A Mesh Generation Algorithm for Complex Geometry

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***Abstract*-An algorithm of mesh generation for curved surface is proposed to investigate an complex structure on a semiconductor substrate. This algorithm relies on the advancing front method with scattered data interpolation through NURBS (non-uniform rational B-spline) surface. This algorithm has been applied to a cell-based simulation and a level set simulation. The NURBS mesh according to our algorithm excellently represented the surface evolution of the topography.**

I. INTRODUCTION

In order to develop a three-dimensional process simulator, it is inevitable to resolve various complex geometric problems such as the delooped surface evolution and the mesh quality maintenance. Two approaches to resolve the looping problem of the advancing surface are level set method and cell method. However, the results from these methods need appropriate meshing algorithm for integration of other numerical simulators. Surface smoothing algorithms for the cell-based representation such as marching cube algorithm construct the polygonal geometry representation [1]. Vertex removal algorithms for reducing the triangle had been applied [2]. These algorithms still have some obtuse triangle meshes due to the difficulty in accurately defining the removal point. In this work, non-uniform rational B-spline (NURBS) surface extraction has been employed for the representation of complicated topography in semiconductor process simulation.

II. SURFACE GENERATION METHOD

NURBS surfaces are widely used in computer-aided design for the representation of free-form surfaces due to their interesting properties such as the handling capability, the lead controllability, and the ability to represent analytical features as well [3]. The ingredients of NURBS surface consist of control points, weight, knot vector, and the basis functions. An NURBS surface is defined by

$$S(u,v) = \frac{\sum_{i=0}^{m}\sum_{j=0}^{n} N_{i,p}(u)N_{j,q}(v)w_{i,j}P_{i,j}}{\sum_{i=0}^{m}\sum_{j=0}^{n} N_{i,p}(u)N_{j,q}(v)w_{i,j}} \qquad 0 \le u,v \le 1 \tag{1}$$

where the S is a point on the surface and the u and v are the location parameters that identifies the location within the length and width of the surface. An NURBS surface of degree p in the u-direction and degree q in the v-direction is a bivariate vector-valued piecewise rational function. The n and m are the number of control points in the u- and v-direction, respectively.

A surface can be formulated by creating a multilevel B-spline surface that approximates scattered points [4]. Fig. 1 illustrates an NURBS surface together with its defining control net. Dotted lines are control net comprising control points while solid lines represent an NURBS surface. We has applied NURBS surface to the surface smoothing of the cell-based geometry representation.

III. MESH GENERATION

We have generated meshes for the NURBS surface by employing advancing front algorithm. Firstly, we initialize the front list that is composed of nodes and edges in two-dimensions. In the mean while, the front list comprises nodes and triangles in three-dimensions along the boundary of the region. After a front is selected from the front list, a new node is generated near the front in accordance with the designated value of node density. The computation for searching the optimum location of a new node should be carried out during the generation of nodes [5].

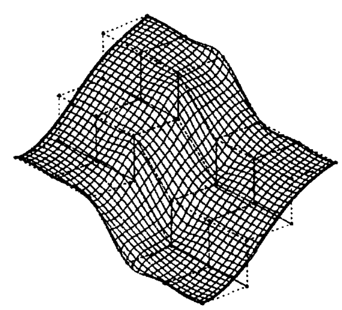

Fig. 1. An NURBS surface with control net.

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Once the new front is generated, the front list is updated. As long as the front in the prior front list remains, the above-mentioned procedure is repeated. We make use of either a PSLG (planar straight line graph) in two-dimensions or a triangulated surface in three-dimensions for initial front structure.

A surface mesh generation with advancing front algorithm is performed as shown in Fig. 2. The curved surface is defined by polygonal boundary description and control points set on the surface. The polygonal structure of the boundary is drawn, and the distribution of node density is assigned at each vertex. The vertices of the polygon should be arranged in an ordered manner according to the normal direction of the polygon.

The polygonal surface with control points is rotated on the xy-plane as shown in Fig. 2(a). NURBS surface is generated with scattered data for the polygonal surface as shown in Fig. 2(b). The vertices of the polygon are located on the NURBS surface as shown in Fig. 2(c). The advancing front mesh generation algorithm is applied for this surface. Edges of the polygon are separated into nodes and edges according to the density value of nodes. The initial front for the advancing front triangulation is composed of boundary nodes and edges. The positions of new nodes are moved on the NURBS surface during advancing front triangulation. Mesh elements are generated from the initial front structure while the front list is not empty.

