# A New Lateral Trench Sidewall Schottky (LTSS) Rectifier on SOI

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## ABSTRACT

In this paper, a new Schottky rectifier structure, called Lateral Trench Sidewall Schottky (LTSS) rectifier on SOI is presented. Based on two-dimensional simulations, we demonstrate that the proposed device is superior in performance as compared to the lateral conventional Schottky (LCS) rectifier. The LTSS structure provides upto 1.9 times higher breakdown voltage with low reverse leakage current as compared to the LCS rectifier. Unlike in the case of the LCS rectifier, the reverse breakdown of the proposed Schottky rectifier is very sharp similar to that of a PiN diode. Moreover, a 60 V LTSS rectifier is demonstrated to have the forward voltage drop as low as 0.28 V at 100 A/cm$^2$. Further, at high temperatures, the LTSS rectifier is shown to dissipate significantly lower power as compared to the LCS rectifier. The reasons for the improved performance of the proposed device are analyzed and the effect of metal field-plate on the forward characteristics is studied.

***Keywords***: SOI, numerical simulation, lateral Schottky rectifier, barrier lowering, field-plate.

## 1 INTRODUCTION

Low-voltage Schottky rectifiers find use in applications such as power supplies for integrated circuits requiring low power dissipation and fast switching speed. To reduce the power dissipation of a rectifier, it is desirable to minimize both the forward voltage drop and the reverse leakage current. For a Schottky rectifier, the tradeoff between the forward voltage drop and the reverse leakage current makes it is difficult to reduce both these parameters simultaneously. Further, the reverse leakage current of a conventional Schottky rectifier increases significantly with increasing reverse bias due to the barrier lowering effect leading to a low and soft breakdown voltage.

In the past, only a few vertical Schottky structures [1-3] have been reported with highly doped epitaxial layers to achieve low forward voltage drop and small reverse leakage current by suppressing the barrier lowering effect. However, the lateral Schottky rectifiers has gained special importance because they are ideally suited in the fabrication of power IC's. Therefore, the objective of the present work is to study for the first time, a Lateral Trench Sidewall Schottky (LTSS) rectifier on SOI epitaxial layer using a sidewall Schottky contact of a trench filled with a metal. To the best of our knowledge, such a structure has not studied in literature.

Based on our two-dimensional numerical simulation results, we demonstrate that the proposed Schottky structure provides significantly higher and sharp reverse breakdown voltage with low reverse leakage current compared to the lateral conventional Schottky (LCS) rectifier. The forward voltage drops of a 60 V LTSS rectifier is as low as 0.28 V at 100 A/cm$^2$ which is significantly lower than that reported for the GD-TMBS rectifier [3]. Furthermore, even at 80 °C, the power loss in the LTSS rectifier is only half that of the LCS rectifier.

## 2 DEVICE STRUCTURE

Fig. 1 shows the schematic cross-sectional view of the LTSS rectifier implemented on SOI in MEDICI [4]. The anode of the proposed device utilizes the sidewall

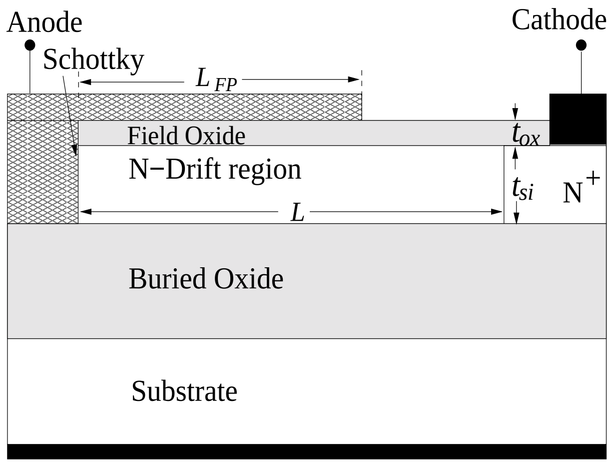


Figure 1: Cross-sectional view of the LTSS rectifier.

Schottky contact of the trench filled with a metal. For the LCS rectifier, the anode is a planar surface Schottky contact. Nickel (Ni) is used for the Schottky barrier (0.57 V) metal [5]. The field-plate termination technique is employed to reduce the electric field crowding at the Schottky contact during reverse bias. The cathode of the device is an ohmic contact taken from the $N^+$ region.

