Rule Based Validation of Processing Sequences

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ABSTRACT

In conventional mechanical engineering the development of a product is influenced only little by the specific requirements of the fabrication processes. When looking at the domain of micro mechanical devices this circumstance is no longer given. The design choices made while constructing a micro system are highly dependent on the manufacturing techniques available. Furthermore the chosen technologies lead to a restriction of the usable materials. Consequently the quantity of possible combinations of the geometries, materials and processing applicable is – due to this multitude of constraints – significantly reduced.

While simultaneously defining the layout and the processing sequence the designer is inevitably confronted with the need for many iterative redesigns. Hence an automated tool, which encloses a compatibility evaluation of the defined sequence, is desirable. This paper introduces a software prototype for tackling this obstacle by employing an inference engine to verify user-defined process sequences.

Keywords: process rules, process compatibility, MST CAD, process configuration.

1 INTRODUCTION

Due to the availability of a high number of standardized components, product design in microelectronics is to a great extent reduced to combining these elements. The modification of 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 micro mechanical 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 micro mechanical 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.

The increasingly complex microsystems being developed recently demand a large number of different processing technologies, which are carried out in a step-wise manner to reach the desired functionality. However, the diversity of technologies available also has a significant impact on the possible choice of materials and processing applicable in the fabrication of a certain device. The designer must consider a multitude of interdependencies in order to define an accurate processing sequence, which will produce the intended micro system flawlessly.

2 COMPATIBILITY REQUIREMENTS FOR PROCESS SEQUENCES

A micro mechanical 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 micro tribological layer (see Fig. 1a).

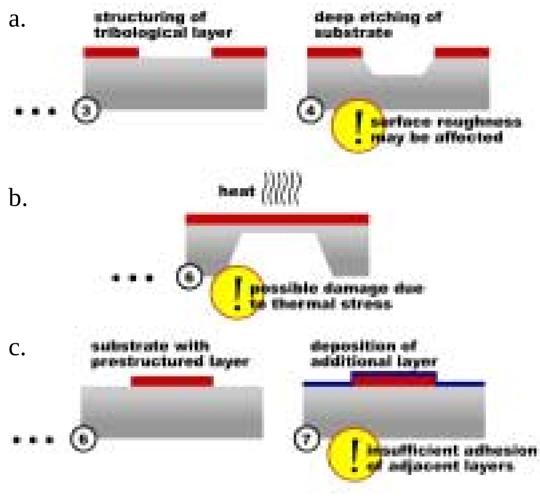

Fig. 1: Examples for process incompatibilities

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 micro component will be twisted or even destroyed due to the mechanical stress caused by it being heated in a given temperature range (Fig. 1b). 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 micro mechanical part in between the processing. These incompatibilities may occur because of e.g. chemical residues caused by the preceding processing (Fig. 1c). 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. A range of stand-alone software tools for process simulation already handles this rather classical demand.

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 THE VALIDATION TOOL

The task of ruling out all possible flaws of a processing sequence demands a large amount of experience and expert knowledge on the part of the designer, since its errors or weaknesses will not be detected until it is carried out in technology. Thus bound to a trial-and-error evaluation the correction of the defined processing sequence is very time and cost consuming.

In order to tackle this problem a computer-based tool is being developed at our institute. Its aim is to automatically check user defined process sequences on internal compatibility according to the requirements explained in the section above. The following gives an overview of the capabilities and handling of the tool, as it has evolved so far.

3.1 User Interface

A straightforward definition of the chosen process/material configurations as well as of the whole processing sequence is offered by a graphical user interface (GUI), which is shown in figure 2.

The table on the right hand side gives a quick overview over the already defined processing steps, indicating their

