Modified Trench MOS Barrier Schottky (TMBS) Rectifier

Jin-Woo Moon†, Yearn-Ik Choi* and Sang-Koo Chung**

Abstract - A trench MOS barrier Schottky (TMBS) rectifier is proposed which utilizes the upper half of the trench sidewall as an active area. The proposed structure improves the forward voltage drop by 20% in comparison with the conventional one without degradation in breakdown voltage. An analytical model for the field distribution is given and compared with two-dimensional numerical simulations.

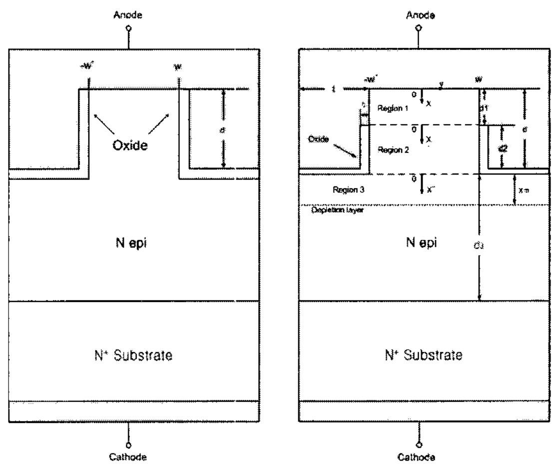
Keywords: Schottky, rectifier, trench, TMBS

1. Introduction

Trench MOS barrier Schottky rectifiers are of interest for applications in low-voltage switch-mode power supplies for integrated circuits. For these applications, it is desirable to have rectifiers with very low forward voltage drop, high switching speed and 20-30V blocking capability. Reverse blocking voltage in excess of three times the plane parallel breakdown voltage with a low leakage current and the forward voltage drop of 0.2-0.3V at $100 A/cm^2$ has been reported[1] previously for a TMBS rectifier fabricated on an epitaxial layer doping of $1\times10^{17} cm^{-3}$. However, the conventional TMBS rectifier has MOS structure built into whole trench regions, reducing active area. The current handling capability of the TMBS rectifier increases directly with increasing active area. In this paper, it is demonstrated that improved Schottky rectifier characteristics can be obtained by utilizing the upper part of the trench sidewall as an active area. In addition, an analytical model for the blocking capability of TMBS rectifier is given and compared with two-dimensional numerical simulations.

2. Simulation Results

Fig. 1 shows cross-sections of conventional and proposed rectifier structures with physical parameters of $d_1 = d_2 = d_3 = 1\mu m$, $w = 0.25\mu m$, $t_i = 500A$ and $N = 10^{17} cm^{-3}$ used in the simulation, where the only difference is given by $d_1 = 0\mu m$ and $d_2 = 2\mu m$ for the conventional one. The equipotential lines of the proposed TMBS rectifier at the reverse voltage of $V_R = 28.2V$ are shown in Fig. 2. The forward I-V characteristics of the conventional and the proposed TMBS rectifier are shown in Fig. 3 (a), where the forward voltage drop of 0.23 V and 0.29 V are obtained at $100 A/cm^2$ for the proposed and the conventional TMBS, respectively, improving the forward voltage drop by 20% for the proposed structure. Similar improved forward characteristics have been obtained by increasing the mesa width for the conventional structure with the same trench depth [1].



(a) (b)

Fig. 1 Cross-sections of (a) conventional and (b) proposed structure with parameters used in simulation.

Fig. 3 (b) shows the reverse characteristics. The breakdown voltage for both the proposed and the conventional TMBS structure is found to be about 28.2V. The leakage current for the proposed structure exhibits about five times that for the conventional one at the expense of lower forward voltage drop.

