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3D MEMS Design Method via SolidWorks

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***Abstract*—To enable MEMS designers to create fabrication-ready models of MEMS devices in an intuitive environment, this paper describes a MEMS design strategy that uses parameterized three-dimensional (3D) part features to construct geometric models of MEMS devices and then generates mask-layouts and process flows automatically. SolidWorks, an outstanding 3D design tool, is utilized to build the 3D model of the MEMS device. Most frequently-used 3D MEMS part features are created in SolidWorks and saved to a user database through Application Programming Interfaces (APIs) of SolidWorks. When designing a MEMS device, the designer develops its 3D model by selecting 3D part features from the database, and then uses Finite Element Analysis (FEA) to refine the model until it exhibits the desired characteristics. Next, the model is used to generate mask-layouts and process flows. Finally, it is necessary to verify whether the mask-layouts and process flows are generated correctly by reconstructing them into a 3D geometric model and comparing it to the designed 3D model. If there are differences between them, the designer is supposed to modify the mask-layouts and process flows until they can result in the desired shape of the MEMS device.**

Keywords-MEMS; design; SolidWorks; mask; process

I. INTRODUCTION

In MEMS, the present design practices focus on mask-layouts design and process development, which can be characterized as a mask-to-shape-to-function process [1]. MEMS designers often use layout software to develop a set of mask-layouts to result in the desired shape and function, which would be a very tedious and experience-guided task especially when the structure of the MEMS device is complicated. In fact, the desired MEMS design approach is exactly the reverse: function-to-shape-to-mask [2]. That is, the shape exhibiting the desired function should be developed first and then mask-layouts are generated from it [3]. This idea has been carried out in a MEMS design tool reported in [4], where two-dimensional (2D) cross sectional features are used to construct the geometric models of the MEMS device. Since 2D section modeling is not intuitive enough and can't be used to perform Finite Element Analysis (FEA) directly, 3D solid modeling is generally regarded as one of the most promising way to design MEMS devices by allowing designers to verify their designs before submitting them for fabrication and offering designers a clear and accurate review of parts and assemblies early in the design cycle. Therefore, incorporating MEMS 3D in the micromachining design cycle will definitely advance the development of MEMS technology. Moreover, many traditional CAD systems are very good at designing 3D structures, for example, Solidworks, Pro/ENGINEER and CATIA. If designers can add some necessary function modules to these systems, they can be used to design 3D shapes of MEMS devices instead of professional MEMS CAD tools [5]. However, until very recently, there is still no systematic means that use 3D part features to construct 3D geometric models of MEMS devices and then generate mask-layouts and process flows from 3D models automatically.

We propose a 3D MEMS design method for surface micromachining MEMS which uses SolidWorks to design the shape of the MEMS device and then generates mask-layouts and process flows by making secondary development to SolidWorks through its APIs.

II. METHOD

In this paper, the shape of the MEMS device is designed in the environment of SolidWorks. But the design procedure is somewhat different from that of traditional macro-scale parts. First, the designer is required to select material information for 3D part features while designing the shape of the MEMS device. Second, since SolidWorks itself can't produce mask-layouts and process files, we need to add some function modules to SolidWorks by creating programs through the APIs.

The function and information requirements of the method can be modeled with ICAM DEFinition method (IDEF) which is a system analysis and design technology. IDEF has several methodologies (IDEF0, IDEF1, IDEF2, etc.), among which IDEF0 is often used to specify the function and information requirements of a method or a system. So we use IDEF0 to model this method (Fig. 1). With this method, the designer conceives of the function of a MEMS device, chooses suitable part features from the user 3D-part-feature database to develop a tentative shape, and then uses FEA method to refine the shape until it exhibits the desired characteristics. Next, the shape is used to determine mask-layouts and process instructions automatically. Finally, the designer needs to combine the generated mask-layouts and process information to create a 3D geometry [6], and then compare it with the designed model. Once there appears differences between the two models, the designer needs to alter the mask-layouts, process flows, or the shape until proper mask-layouts and process flows are found to result in the desired shape. The method can be divided into four steps: creation of 3D part features, development of the 3D model of the MEMS device, generation of mask-layouts and process flows, and simulation of the construction process.