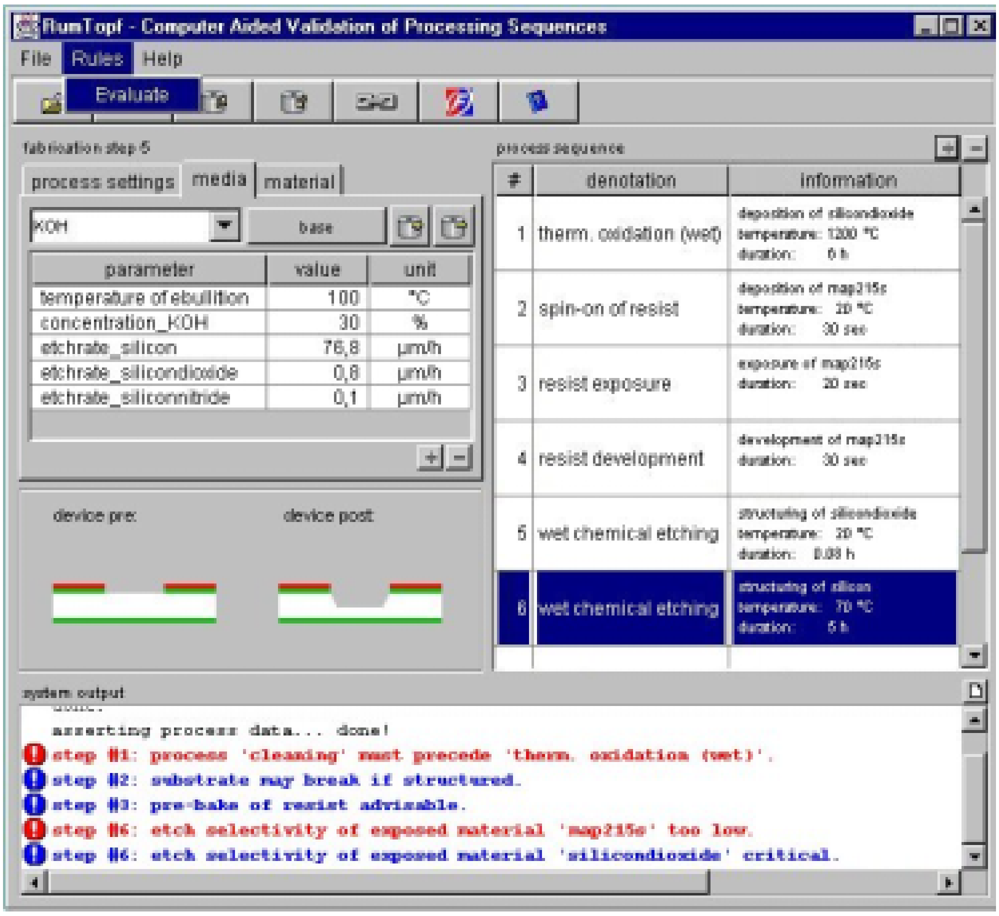

Figure 2: Screen-shot of the user interface of the presented validation tool

order, denotation as well as key informations. A currently selected fabrication step is highlighted and represented in more detail in the tabs on the left hand side of figure 2. The ‘process settings’ tab displays all dedicated parameters, allowing changes in values as well as addition and removal of parameters. Similarly the ‘media’ and ‘material’ tabs offer access to the corresponding medium or material parameters. These two tabs permit the choice of the used medium and workable materials for processing. In the example shown in the GUI a wet chemical etch step is defined using KOH for structuring silicon.

The panel below these tabs depicts a simple graphical representation of the micro device according to its position in the fabrication sequence. Additionally this panel can be used for the definition of passivation layers and the adjustment of the thickness of layers, using an extra dialog not shown in figure 2.

At the bottom of the GUI a message window is placed, which contains the output of the validation in progress. Warnings and errors concerning the feasibility of the process sequence are displayed here.

3.2 Process and material databases

Since the validity of a processing sequence is highly dependent on expert knowledge about the fabrication processes and the materials used, the tool is connected to pertinent databases.

These databases contain a variety of fabrication processes, which are organized hierarchically according to their kind (resp. class, see [1]). Each fabrication process is defined by a set of dedicated parameters, provided with a description and a list of workable materials and usable media. These materials and media are also stored in the database containing adequate parameters representing their properties. The implemented data model allows an interconnected storage of process, geometry and material data and has already been reported on [1].

The user may extend this database by adding new processes and materials or altering the existent data to create new variations.

3.3 Validation rules

In order to check the defined process sequence automatically for possible incompatibilities like the ones mentioned in section 2, the correlations of fabrication process, material and medium have to be evaluated. These can be manifold, since a multitude of combinations are thinkable. Identifying incompatibilities by the simple means of setting up tables stating ‘compatible: yes/no’ will quickly lead to a complex and difficultly manageable system. Due to the large amount of data to be searched the validation routine would inevitably need increasingly more computation time with a growing amount of information on such incompatibilities.

Therefore it seems self-evident to use a more generic technique for identifying errors in the process sequence. A long known method from computer science for tackling such problems is the use of an inference engine. So called forward and backward chaining can be employed to evaluate the suitability of a configuration using simple rules to provide the algorithm with the needed information on possible incompatibilities. These rules must not hold the specifics of an incompatibility (as in the mentioned incompatibility table), but may use varying data, which can be read from process or material parameters. The presented software program makes use of the commercially available inference engine ILOG JRules [2]. Its modular integration in the program architecture is shown in figure 3.