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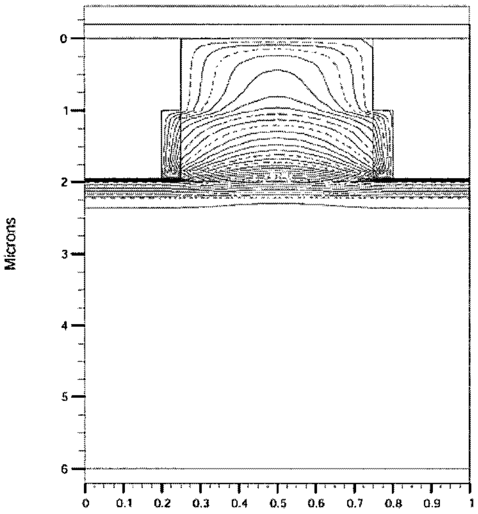
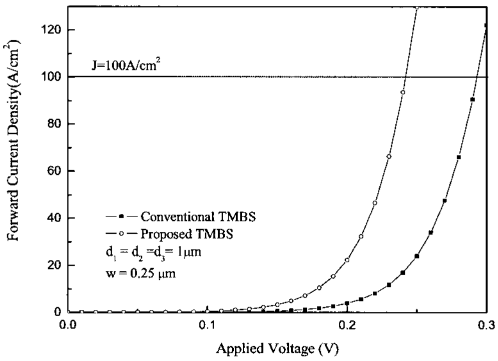
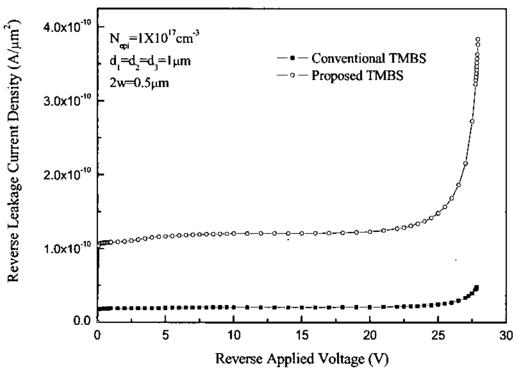


Fig. 2 Potential contours at reverse bias voltage of 28.2V for proposed structure.

The forward and reverse I-V characteristics of the proposed structure are shown in Fig. 4 (a) and (b), respectively, with different epitaxial layer doping levels as a parameter, where $N = 10^{17} cm^{-3}$ is found to be preferable from the viewpoint of a sufficient on/off current ratio.

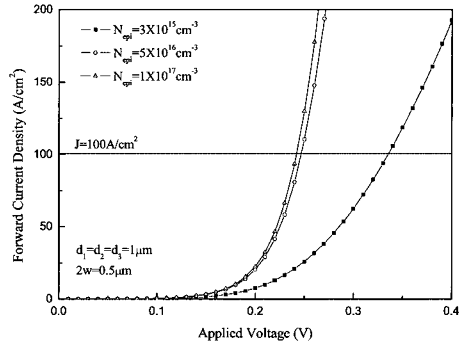


(a)

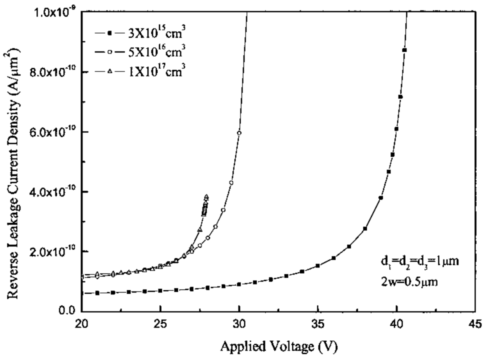


(b)

Fig. 3 (a) Forward I-V characteristics of proposed structure. (b) Reverse I-V characteristics of proposed structure.

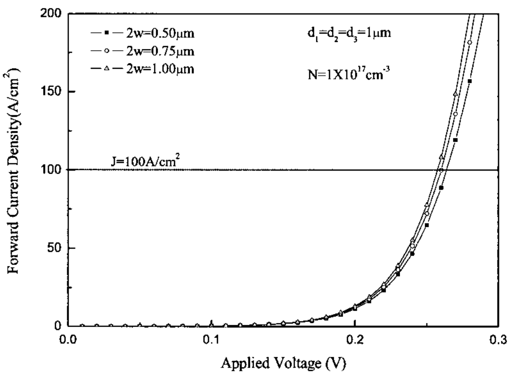


(a)

