GEODESIC: A New and Extensible Geometry Tool and Framework with Application to MEMS

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ABSTRACT

This paper will detail the capabilities of a new geometric modeling tool, called Geodesic, which is being released in source code form to the general community. In addition to providing geometric operations to create geometry useful in MEMS simulation, it uniquely offers a fully integrated 3-D levelset kernel that permits highly accurate physically based deposition and etching simulation.

Keywords: Geometry, MEMS, solid modeling, levelset, TCAD.

1.0 INTRODUCTION

In the field of microsystems, numerous commercial and academic efforts are underway to develop simulation based design (SBD) systems [1]-[5]. Most of these systems consist of closed, proprietary frameworks. This is a disadvantage to the typical designer since it is unlikely that one system can provide all of the desired functionality. In addition, for researchers in the fields of geometric modeling, mesh generation, and numerical simulation, this can complicate and hinder the process of developing new tools.

Interest in automating 3-D geometry construction, using only mask and process information, for VLSI and MEMS applications has been actively pursued for nearly two decades. These efforts can be lumped into two basic catagories: those that utilize commercial solid modeling kernels and efforts based on proprietary code to represent solid models. Examples of the latter include OYSTER [6], 3DTOP [7], and MemCel [8]. Efforts using commercial solid modeling kernels include VIP3D [9] and MemBuilder [10] (the current mechanism used to build geometry in the commercial system MEMCAD [1]). Geodesic falls into this second category.

Geodesic is an effort to increase the interoperability between existing tools by providing an extensible framework for creating geometry suitable for the simulation of MEM devices. Its unique feature set consists of a generic solid modeler interface, user-selectable algorithms for etch and deposition that achieve multiple levels of physical accuracy, and a fully integrated multi-dimensional levelset kernel.

2.0 GEODESIC FRAMEWORK

The input to Geodesic consists of a set of masks (defined in a CIF file) and a process flow (specified using the Composite CAD Process Definition Specification [19]). The geometry is then built in a layer by layer fashion by emulating and/or simulating the processing steps used to build the actual device (i.e. "virtual fabrication"). Currently only geometric steps (e.g. depositions and etches) are supported. Fabrication steps such as implants and diffusions are not modeled within the Geodesic framework.

Figure 1 shows a schematic of the Geodesic architecture. The challenges of integrating diverse tools such as solid modelers and mesh generation software into a unified framework involves tasks of varying computational expense and algorithmic challenge. In addition, in a research setting it is desired to have a tool which permits rapid prototyping and quick testing of new algorithms. For this reason, Geodesic uses Tcl/Tk as a front-end integration environment. Tcl/Tk combines the ease of a powerful scripting language with the ability to imbed C/C++ code for computationally intensive operations. There are four main modules in Geodesic: the object repository, the solid modeling interface, the levelset kernel (section 3.3), and the meshing interface (section 4).

2.1 Object repository

The object repository is a simple hash table of names (character strings) with corresponding object pointers. The repository allows for the basic operations of adding, deleting, listing, and querying of object type. This layer does not know or care about the underlying structure of the objects contained in it, it merely returns the pointers and calls instantiation and deletion methods as required.

2.2 Generic solid modeler interface

At the heart of geometric modeling is a solid modeler. By wrapping the solid modeling function calls used in generic interface layer, Geodesic can be used with multiple solid modeling kernels. This interoperability with multiple kernels is facilitated by designing the system to minimize the number of distinct function calls required to build a geometry. The current implementation can be used with two different commercial solid model kernels (Shapes [11] and Parasolid [12]). So far, only limited results have been achieved using a freely available solid modeler (IRIT [13]). The extension of Geodesic for use with other solid modelers (e.g. ACIS [14]) should be straight forward.

3.0 ALGORITHMS TO ACHIEVE MULTIPLE LEVELS OF PHYSICAL ACCURACY

State-of-the-art commercial MEMS simulation tools rely on purely geometric operations to create geometry. In addition to an efficient and robust method to create geometry using only solid modeling operations, Geodesic provides the capability to smoothly incorporate physically based 2-D and 3-D deposition and etching process simulation results into the geometry.

3.1 Geometric algorithm

An efficient geometric deposition algorithm has been developed. The algorithm provides for surface angle dependent deposition thickness to allow for non-uniform sidewall and step coverage. The algorithm operates independent of the solid modeler and utilizes standard functionality provided in the Visualization Tool Kit [15]. Briefly, the steps of performing a deposition consist of:

