ELIMINATION OF MESHING NOISE IN STATISTICAL TCAD

V. Axelrad, G. Long, P. Kuepper°

PDF Solutions Inc., San Jose, USA
°Siemens AG, Munich, Germany

Introduction

As with any solution technique relying on a numerical approximate solution, TCAD is subject to numerical approximation errors. These have to be considered over and above any inaccuracies in the implemented physical models or their coefficients.

The numerical approximation errors have to be carefully controlled to ensure that the results of the simulation are not masked by these errors. The only degree of freedom that a TCAD user has in this respect is the mesh, i.e. the finite element decomposition of the simulation domain. It is well known that TCAD results are sensitive to the density and quality of the mesh used for the simulation.

The subject of this work is to study and eliminate the effects of meshing noise in the context of statistical simulations. Not surprisingly, it turns out that meshing noise can easily be a source of very significant errors for statistical results, even more so than it is the case for “standard” TCAD simulations such as calculating doping profiles or current-voltage characteristics. The reason is that statistical simulation extracts information from a multitude of simulation distributed in input parameter space. If changes in input parameter values lead to abrupt changes in the simulation mesh, the subtle second-order effects that statistical simulation is interested in become masked by meshing noise. Thus for instance while the relative error of the transistor drive current may be within 5%, its sensitivity to an implant dose or mask dimension may be off by over 50%.

This problem is particularly severe when multidimensional process simulation is used, as is required for the simulation of advanced submicron technologies. The common approach in this case is to use the mesh produced by the process simulator. This mesh is typically rather poorly suited for device simulation. In addition, the placement and density of nodes in these meshes in general depend on the process conditions (so called adaptive meshing), which can easily result in the above mentioned meshing noise when process conditions change. For a more detailed discussion of the problem cf. [1].

In this paper we demonstrate the problem using an industrial 0.5 micron CMOS process, where the use of standard commercial process and device simulation tools[1] is unsatisfactory for obtaining statistical data in a reasonable time. In particular, unless a very fine is used the results (absolute values and even more so sensitivities) are inaccurate. The conventional approach of using a fine compromise mesh for both process and device simulation requires long simulation times and can affect the convergence behavior.

A solution to this problem is replacing the process simulator-created mesh by a new one, optimized for device simulation. As a result, significant speed-up (up to 5-10X) and high accuracy are achieved. This was accomplished using a new product from PDF Solutions called pdMesh [1,2].

Conventional Approach

The current widely used approach to integrated multidimensional TCAD is characterized by the use of the same triangulation for both process and device simulations. The needs of the device simulation thus are incorporated into the mesh utilized during the process simulation. An example is shown in Figure 1, left. This approach suffers from several well-recognized major drawbacks:

- The simulation mesh is typically substantially larger than the one required for either process or device simulation. This is due to the fact that device simulation has very specific needs to mesh density in electrically active

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- Control over both quality and density of the final mesh is rather difficult, since the compromise mesh is a result of an initial mesh specification and subsequent mesh modifications during the process simulation. Especially if adaptive meshing is used during process simulation [3], the mesh is modified substantially during steps such as implantation, diffusion and oxidation. The resulting mesh is usually of poor quality and typically has too many nodes in areas not relevant for electrical device operation.

The new approach addresses both these problems.

Proposed Methodology

The proposed methodology is based on a new tool from PDF Solutions, Inc. called pdMesh. pdMesh uses a robust

