A Data Model for the Representation of Fabrication Dependencies concerning Micromechanical Devices

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ABSTRACT

Conventionally the design of a product is conducted paying only little attention to the subsequent manufacturing. Regarding micromechanical devices this is not practicable, since the design choices taken are highly dependent on the technology used for fabrication. This has a significant impact on the possible combinations of geometries, materials and fabrication processes applicable, since a multitude of constraints have to be considered. This paper presents a proposition for a data model, which aids the development of simulation and optimization tools by the semantic reproduction of the interdependencies of the design phase of micromechanical parts. An overview on the possible incompatibilities of processing and/or part design is given as well as how these can be regarded in the data structure.

The proposed data structure has been implemented for the use with an MST-CAD environment and a rule-based configuration tool for process sequences.

Keywords: MEMS data model, process compatibility, MST CAD, process configuration.

1 INTRODUCTION

The general approach to the development of a device is to subdivide the product life-cycle into different phases like functional specification, product design, manufacturing, sales and marketing, maintenance and lastly recycling. This strategy has proved suitable for many manufacturing domains and also works e.g. for the design of microelectronic devices. The reason for this is the availability of a high number of standardized components, by which the design phase can - to a great extent - be reduced to combining these elements. Modifying single components is in many cases not necessary keeping the influences of the manufacturing phase on the design specification at a minimum. Contrary to this circumstance the design of micromechanical devices usually requires an accommodation of the elementary structures to the intended active principle. Typically the fabrication processes for MEMS are only suitable for producing a very narrow spectrum of geometric shapes needing specific material combinations. As a result a high interdependence of layout, materials and processing is given for designing micromechanical components. The designer has to compose individually adapted processing steps and determine suitable material combinations. Therefore the phases of product design and specifying the manufacturing sequence can not be dealt with separately but must be considered simultaneously while developing the system ruling out incompatibilities that may arise [1].

Analogical to this the data models for storing the information of the different design stages have evolved missing out the interdependence of the device and fabrication process information, which is significant for micromechanics. This conventional data representation is therefore limited to the description of geometry, material or process parameters. The outlined data model overcomes this drawback by incorporating the dependencies between different fabrication processes and the used materials implicitly facilitating their pursuance.

2 COMPATIBILITY REQUIREMENTS FOR PROCESS SEQUENCES

A micromechanical device is usually produced using a combination of bulk and surface oriented silicon structuring technologies. These are carried out successively and can be represented in a processing plan, which has to be checked for consistency in order to assure its feasibility. Several constraints have to be checked while defining such a process sequence. The following paragraphs show how these constraints can be grouped into three main kinds:

Firstly, typical incompatibilities of the processing in the defined sequence may arise from the use of materials, which may be affected in their chemical or mechanical properties by the following processing - or even not withstand it at all. As an example for a case, where the chemical properties of a material are insufficient, may serve the surface roughness of a microtribological layer. Its quality might be affected by an etch process for structuring the substrate, which is carried out subsequently. A slight susceptibility of the tribological material of being etched may therefore make the process sequence impractical. A solution to this problem might be the insertion of an additive process for the creation of a protective coating on the tribological layer, which needs to be removed afterwards in an additional step. However, maybe the simple rearrangement of the process sequence placing the etch step prior to the production of the tribological layer may be a possible remedy as well. A basic example for mechanical mismatch of material properties might be a significant difference in
the thermal expansion coefficient of two adjacent materials, which may have the effect that the microcomponent will be twisted or even destroyed due to the mechanical stress caused by it being heated in a given temperature range. To avoid this alternative materials must be chosen or a way to reduce the thermal effect on these layers (e.g. by adding an insulation layer) must be found.

As a second kind of incompatibility certain manufacturing processes may not be carried out successively without inserting proper treatment of the micromechanical part in between the processing. These incompatibilities may occur because of e.g. chemical residues caused by the preceding processing. Such problems usually will be easily solvable by inserting an appropriate cleaning step. Other difficulties belonging to this kind of incompatibility may arise from insufficient adhesion of adjacent material layers, etc., which may be overcome by inserting additional treatment.

