Methodology and tool support for micro and nano product engineering for SMEs

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ABSTRACT

This paper reflects the product engineering of MEMS with a focus on the involvement of SMEs. Based on a comprehensive MEMS product engineering methodology taking into account the concurrent MEMS technology and structure design as well as the SME requirements an adequate tool support is presented. We take into account opon source tools, as well as EDA programms that are commercially available. The paper ends with the presentation of a design flow control based on a consept of design meta data.

Keywords: MEMS product engineering, tool support, data management, design flow control

1 INTRODUCTION

The development of micro and nano tech devices such as MEMS (micro-electro-mechanical systems) and NEMS (nano-electro-mechanical systems) based on semiconductor manufacturing processes comprises the structural design as well as the definition of the manufacturing process flow. The approach is characterized by application specific product engineering (PE) flows, i.e. design and manufacturing processes are depending on the later product. For micro and nano products technological constraints have a great impact on the device design and vice-versa.

In the first part of this paper we introduce a comprehensive methodology for customer-oriented product engineering of MEMS products taking into account the specific needs of SMEs since many developments are carried out in limited batches by smaller companies. The MEMS engineering process is analyzed with regard to typical SME constraints taking into account application specific procedures and (data) interfaces. The product engineering for SMEs is often determined e.g. by the avoidance of costly tools and the need of short training cycles for a quick time-to-market. The results of this methodology are used to develop and to enable an appropriate CAD support either by incorporating existing CAD tools or by specifying individual tools to be implemented.

Subsequently we introduce an environment for the development of micro and nano devices. The environment provides central data and workflow management for design and manufacturing knowledge, handling the whole range of product engineering related information and their complex relationships. The manufacturing process development for micro and nano devices is a central part of this holistic approach and is supported by XperiDesk, a CAD environment for the management and the design of thin-film-based MEMS fabrication processes. This environment has been developed and commercialized by the authors. The whole development was carried out in an international multi-site research project (CORONA - funded by the European Commission CP-FP 213969-2) and is currently adapted to the needs of SMEs in an on-going project (MIDES -.funded by the Federal Ministry of Education and Research BMBF).

2 MEMS PRODUCT ENGINEERING METHODOLOGY FOR SME

In contrast to the development of planar, purely electronic circuits (IC design and manufacturing), the MEMS product development holds some specific properties. Mechanical components of MEMS (i.e. sensors and actuators) are characterized by masses and volumes, and are therefore three-dimensional structures. The height of structures and their material properties, however, can only be influenced by the appropriate design of the manufacturing processes. Thus, the processes and their application-specific modification or parameterization is of much greater importance, as it is in the case of IC design. This strong and mutual technology dependence is expressed in the pretzel model (see Fig. 1).

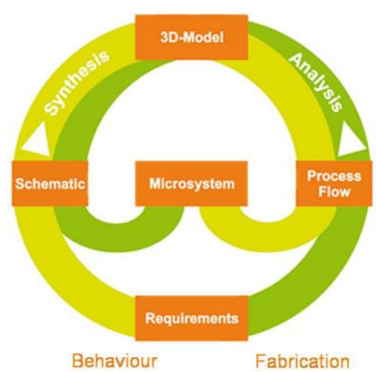

Figure 1: Pretzel model for MEMS design.

The strong interdependence of the process design and the structure of the micro product is commonly known as the MEMS-Law (*One product, one process*) in the literature.

This close relationship between structure design on one side and process design on the other side actually suggests that the complete product development for MEMS, from conception to production has to take place, in a single company. However, this is only true for a few large manufacturers of MEMS, so called IDMs (Integrated Device Manufacturers). A large part of the MEMS market is dominated by small and medium sized enterprises. Because of their expertise they cover only a part of the product development flow. (see Fig. 2) Besides the few IDMs, there are many providers of partial services along the value chain. For example, smaller design houses support the so-called fabless fabless design. Special manufacturing facilities called pure-play foundries offer the MEMS manufacturing service , however, with no design support. Still other companies are responsible for specific tasks such as the packaging of the processed components. Even in the case of IDMs these tasks are often performed within different departments, in different locations.