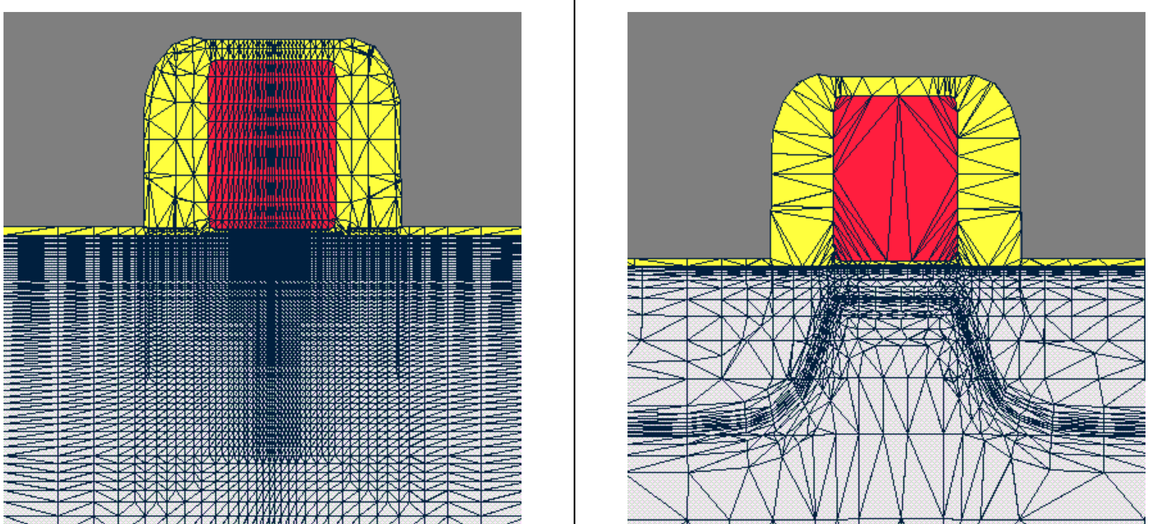

Figure 1 Conventional compromise mesh (left) and an optimized device simulation mesh generated with pdMesh (right). Note the anisotropic mesh layers in the channel and at the pn-junctions in the new mesh. This allows to achieve the same vertical node spacing at a much lower node count than when using the mesh shown on the left (generated by TSUPREM-4).

and efficient meshing strategy to place mesh nodes and element edges in the simulation domain and connect them to a Delaunay mesh. More details on the meshing algorithm are provided elsewhere [1],[2]. The main characteristics of the proposed approach are as follows:

- The tool uses a powerful extension language (Tcl) to adapt to particular device types and specific requirements to the mesh to be generated. Layers of mesh nodes can be placed explicitly where they are needed.
- Original material boundaries as generated by the process simulator are preserved. Only modifications to boundaries as requested by the user in the Tcl control file (device-type specific meshing template) are performed. These can include refining and unrefining the boundary. Complex geometries do not pose a stability problem as commonly observed with quad-tree based algorithms.
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- Highly anisotropic meshes can be created (see Figure 1, right) which are essential to treat inversion layers, junctions, etc.

Statistical Simulation with Conventional Meshing

Conventional methodology for integrated process/device simulation involves running the device simulation with the same mesh as generated by the process simulator. In this approach the needs of the device simulator must be taken into account when setting up the initial mesh for the process simulator since the needs of the two are different.

Implications of this are illustrated in Figure 2 and 3. Case A shows what happens when a coarse compromise mesh is used. While this mesh (about 800 nodes) is sufficient to obtain accurate process simulation results, its channel and junction resolutions are much too coarse to ensure accuracy in device simulation. As seen in Figure 3, the resulting current values (IDsat) are wrong by about 30%, even worse is the sensitivity of IDSat with respect to spacer width.

To achieve reasonable accuracy in the conventional approach we are forced to use a much finer mesh with a higher node count than would ne necessary for either process or device simulation individually. Case B shows that with approximately 4500 nodes it is possible to satisfy the accuracy needs of both the process simulator and the device simulator. Of course, this is paid for by a significant increase in CPU time and memory needs. Similar results can be obtained with somewhat coarser meshes, however most users seem to prefer to err on the high side. The mesh used in Case B was built based on a target vertical channel mesh spacing of approximately 3 nm.

Table 1: CPU times (UltraSparc1) for a 0.5 micron PMOS, cases A,B,C shown in Figure 2.

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Conclusions

Statistical simulation aggravates a well-recognized and serious problem in TCAD: while accuracy of results is sensitive to the mesh, robust and efficient meshing tools to address this need have not been available. Furthermore, sensitivities of electric device parameters to process controls and mask dimensions are even more difficult to obtain with sufficient accuracy.

In the conventional approach the meshing problem is addressed by using a very dense mesh throughout both process and device simulation. This leads to long simulation times and sometimes to poor convergence. To obtain statistical information, multiple TCAD simulations need to be carried out, making the conventional approach less and less feasible. The new meshing procedure eliminates gridding noise and reduces CPU time, making statistical simulations accurate and fast.