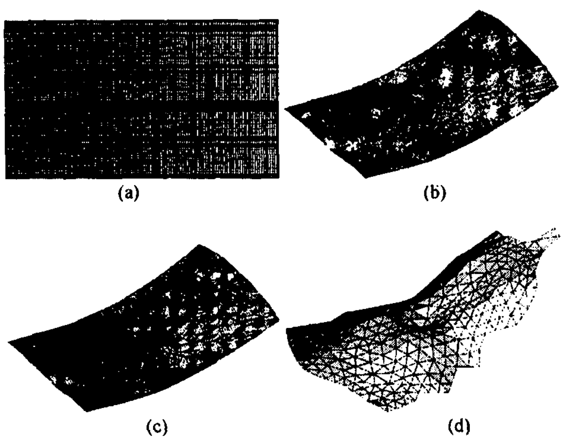

Fig. 2. A plot demonstrating an example of mesh generation for a curved surface: (a) scattered data points set on the surface, (b) generation of NURBS surface with scattered data points set, (c) polygonal surface on the NURBS surface, and (d) triangular mesh for the curved surface.

We describe a method calculating the coordinate of a node on the surface. Firstly, we have to search for a patch, which is defined as a rectangular area composed of four knots in the xy-plane. Since the coordinate of a knot is defined as a height on the xy-plane, we have to search for a patch including a node located on the knot lattice structure. The height of the node is then calculated with reference to the heights of the four knots in the patch through a bilinear interpolation [6]. Fig. 2(d) shows a result of mesh generation for the NURBS surface with 512 nodes, 514 triangles, and 0.92 mean quality factor [7]. The calculation time is only 0.1 second on Sun Ultra 10 workstation.

We have applied our mesh generation algorithm to the cell-based geometry representation for surface smoothing and mesh generation. Fig. 3(a) shows a result of cell-based topography simulation. The triangulation of a surface is initiated by the polygonal boundary description of the various parts of the geometry. Each polygonal surface has scattered data points from surface of a cell structure. NURBS surfaces are generated with scattered data for each polygonal surface as shown in Fig. 3(b). Each polygonal surface is rotated to the xy-plane, and then the polygon is triangulated with advancing front algorithm. After that the triangulated polygon is rotated to the original position. Fig. 3(c) shows a result of mesh generation for the NURBS surface. The surface mesh and the cell surface are matched quite well as shown in Fig. 3(d).

One approach to calculate the advancing surface is the level set algorithm. The level set algorithm defines the geometry with level set surface on a fixed grid points [8]. Each grid point has the distance value from the level set surface. Therefore, we must extract the resulting surface of a moving boundary problem. We have extracted the level set surface using NURBS surface. Firstly, we have extracted the positions that had the zero distance in the grid structure, as shown in Fig. 4(a). We have generated NURBS surface for the extracted points. After that we have triangulated for the NURBS surface as shown in Fig. 4(b).

As the chip density increases with micro-miniaturization, the topology on the semiconductor becomes more complicated and the aspect ratio becomes larger and larger. Accordingly, a great deal of attraction has been made on how to simulate the sophisticated geometry on the substrate. A concave cylindrical DRAM cell structure has been to test the capability of defining the non-planar surface to the NURBS algorithm of this work.

Our methodology of mesh generation comprises the steps of: drawing a mask layout; generating a cell structure from the mask layout; and extracting initial polygons including control points to apply non-planar surface [9]. The initial polygons have been extracted from the cell structure generated by our cell-based topography simulator [10]. The surface of the cell structure has been divided into several polygons that have not included steep or negative sloped surfaces. The control points have been defined with surface vertices of the cell within each polygon region.