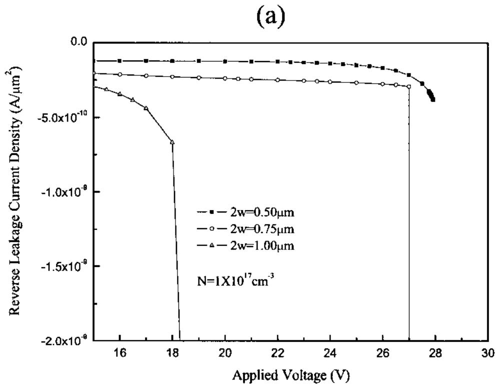


(b)

Fig. 4 I-V characteristics with different epi layer doping levels. (a) Forward characteristics (b) Reverse characteristics



(a)



(b)

Fig. 5 Forward and reverse conduction characteristics of the proposed TMBS rectifier with different mesa widths.

Fig. 5 shows the I-V characteristics of the improved TMBS diode with different mesa width of 2w. Both the forward and reverse characteristics depend on w, especially strong in reverse condition. For the mesa width of $2w \geq 1\mu m$, the leakage currents increase rapidly with increasing the cathode voltage. The depletion layer width is not sufficient to pinch off the mesa region. The large leakage currents may be attributed to the lateral peak field presented at the trench sidewall $x = d_1$ as shown in Fig. 5, where the peak field increases with increasing mesa width from about $5\times10^5 V/cm$ at $2w = 0.5\mu m$ to $9\times10^5 V/cm$ at $2w \geq 1\mu m$. It is, therefore, of critical importance to have a mesa width less than $0.5\mu m$ to obtain suppressed reverse leakage current characteristics for $N = 1\times10^{17} cm^{-3}$ as verified experimentally[2]. Fig. 6 shows lateral electric field variations at $x = d_1$ with the mesa width as a parameter.

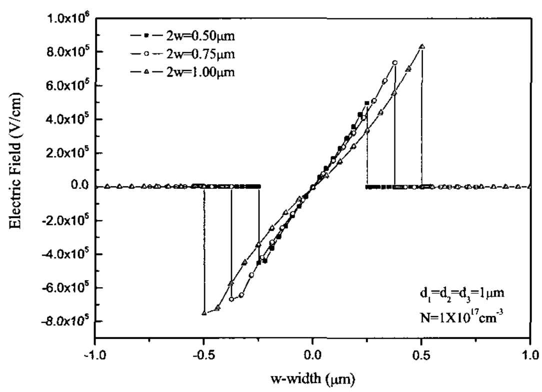


Fig. 6 Lateral electric field variations at $x = d_1$ with mesa widths as a parameter.

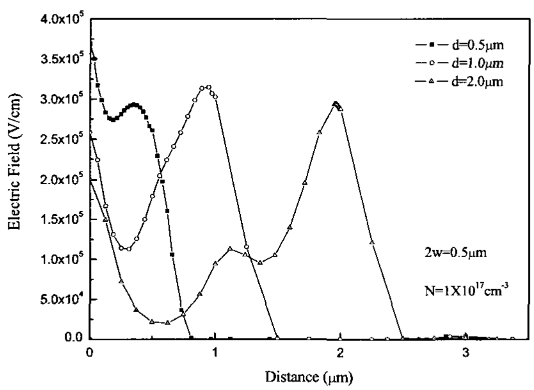


Fig. 7 Electric field variation along the vertical distance at the middle of the silicon mesa with different trench depth.

Fig. 7 shows the electric field variation along a vertical line passing through the Schottky contact at the middle of the silicon mesa with different trench depth. It is to be noted that the vertical peak field of about $3\times10^5 V/cm$ located at $d = 2\mu m$ with $d_1 = d_2 = 1\mu m$ is less than the lateral one of $5\times10^5 V/cm$ at $x = d_1 = 1\mu m$ for the case of $2w = 0.5\mu m$ as may be observed in Fig. 6.