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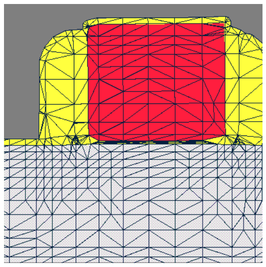
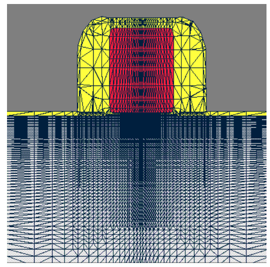
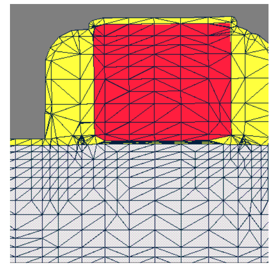
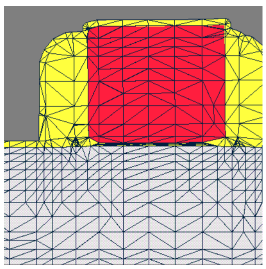
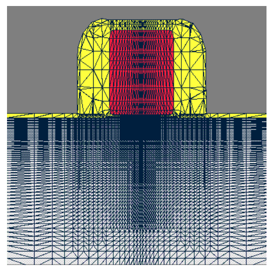
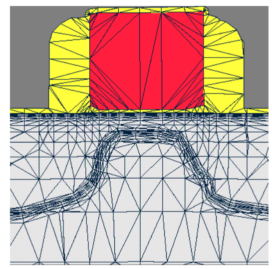
mesh after process simulation	800 nodes 	4500 nodes 	800 nodes 
device simulation mesh	800 nodes 	4500 nodes 	800 nodes 
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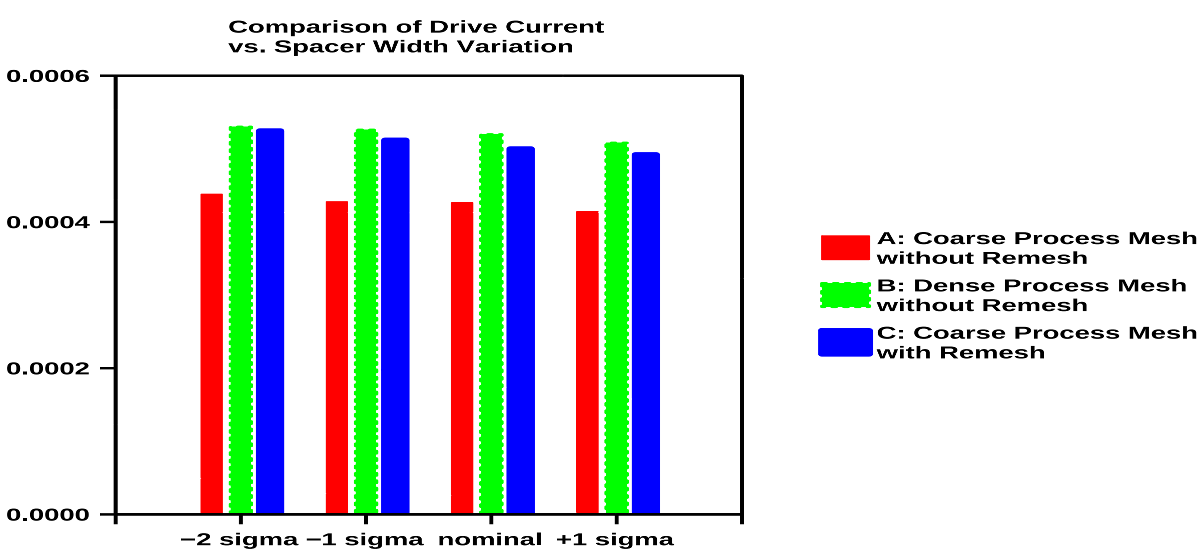

