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Improvement of trench MOS barrier Schottky rectifier by using high-energy counter-doping trench-bottom implantation

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ABSTRACT

A trench MOS barrier Schottky (TMBS) rectifier formed by using high-energy boron trench-bottom implantation has been proposed. As compared to the conventional TMBS rectifier, this proposed device can achieve much larger reverse blocking voltage without considerable degradation of forward characteristics. By this scheme, the large peak electric field near the trench corner can be largely reduced due to charge compensation. In addition, owing to the presence of the counter-doped region, the second peak electric field is created below the trench bottom. Higher trench-bottom implantation energy may form wider boron dopant distribution, which facilitate larger alleviation of the second peak electric field. However, too high boron implantation energy may considerably cause dopant encroachment into the mesa region, which would increase the second electric field. Hence, properly high trench-bottom implantation energy should be employed to simultaneously cause low peak electric field at regions near the trench corner and below the trench bottom, thus providing a relatively high blocking voltage for this TMBS rectifier.

1. Introduction

Power semiconductor devices play a crucial role in the regulation and distribution of power and energy in the world. Among the devices, power rectifier with reverse blocking capability of less than 100 V are required for applications such as switch mode power supplies and automotive electronics [1]. In order to eliminate the reverse recovery problems associated with p-i-n rectifiers, the Schottky barrier diode (SBD) was developed. Furthermore, the junction barrier controlled Schottky rectifier is developed to improve the on-state voltage drop. An even superior low-voltage power rectifier was conceived based on incorporation of a trench MOS structure below the metal-semiconductor contact [2–10], namely the trench-MOS-barrier-Schottky (TMBS) structure. The charge coupling between the donors in the mesa region and the metal on the trench sidewall produces a redistribution of the electric field under the metal-semiconductor contact. In the case of SBD, the electric field reduces linearly with distance from the surface. In contrast to this, the electric field in the TMBS structure exhibits two peaks located at the metal-semiconductor interface and the bottom of trench, allowing a considerably larger blocking voltage than the SBD. The blocking voltage of the TMBS structure is limited by the high electric field at the bottom of the trench. Previously, TMBS structure with graded doping concentration in the *n* epitaxial layer was proposed to alleviate the high electric field at the bottom of the trench [4–6]. However, by using a graded doped wafer, the device cost becomes more expensive than by using a uniformly doped wafer.

In this study, improvement of trench MOS barrier Schottky rectifier by using high-energy counter-doping trench bottom implantation has been proposed to further enhance the blocking capability of the conventional TMBS rectifier. By forming a counter-doped region that encloses the trench bottom in the TMBS rectifier, the high peak electric field at the corner of trench bottom, for the conventional TMBS structure, can be significantly alleviated. Various trench-bottom implantation energies for forming the counter-doped region have been examined to clarify their effects.

2. Device fabrication

A typical TMBS process flow is firstly carried out [3–6]. The process steps include (1) Sb-doped Si wafer of 0.01 ohm-cm with epitaxial *n*-Si layer of 8 μm thickness and of 0.29 ohm-cm in resistivity. (2) Oxide deposition of 600 nm thickness as hard mask, by using low-pressure-chemical-vapor-deposition (LPCVD). (3) Photolithography for defining the trench region, and hard-mask oxide etching. (4) Removal of photo-resist, and trench Si etching of 1.6 μm depth and 0.6 μm width, and then forming a mesa width of

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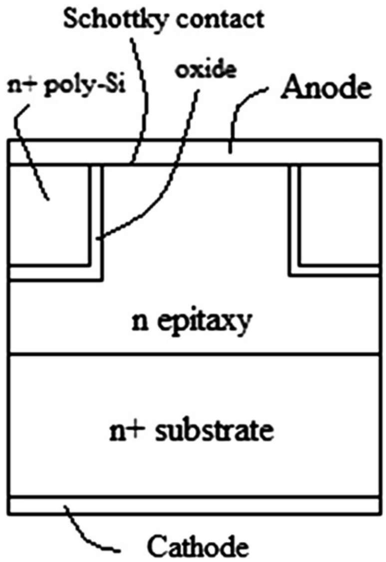

Fig. 1. The schematic device structure of the conventional TMBS rectifier.