A. *Creation of 3D part features*

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Since SolidWorks is not a professional tool for MEMS design, it can't cover all needs in the process of designing MEMS devices. For example, there doesn't exist frequently-used MEMS part features in SolidWorks. The existed features in SolidWorks are for macro-scale parts, which are not suitable for designing MEMS devices directly. If we want to design MEMS devices in the context of SolidWorks, we need to create some typical MEMS features (Fig. 2). These features, just like macro-scale standard parts (e.g. nut, screw) in traditional CAD system, can be used to design MEMS devices conveniently and repeatedly. With these features, designers can create geometric models of MEMS devices conveniently and quickly. To make designers select needed features in different designs, we should create as many part features as possible and save them in a feature database. However, once the features they want don't exist in SolidWorks, designers should create the features as follows:

- Drawing sketches. Sketches are the foundation of creating 3D solid part features in SolidWorks. A sketch is a 2D profile or cross section which is made up of such basic elements as line, rectangle, circle, arch. With menus and speed tool buttons provided by SolidWorks, designers can easily create sketches, specify dimensions for them and add geometric relationships among them.
- Generating 3D solid features. After sketches are finished, designers may extrude, revolve, loft or sweep sketches to create 3D part features, and then specify necessary dimensions to define the 3D part features definitely.
- Saving part features to a feature database. To use these self-made features in the later design, designers should save them to a database which is developed with Microsoft Office Access. The database is composed of multiple feature tables. Each table saves a kind of part features with similar shapes. The features in the database could be deleted or modified by designers if necessary.

B. Development of the 3D model of the MEMS device

In the assembly context of SolidWorks, it's easy for designers to use existed MEMS part features to develop 3D geometric models of MEMS devices. The design procedure is similar to that of macro-scale parts except that designers need to select material for each MEMS part feature in the process of designing models of MEMS devices. In fact, material information is one of the most important information of process flows in our method, because process flows are generated from models. But designers can't select material in the current environment of SolidWorks, because it hasn't this function module. Thus it's necessary to add a material-selecting module to SolidWorks.