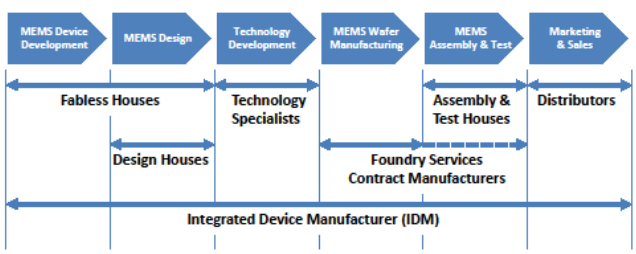

Figure 2: MEMS product engineering value chain

As mentioned above, the interface between design and manufacturing for MEMS is determined by the mutual influence. Handling this interface is much more complex and therefore more difficult than, for example the classic design of IC. For IC design, it is sufficient to comply with the generally known design rules, (a set of geometric and electrical design rules) in order to guarantee the manufacturability of the circuit. Such formalized rules are to be found already in the PDKs (Process Design Kit) offered by the production (the fab or foundry) for common EDA (electronic design automation) design tools. In the case of the MEMS product development so far, there is no common methodology that takes the characteristics of the MEMS design into consideration. For the major manufacturers of integrated IC EDA software the MEMS area is comparatively more of a niche market and is worth no major investments. The small group of MEMS software vendors (including e.g. Coventor) can specifically support only portions of the value chain of MEMS product development.

A complete product engineering methodology and the attempt to deliver comprehensive tool support for MEMS design was first made in a recent EU project (CORONA CP-FP 213969-2 see Fig. 3). [1].

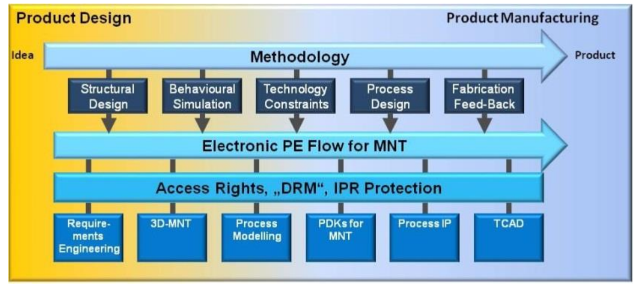

Figure 3: Scope of CORONA project

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3 TOOL SUPPORT AND DATA MANAGEMENT

The pretzel model serves as the foundation for a structural and technology design flow, as it is necessary in the MEMS area. For efficient use, however, a comprehensive design support is needed subsequently.

In its initial phase the MIDES project analyzed most of the tools for MEMS design currently available. A special focus was given to tools that are affordable for SMEs with regard to cost, support and complexity. In addition open interfaces, universal usability, and cost of training are of importance too.

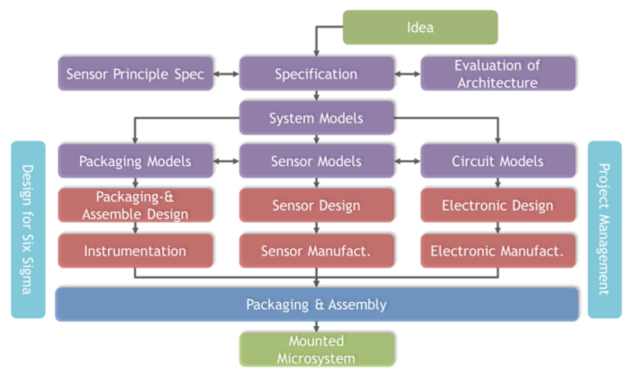

Figure 4: MEMS design flow

Figure 4 shows the MEMS design flow as identified in MIDES. The well-known microelectronics design flow (right branch) consists often of a coordinated set of tools from a single EDA vendor or of a selection of independent tools, where interoperability is provided by standardized file formats. Independent tools for various special purposes are circulating in the internet and are also available commercially. Particularly attractive are tools like e.g. the mixed-core simulator *gnucap* that can be modified and adapted to the needs of the customers.

