O-4-03

A Novel Edge Termination Design for Superjunction VDMOS

Chia-Hui Cheng[1], Chih-Fang Huang[1], Kung-Yen Lee[2]
[1]Institute of Electronics Engineering, National Tsing Hua University Hsinchu 30013, Taiwan, R.O.C.
[2]Department of Engineering Science and Ocean Engineering, National Taiwan University Taipei 10617, Taiwan, R.O.C.

1. Introduction

In order to break the silicon limit between $R_{on,sp}$ and BV, the superjunction (SJ) concept has been proposed and realized [1]. Compared to conventional N^- drift region with the same BV, SJ drift region can be more heavily doped, providing a lower on-state resistance. However, conventional termination designs may not be applicable in SJ devices due to the structure and process complexities [2]. In this paper, we propose a novel termination structure based on a multi-epi process in SJ technology. The termination width can be much reduced compared with the floating guard ring approach.

2. Device Concept and Structure

In theory, the maximum electric field in a PN junction in a cylindrical coordinate as shown in Fig. 1 can be described as [3]

$$E_{max,CYL}=\frac{qN_D({r_D}^2-{r_J}^2)}{2\epsilon_s r_J} \qquad (1)$$

The maximum electric field $E_{max,CYL}$ is enhanced by approximated a factor of $r_D/2r_J$ than the parallel-plane junctions and this is exactly the reason why an edge termination is needed. From Eq. (1) if the junction depth r_J can be increased then $E_{max,CYL}$ will be reduced, and BV is expected to improve. Deep junctions typically are not easy to implement but multi-epi process in SJ technology offers an opportunity. As shown in Fig 2 (a), the mask layout for P-column implantation in our proposed structure can be designed such that multi-zone is created by adjusting implantation window spacings and widths in each zone. In this case, the N-column is formed by N-epilayers and only P-type implants are required to form N- and P-columns (Single Implant). Then, after a thermal diffusion, the P-type islands diffuse and merge with each other as shown in Fig. 2 (b), forming a laterally graded junction with a large radius of curvature. In addition, a vertically graded doping profile can also be achieved by selecting different implant doses for different epilayers. Moreover, in some cases where N-column are formed by N-type implant in the cell region [4], N-type implants can also be introduced without additional process and cost in the proposed edge termination to compensate the p-type doping (Double Implant), as shown in Fig. 3, offering more design flexibility. As a result, a deep junction can be formed in the termination with a large radius of curvature and a reduced net doping near the junction, both of which help relieve the electric field crowding caused by two dimensional or three dimensional effects.

3. Simulation Result

First, the proposed structure is studied with numerical simulation. Fig 4 compares the potential contours and lateral electric field distribution in single implant terminations with and without lateral grading. Device structures of six epi-layers with a total thickness of 57 μm were chosen. As shown in the figure, with lateral grading the electric field distribution is more uniform and the peak electric field is reduced. BV is therefore improved from 586 V to 609 V. Fig 5 compares the potential contours and vertical electric field distribution in single implant terminations with and without vertical grading. As can be observed in the figure, vertical grading has a similar effect and reduces the peak electric field. BV is improved from 586 V to 600 V in this case. The termination with both lateral and vertical gradation shows a BV of 626V. Fig 6 illustrates the potential contours in a termination with a double implant approach to achieve both lateral and vertical grading. In this case, simulated BV is 724V.

4. Experiment Results

SJ VDMOSs with the proposed termination were fabricated in an 8-inch wafer process. Fig. 7 shows the measured (a) Id-Vd(ON) and (b) BV(OFF) curves from a device with an active area of 0.61 mm^2. BV is 660V and Ron,sp is 2.3 $\Omega\cdot mm^2$. The layouts of the proposed termination and the floating guard ring termination with a similar BV rating are shown in Fig. 8(a) and (b). The termination width of the proposed structure is 73μm, much less than that of the guard-ring structure (221μm). A microphotograph image of the fabricated device is shown in Fig. 8(c).

5. Conclusion

In this paper, a novel termination structure for SJ VDMOS is proposed and its performance is verified by simulation and experiment. The electric field distribution within this termination can be adjusted more uniformly with laterally or vertically graded doping design. From the experiment results, a breakdown voltage higher than 600V together with a specific on-resistance is smaller than $2.5\Omega\cdot mm^2$ can be achieved with a drift region layer thickness of 57 μm and a termination width of 73 μm.

Acknowledgement

The authors are grateful to Macroblock Inc. for their support. This work was supported in part by the Ministry of Science and Technology under Grant 105-2221-E-007 -105 -MY2.

Reference

[1] X. Chen and J. Sin, IEEE Tran. Electron Dev. **48** (2001) 344
[2] N. Reinelt et al., 13th European Conf. on Power Electronics and Applications (2009).
[3] Y. Liang et al., Power Microelectronics: Device and Process Technologies (2017) 66
[4] S. Ono et.al, ISPSD (2008) 161

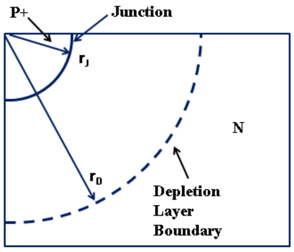
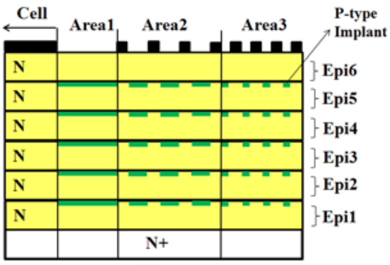
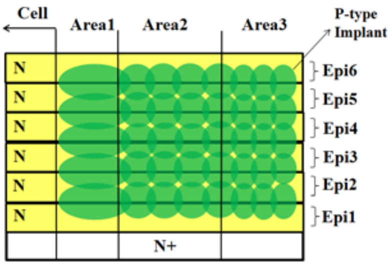


Fig. 1. Structure of a cylindrical PN junction.



