Computer-based process design support for MEMS

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ABSTRACT

This paper introduces a process management and development system for MEMS design. This system allows the specification of processes for specific applications and the tracking of the development procedures. Unlike in microelectronics the process configuration for MEMS is strongly coupled to the intended application. Process engineers on the one side and designers defining the structure on the other side are therefore target user for the system. Configured process flow can be checked with regard to internal consistency. Means to convert the process sequence to a 3-dim layer structure and vice versa are provided as well as assessment tools to compare process variations. The system is based on a dedicated database environment that is able to store and manage all process related design constraints and development related data linked to the fabrication process data itself. The interdependencies between application specific processes and all stages of the design flow will be discussed and a software system will be introduced meeting the requirements of this new approach.

Keywords: design for manufacturability, process tools, TCAD, database, PRINCE

1 INTRODUCTION

The design support for future process technologies in the MEMS domain as well as in microelectronics will have to take the process related issues much more into account than conventional EDA tools currently do. Up to now most design tools still use the strict interface to technology provided by design rules and technology files as introduced by design methodologies (Mead/Conway, Y-chart etc.) some 20 years ago.

MEMS fabrication processes as well as the present edge IC technologies, reaching beyond the 90 nm threshold, prove that technology interfaces consisting only of sets of static design rules are no longer sufficient. For successful design flows in these areas it is necessary to incorporate a higher degree of process related data. A broader interface between process configuration on the one side and the application design on the other side is needed.

This paper proposes a novel approach. A process management system is introduced. It allows the specification of processes for specific applications. The system is based on a dedicated database environment that is able to store and manage all process related design constraints linked to the fabrication process data itself. The interdependencies between application specific processes and all stages of the design flow will be discussed and the software system PRINCE will be introduced meeting the requirements of this new approach.

Based on a concurrent design methodology presented in the first chapter of this paper a system is presented that supports application specific process design. The so called PRocess INformation and management CEnter PRINCE (described in detail in the following chapters) handles the missing link in EDA tool support for the interface between process data that affects design issues and design data requiring specific process solutions ending in modified technology flows.

This tight combination of process flow and structural design resulting in a more or less concurrent development of both parts, is an approach already in use for years in the domain of MEMS. But until now it is not sufficiently supported by EDA software. Future application scenarios in microelectronics concerning design and fabrication point to a similar situation. Planar technologies, following the model of technology independent shapes specified in two dimensional masks, will be more and more extended towards 3-d structures as process effects will have to be taken into account explicitly. With respect to the EDA development this tendency will require new methods and tool concepts. PRINCE is a first prototype based on that methodology.

2 DESIGN FLOW AND METHODOLOGY

Unlike microelectronics the overall design flow in MEMS is heavily dominated by the fabrication. The VLSI design of the last 20 years has benefited from a very clear separation of fabrication and design. This was enabled by some characteristics of VLSI systems. Manhattan- or octagonal design, nearly fixed process flows and shape-independent behavior allowed a reduction of the original three dimensions to 2.5 dimensions. With the opportunities, which are offered by MEMS technologies, new problems arise. The Mead-Conway-abstraction in the known way cannot simply be applied to those emerging technologies. The influence of the fabrication aspects cannot be reduced to design rules as shown in figure 1. The overall design flow is now dominated by the fabrication. Changes at any level of design have an impact on fabrication and vice versa. That is why in contrast to traditional VLSI-design the shape of the components no longer plays a minor role. The three dimensional structure cannot be reduced to 2.5 dimensional view and the fabrication process flows are no longer fixed but vary from design to design. That leads to application specific process flows (ASPF) which implies different design rules and technology files for nearly each design. The development of new MEMS devices demands indeed a comprehensive technology knowledge.

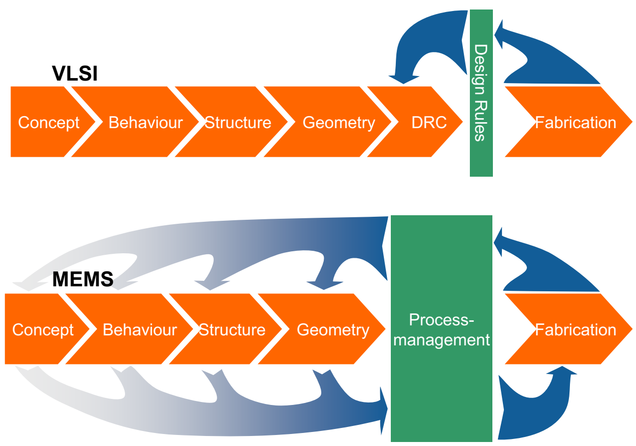

Figure 1: The influence of fabrication is clearly separated in microelectronics. Going ahead to MEMS the influences cannot longer be separated in the usual way.

