A 2D Visualization Tool for SUMMiT V Designs

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ABSTRACT

This paper describes the 2D Process Visualizer, a CAD tool that enables a SUMMiT (Sandia Ultra-Planar Multilevel MEMS Technology) MEMS designer to visualize the results of applying the process sequence to a mask set by generating accurate 2D cross-sections. The 2D mask layer geometry, is extracted from an AutoCAD® design file through an interactive user interface and used to construct a list of polygon edge-crossings. The SUMMiT V fabrication sequence was reduced to a limited set of process step types to simplify the process simulation. Models for each of the steps are applied sequentially to the list of polygon edge-crossings. A uniformly gridded model space at a finite resolution is used. OpenGL graphics are used to display the results within the Windows® NT environment. Window controls are provided to allow the designer to manipulate the view and step through the process views both forward and backward. Other controls allow the designer to query the design space to determine the material type and feature size.

Keywords: MEMS, SUMMiT, cross-section, process simulation.

1   INTRODUCTION

Today's MEMS designers face a difficult design hurdle: combining fabrication process information with two-dimensional mask geometry to create three-dimensional structures. The fundamental problem is that a 2D-mask set does not reveal the true three-dimensional structure because the result is highly dependent on the process sequence. Experienced designers are able to visualize the target structures based on their understanding of the MEMS process. However, it is a significant challenge for new designers to overcome the problem – most are accustomed to constructing the target structure through the use of a solid modeler or a 3D CAD tool and few understand the MEMS process. Traditional IC layout tools used for mask layout do not provide the features required to construct complex mechanical design layouts. Neither do they provide tools needed to visualize the results of an advanced MEMS fabrication sequence. Recognizing these inadequacies, Sandia has developed a MEMS design tool suite formed around a commercial 3D mechanical CAD tool, AutoCAD®. Designed for use with the SUMMiT process [1], it includes in-house written design tools: a 2D Process Visualizer, a 3D Model Generator, and a Design Rule Check system [2].

This paper describes the 2D Process Visualizer, a Windows® NT-based CAD tool that enables a designer to visualize the results of applying the SUMMiT V MEMS process sequence to the mask set by generating accurate 2D cross-sections.

2   2D PROCESS VISUALIZER

The 2D Process Visualizer applies the SUMMiT V MEMS process sequence to the mask set to generate accurate 2D cross-sections (Figure 1). First, the 2D mask layer geometry, represented by closed polygons (currently circles and polylines), is extracted from an AutoCAD® design file through an interactive user interface written in AutoLisp and stored in an intermediate data file. This file is processed to construct an ordered list of polygon edge-crossings by the 2D Edge Extraction module. The processing consists of flattening any hierarchical geometry, approximating curved geometry using chords, and calculating intersections with the user-specified cross-section line.
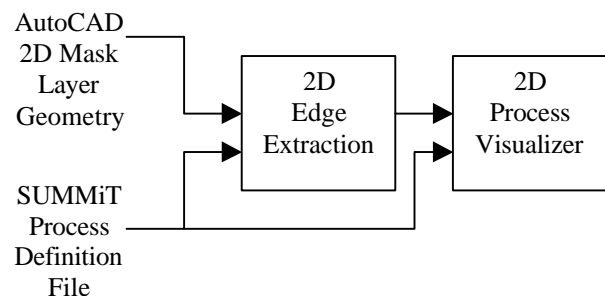

Figure 1. 2D Visualizer data flow

The process definition file (PDF) contains a simplified description of each process step. For each step, the PDF includes: process step name, process step type, mask field type, the associated AutoCAD mask layer name(s), material

type, thickness, display color, and certain process step type dependent parameters. The process step model types are described in the next section.

The 2D Process Visualizer constructs the cross-section model by applying each of the process step models sequentially to a uniformly gridded model space. The model space is constructed with a finite resolution – either 0.1 microns in normal resolution mode or 0.05 microns in high-resolution mode. The height of the model is calculated from the PDF to be the maximum geometry height. The width of the model is the length of the cross-section line.

At each step in the process, an OpenGL display list is generated for the material added during a deposition step or removed during an etch step. This provides a snapshot of the model at each process step. Window controls are provided to allow the designer to step through the process both forward and backward. Additional window controls provide pan and zoom functions to manipulate the view. Other features allow the designer to query the model to determine the material type and feature size.