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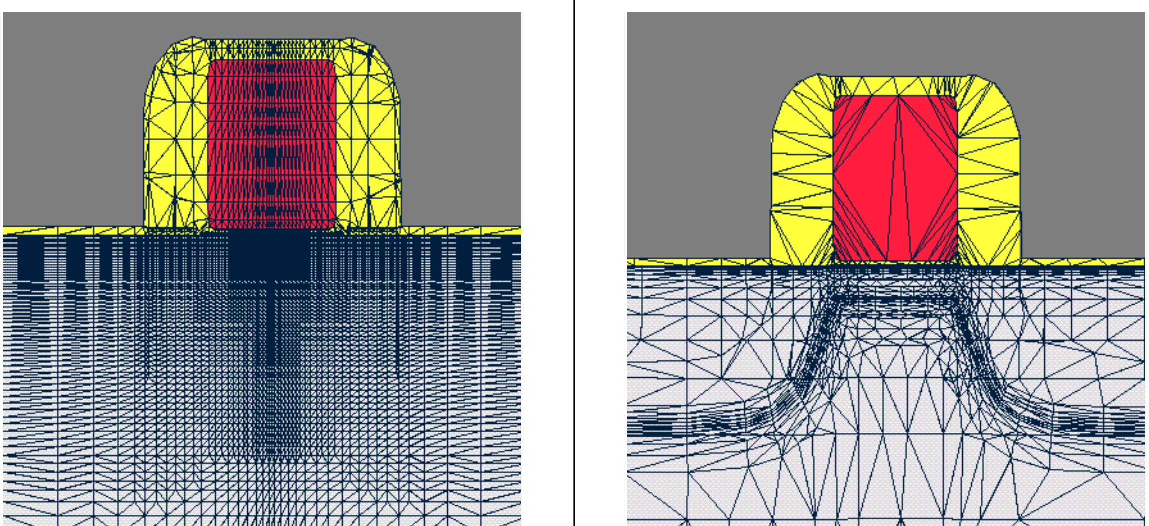

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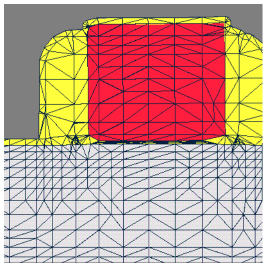
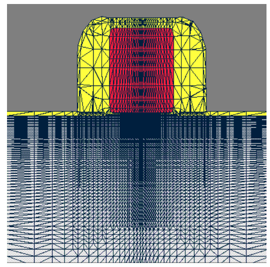
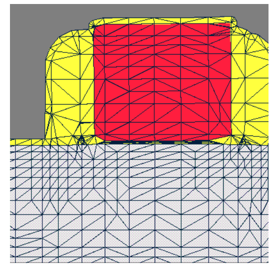
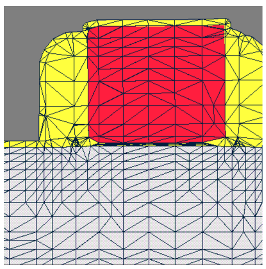
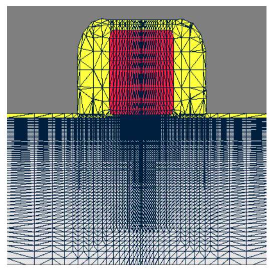
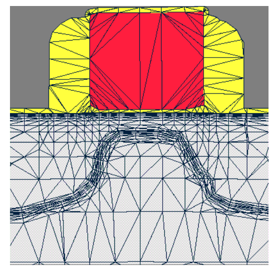
mesh after process simulation	800 nodes 	4500 nodes 	800 nodes 
device simulation mesh	800 nodes 	4500 nodes 	800 nodes 
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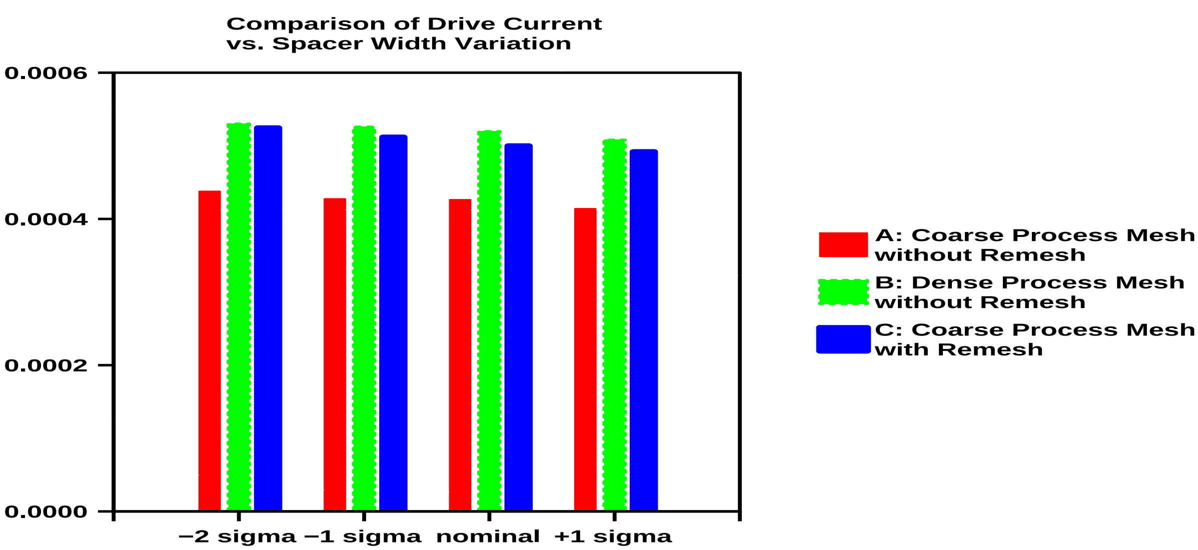

