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A Low Loss Schottky Rectifier Utilizing the Trenched Side Wall as Junction Barrier Controlled Schottky Contact

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A Schottky diode, which has JBS structure vertically along the trench sidewall as well as laterally along the surface, has been proposed. The additional sidewall Schottky contact makes the current density increase by enlarging the active area. The forward voltage drop of a new device is equivalent to that of conventional Schottky diode. Besides a new trench structure push the peak electric field from Schottky contact to the silicon bulk. This effect diminishes the leakage current caused by the barrier height lowering effect. The leakage current of the proposed devices is 60% of that of the conventional Schottky diode at the same forward voltage drop.

1. INTRODUCTION

The low voltage power supply is required to drive the LSI circuits. A Schottky diode has high current density compared with a p-n diode in the low voltage regime (typically less than 0.6 V) but has large reverse leakage current. A JBS (Junction Barrier controlled Schottky) rectifier, which has the p-n junction grid, reduces the leakage current due to the surface electric field relaxation effect under the reverse bias[1,2] and the shape of p^+ region is very influential to the reverse leakage current supression[3]. However, p^+-n diode acts as a dead zone in the low voltage of 0.2~0.5 V. Therefore JBS diode inherently sacrifices the forward voltage drop.

In this paper, a new JBS diode utilizing the trench sidewall as a Schottky contact is proposed to compensate the p^+ dead zone of conventional JBS rectifier without using a shallow p^+ junction as shown in Fig. 1. The forward voltage drop and the reverse leakage current of the proposed device is numerically evaluated with the variation of trench depth and trench interval by the MEDICI. The trade-off relation of the forward voltage drop and the reverse leakage current is investigated.

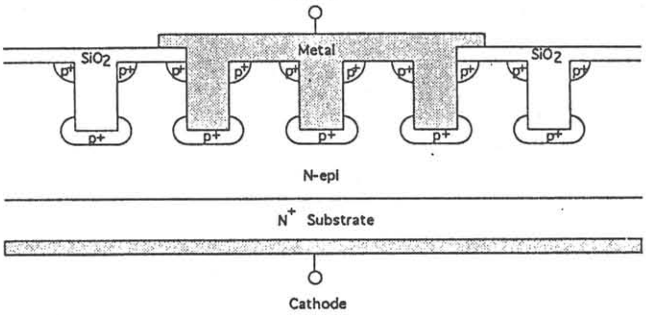

Fig. 1 Cross section view of trenched sidewall JBS rectifier

2. DEVICE STRUCTURE AND PARAMETERS

The unit cell of the proposed device is shown in Fig. 2. The Schottky contact is formed on the sidewall of the trench and the top surface. The thickness of the epi layer is 4 μm and doping concentration is 10^{16} cm^{-3}. These device parameters are chosen to obtain more than 40 V of the breakdown voltage. The barrier height lowering coefficient which influences the reverse leakage current, is fixed to 2×10^{-7} cm. The trench width is 1 μm. Other device parameters are

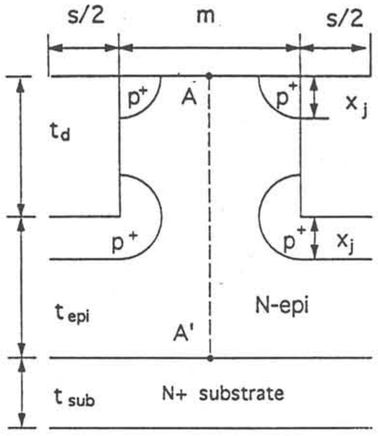

Fig. 2 Simulation structure and parameters

Table 1 MEDICI input parameters for the trenched sidewall JBS rectifier

n^+ substrate	100 μm thickness, $N_d = 10^{19} cm^{-3}$
n-type epi	4 μm thickness, $N_d = 10^{16} cm^{-3}$
p-type junction depth x_j	0.5 μm
m	2,3 μm
t_d	0,2,3,4 μm
s	1 μm
$q\phi_{BN}$	0.6eV
barrier height lowering coefficient	$2x10^{-7}$ cm
Richrdson constant	120 A/cm² K²

illustrated in Table 1. A novel structure may be fabricated without any additional mask by following step: boron implant, trench silicon with RIE, boron implant again and annealing. The proposed device structure is confirmed by process simulator (TSUPREM4) as shown in Fig. 3.

