Super Junction Power MOSFET by Multi-step Trench Process

Jhih-Ming Wang¹, Kun-Yu Tai¹, Li-Cih Wang¹, Chris Lin², Chao-Hsin Huang², Chrong-Jung Lin¹, and Ya-Chin King¹

¹Microelectronics Laboratory, Semiconductor Technology Application Research (STAR) Group, Institute of Electronics Engineering, National Tsing-Hua University, Hsin-Chu 300, Taiwan ² Taiwan Semiconductors CO., LTD.

Phone/Fax: +886-3-5715131-34034 / +886-3-5721804, E-mail: ycking@ee.nthu.edu.tw

Abstract

This work presents a novel way of realizing super junction for above 600V power MOSFET applications by multi-step trench process. This method alleviates the p/n pillar depth and pitch design constraints limited by process capability. In addition, p/n doping levels on each layer as well trench depth in termination region can be independently designed for better optimized super junction performance.

Introduction

In recent years, the super junction structure has been widely used in power device because this device can reduce the specific on-resistance of the power MOSFETs below the Si-Limit [1]. Several methods of fabricating super junction in power MOSFETs has been proposed such as multi-step epitaxial growth [2] and trench filling technique [3]. Trench filling method is generally easier on the process end and less costly than the epitaxial growth. However, it is very difficult to realize high-aspect-ratio n/p pillars though conventional trench filling technique. In this paper, we propose the multi-step trenching/filling technique to implement high-aspect-ratio super junction structure. The proposed the multi-trench process can not only effectively alleviate the deep trench filling problem, but also provide better process margin in the implementation of super junction power devices. This multi-trench process allows additional design freedom in the number of trench and doping concentration in each epitaxial layers, which can lead to better breakdown performance in both the main and termination regions.

Device Structure and Characteristics

Figure 1 outline the process parameters and steps for the following simulation analysis. Figure 2(a) shows the cross section of 40 μ m deep p/n super junction fabricated by the 2-step trenching/re-filling process with p/n doping level equally at 3x10¹⁵ cm⁻³. The p/n pillar pitch is design to be 5 μ m to ensure proper filling and charge balance behaviors of this multi-trench super junction. The simulated breakdown characteristic of this super junction is shown in Figure 2(b), indicating that a breakdown voltage can easily pass 700V. The inset of Figure 2(b) suggested that the highest electric field occurs at the middle to the top trench as a result of the different thermal cycle on the top and bottom layers during this 2-step epi process. Based on the extracted doping profiles along the two cutlines, we found that the pn junction profile can be much more gradual than

that of the top layer, which lead to uneven distribution of potential in this super junction. To reduce the difference in doping level between the top and bottom layer, the doping level of the p-refill of the bottom layer is lower by 10-30% As indicating in Figure 3, a slightly lower p-fill doping levels can effectively enhance the overall breakdown characteristics by more than 5%. The charge imbalance effect of this 2-trench super junction is summarized in Figure 5, suggesting a $\pm 18\%$ tolerance for 600V design. Figure 6 shows cross-sectional view of the planer gate super junction MOSFET, where its threshold voltage is found to be at 1.46V by the gm maximum method. Figure 7 shows the specific on-resistance versus breakdown voltage for this design. As compared to the reported data [4-8], this power MOSFET exhibits slighter better performance level than similar devices realized by conventional methods.

Since the trench angle an limit by process capability, for the same pillar depth, increased number of trench step can effectively enhanced the evenly potential distribution of the super junction. As expected, the IV characteristics in Figure 8 shows by increase the number of trench step, a closer to ideal (90 degree trench) can be obtained, hence, higher breakdown voltage is achieved. However, increase the number of trench steps can lead to two challenges,. First, higher process cost as a results of repeated masking/trenching/refilling process. Second, the thermal budget on the bottom pn junction will increase accordingly to affect the potential distribution vertically. Hence, we believe the number of trench step should be limit to less than 5 to maintain its competiveness. With two different masks in defining the top and bottom layer, the termination region can be better design with an additional parameter of trench depth. As illustrated in Figure 9, by removing the bottom trench at the edge, the breakdown voltage can be improved with evenly distributed potential at the edge. Charge imbalance effect on the termination region is summarized in Figure 10. The drastic drop of breakdown voltage as a result of slightly lower p concentration can be alleviated by independently optimized doping for each layer.

Conclusion

In this paper, super junction MOSFET realized by multiple trenching/refilling steps are investigate by simulation analysis. This method can not only alleviate the process challenge on the trench aspect-ratio by also enhance design freedoms to better enhance super junction performance.

Starting wafer : <100>P-substrate	Process parameters	
N epitaxial Layer<23um>	Trench Angle	87 ⁰
Deep Trench<20um>	Trench Depth	20um & 2 layer
Sidewall implant	N-Epi Temp	1000°C
P epitaxial Layer<20um>	P-Epi Temp	1000°C
N epitaxial Layer<24um>	Sidewall	3X10 ¹² cm ⁻²
Deep Trench<24um>	Implant	Energy=20Kev
Sidewall implant	P-base	3X1013cm-2
P epitaxial Layer<24um>	Implant	Energy=200Kev
P-base Implant	Oxide thickness	0.1um
Deposition oxide and poly-silicon	Source	2X1013cm-2
Source Implant	Implant	Energy=25Kev



(b) the IV characteristics indicating a breakdown voltage of 724V.

Figure. 1 Super Junction MOSFET process flow and process parameters.



Figure 3 Boron and phosphorus doping profile at both the top and bottom trench cutlines.



Figure 6 Parallel gate MOSFET structure for device characteristics simulation



Fig. 9 11-ring termination design (a) with the same top and bottom trench mask (b) with different trench masks.



Figure 4 By decreasing the top trench concentration, Na2, breakdown voltage can be improved effectively.



Figure 5 Charge imbalance effect for 2-trench step super junction











Fig. 8 Number of trench steps can affect the cell's breakdown voltage.

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