As a solution to handle the dependencies between design and fabrication we propose the structured physical design flow as presented by Brück and Hahn [1] and refined by Hahn and Wagener [2]. The so called cycle-model (see figure 2) describes an iterative design flow starting with an initial design. This design suggestion is synthesized to get the corresponding fabrication flow and mask data for lithography.Process Simulation verifies the flow and modifications may be applied to start the cycle again.

This cycle is repeated until the requirements are met. Such a physical design flow is very common in the MEMS-community. But the disadvantage of such a methodology is the poor design support. No integrated development environment for the physical design is available. Only special-tools for simulation are commercially available. Synthesizers were rarely used beyond the academic area.

Based on the proposed methodology we present in the following paragraphs an integrated design environment for physical MEMS design.

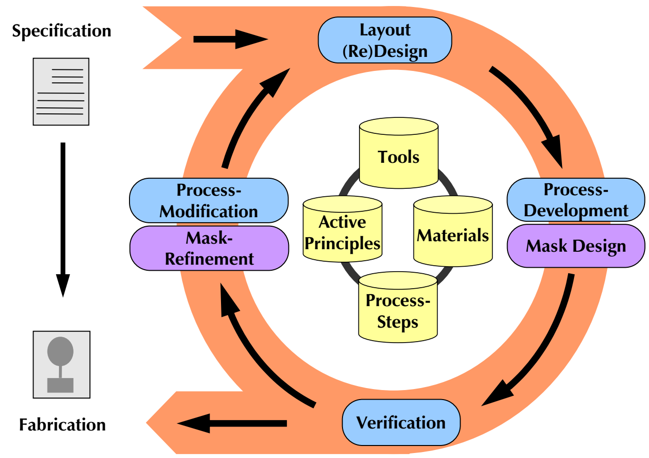

Figure 2: Extended cycle model of physical design

3 PRINCE

PRINCE is an acronym for PRocess INformation and management CEnter. The idea behind this tool is to provide a software that supports the design of the process flow by offering means to store, retrieve, use and analyze all data occurring in the physical design stages.

3.1 System design

Information can only be used successfully if it is shared among the people involved. Today most data is collected in a decentralized way. Nearly every expert has different means of storing his knowledge. To access the information needed can thus become a tedious task of catching the right people. To overcome this deficit the management of information in this area needs to enable the collaborative work of different users at different locations with different types of hardware platforms. So the selection and adaption of an adequate software architecture is very important.

The architecture of choice for the PRINCE system is J2EE[3]. The J2EE framework fulfills the above mentioned requirements by providing a central database and an application layer that can be accessed by multiple users. The application layer processes the raw data from the database and offers means to enter and retrieve data in a structured way. Furthermore algorithms like the consistency check mentioned below are implemented in this layer.

As client a Java program is used. To minimize the administration overhead the software client is distributed using the Java WebStart technology[4]. Once the client is downloaded WebStart checks with every restart if a new client is available and retrieves the latest version if necessary.

3.2 Software modules

The PRINCE system was developed in cooperation with industry and university partners to ensure the practical usability of the tool. It is divided into different software modules for different tasks in the design process. Beside the administrative tools like user and parameter management the main modules are:

3.2.1 The Process Step Editor

The process step editor is divided into two parts. On the left side the hierarchy tree is shown. It offers a comfortable way to navigate through the process steps and to add or remove process steps. In the editor two kinds of objects are supported: (manufacturable) process steps and process step types. A type is not manufacturable. It can be seen as a class of process steps with similar characteristics. Process step types can inherit properties and rules from other types. When rules (like cleaning before deposition) or parameter restrictions are applied to a process step type, the rule is also applied to all inheriting types and process steps. So a hierarchy can be built using the types as templates for new types or process steps. Within the hierarchy multiple inheritance is supported. A process step or a type can thus inherit properties and rules from more then on process step type.

On the left side of the editor (see figure 3.2.1) is the data input window. For each process step and process step type diverse data can be entered:

Process parameter: parameters to adjust process settings (e.g. machine parameter, environment conditions)

Result parameter: predicted or measured results of the process step (e.g. layer thickness, surface roughness)

Documents: related to current process step (e.g. SEM pictures, pdf files)

Pre- and Postprocessing: process steps that must/ must not be run before/ after the current process step (e.g. cleaning before deposition)

Pre- and Postconditions: parameter conditions to be met (e.g. temperature budget)

3.2.2 The Material and Effect Manager

New materials like metal and semiconductor alloys play an increasingly important role in IC and MEMS design. This opens a new problem domain. A slight change in the ratio of the alloys can change the properties of the material. To address this problem the material and effect manager was developed [5].