# 3 SIMULATION RESULTS AND DISCUSSIONS

## 3.1 Current-Voltage Characteristics

The simulated forward characteristics of the LCS and LTSS rectifiers are shown in Fig. 2 for the epitaxial layer doping of $5x10^{16}$ and $8x10^{16}cm^{-3}$. For both the devices, the forward characteristics are identical and exhibit very low forward voltage drop (e.g. 0.28 V at 100 $A/cm^2$). For a smaller drift region doping, the forward voltage drop increases slightly at higher current densities due to an increase in ON resistance of the device. The simulated reverse characteristics of both the LCS and LTSS structures are shown in Fig. 3. As can be seen, the reverse leakage current of the LCS rectifier increases significantly with applied reverse bias giving an extremely soft breakdown characteristic. Whereas, the LTSS rectifier provides 1.6 to 1.9 times higher breakdown voltages with significantly lower reverse leakage current as compared to the LCS rectifier. Further, it is important to note that the reverse breakdown of the proposed Schottky rectifier is very sharp similar to that of a PiN junction diode. This

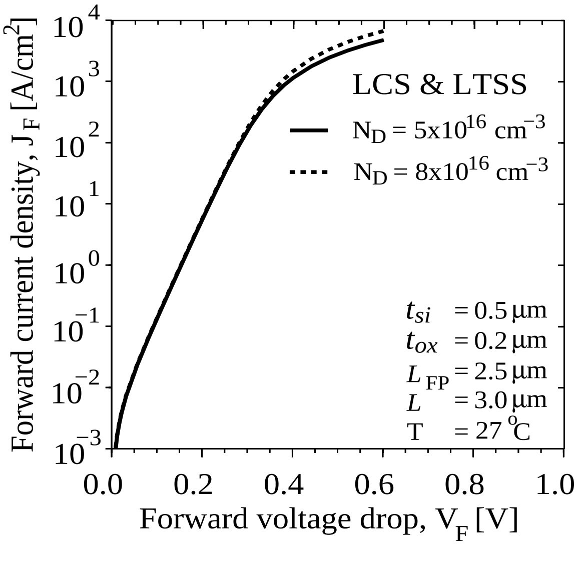


Figure 2: Simulated forward characteristics of the LCS and LTSS rectifiers.

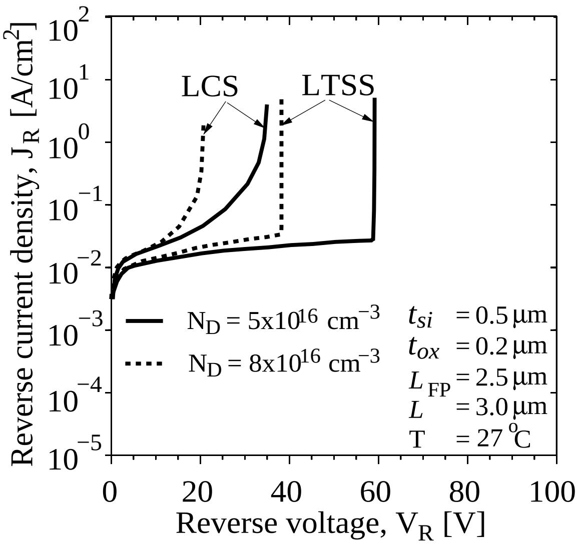


Figure 3: Simulated reverse characteristics of the LCS and LTSS rectifiers.

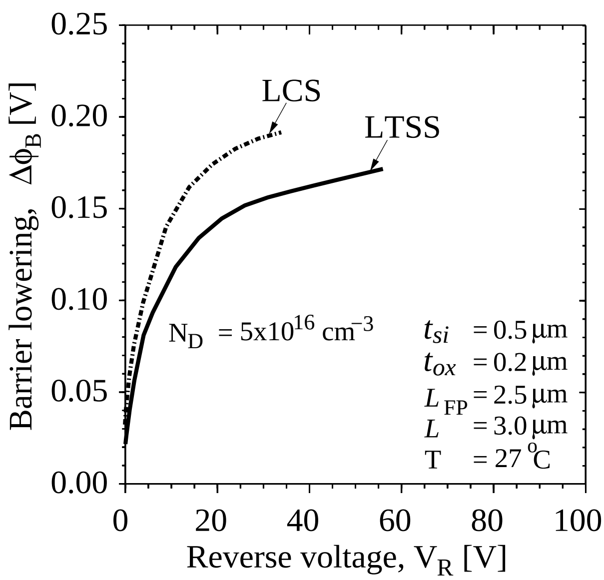


Figure 4: Barrier lowering as a function of reverse bias voltage for the LCS and LTSS rectifiers.

remarkable improvement in the reverse characteristic of the LTSS rectifier is due to the reduced barrier lowering effect at the Schottky contact as discussed below.

