T-CAD Environment for Multi-Material-MEMS Design

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ABSTRACT

In this paper we present a design methodology for multi-material MEMS. The designer is interactively lead through the design process from the formulation of basic specifications to prototypes. Different knowledge bases are attached to enable the designer to choose the right solutions for a certain design idea. One core functionality is a built-in catalogue of building blocks which represent sub-functional elements of MEMS, the data model for this function is described. Each building block contains a parameterized geometrical model as well as alternative process flows which can be used to fabricate the components. After setting up a system all process flows from single building blocks are merged by an interactive algorithm, which is described in this paper. An example will be used to illustrate the methodology.

Keywords: system design, building blocks, knowledge database, multi-material MEMS, T-CAD

1 INTRODUCTION

The design of commercially available MEMS is largely driven by an approach of using foundry processes like MUMPs® or SUMMiT™ and design rules. This design approach has been adapted from microelectronics and keeps the device layout and the fabrication process almost separated. However, there is a growing demand of using non-silicon based technologies. Additionally a wide variety of materials is establishing for the use in sensors and actuators. But due to a lack of holistic approaches for a design methodology, difficulties and costs for a commercial production of such systems still prevent them from being introduced to mass market [1].

In this paper we present an approach to tackle this task. As stated in former papers a rule-based validation tool has been developed [2]. Based on a data model for micro fabrication processes, materials and media and a knowledge database, process flows can be validated for their consistency. This data model has further been enhanced to form a more complex product data model which allows to store all data connected to the design process [3].

2 DESIGN ENVIRONMENT

The main concept is driven by a classical engineering approach for early design stages and the use of ready made building blocks on component level. The task is specified by requirements and demands, sub-functions are specified and the designer sketches a rough outline of the desired geometry. Now the core functionality of the system assists the designer to find solutions for desired sub-functional elements. A building-block database keeps ready made solutions. Each building block is a single component and incorporates a parametric geometrical model as well as alternative process sequences. The data model will be described in the next section.

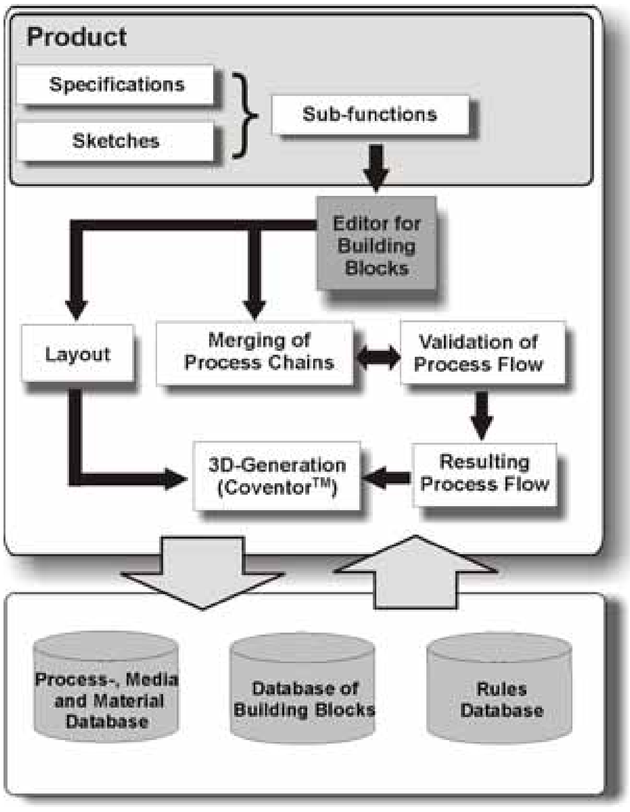

Figure 1: Flow of work in the presented T-CAD Environment

The building blocks are arranged in an editor and geometrical parameters and materials are selected. Afterwards an iterative algorithm is finding material interfaces and layers that can be fabricated in one process step. A process flow for the desired system is generated and validated using the validation tool. If flaws are detected, alternatives are calculated or possible solutions are proposed to the designer. Once a consistent process flow has been generated, the layout data is merged to derive a suitable mask set. Finally, a three dimensional model can be generated to visualize the result and do further computational analysis. An overview of the flow of work is given in figure 1.

3 BUILDING BLOCKS

Building blocks are understood as sub-functional elements. Each building block contains a parametrical model of its geometry and different alternative process chains to build its components. The blocks are stored in a catalogue and can be accessed by a designer via an editor interface. Sorting criteria can be functional (e.g. generate force, guide flux), geometrical (undercut, sidewall angle, aspect ratio) or material based.