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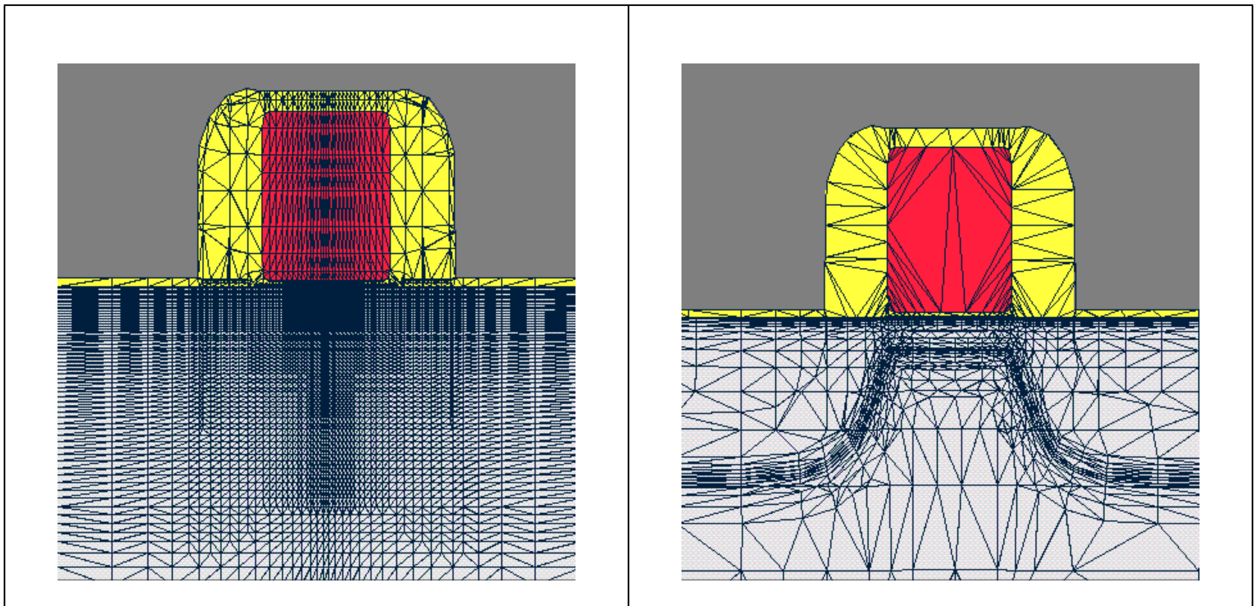

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References

[1] V. Axelrad, "*Robust and Accurate Mesh Generation for Statistical TCAD Applications*", PDF Solutions, White Paper, Dec. 1996
[2] V. Axelrad, "*Automatic Generation of Quality Triangulations for 2D Device Simulation*", to be published
[3] Technology Modeling Associates, "TSUPREM-4", 1996
[4] Technology Modeling Associates, "MEDICI", 1996