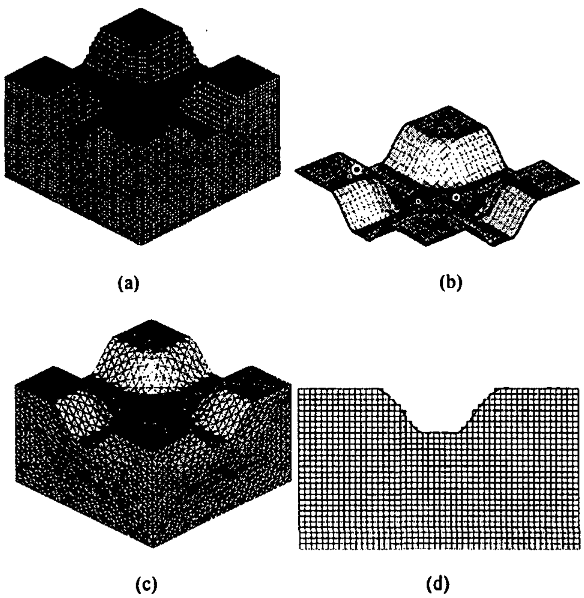

Fig. 3. Schematic diagrams illustrating: (a) an exemplary structure of cell-based geometry representation, (b) a generated NURBS surface for the top surface of the cell structure, (c) the result of mesh generation, and (d) the comparison of the cell structure and the mesh (solid line: cell, dashed line: mesh).

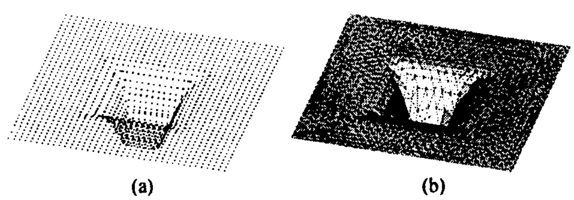

Fig. 4. Schematic diagram illustrating: (a) a point set of level set surface from a grid structure and (b) a result of triangulation for the level set surface.

Fig. 5 shows a result of mesh generation for a DRAM cell structure. Referring to Fig. 5, four cylinder type cell capacitors are depicted over the four word lines and the two parallel bit lines on the substrate. The exemplary structure comprises four storage nodes with a dimension $2.25\times1.75\times3.45\ \mu m^3$. The number of nodes was 70078 with 395064 tetrahedrons. The required CPU time for generating the mesh was approximately 9425 seconds on Sun Ultra 10 workstation. The mean quality factor of the mesh was 0.81.

We have generated surface mesh for an exemplary structure having curved surface as shown in Fig. 6(a). We had separated the surface of Venus to 19 polygonal surfaces having scattered data points. We have rotated each polygon parallel to the xy-plane. After that we generated NURBS surface, and triangulated polygonal surfaces as shown in Fig. 6(b). The final surface mesh for Venus is illustrated in Fig. 6(c). The number of nodes was 3289 with 6571 triangles. The CPU time of generating the surface mesh was only 29 seconds on Sun Ultra 10 workstation. We have obtained very high mean quality factor of 0.92.

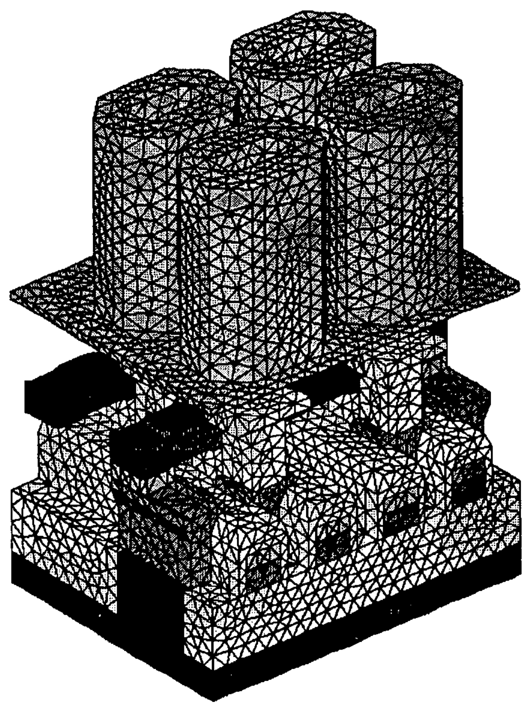

Fig. 5. Schematic view illustrating a result of mesh generation for a DRAM cell.

