A Boundary Conforming Mesh Generation Algorithm for Simulation of Devices with Complex Geometry

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Abstract—An automatic boundary conforming mesh generation algorithm is proposed for device simulation. The algorithm provides meshes with extremely anisotropic elements stretched along the boundaries and gridlines orthogonal to the boundaries and p/n junctions. The meshes created are especially efficient for simulation of MOSFETs with curved channel surfaces.

I. INTRODUCTION

The most popular approaches for creating process and device simulation meshes are the octree/quadtree method [1], which generates a somewhat "structured" mesh, and an advancing front method [2], which generates a "totally unstructured" mesh. An ideal mesh for device simulation using the Scharfetter-Gummel discretization scheme should have gridlines orthogonal to the carrier flow lines [3] (i.e., orthogonal to the channel surface for MOSFETs) and be highly anisotropic in order to reduce the number of mesh nodes.

The octree/quadtree method is close to ideal for simple devices with rectilinear geometry and planar surfaces, but it might not be an optimum choice for a device with complex geometry. Some limitations of the octree/quadtree method are that it can not provide a highly anisotropic mesh along curved surfaces (like a curved MOSFET channel), it does not produce orthogonal gridlines near curved surfaces, it is hard to construct meshes for complex geometries, and it can be very sensitive to small geometry changes.

The advancing front method easily handles arbitrary geometries and the mesh generated is not sensitive to small geometry variations, but it is neither anisotropic, nor orthogonal to the carrier flow lines in the surface conductive layers.

This paper presents a new mesh generation algorithm which creates highly anisotropic elements with gridlines, orthogonal to the region's boundaries.

II. ALGORITHM

The proposed mesh generation algorithm is illustrated in Fig. 1. First, mesh edges are created along the region's boundaries. Then, for each region, mesh elements are constructed in sequential layers while moving from the boundary towards the region's interior. These layers can be constructed in a robust and efficient way by moving the boundary using the level set method [4].

For box-like regions with adjacent rectilinear external boundaries (for example, region "Silicon" in Fig. 1), the mesh layers are generated starting from the part of the region's contour which is curved or interfacing with other regions of the device. For all other regions (such as the region "Oxide" in Fig. 1) the mesh layers are generated starting from the entire boundary.

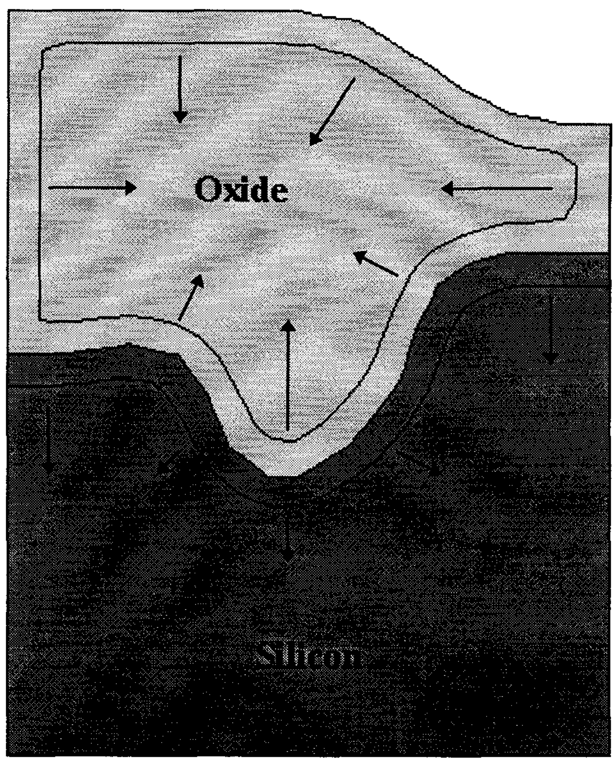

Fig. 1 Boundary conforming meshing algorithm. The arrows show advancement of the mesh layers. The length of the arrows indicates normal mesh spacing.

The layers form one set of the gridlines which are conformal to the boundaries. The elements are formed by constructing an orthogonal set of gridlines. The mesh is refined according to the local curvature in order to avoid obtuse elements.

Besides the region boundaries, p/n junctions can be meshed separately in order to create gridlines, orthogonal to the junction to simulate carrier injection through the p/n junction.