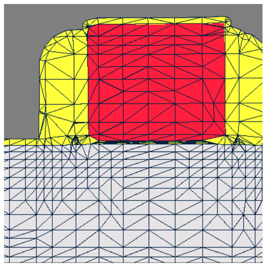
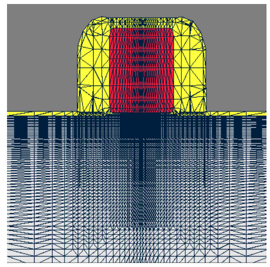
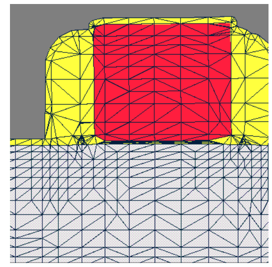
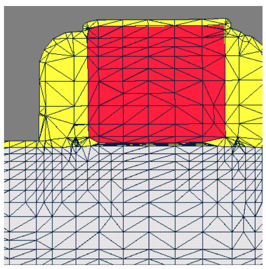
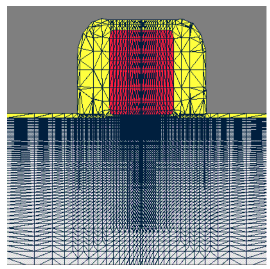
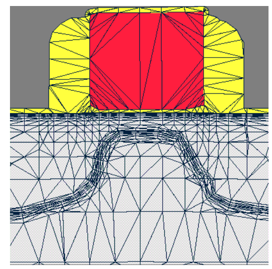
	A: no pdMesh (coarse)	B: no pdMesh (fine)	C: pdMesh (coarse)
mesh after process simulation	800 nodes 	4500 nodes 	800 nodes 
device simulation mesh	800 nodes 	4500 nodes 	800 nodes 
	fast, inaccurate	slow, reference	fast, accurate

Figure 2 A summary of meshing experiments. A: coarse compromise mesh, B: fine compromise mesh, C: remeshing using pdMesh decoupling the device mesh from the process mesh.

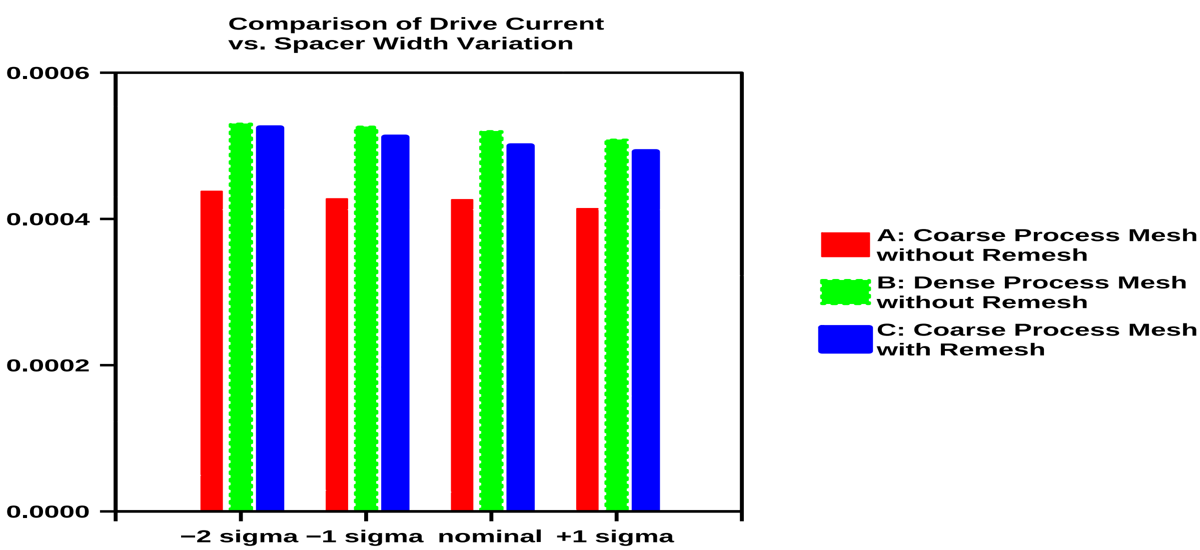


Figure 3 Calculated values for Idsat vs. spacer width