1.2 μm (5) Sacrificial oxidation of about 15 nm thickness in an N_2O ambient at 950 °C (6) Removal of hard-mask oxide and sacrificial oxide, and then MOS gate oxidation of 200 nm thickness at 900 °C (6) LPCVD n^+ poly-Si gate. (7) N^+ poly-Si etching back, to form n^+ poly-Si plug as the trench-gate. (8) Removal of MOS gate oxide on mesa region, for forming Schottky contact. (9) Deposition of thin palladium film of 50 nm thickness, by using sputtering. (10) Annealing for silicidation process, which forms palladium silicide at the mesa and the n^+ poly-Si plug regions. (11) Al sputtering of about 4 μm thickness, for forming the anode region. (12) Back-side Al sputtering of about 4 μm thickness, for forming the cathode region. As a result of the above device fabrication process, Fig. 1 shows the resultant device structure of the conventional TMBS rectifier.

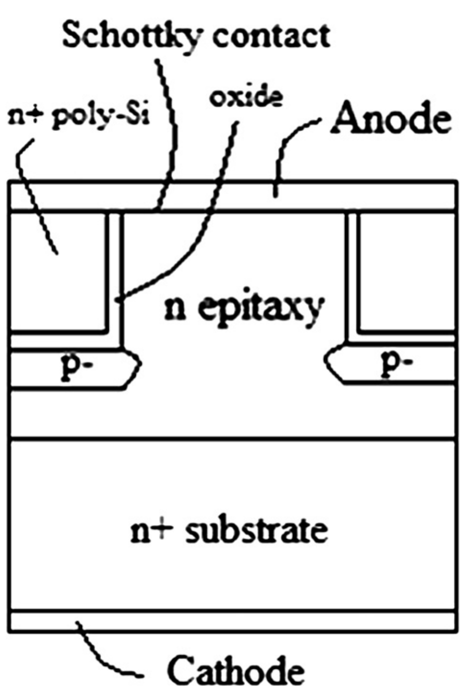

Fig. 2. The schematic device structure of this TMBS rectifier with a counter-doped region enclosing the trench bottom.

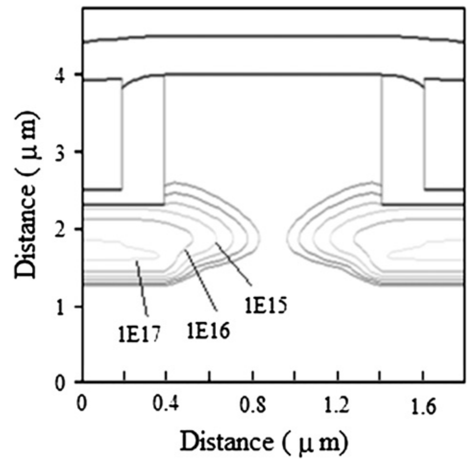

Fig. 3. The reverse I–V characteristics for the conventional TMBS rectifier and these TMBS rectifiers with counter-doped regions being formed by trench-bottom boron implantation at energies of 10–70 keV, respectively.

On the other hand, immediately after the step (5), part of the samples would receive an additional trench-bottom boron implantation at energies of 10–150 keV to a dose of 5×10^{12} cm^{-2}, respectively. Hence, a counter-doped region in the *n* epitaxial layer below the trench bottom may be formed. Then, following the same subsequent process steps as the conventional TMBS structure, this TMBS rectifier with a counter-doped region enclosing the trench bottom was implemented. Fig. 2 shows the resultant device structure of this TMBS rectifier with a counter-doped region enclosing the trench bottom. The resultant I–V characteristics are normalized to be the conduction current for a unit cell including one mesa region and two half-trench regions. The electric field distribution and the counter-doping boron profile in the trench bottom region were obtained by using the SILVACO process and device simulators [11,12].

3. Results and discussion

For the conventional TMBS rectifier, the resultant reverse blocking voltage is about 62 V. When the boron implantation is additionally performed in the region of TMBS trench bottom, a counter-doped region enclosing the trench bottom is formed.

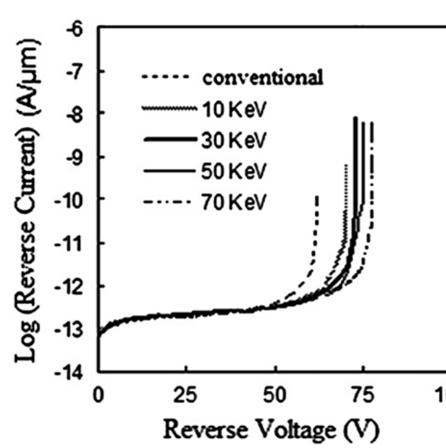

Fig. 4. The reverse I–V characteristics for the conventional TMBS rectifier and these TMBS rectifiers with counter-doped regions being formed by trench-bottom boron implantation at energies of 10–70 keV, respectively.