For the behavioral design of the non-electronical parts of MEMS integrated development environments such as CoventorWare from Coventor already exist. They are mostly based on classic IC design flows. The tools close to production, however, are the domain of TCAD (Technology CAD) from vendors such as SILVACO, or technology and data management tools such as XperiDesk from Process Relations. Basic Features of XperiDesk were developed by the authors in the framework of the EU project PROMENADE (IST-507965)[2] in collaboration with SILVACO. Coventor was also partner is in the project CORONA.

In combination CoventorWare and XperiDesk already allow a fairly comprehensive coverage of the pretzel model [3]. The *CoventorWare Architect* module and the associated component library allow the efficient design of MEMS behavioral descriptions (Schematic). The Designer module can be used to generate the behavioral description from a suitable 3D model. The Analyzer module enables a behavioral analysis of the physical behavior of the 3D model. In the manufacturing environment, the process emulator SEMulator can be used for the analysis step between process and 3D model [4].

XperiDesk (see Fig. 4) is designed as a Process Development Execution System (PDES), and as such serves primarily for modeling and analysis of production flows. This involves a centralized knowledge management that reflects the diversity of process-relevant data and the complex dependencies among them. The system includes modules for rule-based consistency checking [5] (see Fig. 5), the virtual prototyping with TCAD [2] tools and for the planning and execution of laboratory experiments and prototypes. This allows the support of synthesis steps between 3D model and process, as well as between process and prototype. The knowledge base and the consistency check provide support for the analysis step between the requirements and the virtual prototyping supports the analysis step between process and 3D model.

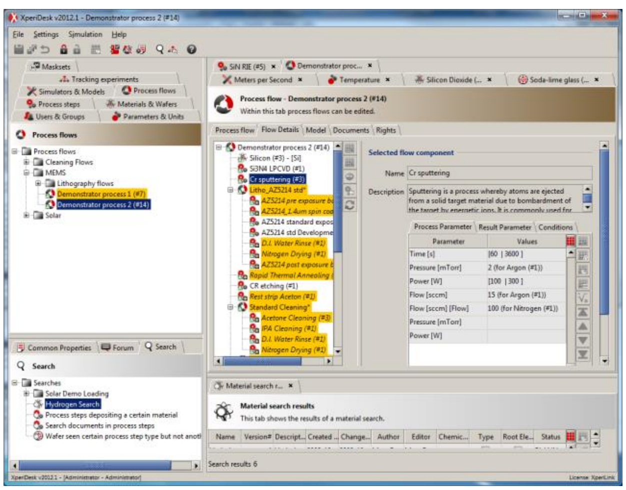

Figure 5: XperiDesk (Process Editor)

The core areas of technology-oriented MEMS design are therefore already supported quite well. CORONA focused on the software support of two interfaces in the product development flow:

A key interface defines the data exchange between the 3D model and the behavior model. Changes to the model of behavior have an impact on the 3D model and vice versa. Appropriate behavior models are created mostly consuming FEA tools and need to be rebuilt for even minimal changes to geometry or material.

The second type is the relevant interface between the 3D model and the production technology. PDES programs like XperiDesk do support the engineer in the selection of manufacturing technology. The actual synthesis step from the 3D model to the process requires the creativity and experience of the engineer, and is therefore called by Senturia as "creative art" [6]. A draft support for this operation was developed within CORONA[2].

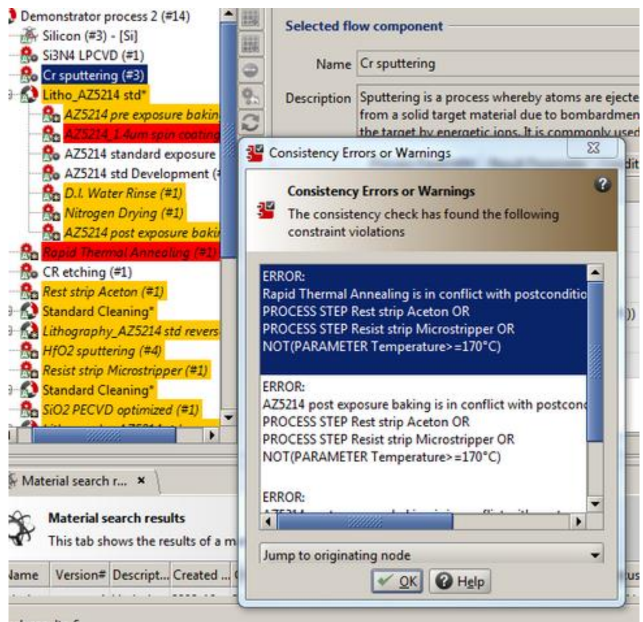

Figure 6: XperiDesk (Consistency check)

As tools like XperiDesk can store and give access to design data the metadata concerning a flow with different design tools itself has to be taken into account as well.