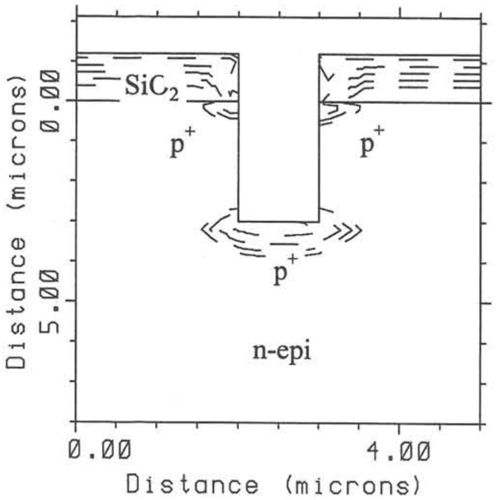

Fig. 3 Trenched sidewall JBS structure verified by TSUPREM4 : implant boron (40 KeV, $10^{15} cm^{-2}$), trench silicon with RIE, implant boron, and drive-in (1000 °C, N_2 ,30 min)

3. FORWARD CHARACTERISTICS

The forward voltage drop is theoretically calculated. V_F is defined as the forward voltage drop at the 60 A/cm^2 of current density. The current component through the p-n junction is negligible. The forward voltage drop of a new device can be mathematically expressed as follows.

$$J_{FC} = \frac{m + t_d - 3.4x_j}{m+s} \cdot J_{FS} \tag{1}$$

where J_{FC} is the current density per unit cell area and J_{FS} is the current density of Schottky diode. J_{FC} increases as the trench becomes deeper. Also it can be found that J_{FC} can be larger than J_{FS} when $t_d - 3.2x_j > s$.

$$V_F = \Phi_{BN} + \frac{kT}{q}\ln\left(\frac{m+s}{m+t_d-4w-3.4x_j}\cdot\frac{J_{FC}}{AT^2}\right)+$$
$$\left(\frac{\left(x_j+t_{epi}\right)(m+s)}{m+s-\left(m-2w-1.7x_j\right)}\ln\left(\frac{m+s}{m-2w-1.7x_j}\right)+t_d\right)\rho_{epi}J_{FC}$$
$$+t_{sub}\,\rho_{sub}J_{FC} \tag{2}$$

where w is junction depletion width.

The equation (2) expresses the forward voltage drop of Schottky diode connected with series resistance[4)]. The series resistance of the proposed device consists of the substrate, epi and trench region resistance. Fig. 4 illustrates the forward voltage drop of the trench structure with variation of the trench depth(t_d) and interval(m). Forward voltage drop of the proposed device becomes smaller with increasing the trench depth(t_d) and trench interval(m). As the trench interval increases, the forward voltage drop of the trenched JBS diode approaches to that of the conventional Schottky diode. When t_d=4 μm and m=3 μm, forward voltage drop is 0.3 V that is less than the conventional JBS by the 40 mV and is equivalent to that of conventional Schottky diode. The forward voltage drop of the trenched JBS diode is less dependent of trench interval(m) than those of the conventional untrenched JBS.

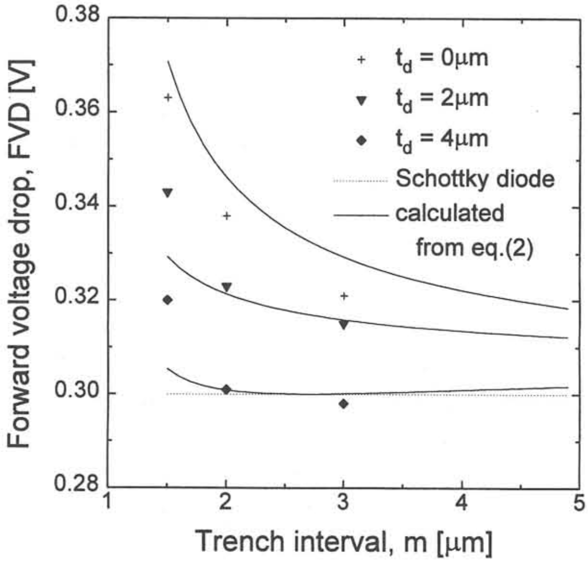

Fig. 4 Forward voltage drop with variation of trench depth (t_d) and trench interval (m) (J_f = 60 A/cm^2)

