A visual approach on MEMS process modeling using device cross-sections

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ABSTRACT

With MEMS entering fast moving consumer markets the need for more efficient design concepts becomes apparent. Without a common technology platform in sight, the only feasible solution seems to be extensive modularization and re-use of existing manufacturing technology. In this paper we propose a visual approach on process modeling by presenting a software tool that supports the device engineer in specifying a set of device cross-sections that satisfy the specific requirements of thin film manufacturing processes. The drawing tools are modeled to represent typical effects of thin-film semiconductor fabrication techniques. Geometrical analysis algorithms ensure adherence to manufacturing constraints. The tool is currently under evaluation within the European project CORONA (CP-FP 213969-2).

Keywords: mems, tcad, cross-section, process, manufacturing

1 INTRODUCTION

The MEMS industry is characterized by a large variety and diversity of application and technology domains[10]. Depending on the application a MEMS device may integrate electrical, mechanical, optical, or fluidic components. The diversity prevents the establishment of a common technology platform like CMOS for the IC-industry. Consequently nearly every MEMS device has a unique device architecture that requires an application specific manufacturing process. This is so typical for MEMS that it has been coined as the MEMS-Law ("One device, one process") [13].

With MEMS entering fast moving consumer markets the need for more efficient design concepts becomes apparent. A technology centered approach where a product has to be designed around a highly specialized and optimized technology is unable to cope with short product cycles and fast changing market demands. Without a common technology platform in sight, the only feasible solution seems to be a structured modularization modularization and extensive re-use of existing manufacturing technology. Successful process design thus depends on a comprehensive management of manufacturing related knowledge. In [11] the authors introduced the first concept for an PDES (Process Development Execution System) that provides an environment for management and design of MEMS manufacturing processes. The environment has since been extended with a rule based consistency check that ensures the feasibility and manufacturability of a manufacturing process [12] and a TCAD interface decouples technology data from simulation models [7]. Finally the complete system (see [6] for a summary) has been released as XperiDesk PDES by Process Relations.

While the aforementioned PDES has proven itself as a valuable tool for knowledge management of manufacturing technology and verification of newly designed manufacturing processes, the initial task of selecting an appropriate set of process steps based on a device model is still almost unsupported. First approaches that foster the synthesis of MEMS manufacturing processes have been introduced by [4], [5]. In [8] the authors presented a visual approach that is roughly based on [4].

In this paper we supplement the visual approach with a software tool that supports the device engineer in specifying a set of device cross-sections that satisfy the specific requirements of thin-film manufacturing. The drawing tools are modeled to represent typical effects of thin-film semiconductor fabrication techniques. A geometrical analysis performed in the background ensures that it adheres to the constraints of thin film manufacturing. Additional functional aspects and non-geometric constraints can be specified for every geometric component. Further integrated analysis algorithms provide automatic identification of layer structures and layer modifications. The tool is currently under evaluation within the European project CORONA (CP-FP 213969-2).

2 MEMS DESIGN

For MEMS design two different design approaches can be distinguished. On the one hand there is a behavioural driven top-down approach. The procedure is very similar to the design flow known from IC design and depends heavily on fixed and fully characterized manufacturing technologies. Therefore this approach implies many restrictions regarding specific shapes and materials. Nevertheless it is well defined and supported by several commercially available design tools (e.g. the

CoventorWare tool suite). On the other hand there is a physical or bottom-up approach that concentrates on the available technology. It offers much more flexibility by taking into account the full bandwidth of fabrication technology and materials. This approach is supported by TCAD (Technology CAD) tools and PDES (Process Development Execution System).

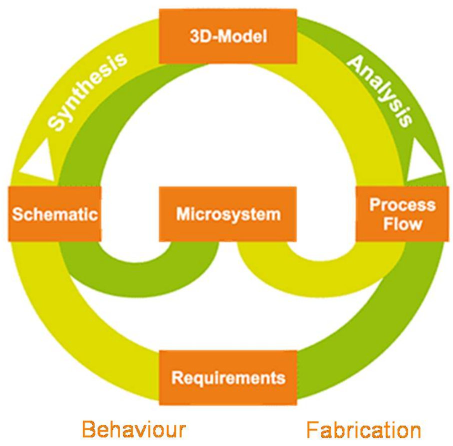

Figure 1: Pretzel Model for MEMS Design

The so called pretzel model[3] shown in figure 1 combines the two design approaches. It has five states that describes certain groups of design artefacts and two interwoven flows: a top-down synthesis flow and a bottom-up analysis flow. The top-down synthesis flow starts with creating a structural description (schematic) based on the system requirements. From this structural description a corresponding 3D-model of the device is built. The next synthesis step is the development of an manufacturing process based on the 3D-model. Finally, the manufacturing process is used to create a physical prototype of the MEMS.