The simulated Schottky barrier lowering as a function of reverse bias is shown in Fig. 4 for the LCS and LTSS rectifiers. As seen, in the case of the LCS rectifier, the enhanced barrier lowering causes a rapid rise in the reverse leakage current resulting in a low and soft breakdown voltage. On the other hand, in the case of the LTSS structure, the suppressed barrier lowering

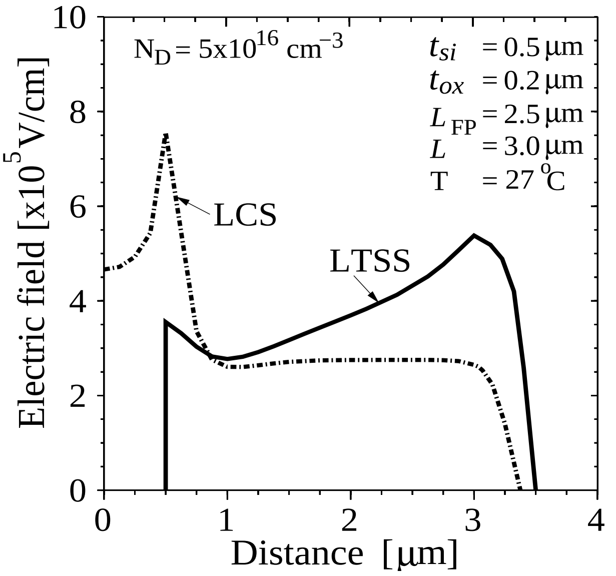


Figure 5: Electric field variation along the horizontal line near the field-oxide/silicon interface.

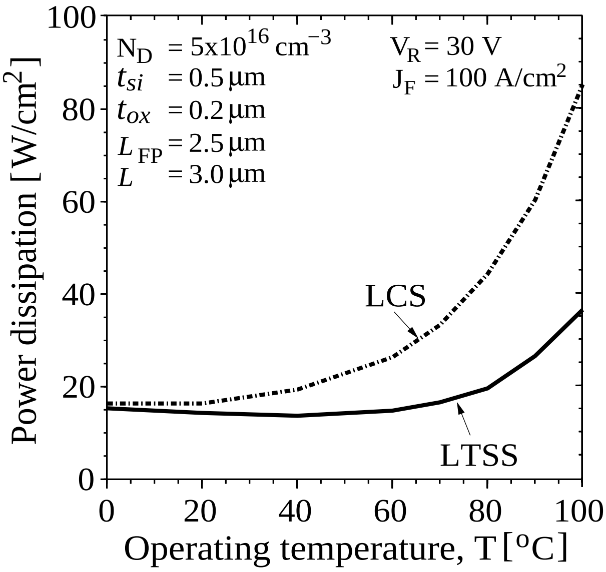


Figure 6: Power dissipation as a function of temperature for the LCS and LTSS rectifiers.

reduces the reverse leakage current significantly eliminating the soft breakdown of the device. This can be better understood from Fig. 5 which shows the electric field variation along the horizontal line at the field-oxide/silicon interface near breakdown for both the devices. As seen, in the case of the conventional Schottky, the presence of peak electric field at the Schottky contact causes a soft breakdown characteristic due to an increased barrier lowering effect. Whereas, for the LTSS rectifier, the reduced electric field at the Schottky contact suppresses the barrier lowering effect resulting in a smaller reverse leakage current. Further, we note that the peak electric field in the proposed structure occurs at the end of the field-plate causing the avalanche breakdown to take place at this point (away from the Schottky contact). This gives a large improvement in the breakdown voltage of the LTSS rectifier.

## 3.2 Power Dissipation

The power dissipated by a rectifier depends upon its operating temperature due to the variation in both the forward and reverse characteristics with temperature. For a 50% duty cycle, the calculated power dissipation as a function of temperature for the LCS and LTSS rectifiers is shown in Fig. 6 at a forward current density of 100 A/cm$^2$ and reverse bias of 30 V. It can be observed that at low temperatures, both the rectifiers dissipate approximately equal power due to their identical forward voltage drop which dominates the power losses for these temperatures. As the operating temperature is increased, the rise in the reverse leakage current dominates the power losses in the device resulting in an increased power dissipation with temperature. We notice that at higher temperatures, the LTSS rectifier dissipates significantly lower power as compared to the LCS rectifier. For example, at 80 °C, the power loss in the LTSS rectifier is only half that of the LCS rectifier. This improvement in the power dissipation of the proposed device is due to its lower reverse leakage current as compared to the conventional device.

