TWO-DIMENSIONAL MULTI-LAYER PROCESS SIMULATION.

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The development of ULSI technologies toward sub-micron dimensions requires powerful two-dimensional (2D) process simulation tools. In order to accurately predict the doping profiles evolution during the fabrication of complex devices, such as advanced self-aligned bipolar transistors, the simulation area has to cover the entire multi-layer structure. More precisely, the basic impurities redistribution equations have to be solved in all the present materials together with the corresponding multiple interface segregation effects.

Several numerical approaches have already been proposed [1,2]. Most of them utilize several types of spatial representation at the same time: string model for topology and shape interpolation to rectangular grid for impurity diffusion, for example.

In this abstract, we propose an elegant solution based on the finite element method in which a single mesh strategy is used for all the current ULSI fabrication steps. This technique is implemented in the new ISEN process simulator IMPACT-4 [3].

Mesh and string models.

The structure topology is described with the classical string model, so that each layer is defined by its envelop, with an inter-node spacing length considered as the key spatial discretization parameter.

The mesh is generated indepently for each layer, except for the location of the common boundary nodes (double or triple points). Starting from a list of nodes composed by the boundary nodes, followed by automatically generated internal nodes, the triangulation is performed using the Delaunay criterion, that ensures a minimal number of obtuse triangles. This triangulation is realized by the mesh generator MSHPTS [4] from the INRIA library. Following this, a regularization technique is applied that iteratively moves the nodes to the gravity center of its first neighbours.

Topology simulation.

During the deposition and etching steps, the boundary nodes move accordingly to the chosen displacements models. Layers are created, deleted or merged in a way that interfaces between 2 layers composed with the same material are automatically removed. String points are created or deleted according to the governing key spacing. This control enables us to use the string points as boundary nodes for the mesh generation.

Diffusion and implantation.

The diffusion equations are solved on finite triangular elements with linear shape functions (P1). The number of triangles needed to accurately describe the layer boundary shape is compatible with a reasonnable CPU time requirement for the diffusion problem. The temporal discretization is assumed by an incomplete implicit scheme: within each time step, the diffusion equation is solved once for each impurity. All the discretized layers are assembled , the coupling between them is achieved by appropriate equilibrium segregation fluxes. The resulting linearized problem is solved by the conjugate gradients algorithm with incomplete LDU decomposition.

2D implanted profiles are analytically calculated with the classical Runge's method that has been extended to the multi-layer problem by the dose matching model.

Oxidation.

The 2D oxidation is simulated by the incompressible viscous flow model. The same triangulation is used for dopants and oxidants diffusions and for the Navier-Stokes equations. Both pressure and oxidation velocities are solved with P1 elements with the Chorin iterative scheme. This discretization has been validated with cross checking with solutions obtained with higher order elements.

The application of the overall solution technique to the simulation of a self-aligned polysilicon emitter transistor is illustrated in fig.1.

Dynamic mesh refinement.

A dynamic mesh refinement technique has been developed to ensure extremely accurate 2D doping profiles in the cases of implantations and diffusions. Starting from a coarse mesh, the triangles are split when their internal nodal concentration range is greater than a factor (*alpha*), for a given impurity. Numerous node addition algorithms are applied, depending on triangle configurations. The refinement scheme is validated by checking the punchthrough voltage of bipolar transistors. The punchthrough voltage is analytically calculated with the Gummel number, integrated from the simulation results. The fig.2 gives the variation of the punchthrough voltage versus *alpha* for different initial mesh spacing value for 1D and 2D cases. From this figure, the choice, $alpha = 10$, seems to be a good compromise between CPU time and accuracy level. A typical final mesh obtained for this test example is displayed in fig.3.

Conclusion

An unified meshing technique has been presented for 2D multi-layer process simulations together with a dynamic mesh refinement strategy. The algorithms will be detailed during the oral presentation.

[1] C.P. HO *et al.*, IEEE Trans. Electron. Devices, Vol.ED-30, p.1438, 1983.

[2] K. NISHI *et al.*, IEEE Trans. Computer-Aided-Design, Vol. CAD-8, p.23, 1982.

[3] B. BACCUS *et al.*, Proc. of SISDEP-3, ed. G. Baccarani and M. Rudan, p.255, 1988.

[4] F. HECHT *et al.*, INRIA internal report, Rocquencourt, France, 1986.