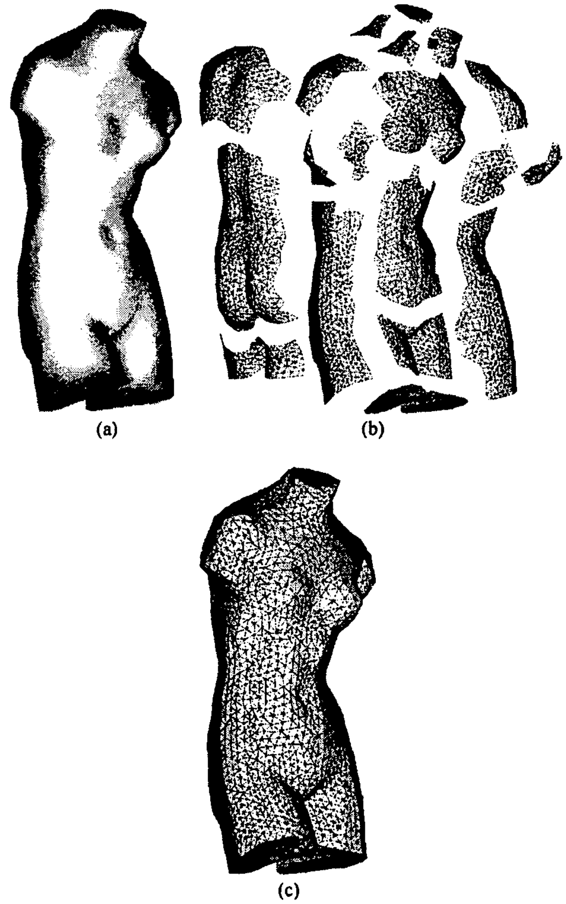

Fig. 6. Schematic diagrams illustrating: (a) an original structure of the Venus, (b) separated polygonal surfaces, and (c) the final mesh.

IV. CONCLUSIONS

We have proposed a mesh generation algorithm with NURBS surface from the scattered data of three-dimensional structure. This algorithm has been applied for a cell-based simulation and a level set simulation. The NURBS mesh according to our algorithm excellently presented the surface evolution of the topography on the wafer. A cylinder type DRAM cell structure and a plaster figure of the Venus have been chosen to test the capability of our algorithm. We have obtained the mesh with high quality factor and fast CPU time for curved surface.

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REFERENCES

[1] W.E. Lorenson and H.E. Cline, "Marching cubes: a high resolution 3D surface construction algorithm," *ACM Computer Graphics*, vol. 21, pp.163-170, 1988.

[2] E. Bär, J. Lorenz, "Control and Improvement of Surface Triangulation for Three-Dimensional Process Simula-tion," *Simulation of Semiconductor Processes and Devices*, pp. 75-78, 1999.

[3] L. Piegl and W. Tiller, *The NURBS Book*, Second Edition, Springer, 1997.

[4] S. Lee, G. Wolberg, and S.Y. Shin, "Scattered Data Interpolation with Multilevel B-Splines," *IEEE Trans. Visualization and Computer Graphics*, vol. 3, no. 3, pp.228-244, 1997.

[5] E. Seveno, "Towards an adaptive advancing front method," *Proc. 6th Annual International Meshing Roundtable*, pp.349-360, 1997.

[6] W. Press, B. Flannery, S. Teukolsky, and W. Vetterling, *Numerical Recipes in C*, Second Edition, Cambridge University Press, 1992.

[7] N.A. Golias, T.D. Tsiboukis, "An approach to refining three-dimensional tetrahedral meshes based on Delaunay transformations," *Int. J. for Numerical Methods in Engineering*, vol. 37, pp. 793-812, 1994.

[8] J.A. Sethian, *Level Set Methods and Fast Marching Methods*, Cambridge University Press, 1999.

[9] S. Yoon, O. Kwon, and T. Won, "A Methodology for Modeling a Complex Geometry on Wafer from a Layout Data," *Proc. Modeling and Simulation of Microsystems*, pp. 437-440, 2000.

[10] O. Kwon, S. Yoon, Y. Ban, and T. Won, "Modeling and Simulation of 3D Structures for Gigabit DRAM," *Proc. Modeling and Simulation of Microsystems*, pp. 688-691, 2000.