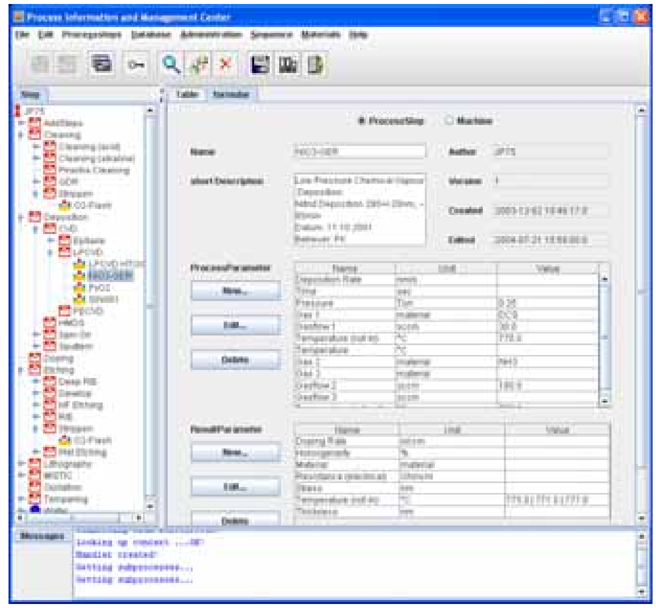

Figure 3: Process Step Editor

The material editor offers means to manage materials and material types. Like process steps materials are sorted into a hierarchy. This enables the classification of materials and ease the search. Multiple inheritance is supported. By using the material manager appropriate materials for processing can be selected and clearly identified.

The effects between two or more materials or materials and process steps are handled by the effect manager. The task of the effect manager can be explained by the example of etching. An etch effect can be gained by chemical substances, physical removal or a combination of both. Two materials are involved in a chemical etch effect: a substrate material and an etchant. For a physical etch process a substrate and an etch process is needed. Parameters like etch rate (or etch rate diagram) and temperature characterize the effect. A specific editor is provided to enter effects.

3.2.3 The Process Flow Manager

The process flow manager supports the system or device designer to find an appropriate process flow for fabrication. A process flow consists of a sequence of arbitrary process steps or process flow modules. The latter are predefined process flows, which consist of a fixed sequence of process steps. For instance the RCA-cleaning is a fixed set of piranha-cleaning, ammonium hydroxide cleaning etc. Such modules can ease the development of process flows.

One of the main problems in designing process flows is the consistency of the flow. In most cases the process flow has to consider constraints from the other process steps. The process flow engineer is not always a special-

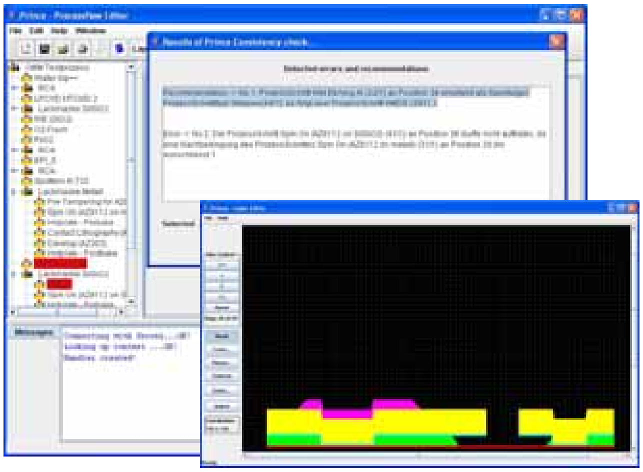

Figure 4: Process flow manager and layer editor

ist for each involved process. Using the rules introduced in the previous section a automated check is possible for all rules provided by the process step specialists. A first version of such a sophisticated consistency checker was implemented.

The consistent flow can be simulated using the layer editor. The layer editor offers means to manage the interfaces to and show the results of the simulation software. As an example simple algorithms for etching, deposition, and lithography were implemented. These algorithms use the data gathered from the process steps and effects - like etch time and etch rate - as well as line masks drawn by the user to built up a profile of the device under construction.

Figure 4 shows the process flow manager. On the left side a tree is showing the process flows. As a proof of concept a real process flow for a electromechanical cantilever is realized. The result of the simulation is displayed in the Layer Editor window. In the other window the result of a consistency check is shown. Consistency errors are described textually and by highlighting the conflicting process steps.

3.3 Interfaces

The management of data is an important task of the software. These data offer the possibility to improve simulations, check the consistency of process flows and compile layout rules for mask generation. However not every task can be reimplemented within such a software. Many specialized tools like FEM-, device- and process simulators are commercially available. Interfaces are necessary to use this tools.

To solve this problem an universal interface language for process design is needed. This problem is already known in other areas. As a platform and software independent description language XML (eXtensible Markup Language) [6] was introduced. In [7] we have presented an XML based language called Process Description Markup Language (PDML). It offers the ability to transfer data to simulation tools and to get data from other tools like process tracking software.

4 Conclusion

In this paper a new design flow towards the design for MEMS processes was proposed. The approach improves the traditional interface between layout and technology by a process management system. [8] It allows the specification of application specific process flows. The software is based on a database environment. It is able to store and manage all process related design constraints linked to the fabrication process data. Tools working on that database were presented that facilitate the concurrent generation of appropriate process flows. A prototype of the complete environment was developed and will be extended in an European project within the next years. The main focus of the future work will be the extension to further process simulation tools provided by commercial vendors.

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