Optimization of Industrial High Voltage Structures by Three-Dimensional Diffusion Simulation

Johann Cervenka, Peter Fleischmann, and Siegfried Selberherr
Institute for Microelectronics, TU Vienna
Gußhausstraße 27–29, Vienna, Austria
cervenka@iue.tuwien.ac.at

Martin Knaipp and Franz Unterleitner
Austria Mikro Systeme International AG
Unterpremstätten, Austria

Abstract

A major goal in the process development of high voltage processes is the design of devices with given breakdown voltages and low switch on resistances. To reach this goal it is necessary to optimize the space charge regions of the device. Unfortunately these effects are three-dimensional and a device optimization needs the support of accurate three-dimensional simulation, which is shown in this article.

1. Introduction

The requirement for a low switch on resistance ($\mathrm{R_{on}}$) is to design a single device as small as possible. The reduction of space charge regions is limited by the dopand surface concentration of the wells which may result in impact ionization effects in case of too high doping concentrations. On the other hand, lowering the doping concentrations is limited by the required punch-through voltage. To fulfill these conflicting criterions the doping concentrations must be optimized.

2. Simulated structure

The investigated device is the tip of a drain finger of a high voltage PMOS transistor. To optimize the two-dimensional PMOS transistor it is necessary to ensure that no three-dimensional effects dominate the device behavior. The drain finger is implanted using a PTUB mask. To obtain proper electrical isolation from the wafer substrate, the PTUB is located in a shallow NWell (SNTUB) deep NWell (DNTUB) combination (SDNTUB). The PTUB, SDNTUB and the substrate form a pnp structure and under normal operation the PTUB/SDNTUB junction is biased in reverse direction. The optimal drain finger layout ensures that when applying maximal $\mathrm{V_{dd}}$ no punch-through between PTUB and substrate happens and no avalanche breakdown occurs at the surface of the wells. The complete device is embedded in the SNTUB so that there is no direct connection between PTUB and substrate. Only in the area of the PTUB, the DNTUB determines the distance between the pn- and the np-junctions. The PTUB/DNTUB mask layout is given in Fig. 2, which shows that the DNTUB

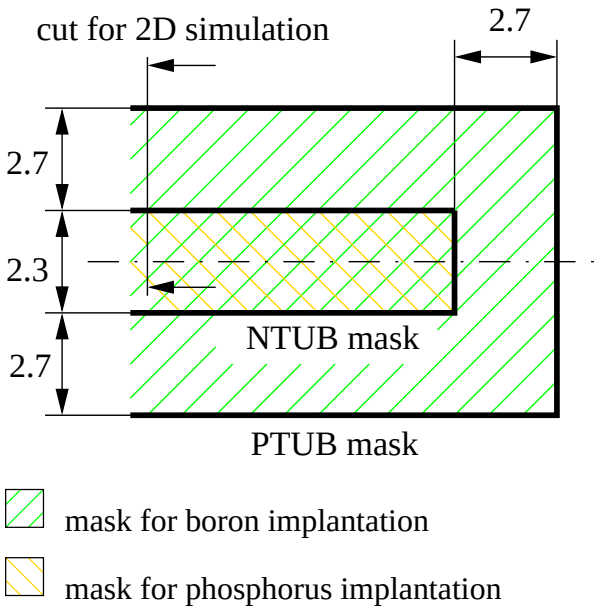

Figure 1. Well mask layout, units in μm

mask is enclosed by the PTUB mask. To enlarge the distance between the two junctions it is necessary to use a long DNTUB diffusion time so that at the tip of the drain finger the DNTUB dopands nearly diffuse spherically. This long DNTUB diffusion finally leads to a DNTUB formation which starts outside of the PTUB mask. The three-dimensional consideration is necessary because the spherical diffusion of the DNTUB dilutes the DNTUB concentration in the area of the finger's tip and thus reduces the punch-through voltage of the PMOS device.