4. REVERSE CHARACTERISTICS

Under the reverse bias, the n-epi region between the trenches is depleted and the depletion region is expanded from the surface to the bulk semiconductor. The electric peak field shift to the bulk region and the surface electric field is reduced. The trenched sidewall JBS has reduced electric field not only at the surface contact but also at the sidewall contact. Fig 5. shows the electric field distribution at the reverse bias of 40V along A-A' of Fig. 2. With increasing the trench depth, the surface electric field decreases. The surface electric field of a new device is the quarter of the conventional Schottky diode. This effect diminishes the leakage current caused by the barrier height lowering effect.

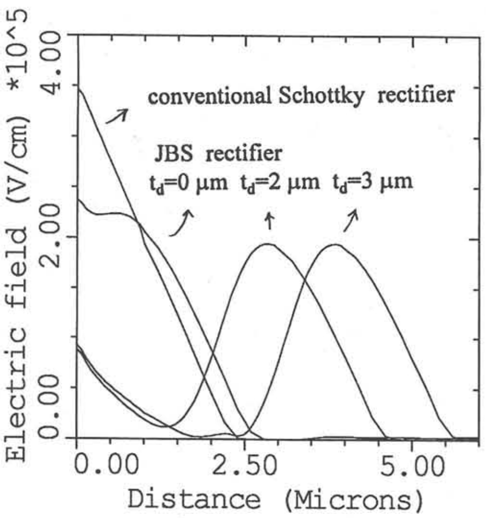

Fig. 5 Electric field distribution along A-A'(Fig. 2) (m = 2 μm, V_r = 40V)

Fig. 6 represents the trade-off relation of the forward voltage drop (V_F) and reverse leakage current at 40 V of reverse voltage. The proposed devices have improved the trade-off relation in comparison with the conventional Schottky diode. The edge of the device is terminated with the floating limiting ring. A new device with two floating rings has breakdown voltage of 45 V that is 90% of the 1-dimensional breakdown voltage for the $N_d=10^{16}$ cm^{-3}. The distances between the floating rings are 0.5 μm and 1 μm respectively.

5. CONCLUSION

The trenched JBS rectifier with side wall Schottky contact has been proposed to compensate the p^+ dead zone of the conventional JBS rectifier. Also the device is found to suppress the surface electric field, so the leakage current caused by the barrier height lowering effect is reduced. Consequently the forward voltage drop and reverse leakage current trade-off relation is improved. The reverse leakage current of the proposed device is less than 60 % of the conventional Schottky diode for the same forward voltage drop. Besides, 45 V of the breakdown voltage is obtained for $N_d=10^{16}$ cm^{-3} with two guard rings. The vertical JBS structure is expected to be applied to the lateral Schottky diode.

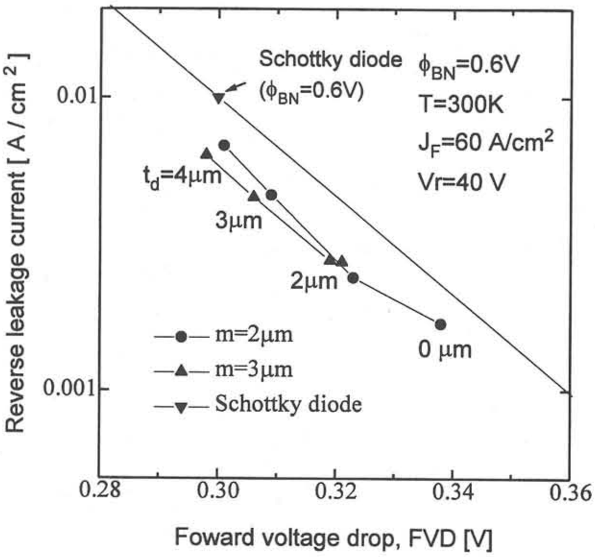

Fig. 6 Trade-off relation of forward voltage drop and reverse leakage current.

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