1. Extract a faceted representation of the exterior of the current state of the wafer (this corresponds to creating a vtkPolyData file of the exterior).
2. The vtkPolyData object is then preprocessed by three VTK filters. First, the duplicate points inside of the data file are eliminated (vtkCleanPolyData). Then, all polygons are decomposed into triangles (vtkTriangleFilter). Finally, the facets are consistently oriented (vtkPolyDataNormals).
3. The bottom of the wafer is detected (this is currently done by assuming that the bottom of the wafer lies in plane z=0). The facets corresponding to the bottom and the sides of the wafer are then fixed so deposition only occurs on top of the wafer. The sign of the outward normals is determined by checking the orientation of the bottom facets.
4. For each facet, the position of a corresponding infinite plane is calculated by translating and rotating the plane as a given function of the initial orientation of the facet. In the case of isotropic deposition, this corresponds simply to translating the plane in the outward normal direction by the given deposition thickness.
5. The vertices of the model are then looped over and at each vertex the intersection of the infinite planes meeting at the vertex are calculated. There is additional code to handle the special cases of adjacent coplanar facets and free edges.
6. Once the new vertices are calculated, the topology is copied from the original vtkPolyData object and a new vtkPolyData object is created which corresponds to the exterior of the geometry after the deposition. The

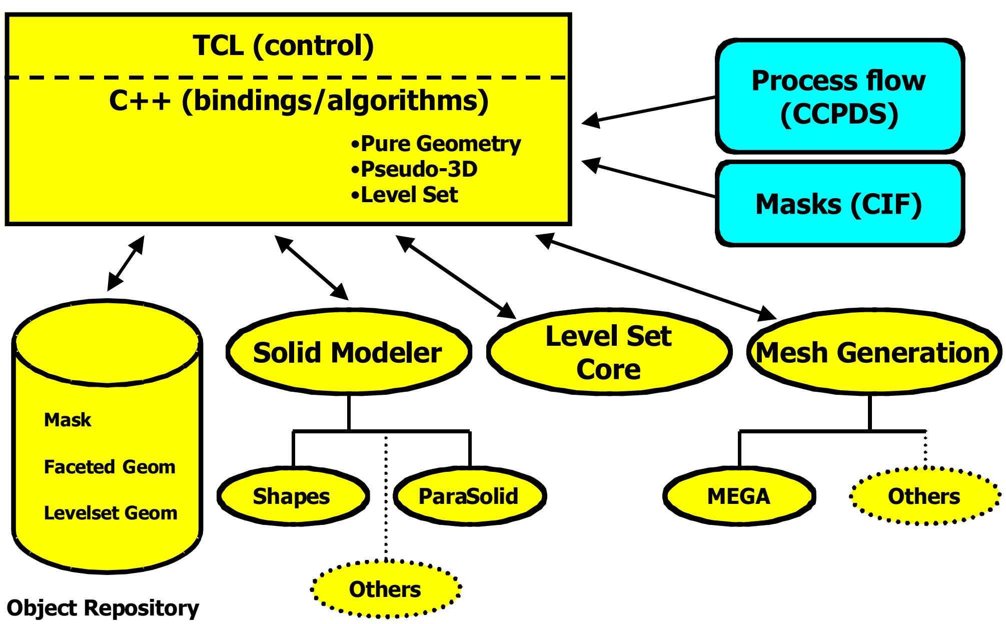

Figure 1: Geodesic Architecture.

vtkPolyData object can then be used to create a solid model.

7. The material deposited for this given step is calculated by subtract the original geometry (step 1) from the final geometry (step 6).

Figure 2 shows a comb drive created using the geometric algorithm to create the conformally deposited layers.

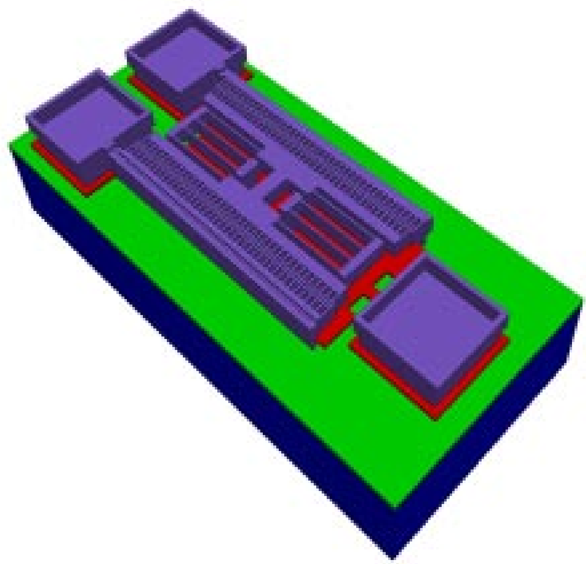

Figure 2: Comb Drive created using geometric operations inside of Geodesic.

3.2 Domain decomposition

To improve the overall efficiency, complex structures are decomposed into regions identified as needing 1-D, 2-D, or 3-D process simulation. Different geometric and physical approaches to geometry manipulation can be arbitrarily applied among these regions. This technique is detailed in [16]. Figure 3 shows a dual electrode switch created using the domain decomposition.

Figure 3: Dual electrode switch created using process using 2-D process simulation, domain decomposition, and geometric operations.

