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Scaling the Floating Field limiting Ring (FLR) Edge Termination with a 'bell shape' Surface Electric Field Profile to High Voltages

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Summary

For the first time, this paper demonstrates scaling of the FLR (Floating Limiting Ring) or guard ring edge termination with a 'bell shape' surface electric field profile. The p-type FLRs are implemented using lightly doped deep p-well ($\sim 10^{16}$cm^{-3}) implant and a second implant (known as p-base) done after the p-well drive, to boost the surface doping in the region of ($\sim 10^{17}$cm^{-3}). The later provides immunity to variation in Si/SiO_2interface charge due to inadvertent variation in processing. Experimental data shows that the p-well/p-base FLR structure is area efficient, robust and verified for 1.2 kV, 1.7kV and 3.3kV MOS controlled devices such as the IGBT (Insulated Gate Bipolar Transistor) and CIGBT (Cluster Insulated Gate Bipolar Transistor).

Introduction

Conventional FLR edge termination for high voltage power devices employing FLR include field plates in conjunction with FLR and hybrid JTE with FLR [1,2] all use highly doped deep p+ rings. They are area inefficient because the depletion region mainly extends into the lightly doped n- substrate, leaving a large redundant region area within the deep p+ FLR not used in supporting voltage. The 3D Resurf-Super junction concept is very area efficient but requires tightly controlled charge balance [3]. In the 'area efficient' FLR concept [4], deep lightly doped p-wells enable the depletion region to extend significantly into ring compared to deep p+. Hence efficient use of silicon is made in blocking voltage because the redundant area is greatly reduced. Additionally, a shallow p+ off-set implant ($\sim 10^{19}$cm^{-3}) was used to improve immunity to inadvertent variation in SiO_2/Si interface charge. However at high voltages the p+ prevents the depletion moving into the rings resulting in field crowding and high surface fields. To extend the capability, the shallow p+ is replaced with a p-base implant (peak doping $\sim 10^{17}$) [5]. However the p-base implant is not off-set relative to the p-well.

P-well/p-base Edge Termination structure Design and Results

The design methodology used to determine ring distances ensures consecutive ring spacing increases by a constant r (typically $< 2\mu$m) as in equation 1 [4]. The methodology results in a surface electric field that is a 'bell shape'. The 'bell shape' electric field profile provides immunity to instability effects at the interface causing

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electric field variations. Moreover, the bell-shape profile ensures bulk rather than surface breakdown.

$$d_m = d_{m-1} + r \quad (1)$$

$$V_m = V_{PT}(d_m) + V_{dep} \quad (2)$$

Equation 2 describes the potential supported by each FLR and the voltage capability of a structure is a sum of these. The process simulator Tsuprem4 has been used to derive simulation structures while the device simulator Medici, used to compute the number of FLRs required for a given voltage capability based on given r and d_1[6]. Although this paper shows experimental results for 1.2 kV, 1.7kV and 3.3kV devices [7], extensive simulations have shown that the methodology can be used to design FLR with wider voltage ratings.

References

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