Green's Function Approach for Three-Dimensional Diffusion Simulation of Industrial High Voltage Applications

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Abstract

In todays high voltage processes the optimization of process and layout design is a key point to get competitive products. Effects like punch-through between two junctions and breakdown near the surface of the wells make it necessary to analyze complex three-dimensional process steps by simulators which give accurate answers to the process engineers.

1 Introduction

In multiple well technology the relatively low dopant concentration and the high applied voltage cause large space charge regions, which results in a big waste of space and an increase of the on-resistances.

The investigated structure is part of a high voltage PMOS transistor. To optimize the two-dimensional section of the PMOS transistor, it is necessary to ensure that no other three-dimensional effects dominate the device characteristic. In the actual device the critical three-dimensional part is the area at the tip of a drain finger where the drain PTUB is placed inside a Shallow/Deep NTUB combination (SDNTUB) which is located above a p-doped substrate. In normal operation the PTUB is biased up to 90V so that the PTUB/SDNTUB junction is biased in reverse direction and a space charge fills the area between the PTUB/NTUB junction and the SDNTUB/substrate junction. The complete device area is located in a shallow NTUB. To achieve the required PTUB/NTUB reverse voltage, a DNTUB mask should enlarge the distance of the PTUB/NTUB and the SDNTUB/substrate junctions. The layout of the well masks is shown in Fig. 1. A small DNTUB finger mask is located inside the PTUB mask. The long diffusion of the NTUBs finally leads to an NTUB/substrate junction which is located outside of the PTUB mask. The three-dimensional simulation is necessary because the spherical diffusion of the DNTUB implant dilutes the DNTUB concentration in the area of the finger's tip. This leads to punch-through at low bias between the PTUB and the substrate.

2 Simulation Method

The conventional simulation procedure is to simulate the whole ion implantation process first [1] and then the three-dimensional transient diffusion [2]. Thereby both steps require a particularly refined grid to achieve the needed accuracy [3] and, therefore, the vast amount of memory and huge calculation times constitute prohibitive demands in practice.

Alternatively we have chosen a method, specially adapted to this problem. Because of the long diffusion ranges, the exact simulation of the ion implantation process could be neglected and the implanted ions were assumed as Dirac impulses only located at the

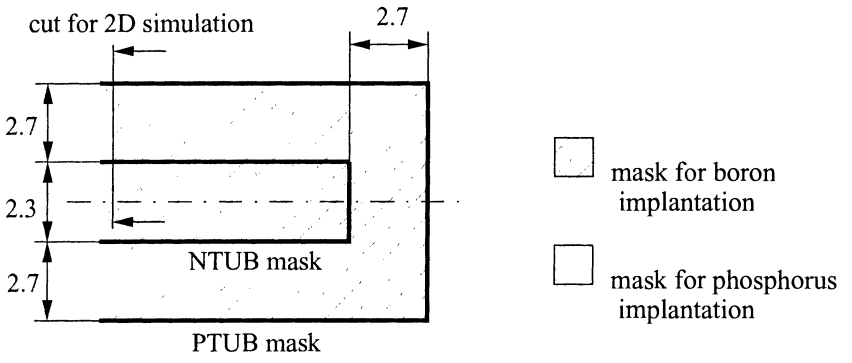


Figure 1: Layout of the well masks, units in μm

wafer top. With this simplification the final diffusion profile inside the wafer can be calculated as the sum of some partial diffusion processes, represented by the Green's function of the diffusion equation [4].

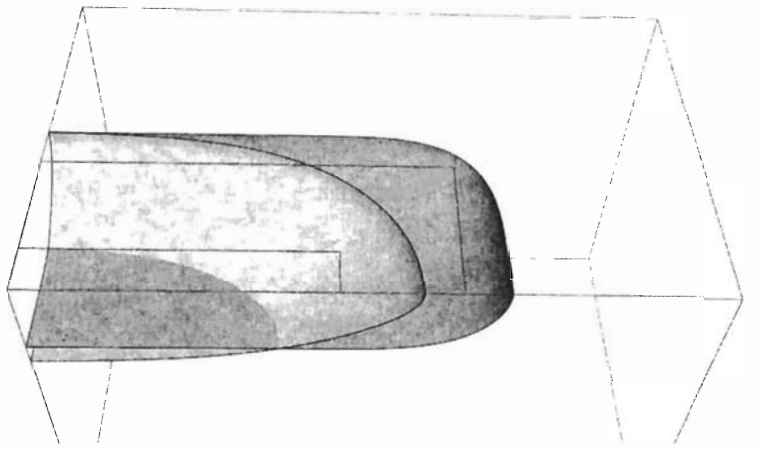
Attention must be placed to preserve the dose of the implanted ions and therefore a dose integration after implantation and after simulation must be carried out. In addition these models have to be calibrated by the two-dimensional simulation results which are available far away from the tip of the finger. For the full three-dimensional simulation a sufficiently fine grid in the areas of high diffusion gradients must be granted and therefore the simulation time was enormous, whereas for the simplified algorithm a grid is only necessary at the surface of the wafer and the resulting doping can be calculated at any point of interest. It is to note that a limitation of this method occurs, if the ranges of the implantation depth and diffusion width get in the same size.

The assessment criterion of the new layout parameters is given using the fact that the dopant concentration of the PTUB/SDNTUB junction at the surface of the wells is the same for the two-dimensional case and the three-dimensional finger case. This ensures that the breakdown at the surface in the three-dimensional structure takes place in the same voltage range as compared with the two-dimensional structure.