(a)



(b)

Fig. 2 (a) Doping distribution after P-type implant and before thermal diffusion. (b) doping profile after thermal diffusion

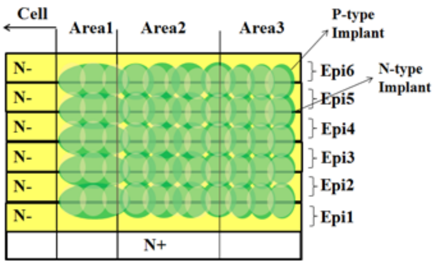
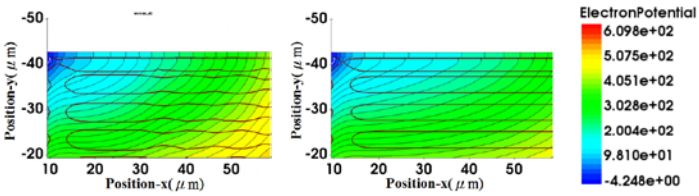
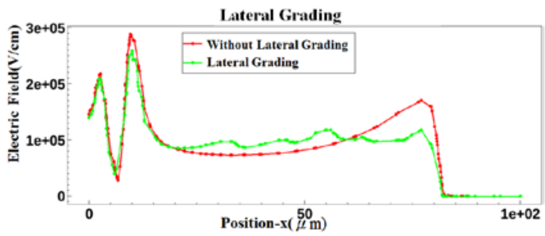


Fig. 3 Doping distribution after thermal diffusion with both P-type and N-type implants introduced in the termination

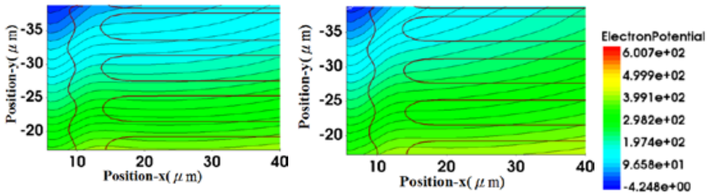


(a) (b)

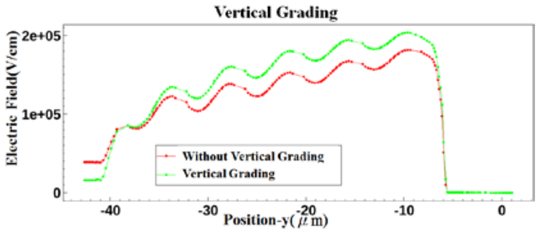


(c)

Fig.4 (a) Potential contours in the proposed structure with lateral grading (b) potential contours without lateral grading (c) comparison of surface electric field distribution.



(a) (b)



(c)

Fig. 5. Potential contours in the proposed structure with vertical grading (b) potential contours without vertical grading (c) comparison of electric field distribution in the vertical direction.

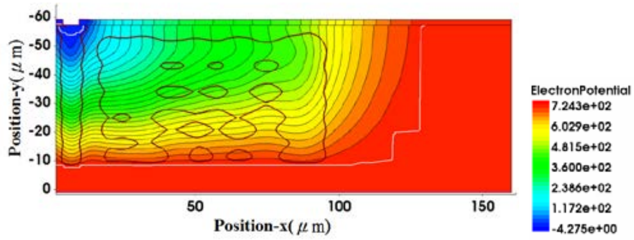


Fig. 6 Potential contours in a double implant structure with both lateral and vertical grading.

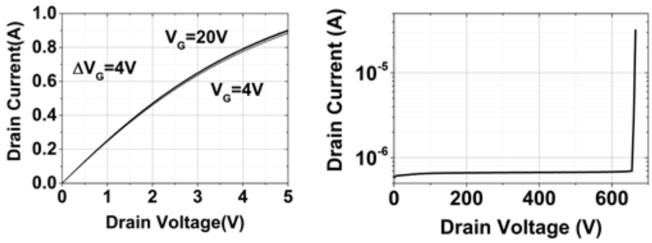
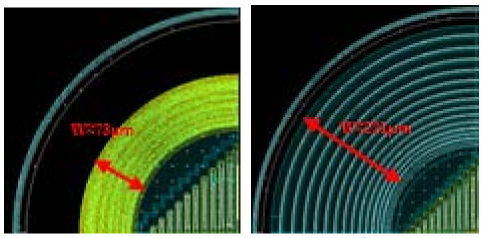
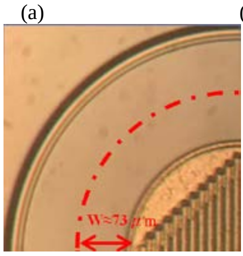


Fig. 7 The measured (a) I_D-V_D (b)BV of a fabricated device.



(a) (b)



(c)

Fig.8 (a) Layout of a proposed termination (b)layout of a floating guard ring termination (c)microphotograph of a fabricated device with the proposed termination.