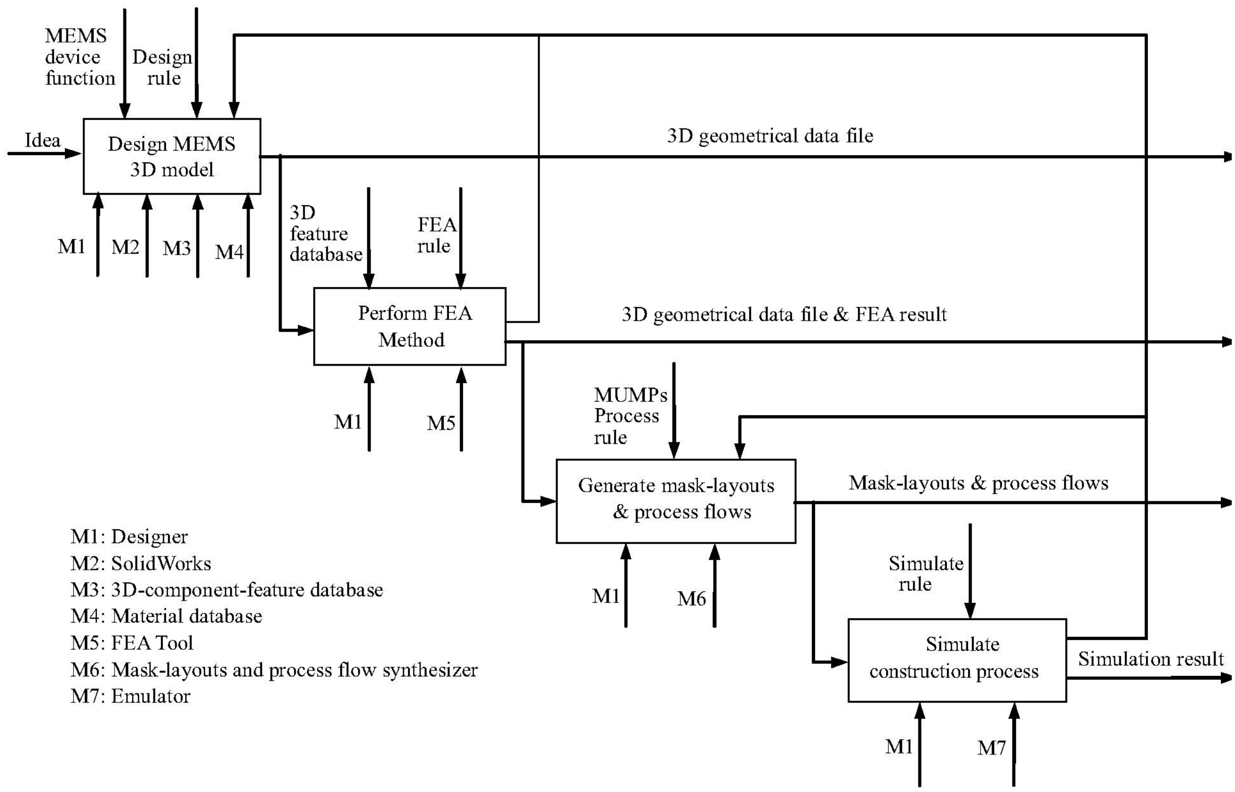


Fig. 1. IDEF0 of 3D MEMS design method.

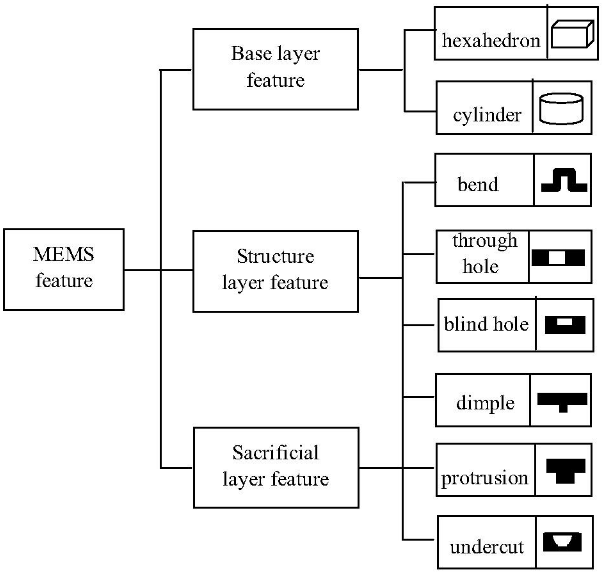


Fig.2. Some typical part features.

To add this module to SolidWorks, we should create a material database including some typical process materials (silicon, polysilicon, silicon nitride, etc.) and their properties (strength, density, conductivity, thermal characteristics, etc.). And then we can develop a material-selecting interface with programming language such as VB, VC++ or Delphi to SolidWorks. That is, we create user programs through the APIs of SolidWorks. SolidWorks provides several hundreds of APIs, which are open to all users. Therefore users can make secondary development to SolidWorks by accessing the design information of the shape to develop some function modules to meet their needs (Fig. 3). Most design information is saved in three important doctrines: PartDoc, AssemblyDoc and DrawingDoc.