Lastly, the third main kind of constraints to be evaluated is the feasibility of generating the intended geometry using the specified fabrication process. This rather classical demand is already handled by a range of stand-alone software tools for process simulation.

The described incompatibility types are, of course, not always clearly separable and it can sometimes not be stated explicitly, what is the cause for the incompatibility at all. In many cases mixtures of several cases may take place.

3 PROPOSED DATA MODEL

In order to enable a straightforward evaluation of these constraints the data model was designed to represent the process sequence semantically correct making the connection of the part and fabrication process information of the regarded microsystem.

A simplified excerpt of such a data model, which is taking the dependencies described above into account, is shown in figure 1. The micromechanical device is viewed at its different stages of production as an object of class part, itself being an assembly of several components (class component) or other sub-parts, allowing the clustering of information. Each component represents different aspects of the part it is referenced by, e.g. a masking layer, regions of dotation within a layer or the substrate itself. This class encloses the actual geometric and material information, the representation of which was based on the integrated resources of the international standard STEP\(^1\) [2,3].

The corresponding fabrication process (class fab_process), which will be used to alter the geometric or material information of this part, is determined by its process parameters (class parameter) as well as the additives (class material) needed. The linkage of the part and fabrication process information is made by the class fab_step (fabrication step), itself being a part of an ordered list of the complete process structure (class process_chain). Each fabrication step is linked to its predecessor as well as its successor, if available. The part information contained in a fabrication step describes the micromechanical device before the corresponding fabrication process is applied to it. The resulting structure, also of class part and carrying presumably slightly changed component information, is stored in the part attribute of the succeeding fabrication step in the process sequence. Additionally each fabrication step may include several fab_sim objects, which hold simulation data of the actual processing. It encloses a reference to the fabrication process to be simulated and two objects of type part to represent the treated components before and after the simulated processing. Furthermore a set of parameters is included, which may comprise the tool-specific settings for the simulation run.

Figure 2 gives further insight on the class fab_proc- ess, which is the root class for object-oriented data structure able to represent the different kinds of fabrication processes existent. With increasing level in this inheritance hierarchy the classes are specialized to accommodate the requirements of the described processes, whilst fab_pro- cess only comprises the information which is relevant to all types of processes. This is e.g. a text based description of the process and notes about the experience other users have gathered, information about its performance characteristics, stability and susceptibility, needed equipment, environmental conditions as well as a list of process pa-

\(^1\) Standard for the Exchange of Product Model Data (ISO 10303)
parameters and process additives. Furthermore, references to advisable pre- or postprocessing are possible and also alternative processing may be specified. This information may be helpful while defining or adjusting a process sequence.

By providing the fabrication and device data in an ordered linked list, the compatibility of a number of fabrication steps belonging to a subprocess chain can be evaluated in a straightforward manner and additionally needed processing can be easily inserted by redirecting the references of the predecessor and successor to the new fabrication step.

Lastly, the affirmation of the feasibility of obtaining the intended device characteristics using the chosen fabrication process is supported by allowing the simulation data to be stored in the according simulated fabrication step.

This structuring qualifies the data model for the internal data representation of configuration tools for process sequences as explained below or published in [4,5].

4 APPLIANCES

The proposed data model was implemented to an object-oriented database system, which is operated as a central project database of an MST-CAD environment for the design of micromechanical actuators currently being developed at the Institute for Microtechnology (IMT). This database is utilized for the persistent storage of microsystem-related product data as well as a knowledge base for fabrication processes based on class fab_process.

4.1 MST-CAD environment BICEPS

The intention of BICEPS is to provide a modular design environment to the engineer in order to facilitate the development of active Microsystems. Presently this workflow-based environment focuses on the wet chemical etching of silicon using KOH. It includes a commercial CAD-software for specifying the intended silicon structure as well as means for FEM-analysis to verify its functional properties and check on given constraints. Using the approved structure, optimized mask layouts for the lithographic processing can be synthesized and validated using an atomistic simulation tool. BICEPS allows the concurrent working on projects at different locations assuring access to the database system via a CORBA-based information management architecture. Further facts on the implementation and organization of this MST-CAD environment have been published elsewhere in further detail [6,7].