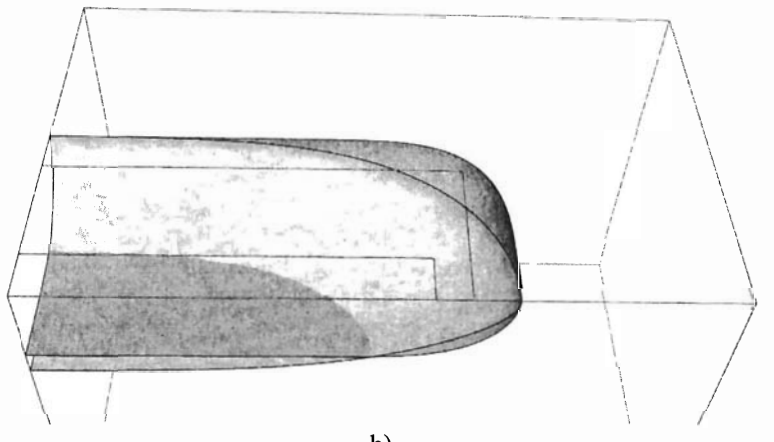
3 Results

The simulation results show that the spherical out-diffusion of the DNTUB is larger than expected because of the large NTUB depth. This depth is about 7.5 μm in the two-dimensional simulation. The spherical diffusion length is also in the same size from the top of the DNTUB finger to the direction of the two-dimensional case. In fact the two-dimensional situation is given when the DNTUB mask is enlarged by about 7 μm as compared to Fig. 1. This means that the DNTUB mask even can exceed the PTUB mask. However an enlargement of 7 μm would cause impact ionization near the surface's PTUB top. So the limiting case of the DNTUB enlargement is the dopant concentration of the two-dimensional simulation at the surface of the junction. This critical concentration is given when the DNTUB mask is shifted by 2 μm towards the PTUB mask. This is shown in Fig. 2, where the upper one represents the original mask layout and the lower one shows the enlarged finger behavior.

Another interesting effect is that the punch-through in the three-dimensional case does not occur directly under the symmetry line of the finger. The explanation is that the DNTUB dopant diffuses in spherical coordinates while the PTUB dopant diffuses in cylindrical coordinates. The punch current therefore has its maximum density near



a)



b)

Figure 2: Relevant iso-surfaces of the phosphorus and boron dopings, with a simulation domain of 15.7μm x 10μm x 10μm

the edge of the PTUB mask, confer Fig. 3, a). With the enlargement of the finger the punch-through is completely avoided as shown in Fig. 3, b).

4 Conclusion

With these careful considerations the device has been optimized to fulfill electrical strength, particularly with regard to punch-through between the junctions and break-down by impact ionization. Without the outlined simulation methodology it would not have been possible to fully optimize the structure.

Acknowledgment

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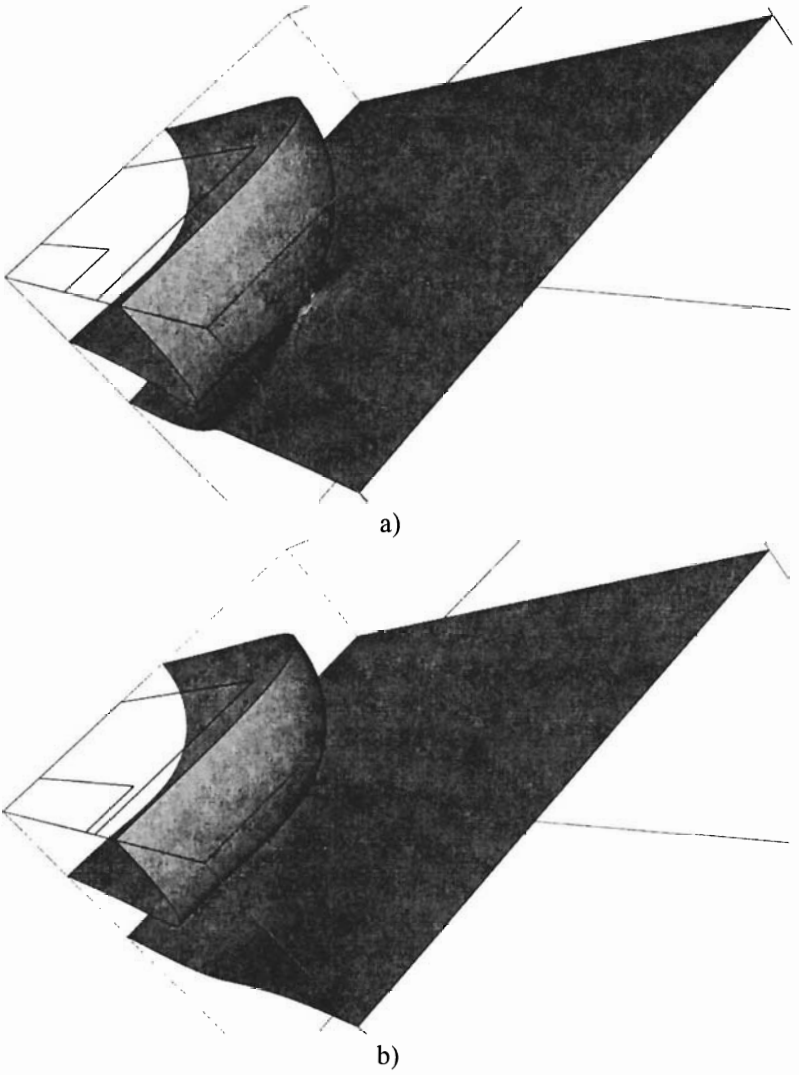

Figure 3: Surfaces surrounding the space charge regions

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