3. Comparison of simulating approaches

The conventional 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 appropriate 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 can be neglected and the implanted ions were assumed as Dirac impulses only located at the 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].

4. Calibration and evaluation

Attention must be put 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 distribution can be calculated at any point of interest. It is to note that a limitation of this method is obviously given, if the ranges of the implantation depth and diffusion width get in the same size.

The assessment criterion of the new layout parameters is 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.

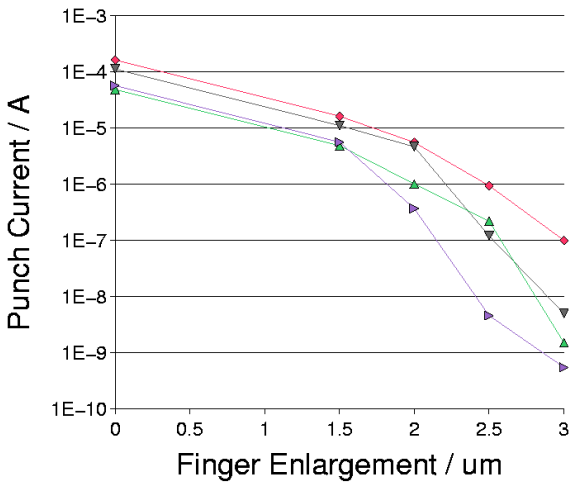

Figure 2. Measured punch current of four test devices, depending on the finger enlargement, substrate connected to -90V

5. 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 micron 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 micron as compared to Fig. 2. This means that the DNTUB mask even can exceed the PTUB mask. However an enlargement of 7 microns 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 microns towards the PTUB mask (see Fig. 3).

The simulation results are validated by a set of test devices. Figure 2 shows the punch current dependence of the finger elongation starting with the initial layout (Fig. 2).

Another interesting effect is that the punch-through in the three-dimensional case does not occur directly under the symmetry line of the finger (see Fig. 4). The explanation is that the DNTUB dopands diffuse spherically while the PTUB dopands diffuse cylindrically coordinates. The punch current therefore has its maximum density near the edge of the PTUB mask.

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

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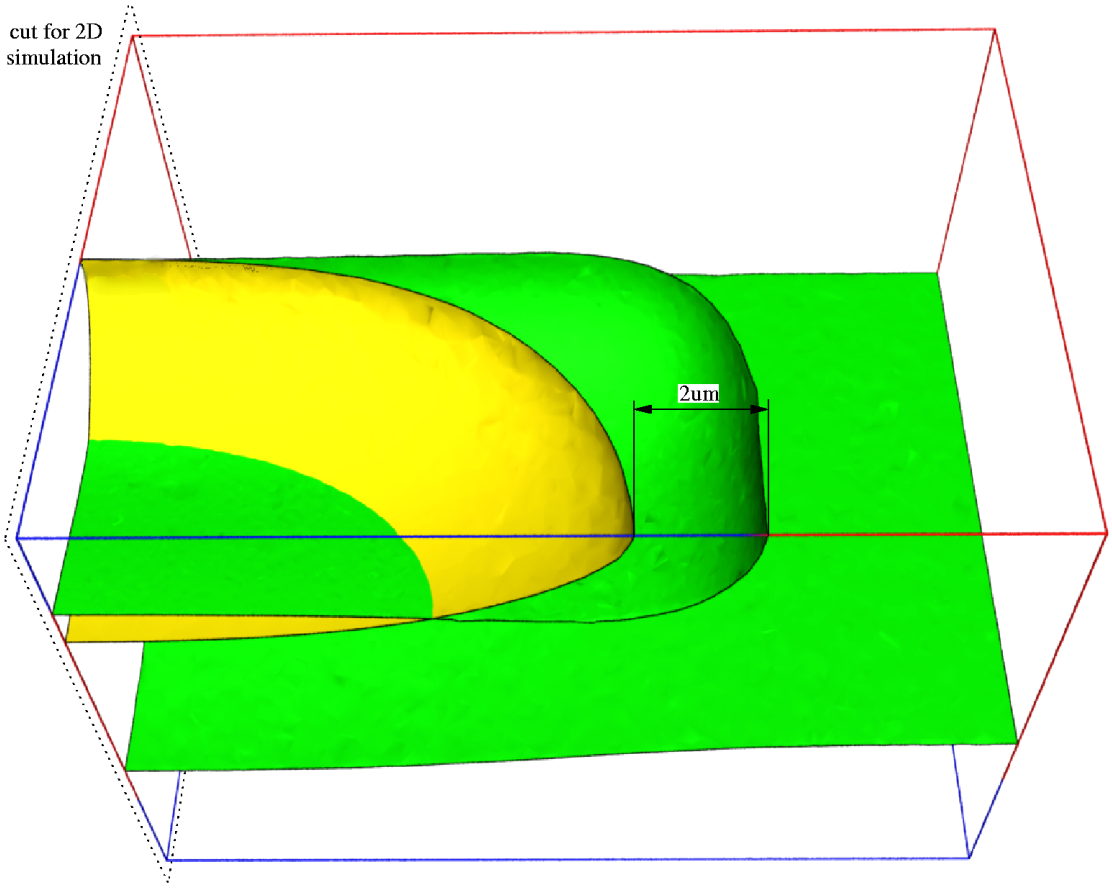