3 PROCESS STEP MODELS

Since the actual SUMMiT V fabrication sequence features hundreds of physical steps, the process simulation was simplified by reducing the process step types to a fundamental set of operations. The process step types supported by the 2D Process Visualizer are:

Uniform deposition
Conformal deposition
CVD deposition
Planar deposition
Dry etch
Wet etch
Release etch

Each process step is described below.

3.1 Uniform Deposition

The uniform deposition model adds material with a constant thickness. Figure 2 shows several layers deposited with the uniform deposition model. This model is typically used only for the base substrate layer where no underlying topology exists.

Figure 2. Uniform Deposition

3.2 Conformal Deposition

The conformal deposition model adds material using a constant thickness on top surfaces blended into a different thickness on vertical walls. The blend is defined by
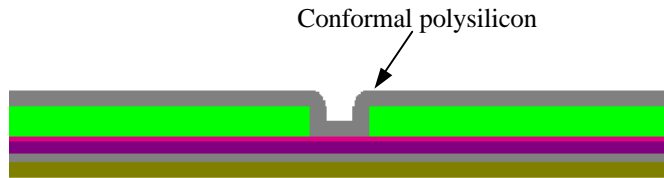

Figure 3. Conformal Deposition

sweeping an ellipse along the corners. The major radius of the ellipse defines the top surface thickness and the minor radius defines the vertical wall thickness. Figure 3 shows a polysilicon layer added using the conformal model.

3.3 CVD Deposition

The chemical vapor deposition (CVD) model adds material by sweeping a double ellipsoid along on top, vertical, and overhang surfaces. The major radius of the upper hemisphere of the ellipsoid defines the top surface thickness and the minor radius defines the vertical wall thickness. The major radius of the lower hemisphere of the ellipsoid defines the overhang thickness. Figure 4 shows the deposition of oxide for a hub. It has different thickness for the top surfaces, vertical surfaces, and the overhang surfaces.
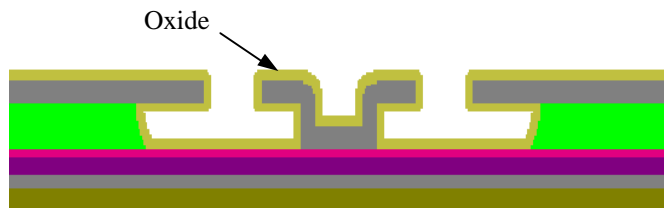

Figure 4. CVD Deposition

3.4 Planar Deposition

The planar deposition model has a variable thickness so that the top surface is flat. The resultant thickness is defined from the highest possible previous deposition. It is used to simulate a deposition step followed by a chemical-mechanical polishing (CMP) step used in SUMMiT. Figure 5 shows the simulation results after an oxide layer was deposited and the CMP process applied.
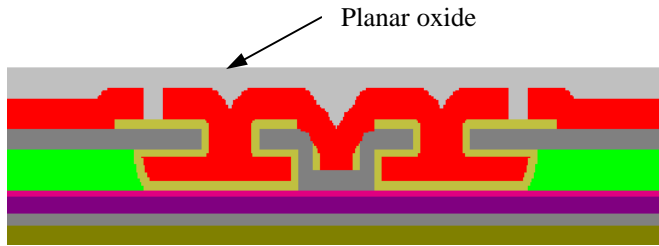
Figure 5. Planar Deposition

3.5 Dry Etch

The dry etch step removes material based on an angled side wall model. Figure 6 shows the results of a dry etch cut on an oxide layer. In this example, the side wall angle is 90 degrees. Other angles may be specified in the process step definition.

Figure 6. Dry Etch

3.6 Wet Etch

The wet etch step simulates an isotropic etch by removing material using a ray casting algorithm. This will create curved undercuts. Figure 7 shows a wet etch used to create a cavity in an oxide layer. This cavity is typically used to form a pin joint in the SUMMiT process by filling it with polysilicon.

Figure 7. Wet Etch

3.7 Release Etch

The release etch step will remove all material specified. Since this is a 2D cross-section, any adjacent etch release holes or other etchant paths outside the cross-section line cannot identified. Therefore in this simplified model, any trapped material will be removed. Figure 8 shows the results of the release etch removing all of the sacrificial oxide.