3.3 Levelset process simulation

Geodesic contains a fully integrated general multi-dimensional levelset kernel which can be used for process simulation. The level set method has been shown in [17] to be useful for modeling surface movement in back-end wafer processing. The Geodesic framework incorporates a numerical module for performing 2- and 3-D level set calculations. The integration of this module with the rest of the Geodesic system enables level set based modeling to be done in conjunction with the other geometric techniques described above. Figure 4 shows a two-layer corner structure undergoing material-dependent etching. Dynamic grid reduction techniques based on those described in [17] are used to lower the computational cost of level set calculations.

4.0 MESH GENERATION

Geodesic also contains a generic meshing layer. In the current implementation, only the MEGA automatic mesh generation package [18] is supported. Its functionality includes "meshing through the thickness," which is useful in the simulation of thin material layers frequently encountered in MEMS. It also possesses special boundary layer meshing capabilities useful in microfluidics. Figure 5 shows a coarse mesh of a micromirror, while Figure 6 shows the mesh of a simple switch with refinement near the stepup. Please note, the source code for MEGA will NOT be provided with Geodesic (contact [18] for details about obtaining the SCOREC meshing tools).

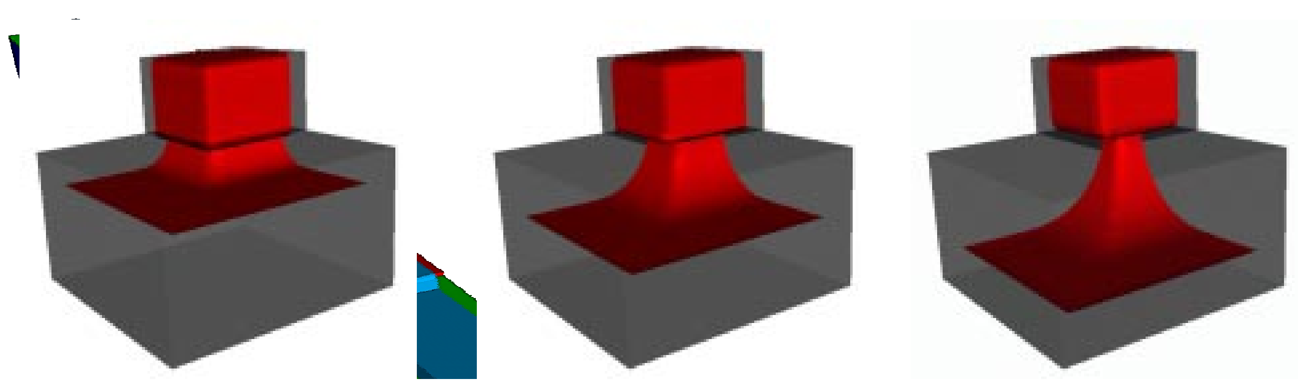

Figure 4: Example of a selective corner etch using the integrated 3-D Levelset kernel in Geodesic. The figure shows three steps in the evolution of the boundary surface, where the red surface indicates the level zero function. As can be seen, the small block on top of the larger block is more resistive to etch.

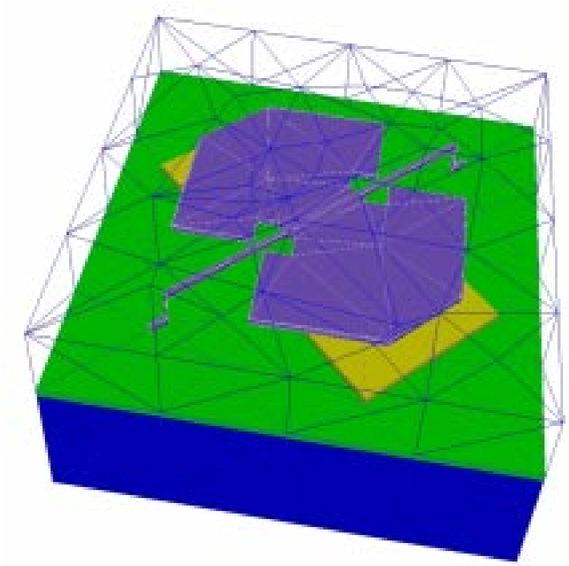

Figure 5: Meshed micromirror.

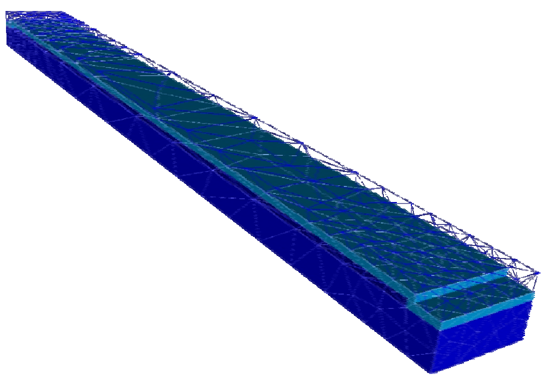

Figure 6: Simple switch with mesh refinement.

FUTURE WORK

Future work on the geometric algorithm will include enhancements that detect and avoid many of the solid modeling related difficulties with small features such as release holes and dimples. Work on levelset performance enhancements is also on-going.

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