3.1 Data Model

Figure 2 shows the data model of the implemented building block structure. Each block can be referenced by other bocks and belongs to a certain class. The two dimensional layout of the mask as well as the topological layout is stored in a cell based model. Each block can contain a list of several cells. A cell in turn is formed by elements which belong to a certain layer to assign it to different materials and process steps. All geometrical operations can be controlled by Tcl [4] scripts and commands, which makes automated generation of user defined building blocks possible. A three dimensional origin allows to position the block absolute to the coordinate system.

The main innovation is a connection to a list of possible fabrication sequences. Such a sequence stores consistent process flows for the fabrication of the given component and is composed of several single processes, which are specified in the data model described by Hansen [5].

3.2 Geometrical Representation

Figure 3 shows selected components for micro coils, as an example. The geometrical parameters are used to define layout data on the one hand and process parameters on the other. In case of the helix coil width (a), distance (b) and number of windings (w) will define the two dimensional layout of a photolithographic mask, whereas the heights (h_1 + h_2) will each determine the layer thickness of a deposition process in the process chain. After a building block was selected from the database the user can define all geometrical parameters in a dialog.

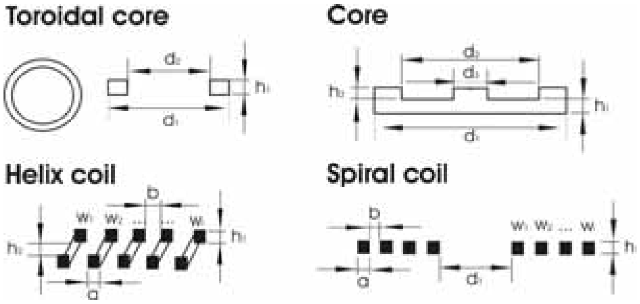

Figure 3: Parameterized model for selected building blocks from the micro coil catalogue

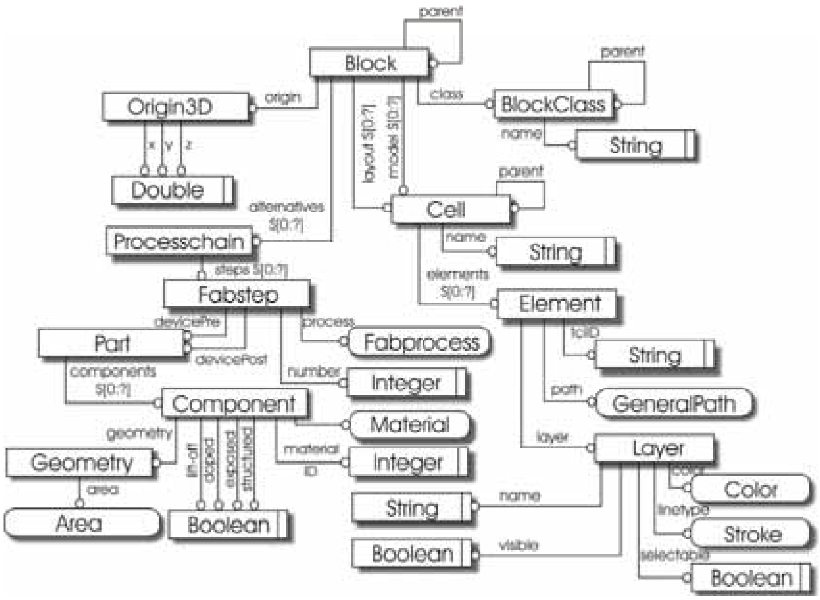

Figure 2: Express-G notation of the data model used to store all data connected to a component building block.

4 MERGING OF PROCESS CHAINS

Having specified the geometrical parameters the next step is to merge the single process chains into one flawless process flow. This is achieved iteratively and involves the following steps:

- Detection of layers that can be fabricated in one process step
- Merging of layout structures, which are on the same masking layer
- Validation of the generated process chains and consideration of alternative processing to generate a flawless sequence.

The detection of layers, that can be fabricated in one process step is the most difficult part of the algorithm, and will be described here. First, all layers of the models are listed and arranged in a matrix. Then a material is allocated to each layer. According to the material used, matches are performed. Additionally geometrical parameters are taken into account to decide whether two components can be fabricated within the same step.

Take a via and coil windings (see figure 4) as an example. Though it appears as if both structures have different structure heights, they can easily be deposited in the same sequence of process steps, as the via hole is completely filled during the deposition process for the coil windings. This makes it difficult to simply use geometrical matching algorithms to detect such components. Some components can be deposited in one step, but have to use different structuring technologies to achieve the desired geometrical results. Using the same photolithographic process for via and coil resist moulds will not be possible, in all cases. Different resist heights in the via and the coil structure will result in extended exposure and development times for the via, if a classical spin-coated photoresist is used. The use of an electrochemically applied resist like EAGLE can avoid that behaviour. This makes clear that detailed process knowledge is needed to decide whether two components can be fabricated in one single step. The used algorithm takes geometrical as well as process parameters and tries to find matches in either of them. If the same process fabricates two components all process parameters are being checked for matching values. Hereby the algorithm does not only include directly equal values, but also dependent parameters, e.g. the same layer thickness can be achieved by a deposition rate of 10 nm/min and a process time of 30 min as well as by a deposition rate of 25 nm/min and process time of 12 min. This again shows the complexity of the given problem. Until now a large extend of user interaction is needed to determine, whether two components can be fabricated within the same process step. Work regarding the development of a fully automated algorithm is still ongoing. The degree of automation in this process will decide about the economic advantages of the postulated design process.