The mesh, created by such an approach, resembles tensor product meshes, generated by conformal mapping method, because they both have gridlines, orthogonal to the boundaries. The major difference is that it is a finite element mesh and all redundant gridlines can be easily terminated to keep the number of nodes low.

III. RESULTS

The proposed mesh generation algorithm allows the creation of meshes with extremely anisotropic elements stretched along the boundaries, which is an important requirement for MOSFETs and other devices with surface conductive layers.

Fig. 2 shows a MOSFET with a slightly curved channel meshed using the boundary conforming algorithm. A normal grid spacing of 10 angstrom is used in the channel. A normal grid spacing of 10 angstrom is also used in the polysilicon gate to accurately account for polysilicon depletion effects. With such small normal grid spacings, lateral grid spacing along the channel reaches 500 angstrom in the middle of the channel to keep the number of nodes low.

The mesh resolves the MOSFET inversion layer all the way from the middle of the channel to the drain junction under the curved part of the semiconductor-insulator interface and lateral gridlines virtually follow current flow lines along the channel.

The overall number of nodes is reduced by increasing the normal mesh spacing as the mesh layers move away from the boundary. Thus, the mesh is very fine near the boundary and rather coarse in the region's interior.

Accuracy of calculating threshold voltage of the MOSFET, shown on the Fig. 2 is plotted on Fig. 3 versus number of mesh nodes for the boundary conforming mesh and conventional mesh. It can be seen, that in order to get the same simulation accuracy, the boundary conforming algorithm requires only about half the number of nodes for a typical conventional mesh. This advantage increases as geometry gets more complicated.

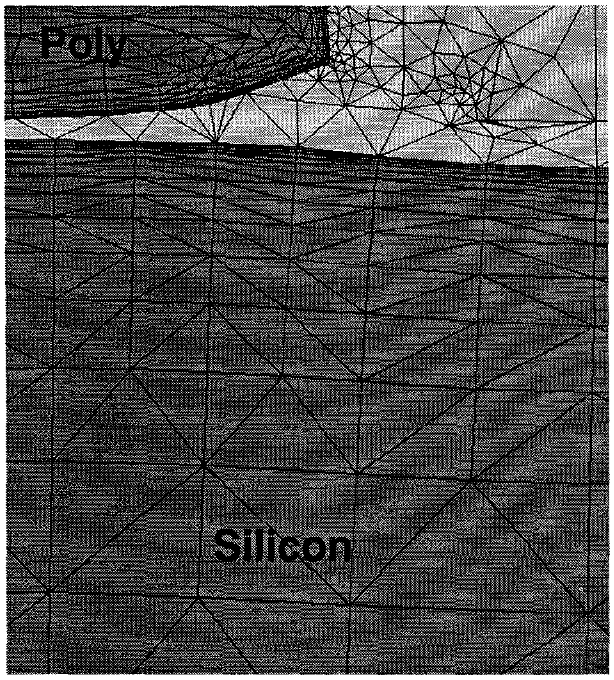

Fig. 2 Boundary conforming mesh generated in silicon substrate and polysilicon gate of a typical MOSFET. Normal grid spacing in silicon and polysilicon is 10 angstrom. An unstructured mesh is used in the gate oxide and sidewall oxide.

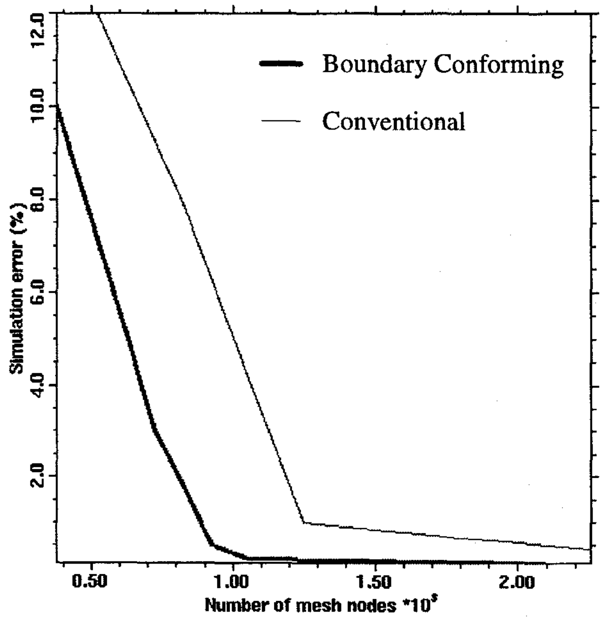

Fig. 3 Accuracy of threshold voltage calculation versus number of mesh nodes for the boundary conforming mesh and conventional mesh.