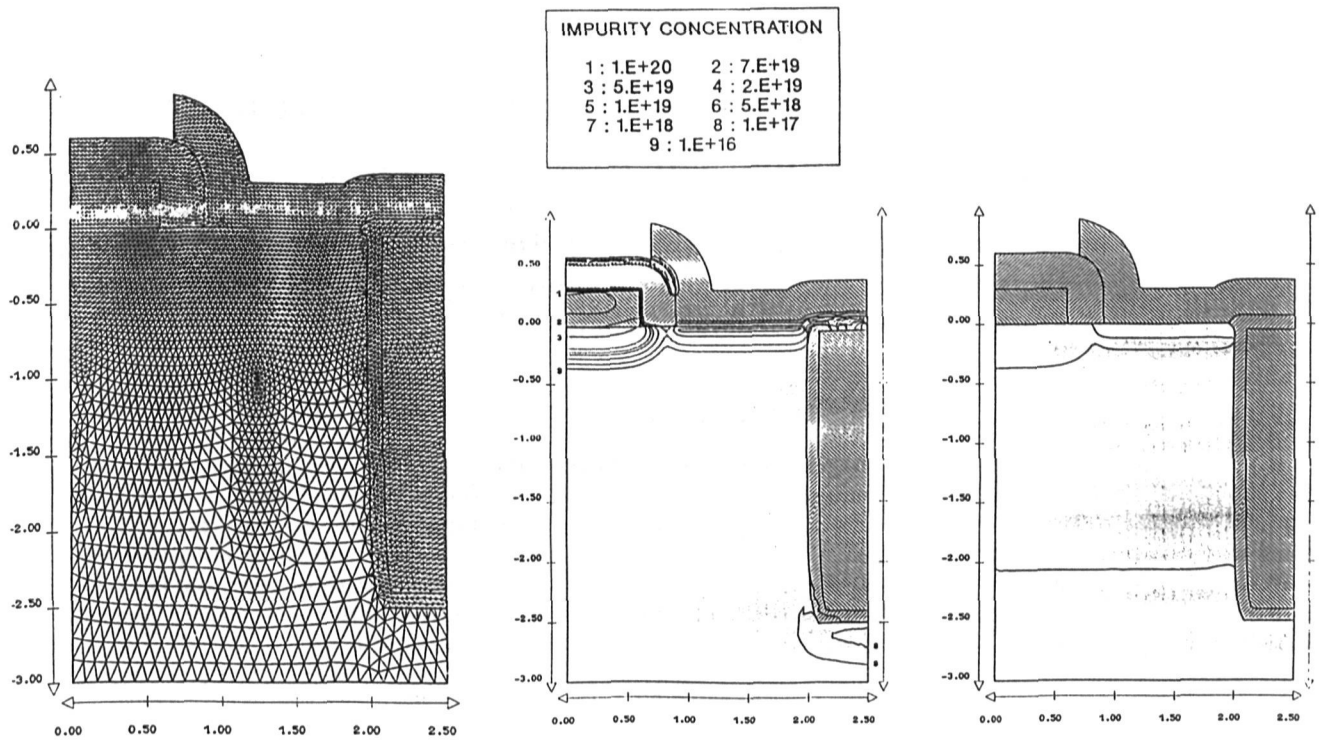

Fig.1 : Simulation of a self-aligned polysilicon emitter bipolar transistor. (a) Mesh. (b) Boron profile. (c) Junctions plot.

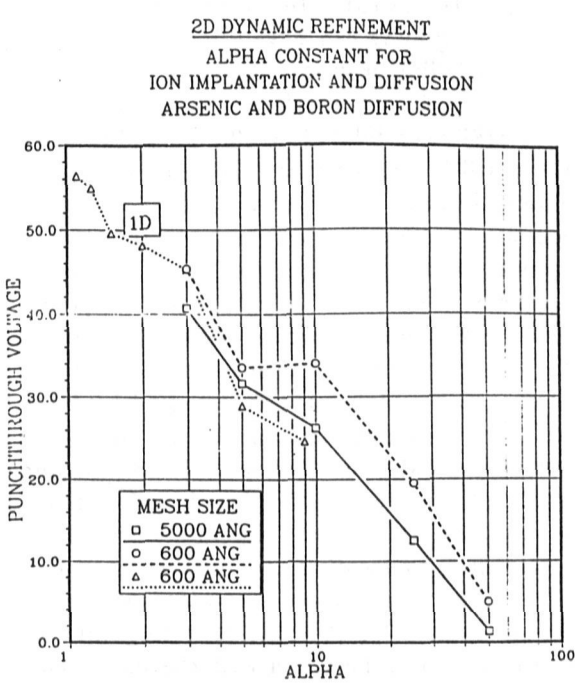

Fig. 2 : Variation of punchthrough voltage with α . Initial mesh size effect and comparaison with 1D results.

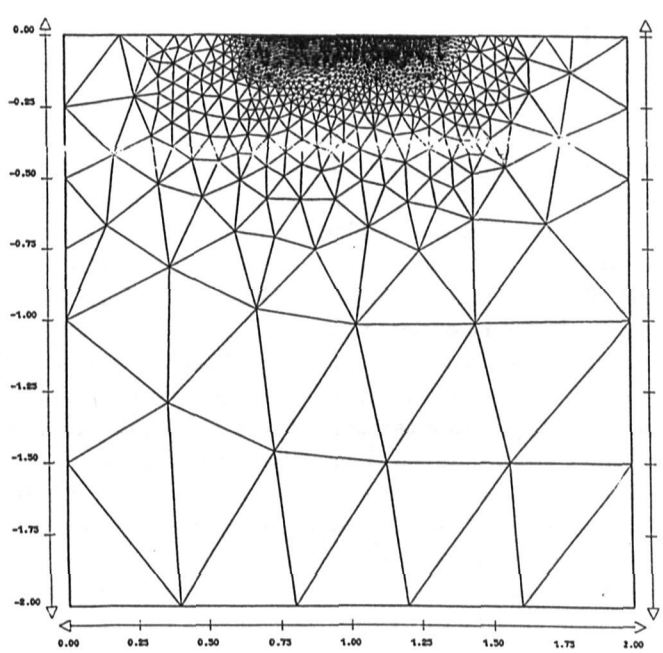

Fig. 3 : Typical mesh generated for test example with arsenic and boron diffusion. α = 10, 2147 nodes and 4085 elements.