After the material-selecting module is created, the designer can create the 3D solid model of the MEMS device in SolidWorks environment. They are expected to conceive of the function of the MEMS device and its shape first, then choose proper 3D part features from feature database and insert them into the graphic area of SolidWorks to assemble the model of the MEMS device layer by layer from bottom (substrate layer) to up (structure layer). The design procedure can be described as follow:

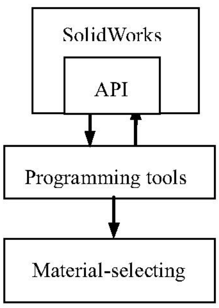


Fig. 3. The secondary development to SolidWorks

- Select a thin cylinder feature or hexahedron feature to design base feature layer, specify its dimensions and select material for it.
- Design sacrificial feature layer or structure feature layer on the top of the previous layer, and select material for it. This layer may contain multiple part features, so the designer need to specify each of their dimensions and add assembly mating relations for them. These part features are manufactured at the same time and in the same process (deposit), so we regard them as one layer.
- Repeat the second step until the solid model of the MEMS device is finished.
- Hide sacrificial feature layers to get the shape of the MEMS device.
- Use Finite Element Method (FEM) to analyze the shape. If the analysis result is unacceptable, the shape need be modified until it exhibits the desired characteristics. In this step, the shape of the MEMS device could be analyzed in FEM system such as ANSYS.
- Save the design information. Three kinds of information need to be saved: geometric information, material information and topological information. Geometric information can be automatically saved in Assembled file of SolidWorks. The designer should create two doctrines. One of them is for material information, the other for topological information. While saving topological information, part features of all layers are organized in a topology tree that can represent their topological relationship. For example, the following structure can be organized into a topology tree (Fig. 4 and Fig. 5).

C. *Generation of mask-layouts and process flows*

SolidWorks is a CAD system for macro-scale parts designing and can't produce mask-layouts and process files. Thus we need to add a function module to SolidWorks to generate mask-layouts and process flows. That is, we should use programming language to actuate the secondary development of SolidWorks through its APIs.

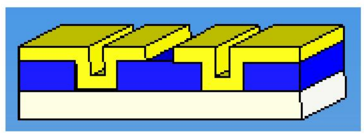


Fig. 4. The illustration of a three-layer structure.

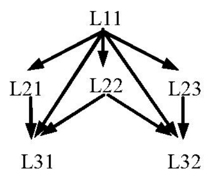


Fig. 5. The topology tree of the three-layer structure.

Before creating this module, we need to develop a process database including some typical process information (process name, thickness, deposit type etc.), because generating process flows from 3D shape will look up this database to find necessary process information to form a process information file.

The following is the algorithm:

- Decompose the 3D model of the MEMS device into layers. In this step, the topology tree is traversed to find all the layers. For example, the structure in Fig. 4 includes three layers, because each layer is made of different material from the others.
- Find part features of each layer and perform Boolean operation on the horizontal cross sections of these features. In Fig. 4, the bottom layer has one feature; the middle layer has three features and the top layer has two. If we perform Boolean operation on the horizontal cross sections of the top layer, the result should be described as a two-rectangle area.
- Find the location where deposition boundaries must lie, identify candidate mask-layouts and finally get mask-layouts for the 3D model. For example, in Fig.4, the middle layer has three part features, its deposition boundary depends on the shape of the top face of the bottom middle layer. For the middle layer, the shape of candidate mask-layouts depends on Boolean operation of the part features and the polarity of the candidate mask-layouts.
- Extract all possible process flows from the layer sequence in terms of fundamental processing steps such as deposition, etching.

D. *Simulation of the construction process*

In the preceding step, mask-layouts and process flows are generated from the 3D geometric model. But sometimes the designer could get several suites of mask-layouts and process flows from the same geometric model. Some of them can result in the desired shape of the MEMS device, but some can't. So it's necessary to check which suite is the most suitable for fabricating the MEMS device. A simulating module should be added to SolidWorks by creating programs through the APIs. In fact, the module is a 3D emulator, which picks up 2D topological information from mask-layouts, and thickness and polarity of mask-layouts from process flows to construct a 3D geometric model. With the simulating module, the designer may take each suite of mask-layouts and process flows as inputs and simulate the 3D structure of the MEMS device (Fig. 6). In this way, the designer can get several 3D structures. So he/she ought to compare these structures to the desired shape of the MEMS device and select the one that is most approximate to the desired shape. We could call the most approximate one *object 3D structure*. If the object 3D structure is not identical to the designed 3D geometric model, the designer is supposed to modify the mask-layouts or the process flows. Sometimes the designed 3D geometric model is needed to modify as well.