## 3.3 Effect of Field-Plate on Forward Characteristics

The forward characteristic of the LTSS rectifier can be significantly improved by reducing its ON resistance for a given drift region doping. This can be achieved by choosing an appropriate field oxide thickness such that an accumulation layer is formed under the oxide during the forward bias. To the best of our knowledge, the effect of this accumulation layer has not been studied in literature for a lateral device. To study this effect, the simulated forward characteristics of the LTSS rectifier with and without field-plate for an oxide thickness of 100 A° are shown in Fig. 7. In this figure, we have also plotted the forward characteristic of the LTSS structure by replacing the field oxide (dielectric constant of 3.9) with the silicon nitride (dielectric constant of 7.5). We note that the presence of the field-plate in the LTSS rectifier provides significantly higher forward current densities (e.g. 38% and 64% with $SiO_2$ and $Si_3N_4$ respectively at $V_F = 1$ V) as compared to the unterminated structure. This is due to the formation of an accumulation layer in the drift region below the field dielectric during the forward bias which results in

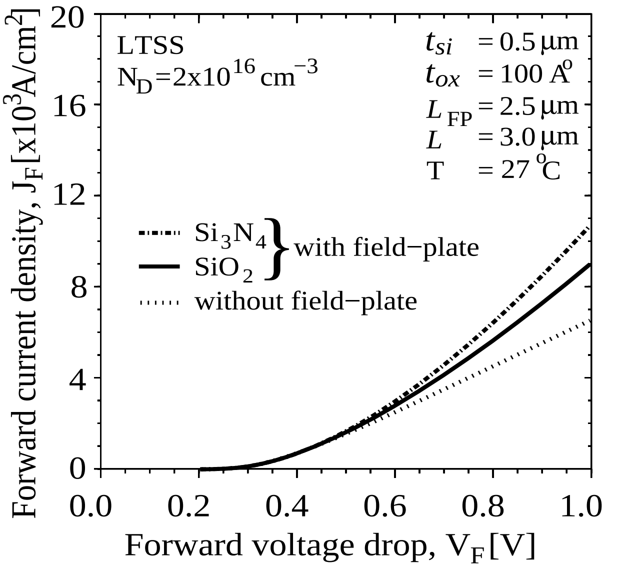


Figure 7: Simulated forward characteristics of the LTSS rectifier with and without field-plate termination.

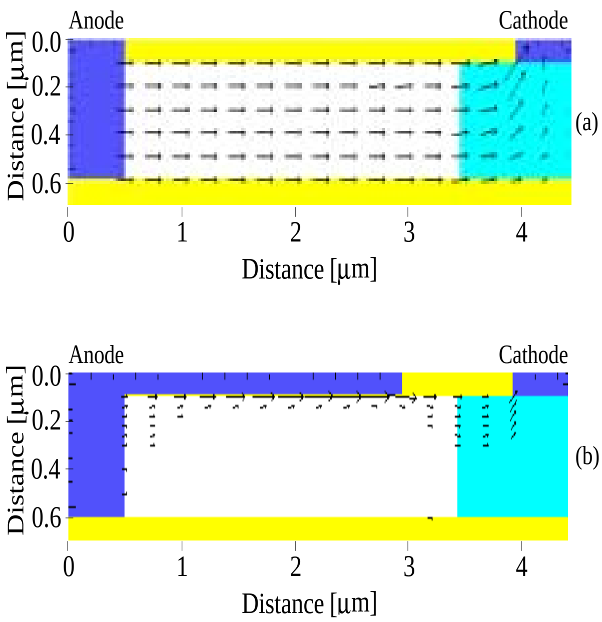


Figure 8: Current vectors in the drift region of the LTSS rectifier (a) without field-plate and (b) with field-plate termination for a forward bias of 1 V.

a reduced ON resistance. This can be easily understood from the current vectors shown in Fig. 8. As can be seen, for the unterminated structure, the current flow is uniform in the entire drift region. On the other hand, for the device with field-plate termination, most of the forward current flows through the accumulation layer closer to the field-dielectric/silicon interface. Further, the higher dielectric constant of the $Si_3N_4$ leads to the formation of a stronger accumulation layer resulting in a higher forward current density as compared to the $SiO_2$.

## 4 CONCLUSIONS

The novel characteristics of the Lateral Trench Sidewall Schottky (LTSS) rectifier on SOI have been presented. Using two-dimensional simulation, we have demonstrated that the proposed device provides a low forward voltage drop, low reverse leakage current and higher reverse breakdown voltage as compared to the LCS rectifier. It is important to note that the proposed LTSS structure is shown to have extremely sharp reverse breakdown voltage. By studying the electric field distribution and the barrier lowering at the Schottky contact, we have analyzed the reasons for this remarkable improvement in the reverse characteristics of the LTSS rectifier. Furthermore, at higher temperatures, the power losses in the LTSS rectifier are found to be significantly lower as compared to the LCS rectifier. For the first time, we have shown that the presence of field-plate improves the forward current density significantly. The combined low forward voltage drop, low reverse leakage current, low power dissipation, make the proposed device most suitable for low-voltage low-loss high-speed power IC applications.

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