respectively. This is also expected since the 2-μm device structure provides better electric field shielding than the 3-μm device structure. The source of the leakage current for both the planar and the DMT devices is related to the area of the device and not to the perimeter of the device.

The breakdown voltage of the devices was experimentally found to be reduced from that of the planar device structure. The breakdown voltage of about 450 V correlates well with the trench corner field crowding predicted by MEDICI simulations and shown in Fig. 2(c). The experimentally measured breakdown voltage of the planar Ni device with boron implant edge termination is 1720 V and the theoretical parallel plane breakdown voltage of the material structure is 1980 V. It should be noted that the planar device has a thickness of 13 μm and the DMT device has a thickness of 11 μm from the bottom of the trench to the substrate.

IV. Summary and Conclusions

A pinch rectifier has been fabricated in SiC using a DMT device structure. Ti/Ni DMT devices have been experimentally shown to have forward bias characteristics similar to a small barrier height Schottky rectifier (Ti) and reverse bias characteristics similar to a large barrier height Schottky rectifier (Ni). Therefore, the DMT device structures is a promising technology for improving the performance of power SiC Schottky rectifiers.

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