Figure 8. Release Etch

Note that the trapped oxide inside the center post was removed also. This is shown in detail in Figure 8a.
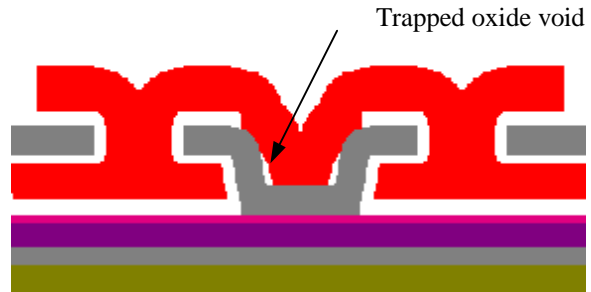

Figure 8a. Trapped oxide void detail

4 RESULTS

The deposition and etch models correlate closely to scanning electron micrographs (SEM) taken of fabricated devices. Examples are shown in Figures 9-14.

Figures 9-11 show a typical SUMMiT gear design with a pin joint. Note the cross-section line on the 2D-mask layout shown in Figure 9. This corresponds to the cross-sectional view through gear hub and pin joint generated by the 2D Process Visualizer shown in Figure 10. A focused ion beam (FIB) was used on a fabricated device to create the cross-section picture shown in Figure 11.

Figures 12-14 show another example using a double-cantilevered beam. The 2D-mask layout is shown in Figure 12. The cross-section was chosen to cross a section where a polysilicon layer overlapped an oxide layer. The 2D Process Visualizer cross-sectional view, in Figure 13, predicts a slot created after removal of the oxide layer. A SEM, shown in Figure 14, verifies that the slot occurred during actual fabrication.

Examples such as these demonstrate the effectiveness of the 2D Process Visualizer to help designers visualize the results of the SUMMiT process on their design.
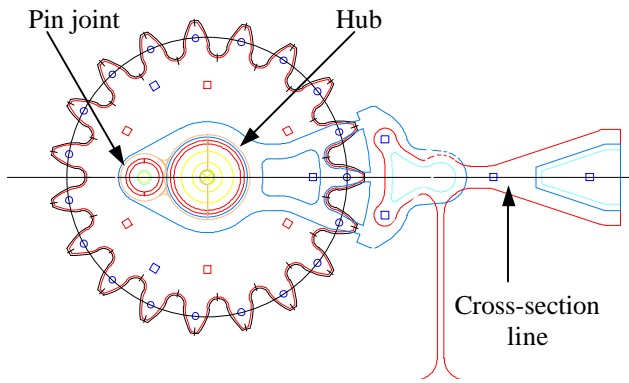
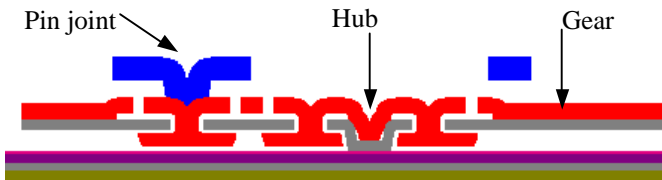Figure 9. 2D mask drawing of a gear and pin joint

Figure 10. 2D Cross-section of a gear and pin joint
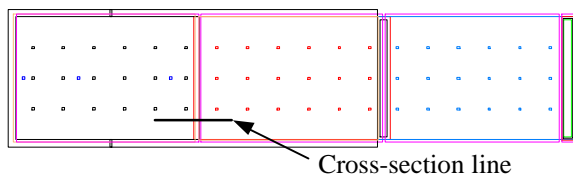

Figure 11. FIB of fabricated gear and pin joint

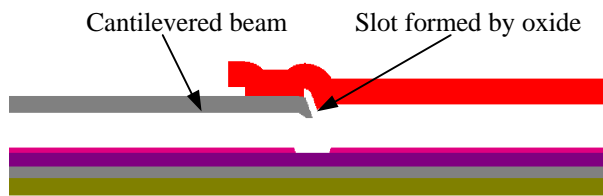

Figure 12. Double cantilevered beam
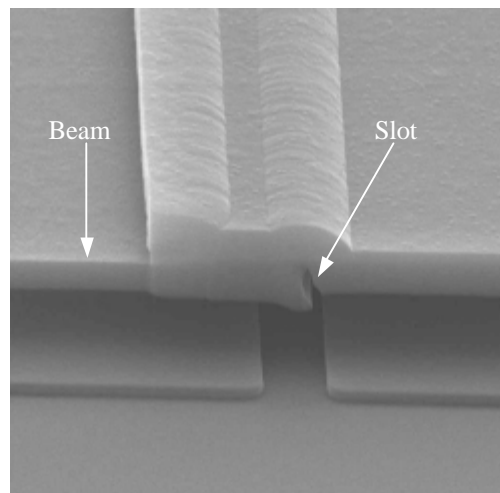

Figure 13. 2D Cross-section of beam

Figure 14. SEM of beam

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