Design of Experiment Tools for Process and Device Development

N. Olij MScEE (Niels), A.F. Bakker MScEE (Arjen), A.C.G. Nutt PhD (Alan)

PhoeniX BV, PO Box 545, 7500 AM Enschede, The Netherlands
http://www.phoenixbv.com, info@phoenixbv.com, phone: +31 53 4836460

ABSTRACT

The functionality of a Micro and Nano Technologies (MNT) device is mainly defined by its shape; for instance a membrane sensitivity to pressure depends on its size and thickness. An MNT device therefore needs a multi disciplined approach for design and fabrication. A common design strategy for optimizing device performance is the Design of Experiments (DOE). Multiple packages are available to define such an experiment series and analyze the results. A problem arises however when the defined experiments are to be translated into proper and workable designs for MNT devices. PhoeniX has created manufacturing software based tools that act as the missing link in a proper MNT based DOE. This platform allows an MNT designer to define a DOE and retrieve results of the DOE with minimal human interaction. As a result the designer can concentrate on interpretation of the DOE, which saves time and cost. A faster and more (cost) effective design cycle is now established.

Keywords: design of experiment, DOE, parametric design, mask layout, process flow

1 INTRODUCTION

The functionality of a Micro and Nano Technologies (MNT) device is mainly defined by its shape; for instance a membrane sensitivity to pressure depends on its size and thickness. This thickness is directly related to the process which fabricates the device. Therefore when making a manufacturable design, an in depth knowledge of the process is required. This differs very much from Integrated Circuit (IC) technology, where the physical levels are completely standardized, such that high level designers do not need knowledge of the technology used to create the required functionality. The complexity in the technology and in the amount of standard elements that are connected together to make the functionality not as complex as MNT devices and much more understood

An MNT device therefore needs a multi disciplined approach for design and fabrication. The fact that in a typical MNT device multiple physical domains are used (in contrast to IC technology that uses only the electric domain), dramatically increases the complexity within a useful design.

2 DESIGN STRATEGY

A common design strategy for optimizing device performance is the Design of Experiment (DOE). Multiple packages are available to define such an experiment and analyze the results. A problem arises when the defined experiments are to be translated into proper and workable designs for MNT devices. Design typically includes variations in both the mask and in the fabrication process. Using conventional tools, implementing the variations is a most precise and time consuming endeavor. Also gathering detailed information of the fabrication process of the device is labor intensive. Standard tools for IC industry supply such functionality, but these tools are not flexible enough and too expensive for proper use in the field of MNT.

3 PARAMETRIC TOOLS TO SUPPORT THE DOE

PhoeniX has created manufacturing software based tools that act as the missing link in a proper MNT based DOE. The starting point for all the developments within the software has been the need for flexibility in the definition of the problem. To cope with this flexibility, all tools are based on a Parametric approach. Parametric Design means that all the properties of elements in the design can be described in a straight forward manner using mathematical relations. Parametric design allows the simple variation of device elements, while base libraries allow the reuse of design elements which saves errors, saves cost and improves the devices chances of being operationally stable.

The platform PhoeniX has created allows an MNT designer to define a DOE and retrieve results of the DOE with minimal human interaction. As a result of this, the designer can concentrate on the interpretation of the DOE, which saves time and cost. A faster and more (cost) effective design cycle is now established.

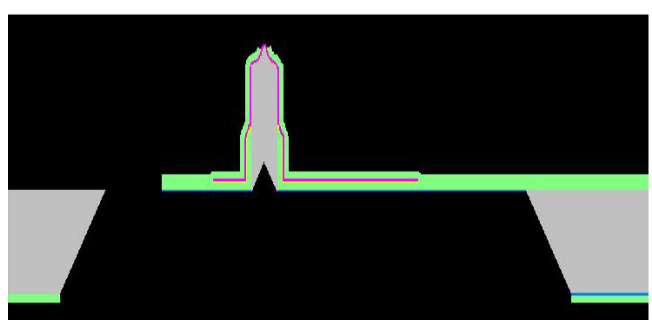

Figure 1 : Example of process visualization of an AFM/SECM tip [1]

3.1 FlowDesigner

FlowDesigner gives the design engineer the chance to visualize and to document a first pass of the device process flow before the device gets to the manufacturing stage. The device cross-section can be viewed at any process step and consequently simple geometric process errors can be discovered before expensive mask sets are manufactured. It allows the designer to check proximity issues in the photoresist patterning and etching stages so that the most basic process mistakes can be caught before the manufacturing cycle begins. What is also important is that all dimensions are in microns (to nm accuracy). The axis scales however can be different if required to view the structures more easily. Any number of mask steps can be used and where needed multiple wafers can be bonded together. One of the strengths of this software is that it allows the use of 'user libraries' so that actual process information can be used in all of the process steps – although libraries of standard processes and materials are included

Figure 1 above shows a process cross section taken from a process flow in FlowDesigner. The picture is a AFM tip after the wet chemical etch step. Figure 2: below illustrates the capability of stacking glass and silicon wafers together in order to get the required functionality.