The configuration data needed to define the wet chemical etch process like etchant concentration and temperature will be read from the fab_process object attached to the simulation data (fab_sim) in the database (see fig. 1). Further data like the orientation of the used wafer type or possibly existing pre-structuring of the substrate can be obtained from the geometric and material information stored in the attribute pre_structure.

During the flow of work, the emerging simulation and optimization results for the wet chemical etching fabrication process are then stored within a fab_sim object inserted into the corresponding fabrication step data structure. Analogous to the fabrication process class hierarchy the
information for simulation and optimization procedures is organized in an inheritance tree originating at fab_sim.

Since it is very probable, that several simulation runs will have to take place while twisting the parameters of the simulation tool before a suitable solution is found, the fab_step object is designed to hold various independent simulation objects. Next to process and part information additional tool-specific data is stored in order to be able to reproduce the optimization and simulation runs. Thus all occurring data can be stored persistently.

As is apparent the described part of BICEPS deals with microsystems on a component level. With respect to the compatibility requirements mentioned in section 2 this corresponds with checking the feasibility of the intended component characteristics using a certain fabrication process.

4.2 Rule based process configuration

As further extension to the described MST-CAD environment a tool for the support of design decisions on the system level of micromechanical devices is being developed. Its aim is to check user defined process sequences on internal compatibility according to the requirements explained in section 2.

It utilizes the data structure of the process_chain object evaluating the contained fabrication process with respect to the part data making direct use of the benefits of the proposed data model. Of great importance is the order in which the processing takes place, since incompatibilities may be avoided by insertion of additional treatment or a rearrangement of the processing order (see section 2). For this it is advantageous that the information is kept in a linked list, which can be easily modified or extended.

The data stored in the part attribute to each fabrication step always represents the complete microsystem with all the geometry and material information, so that by going through the list of steps the change due to the preceding processes can be viewed. This has the advantage, that - opposed to an incremental storing of the part changes taking place within the steps of the list - the whole information may be accessed straight away without having to read from prior fabrication steps. The overhead on storing redundant data can be met by falling back on the 'lazy versioning' technique known from object-oriented database systems.

For defining process sequences the employed fabrication processes need to be sufficiently defined. To facilitate the associating a persistently stored process catalog can be accessed to select default processing parameters, which can then be adapted to the actually needed conditions. Successfully validated process sequences may be added to this catalog. The software program makes use of a commercially available rule based configuration tool [8]. Defined rules for checking the constraints on the compatibility of processes allow the parsing of the whole process chain, whenever a fabrication process is inserted into the sequence. These rules may reproduce simple relationships of process and/or material parameters e.g. for inspecting, whether the heat resistance of the used materials is sufficient with regard to the following processing. More complicated dependencies must be evaluated from theoretical considerations and practical testing to be able to subsume them into such rules.

5 CONCLUSION AND PERSPECTIVE

Opposed to most domains of manufacturing, the design of micromechanical systems is strongly dependent on the fabrication techniques used and the materials chosen. This characteristic underlines the need for simulation and optimization tools aiding the design engineer and asking for a qualified internal data representation adapted to the restrictions of microsystem design. The presented data model was composed to satisfy the needs of tools for simulation and optimization of microsystems on a component level as well as optimizing process sequences on the system level.

It is planned to expand the model to other life cycle stages apart from the early design phase and to enforce the work on the mapping of the data constructs to the international STEP standard.

ACKNOWLEDGEMENT

The presented work was funded by the Deutsche Forschungsgemeinschaft (DFG) within a Collaborative Research Center (Sonderforschungsbereich 516) titled ‘Design and Fabrication of Active Microsystems’.

REFERENCES