The bottom-up analysis flow works in the opposite direction. It starts by comparing the system requirements with the technological constraints of the manufacturing process. Thus giving an assessment if the selected manufacturing technology is adequate. Next step is an assessment if the concrete manufacturing process is able to create the structures specified in the 3D-model. This task typically involves a technology simulation / virtual manufacturing. The analysis step that assesses if the 3D-Model matches the schematic specification of the MEMS can be done by simulation (e.g. FEM). The final step of the analysis flow is the comparison of the schematic with the physical prototype. A typical way to do this would be the generation and application of appropriate test patterns.

In summary, the left part of the pretzel covers mostly behavioural design aspects whereas the right part concentrates on manufacturing and technology aspects. The model does not imply a fixed order of the design steps. Similar to the Y-Model[1] in IC-design many different design flows can be devised.

3 PROCESS SYNTHESIS

As has been pointed out in [2] there are structured methods and design tools for nearly every design step in the pretzel model with the exception of the synthesis step between the 3D-Model and the Process state. While the related analysis step is well supported with process simulation TCAD tools, there is currently only very limited design support for the synthesis task. Deriving a manufacturing process from a geometrical device model is still mostly based on the creativity and experience of a small number of technology experts. An apposite definition of this task has been given by Senturia: *"Good process design is a creative art, supported by careful engineering analysis and experiment"* [9].

First assessment of the current practice in the MEMS industry revealed that cross-sections are used by technology providers to specify manufacturing capabilities as well as by MEMS designers to specify their requirements on a manufacturing technology. The visual representation of manufacturing capabilities as a cross-section bridges the gap between manufacturing and device design. An approach on structured process modeling that picks up this common practice could be seamlessly integrated with the intuitive approaches currently in use. Another important aspect is that the drawing of two-dimensional cross-sections is usually more straightforward and requires less training than 3D-modeling tools. A drawback of using cross-sections is that a single cross-

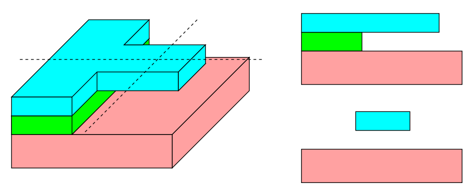

Figure 2: Characteristic cross-sections of 3D-model

section is most cases not sufficient to thoroughly describe the geometries of a three-dimensional MEMS device. Even the simple cantilever structure shown in figure 2 would require at least two cross-sections to capture all relevant features. Therefore the proposed approach uses a set of cross-sections that are characteristic for the MEMS device under development.

The design approach is divided in two subsequent phases. During first phase a thorough analysis of the cross-sections is performed. Objective of this phase is to identify the geometric features relevant to thin film manufacturing technology. Similar features are grouped into

 NSTI-Nanotech 2010, www.nsti.org, ISBN 978-1-4398-3402-2 Vol. 2, 2010

material layers, possible modification steps like etching are identified, and geometric constraints between them extracted. Result of the analysis phase is an annotated layer model of the MEMS device. The second phase is a synthesis phase that starts by constructing process frames from generic process steps like deposition, lithography, and modification steps. The process-frames can be used as templates for process design or as search pattern for a PDES like XperiDesk. The whole approach is described in more detail in [8].

4 THE EDITING TOOL

In current industrial practice cross-sections are drawn using general technical drawing tools like AutoCAD, office tools like PowerPoint, or simply pen and paper. While these tools are sufficient for documentation purposes and business presentations, they lack some features needed for design specification and especially for design automation:

- There is no straightforward way to specify non-geometric constraints (e.g. material properties).
- Drawing and modifying geometries that are typical for MEMS is rather cumbersome.
- The output is usually a picture format without proper dimensioning and domain specific meta data.

The cross-section editing tool presented in this paper addresses those shortcomings by providing a specialized environment for the specification of two dimensional cross-section representations. The goal is to enable MEMS designers as well as technology experts to visually specify their requirements and constraints on a manufacturing technology in a straightforward, non-ambiguous way. Figure 5 shows a screenshot of the tool.

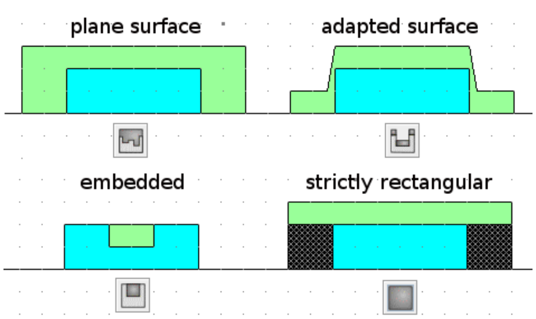

Figure 3: Basic cross-section drawing tools

The look and feel of the user interface follows established models, so that potential users will become quickly familiar with the tool. The drawing tools are modelled to recreate typical effect of thin-film semiconductor fabrication techniques as shown in Figure 3. For example the "adapted surface" tool is modelled after typical deposition steps and the "embedded structure" tool creates structures typical for doping of semiconductor material. During drawing there are several analysis algorithms running in the background. Some of them make the drawing tools sensitive to adjacent geometries and are constantly checking a set of basic geometric rules to ensure that the cross-section adheres to the geometric constraints of thin film manufacturing and is therefore – in principle – manufacturable. Others are used to classify the shape of the geometry into one of six shape types and detect typical process features necessary to select a proper manufacturing technology later on. Additionally it is possible to group multiple geometries into layers. The tool gives recommendations which geometries should be grouped into layers based on shape analysis and topological dependencies.