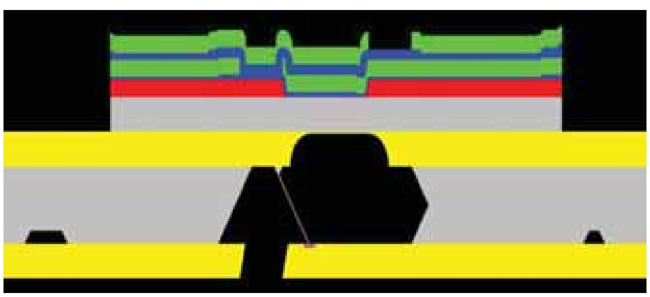

Figure 2: FlowDesigner Illustration with Multiple Wafer Types

3.2 MaskEngineer

MaskEngineer is the first real parametric mask layout tool. It can be used to translate the mathematical variations within the device designers equations into actual structures which can then be simply translated into standard mask languages such as CIF and GDS. Standard parameterized and fully connected layouts can be created and organized with the right settings for each variation. Design variations can be created with simple 'For' loops and 100% connectivity is guaranteed. Visualizing complex variations is immediate and the 'C-like' script language is simple and intuitive. Text is editable and any number of layers can be created Sections of structures can also be tested within the FlowDesigner software.

Figure 3 shows the variations that are possible within the software with only a couple of nested 'For' loops. Design iterations that would have taken a considerable amount of layout time and skill can now be completed optimally. Unlike other scripting languages the software allows the write to see visually what is being programmed.

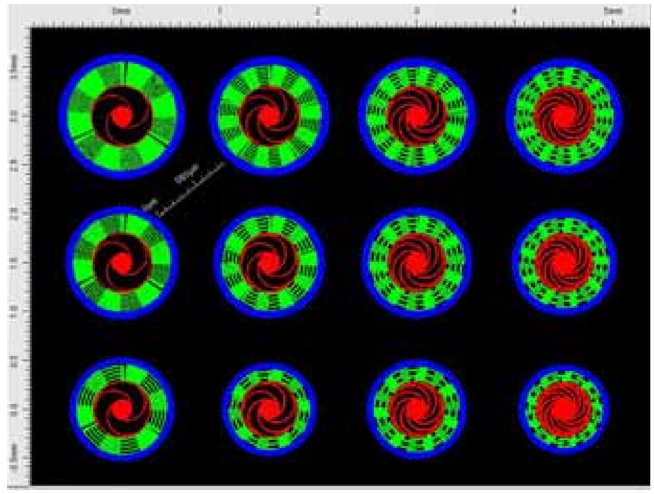

Figure 3: Example of a parametrized mask layout of a gyro-like device, where a single element is placed with (in this case) 12 different parameter settings.

The above two pieces of software can reduce the design cycle considerably however they are only part of the equation. The design of the process flow and the correct layout of photo mask designs are obviously very important however the fabrication variations within the process must also be controlled and monitored in order to create a truly useful DOE and therefore create a manufacturable design.

3.3 The Living Database

The Living Database (LDB) is a set of software designed to give a larger degree of accountability, control, documentation and SPC within the MNT cleanroom environment. It allows for the parametric design of the process flows and can be used in a comparable way to FlowDesigner and MaskEngineer. Moreover, LDB also implements the data storage and retrieval of process results. This high degree of control within cleanrooms is to be expected within the IC industry however because most the MNT devices have been created within a University or Start-Up environment the same degree of control has been lacking. In order to take MNT devices from the single piece part to the production regime it is necessary to get this degree of control in place. Actually because of its ease of use and proven worth the LDB has a place even within University fabrication facilities where the turn over of process engineers is high and often the skills learned in processing have to be relearned when students finally graduate.

Process costs [2] have also to be controlled and the process flow rationalized before the flow can truly be thought of as production compatible. Often a DOE is the best was to sort out these issues as well.

NSTI-Nanotech 2005, www.nsti.org, ISBN 0-9767985-2-2 Vol. 3, 2005

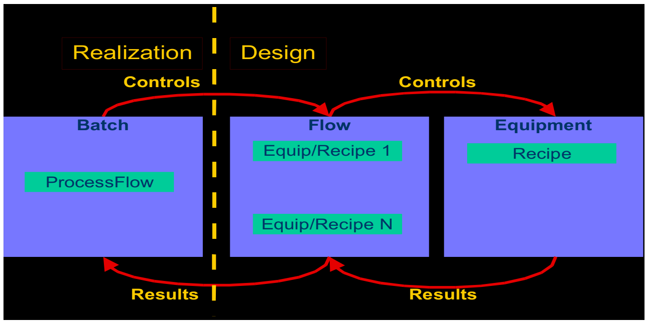

Figure 4: Concept of Data Streaming for Parametrized Process Flows using The Living Database.