3.1 MEMS design metadata

Tool-specific data and design flow-specific information is called metadata. This data represents e.g. the properties of tools like cost and availability, the specification of the input and output data formats, the system requirements, networking, supporting software, etc. In addition, this data describes the sequence of the flow and the sequence of tool use.

The MIDES project developed a metadata description language based on XML called Mides Tool Language (MTL). Figure 7 shows how metadata can be used to provide information about the tools and formats converter for converting data between the tools.

The left side of the figure shows the concept, and the right side refers to an example of an XML metadata description. The blue part is the design flow. The design flow includes e.g. elements of the sensor design and electronic design. Each step design specification requires appropriate tools (e.g. COMSOL, XperiDesk MeXX, LayoutEditor, etc.). The tool includes several parameters. The parameters include e.g. name, cost, format, system requirements, etc.

This approach allows the specification of a flow parameterized with tools and parameters. A flow control can now take advantage of this data.

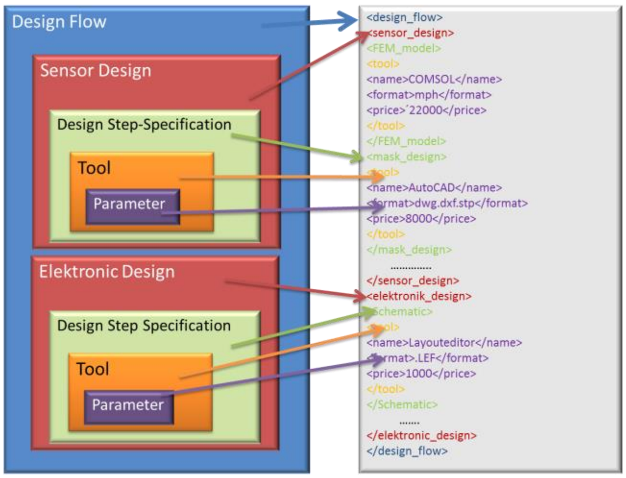

Figure 7: MIDES Tool Language MTL

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4 MEMS DESIGN FLOW CONTROL

For the interoperability of the recommended tools within the project a flow control is developed, which enables the use of meta data as possible design flow description. The design flow control is currently implemented in Python. It is based on the TRAC system, an open source web-based project management and bug tracking system. [7].

A flow control support aims to guide the user through the design flow, and to facilitate the creation of a correct manufacturing specification as well as to create all necessary design documentation for production control. It enables the monitoring and control of the draft sequence of steps, and supports the designer to make the right design decisions.

The degree of automation of such a design flow support can be defined in different ways.

The concept we follow is a semi-automated solution. It consists of a web-based electronic design flow that is based on product-specific flow results (from a knowledge base in the MTL format). It uses sign-off mechanisms to ensure that all deliverables of a design step are present (and so the next step can be performed in a valid way). Based on TRAC it offers the possibility of linking additional information as wiki data for the use of tools to the user.

Technically the programming is based on the selection of product-specific flows (and associated tools) that may be represented by decision trees. The flow controller will have a homogeneous user interface. The goal is an easy-to-use and user-friendly solution. A step by step guided web-based application through the design flow enables the integration of necessary tools to create a virtual design framework. On the meta data level it controls the communication between the tools.

Its main tasks are the tool selection, the adaption of a generic flow to a product specific design flow, the activation of necessary steps (sign-off), verification steps to initiate for partial results, as well as consistency and completeness check of design flows.

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5 CONCLUSION

In this paper we presented a concept and tools support for MEMS product engineering taking into account the interdependent technology and structure design for MEMS and considering the constraints of SMEs. The work is still omngoing in a project (MIDES) funded by the Federal Ministery of Education and Research (BMBF).

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