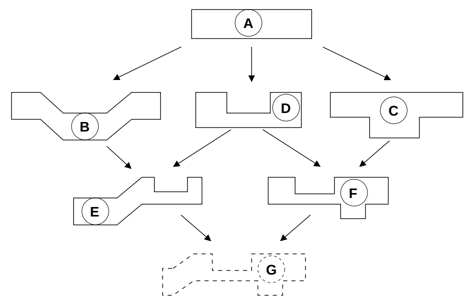

Figure 4: possible shape types

Every geometry is related to a drawing material that contains non-geometric constraints (e.g. conductivity, material, Young's modulus) and can be annotated with functional aspect (e.g. this component is a cantilever). While these annotations have no real effect on the graphical representation of the cross-section, they are necessary for design specification. For data exchange and interfacing with PDES and TCAD tools a XML-based data format is used. The data format is extendable with user defined data objects and can manage sets of multiple correlated cross-sections and their constraints.

5 CONCLUSION

In this paper the basic concepts of the authors approach on MEMS design and a visual approach on the specific task of manufacturing process synthesis based on device cross-section have been discussed. A software tool tailored specifically to the specification of cross-section representations has been presented. The tool provides drawing tools that are modeled to mimic typical thin-film manufacturing technologies and provides means to define non-geometric constraints. Additional analysis algorithms allow real time checking of manufacturing constraints and give recommendations on process

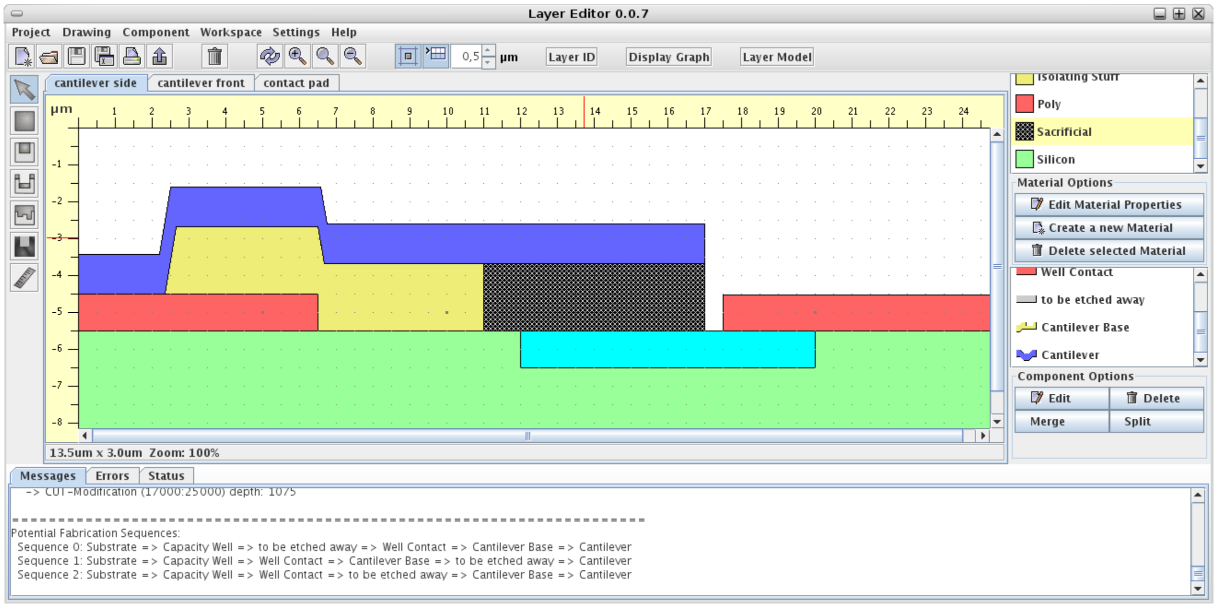

Figure 5: Screenshot of cross-section editing tool

design. The open XML-based data format enables the usage of the tool in context of third party design tools.

The authors would like to acknowledge the financial contribution of the European Commission financing the *CORONA* project under the 7th Research Framework (contract number CP-FP 213969-2). Additional thanks go to all project partners providing valuable knowledge from other domains.

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