Figure 4 shows the way the data stream flows in a controlled cleanroom environment. What is important is that the engineers see the data they need in order to do their process step efficiently. This set of data is necessarily different from the input information supplied by the designers and will be completely different to the basic machine information that the operators require to do the process step efficiently.

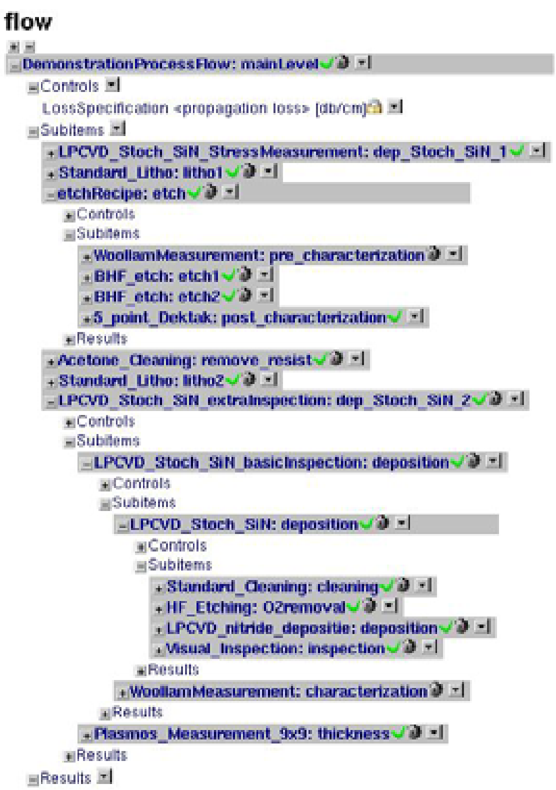

Figure 5: A section of a process flow as set up in the LDB

Figure 5 shows a section of a process flow that the process engineer will create. The data is an extension of the basic 1st order process flow created from the FlowDesigner software. This 1st order flow has all the basic process steps however it usually does not have the degree of detail necessary in the fabrication environment. This is where the Process Engineer becomes invaluable. His skill translates the 1st order flow into the LDB process flow, a section of which you can see in Figure 5:. The LDB does not negate the need for the process engineers experience, it only captures that experience so that is can be used by others in the future.

This process control in itself is insufficient to provide a production ready device because the machine etch rates, coating thicknesses and lithographic line dimensions are to some extent process variables in time. The only way to control this variation, which is critical in most MNT devices, is by using SPC (see Figure 6:). The standard test structures used in the IC industries go a long way to providing this information, however a more standardized array of MNT structures still have to be developed.

4 CONCLUSIONS

Only through control of the layout design processes and with carefully implemented process flows can a true and realistic Design of Experiments be undertaken. With full control of the variances in the manufacturing process, a device level DOE is possible. The final manufacturing processes can only be controlled if the same degree of automation and continuous SPC is in place. There are many pieces of software that can define and analyze a DOE. The missing link is to put the DOE within useful designs, that can then be used in a production cleanroom. PhoeniX software products allow this to happen within the MNT environment.

The main challenge for all MNT devices is to move to procedures where SPC and product validation by DOE is the norm. This requires a change in the way design and prototype fabrication is being conducted, only then will true MNT products become more generally available.

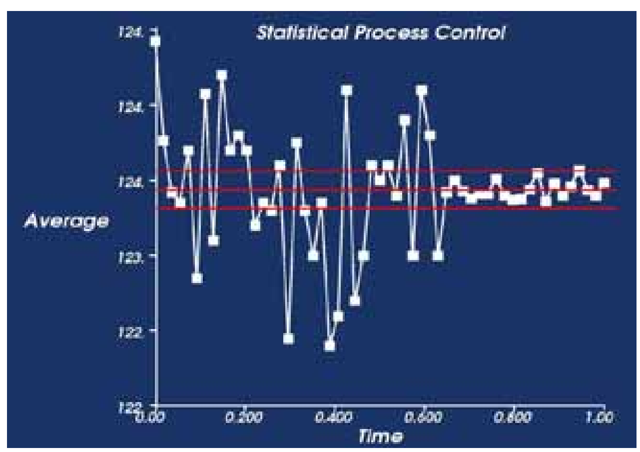

Figure 6: SPC Control in Action (Before/After)

REFERENCES

[1] Y.Tao (Eric Tao), R.J. Fasching, F.B. Prinz, "Ultra sharp High-aspect-ratio Probe Array for SECM and AFM Analysis", http://www-rpl.stanford.edu/files/Paper/smart%20structures%202004.pdf

[2] N.Olij, A.F. Bakker, H.H. van den Vlekkert, "Trends in Micro- and Nano Software" Paper B12–T8 COMS 2003