3. Discussion

An analytical model of potential distribution for the TMBS structure can be obtained from Poisson's equation using different boundary conditions for three divided regions as indicated in Fig. 1 (b). Assuming that the epitxial layer is fully depleted, the potential with an even function of y may be derived in like manner as published previously [3,4]. The results are;

$$\Phi_1 = \left[1-(y/w)^2\right]\times\left[\sigma_1 + \frac{(V_1-\sigma_1)\sinh a_1 x - \sigma_1 \sinh a_1(d_1-x)}{\sinh a_1 d_1}\right] \quad (1)$$

and

$$\Phi_2 = \left[1-\frac{y^2}{w(w+2t_i/k)}\right]\times\left[\sigma_2 + \frac{(V_2-\sigma_2)\sinh a_2 x' + (V_1-\sigma_2)\sinh a_2(d_2-x')}{\sinh a_2 d_2}\right] \quad (2)$$

and

$$\Phi_3 = [V_R + V_D - \Phi_2(d_2,y)](x''/d_3) - V_D(x''/d_3)^2 + \Phi_2(d_2,y) \quad (3)$$

for the PT case and

$$\Phi_3 = \Phi_2(d_2,y) + (qN/2\varepsilon_s)[x_m^2 - (x''-x_m)^2] \quad (4)$$

for the NPT case with $x'' \leq x_m$ where $x_m = [(V_R - \Phi_2,(d_2,y))/(qN/2\varepsilon_s)]^{1/2}$ $\sigma_1 = (qN/2\varepsilon_s)w^2$, $\sigma_2 = (qN/2\varepsilon_s)$, $[w(w+2t_i/k)]$ $a_1 = (2/w^2)^{1/2}$, $a_2 = (2/[w(w+2t_i/k)])^{1/2}$ and $V_D = (qN/2\varepsilon_s)d_3^2$ are used with $k = \varepsilon_{si}/\varepsilon_{ox}$. Determination of the potential distribution is completed by finding V_1 and V_2 for a given reverse voltage of V_R using the field continuity condition at $x = d_1$ and $x' = d_2$. The breakdown voltage for both the proposed and the conventional TMBS structure is found to be about 28.2 V. The simulation results are $V_1 = 7.1V$ and $V_2 = 22.5V$ for $V_R = 28.2V$ whereas $V_1 = 7.27V$ and $V_2 = 22.6V$ with $x_m = 0.27\mu m$ are obtained analytically for the same value of V_R.

The potential lines along a vertical line passing through the Schottky contact at the middle of the silicon mesa for the proposed TMBS rectifier are shown in Fig. 8, where the analytical curve is also shown for comparison. The curve at $d = 2\mu m$ in Fig. 7 corresponds to the electric field variation for the case.

Fig. 9 shows the silicon processing for the proposed TMBS rectifier. The MOS structure can be formed by two steps of RIE (Reactive Ion Etching) process. The first trench etch is performed by using Si_3N_4 as a mask. After the trench etch, Si_3N_4 layer is deposited on the entire surface region and RIE process is then performed to form the sidewall which is used as a mask for the second etch. After the sidewall etch, the second trench etch is performed by using the sidewall as a mask. Then thermal oxidation is carried out for filling the second trench.

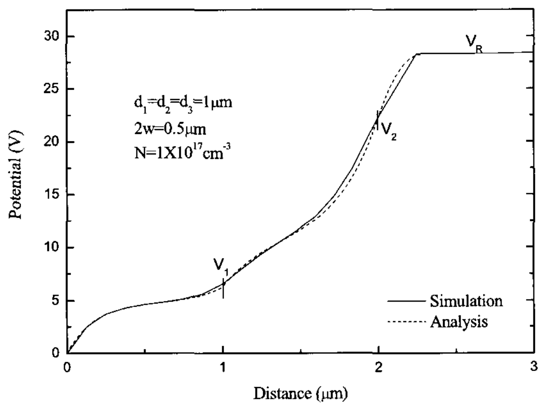
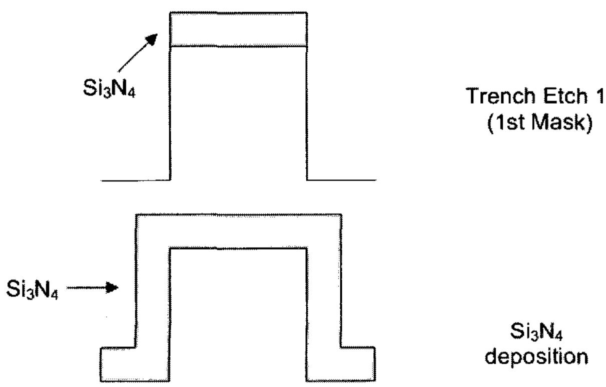