Fig. 4 shows a corner of a MOSFET utilizing the shallow trench isolation technique (STI). It is especially important to have an adequate mesh at the oxide/silicon interface in the corner, because in such a structure the inversion layer forms in the corner at a lower gate bias, than in the flat part of the channel. The mesh in the polysilicon gate is coarse, because polysilicon depletion effects were not investigated in this example.

Fig. 5 shows top portion of a power IGBT with a tilted channel, meshed using the boundary conforming algorithm. The p/n junctions in silicon substrate are meshed separately in order to create a junction conforming mesh with gridlines, orthogonal to the junctions. This allows accurate simulation of carrier injection through the p/n junctions at the surfaces as well as in the bulk of the device.

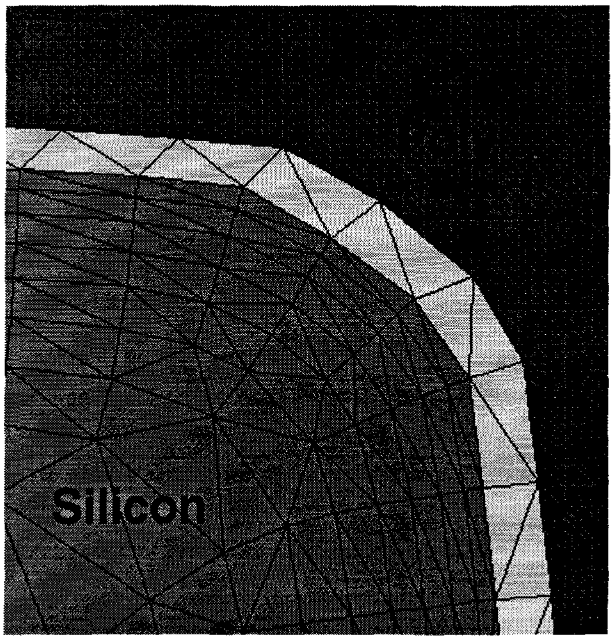

Fig. 4 Boundary conforming mesh in the corner of a shallow trench isolation (STI) MOSFET.

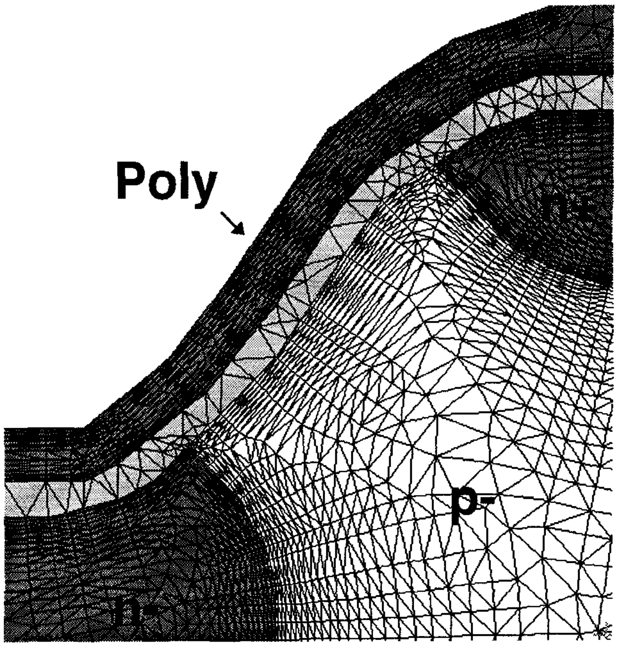

Fig. 5 An IGBT with a boundary conforming mesh. The two n-type and one p-type doped regions in silicon are meshed separately to create a junction conforming mesh.

IV. CONCLUSION

The proposed automatic boundary conforming mesh generation algorithm allows creation of meshes with extremely anisotropic elements stretched along the boundaries. The algorithm is especially efficient for device simulation of MOSFETs with curved channel surface, because it creates gridlines that are orthogonal to the semiconductor-insulator interface and nearly orthogonal to the current flow lines. For a typical MOSFET simulation, the number of mesh nodes required by the proposed algorithm is about half of the number of nodes, required by conventional meshing approaches for the same simulation accuracy.

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