pn-junction, where the upper one also represents a boron iso-surface

phosphorus iso-surface

Figure 3. Relevant iso-surfaces of the junctions and the phosphorus doping with a simulation domain of 15.7μm x 10μm x 10μm

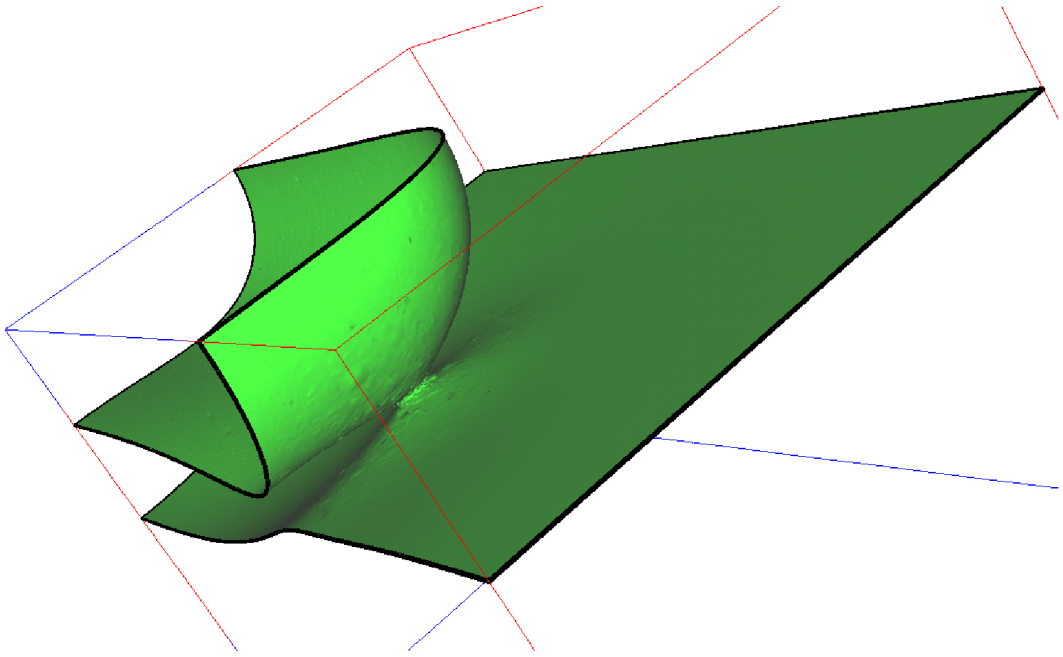

Figure 4. Surface surrounding the space charge region between both pn-junctions