Fig. 8 Analytic and simulated potential lines along a vertical line passing through the Schottky contact at the middle of the silicon mesa

4. Conclusion

In conclusion, we have demonstrated that the current handling capability of the proposed TMBS rectifier can be increased significantly by using upper part of trench sidewalls as active area. Analytical expressions for the potential distribution are also derived, which allow a good accordance with the simulation results.



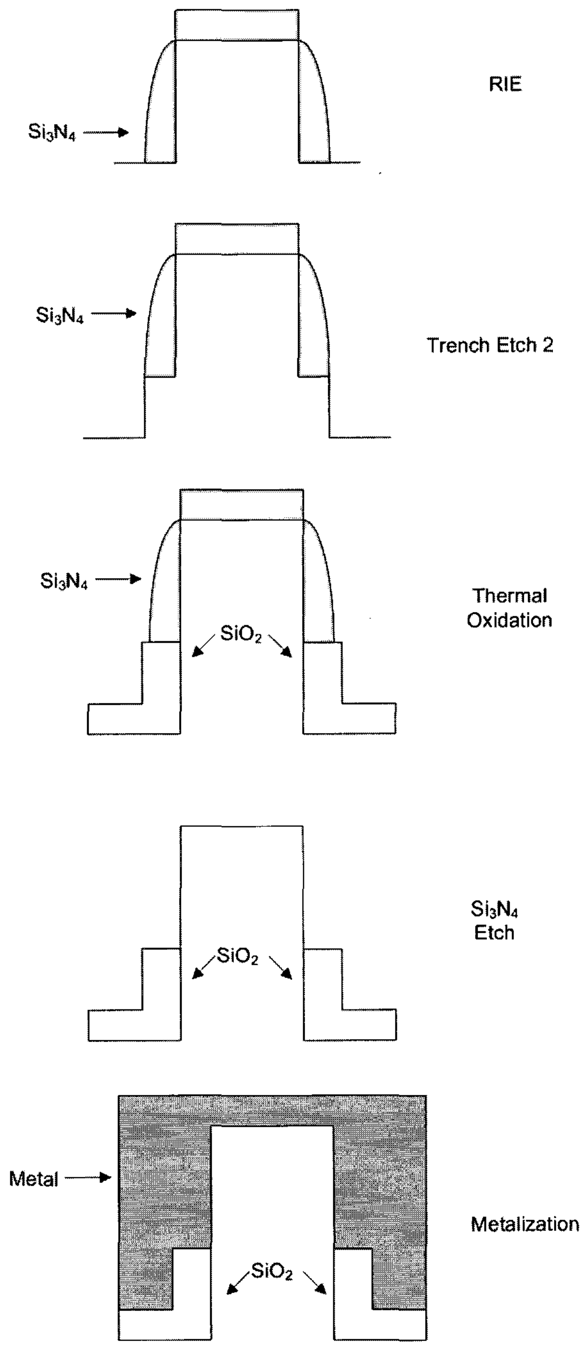


Fig. 9 Silicon processing sequences for proposed TMBS rectifier.

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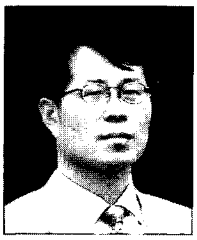

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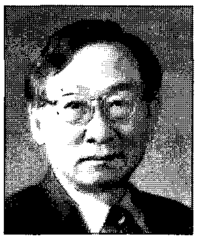

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