III. EXAMPLE

As an illustrative example of this method, Fig. 7 depicts the structure of a sensor which is designed in SolidWorks with 3D part features. In Fig. 7, the sizes of each feature are not as accurate as the real sizes. Its structure is organized into a topology tree as shown in Fig.8.

With the method, the mask-layouts and partly important process of the structure can be achieved as shown in TABLE 1. In TABLE 1, the minus (-) shows that the mask is negative and the plus (+) means the mask is positive.

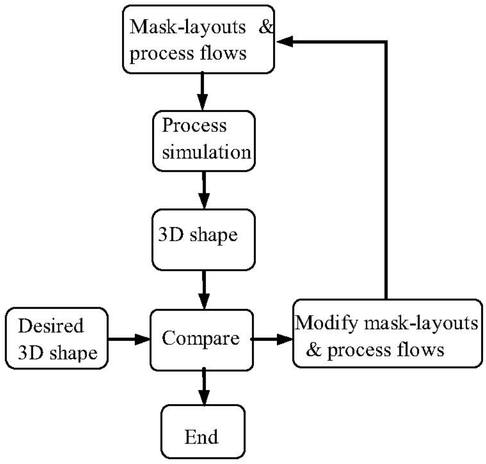


Fig.6. The simulation of construction process.

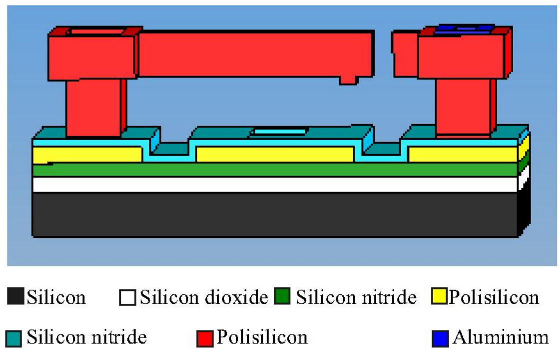


Fig. 7. Illustration of the structure of a typical device.

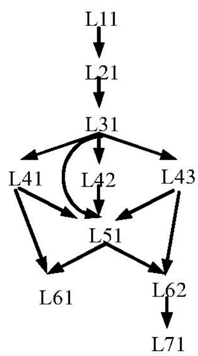
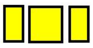
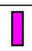
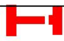


Fig.8. The topology tree of the structure

TABLE 1. MASK-LAYOUTS AND SOME PROCESS STEPS

Process name	Material	Polarity	Thickness (um)	Mask-layouts
Ground	Silicon		400	
Deposit	Silicon dioxide		0.30	
Deposit	Silicon nitride		0.22	
Deposit	Polysilicon		0.30	
Etch	Polysilicon	+		
Deposit	Silicon nitride		0.22	
Etch	Silicon nitride	-		
Deposit	PSG		2.00	
Etch	PSG	-		
Etch	PSG Silicon nitride	-		
Deposit	Polysilicon		2.00	
Deposit	Aluminium		0.80	
Etch	Aluminium	+		
Etch	Polysilicon	+		
Deposit	PSG		2.00	

IV. CONCLUSION

This method that the traditional CAD system (SolidWorks) is used to design the shape of MEMS device instead of professional MEMS CAD system is proposed. It is very intuitive and capable of generating mask-layouts and process flows from the 3D geometric model of the MEMS device by focusing on the topology tree and material information of the model.

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