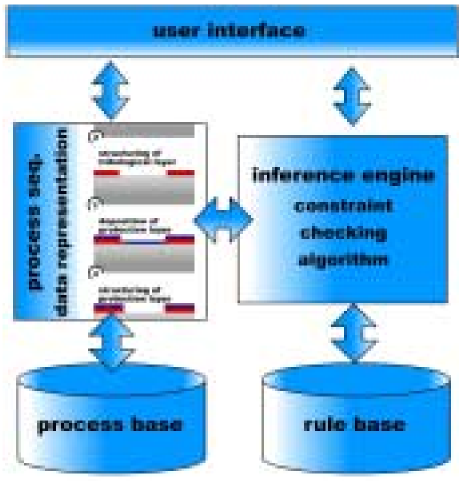

Fig. 3: Schematic overview on the tools architecture.

Generally rules are expressed in an 'IF – THEN' style, stating what action has to take place, when a certain condition is met. Thus invalid combinations of processing, medium and material (IF clause) may cause a rule to be fired and an error message to be generated (THEN clause). A generic rule for checking the compatibility of the operating temperature of a fabrication process with the used materials in the device at the current processing step might be formulated as shown in figure 4.

The expressions in the IF – THEN statements are put in plain text as to make the working of the rule more understandable. These expressions can easily be coded so as to make the rule interpretable for the inference engine.

The shown rule is adequate for every fabrication process and must therefore be evaluated for each step in the process sequence. For this reason we refer to it as a global rule. Supplementary to this kind there are more specific rules, which suffice the characteristics of process classes or a particular fabrication process. For example lithographic processing as a whole (meaning exposure) only makes sense, if the micro device has been coated with some kind of resist. Likewise creating a silicon dioxide layer using thermal oxidation is only possible on a silicon substrate or layer, which may serve as an example for a process specific rule.

Rule definitions may be fairly simple, as the first three examples in the message window of figure 2 affirm. The error produced by the first fabrication step simply refers to

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IF (
  (a process exists, which has the
   parameter ’operation temperature’
   defined)
 AND
  (the corresponding device contains a
   material with the parameter ’mel-
   ting point’ defined)
 AND
  (the operation temperature is close
   to or higher than this melting
   point)
    )
THEN
  (print error message, that device
   will be damaged while processing)
```

Fig. 4: Example of a generic rule

a definition of the required preprocessing of this process (thermal oxidation needing a cleaning step beforehand). The following two outputs demonstrate typical warnings coherent with a process. Lastly the two messages associated with fabrication step #6 (wet chemical etching of silicon using KOH) are examples for more complicated rule definitions. The etch selectivity is a value, which needs to be calculated for all exposed materials of the device and checked against a user defined value for acceptable resp. not acceptable selectivity. Furthermore this rule needs information about which layers should be etched (default: all) and which serve as passivation (configurable in the device panel, figure 2).

The actual parsing and checking of all rules applying to the process sequence is carried out by explicitly activating the inference engine.

3.4 Comparison to other work

Other groups have already spotted the need for an automated validation of processing sequences. At the University of Siegen, Germany, a tool has been developed in order to describe processing sequences for LIGA-technology with extensions for silicon technology [3,4]. It is equipped with a generic description language for process definitions (PDL – process definition language), which is also capable of defining specific rules for these processes. However, the scope of these rules is very limited and mainly concerned with proper pre- and post-processing for a certain fabrication step. Incompatibilities to other processes and/or materials must be expressed explicitly in incompatibility tables. The definition of generic rules concerning all processes or certain kinds of processing is not possible. Yet, the tool also offers an optimization capability for refining the process sequence with respect to time and cost consumption of the processing, using the corresponding parameters of the process definitions [5].

In a collaborative research project of the german BMBF Kiehnscherf et al. developed a tool for the validation of sequences concentrating on the assembly of micro components. The enclosed rules cover mostly layout specific constraints. Rules concerning processing are also available, but not generically definable [6,7].

4 CONCLUSION AND PERSPECTIVE

Opposed to most domains of manufacturing, the design of micro mechanical 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.

Software for the simulation of certain fabrication techniques is already existent for a wide range of processes. However, tools for the validation of processing sequences are still scarce and not generically extensible. This paper presents a first approach to overcome this handicap by combining a commercial inference engine with an accommodated object oriented data model.

Further work will concentrate on extracting and defining more generic rules as well as simultaneously extending the process and material database. Additionally the tool will be enhanced by adding supplementary convenience functionality. At the same time it will be integrated as a further extension to the MST-CAD environment BICEPS being developed at our institute [8].

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‘.

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