Figure 4: Example for merging two blocks: though the via appears to be higher than the coil structure, the same deposition process can be used.

5 EXAMPLE

The design of a toroidal helix coil will be used to illustrate the usefulness of the given approach.

Having identified single functions, the designer will search the catalog of building blocks for suitable functional elements. For fulfilling desired electrical parameter specifications an iterative optimization process has to be carried out to find a preferable configuration for the device. This involves design methods on the component level, which is supported by several specialized tools being linked to the design environment via sub workflows. For the given example a FEM tool can be used, to analyze the influence of parameters like wire thickness, distance of wires and number of windings.

Once geometrical dimensions and materials have been optimized and suitable building blocks have been found, all individual process chains have to be merged to one single processing sequence. Figure 5 shows a cross-sectional view of the proposed layout. The device consists of two of the building blocks shown in figure 3: a toroidal core structure and a copper helix coil embedded into insulating SU-8. Pads are used to contact the coil windings.

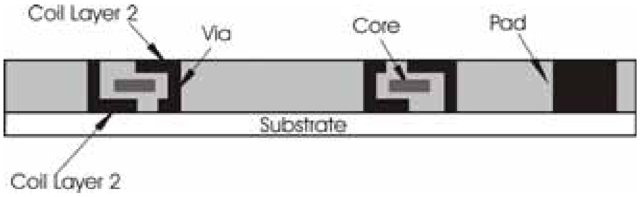

Figure 5: Cross sectional view of the proposed layout

In a first step the designer chooses the building blocks and specifies all geometric parameters of the given models. Then the blocks are positioned relative to each other by stating the position of their origins in the global coordinate system and material properties are defined for the single deposition steps. Now the blocks are searched for matching materials and the user can predefine which layers should be fabricated in one step. By analyzing parameters like process duration, deposition rate or structuring depth possible combinations are found and step-by-step a possible process flow is generated. The resulting process flow is now validated using the validation tool described earlier [2]. If incompatibilities are stated process parameters can be directly changed or alternative process sequences are tried to omit these errors.

After a flawless sequence is generated it is searched for photolithographic processes to allow layout data to be attached to it. A second merging process is used to combine the single layouts to one mask layout. Combining the layouts is much easier than merging the process sequences. All geometric data supplied by the user is used to arrange the lithographic patterns on the mask. The layer of in which a structure has to be placed has been determined earlier during the matching phase of the process sequences.

A commercial process emulator (DESIGNER^{TM}, Coventor Inc.) generates a 3D model of the proposed device. Process sequence and layout data are transferred into the system using specially designed interfaces. This is easily possible due to the TCL script based control mechanism offered by CoventorWare^{TM}. The resulting structure can be used for further computational analysis and validation of the design. Figure 6 shows the resulting 3D Structure.

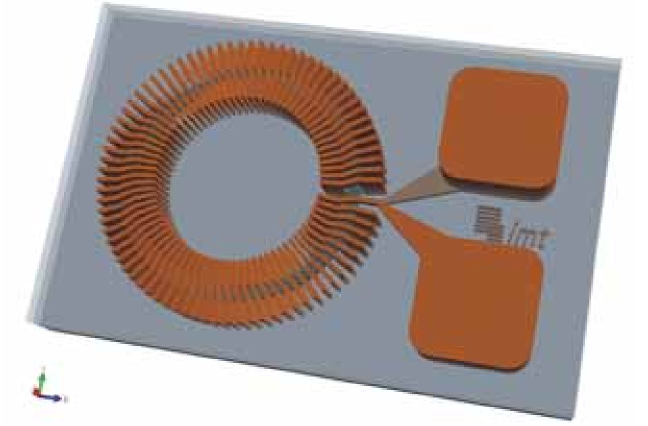

Figure 6: The generated three dimensional model can be used for further computational analysis and design validation.

6 SUMMARY AND PERSPECTIVE

The presented approach delivers a design tool for multi-material MEMS and can act as a system level tool with interfaces for component level analysis tools. The platform provides interfaces to different knowledge bases which either can act as source of information or as editing tools for database maintenance. The main advantage of the system is a built-in setup of a consistent process flow. Together with the reuse of ready-made building blocks this leads to a decrease in development time and costs.

7 ACKNOWLEDGEMENT

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