**PHOENIX DESIGN OF EXPERIMENTS SOFTWARE**

**FOR ALCATEL-MMS DEEP REACTIVE ION ETCHING FOR SILICON DIOXIDE**

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**Introduction**

Over thirty years the manufacturing of micro-system devices has made a vast breakthrough. New compounds, more refined machines and technologies enable people to father new inventions which were not too long ago considered to be a novel physics.

Deep, thin microscopic channels to accommodate high speed micro-optical chips and advanced MEMS chips processing are now feasible to be made. Such chips support the ever increasing demand for bandwidth at lower cost, eg. “video on demand” or high speed internet services.

Also the highly integrated Intelligent Ambient Technology, which notoriously requires compact and low-energy chips, can be round up by human's hands. Quantum electronics which allows super electronics is now within the realm of reality.

However, by far we have not taste the benefit from all these happenings. The so-called “technology's immaturity to the market” is the general term to answer the arisen question: Why.
Abstract

One practical, and unfortunately also crucial factor that causes the MNT technology's immaturity to the market, is actually to ‘tune’ the equipment's settings 'just right' to produce the desired result. Too much trial and error are involved in production. In turn, it leads to a costly product that puts the markets off.

There is no textbook, nor software that could guarantee the perfect match between the equipment's settings with the result. Using equipment to produce a micro-system device is like using an oven to make a cake. There are recipes. There are superb equipments. But in the end, it was the experience and intuition that can work the magic to produce the desired result in a most efficient production.

Experience is gained by performing a lot of experiments. Intuition is the ability to archive, analyze and to interpret the experiences. Both are the true assets to stand the challenge of the technology's immaturity to the market.

Experience and intuition comes from individuals. If the individual keeps the expertise to oneself, the knowledge stands still. The assets go as the individual goes. Monopoly is never supporting the progressive products.

Hence the need to conserve and to incubate the knowledges in PhoeniX Living Database. PhoeniX Living Database collects the experiences, while PhoeniX R module is the artificial version of the human's intuition.

The statistical process control behind the R MODULE allows the mutual analysis on the equipment's settings and the result. This analysis mimics human's intuition to interpret the event's correlation.

PhoeniX wxRieApp resembles the visualization of human's memories, and one's ideas.

PhoeniX wxRieApp visualizes the ideas created by either PhoeniX R module, or Process Engineer. It also shows the SEM images or any other pictures from the experiments archived in the Living Database.

All PhoeniX modules complement the Alcatel Deep Reactive Ion Etching for Silicon Dioxide. This application note summarizes the improvements PhoeniX Software and the Alcatel DRIE\(^1\) machine contribute to the DRIE process for Silicon Dioxide. The complete achievement is reported in the European project DRIESO\(^2\).

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1 DRIE: Deep Reactive Ion Etching
2 DRIESO: Development of DRIE process for Silicon Oxide etching
Design of Experiment

Design of experiments includes the design of all information-gathering exercises where variation is present, whether under the full control of the experimenter or not. Often the experimenter is interested in the effect of some process or intervention (the 'treatment') on some objects (the 'experimental units')¹.

In the DRIESO project, PhoeniX Software and Alcatel performed a Design of Experiment to optimize the recipe (equipment settings) for Deep Reactive Ion Etching process on Silicon Dioxide. Illustration below summarizes the utilized Design of Experiment:

Illustration 2: PhoeniX Living Database preserves the experiences (experiments, data, photos). PhoeniX R MODULE is the artificial intelligence which analyse the experiences by looking into the data's correlation which in turn will improve the recipe. PhoeniX wxRieApp visualizes new ideas for the recipe, and memories (photos, process) from the old recipes stored in Database.


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A database has been build to facilitate the process descriptions for the DRIESO project. The database is installed at the sites of all project partners, and the whole communications of process have been done via this database.

**The process descriptions used in the DRIESO project are fed into this database.**

Much effort has been put in structuring the data and improving the user interface's aspects to represent the hierarchical character of the process appealingly.

Splitting the processes into the small and task's specific blocks proves to be an ideal approach to compose the hierarchical character of the process and to re-use the information seamlessly.

Underneath is a screenshot of the graphical user interface embodying the hierarchical character of the process flow:

![Hierarchical Flow Definition](screen_shot.png)

Illustration 3: The user interface interpretation of the hierarchical Process Flow

The DRIESO process contains all the details required to perform the etching, including all the mask depositions and the cleaning processes.

The process design is thoroughly hierarchical. The step “3 - Standard Litho : litho” for example shows the blocks to perform a standard lithography. All these blocks (may) have sub levels until the level of the equipment is reached.

At the equipment level, the detailed machine's parameters (controls and results) are defined, and are stored in the logbooks when the process flow is executed on the wafers in the cleanroom.

Each parameter is logged in the logbook, including the information of who performed the process, when was it done, etc.

Such a logbook looks like the illustration below.
Illustration 4: PhoeniX LOGbook to store all process data, including the SEM images of the results. Further, the data in the LOGbook can be recycled to improve the process and the recipes by means of the Design of Experiment Modules. Secondly, the data can be consumed to improve the project schedule and management through PhoeniX PlanDB.

Of special importance is the ability to attach (an unlimited amount of) photo-shoots and pictures to the logbook.

The pictures are stored at the exact place where they were taken in the process and are the ‘five senses’ of the process operator.

The reference model allows the extraction of process related information by using a search interface.

Combined queries are possible, such as “list recipes with an etch depth between 70 and 80 micron and an etch speed higher then 1.5um/min”. Values like the etch speed can be calculated automatically using individual etch time, which can be measured on different wafers, but are stored individually. This allows extraction of process results into more abstract numbers and allows easy data interpretation.

The technology to extract and recycle the process LOG data is used to feed the Design of Experiments (DOE) analysis. Furthermore, the data can be passed on to PhoeniX PlanDB to schedule and manage the whole project.
**PhoeniX R MODULE**

PhoeniX R MODULE is the brain of the PhoeniX DOE (Design of Experiments) Module. The intelligence behind the R MODULE is **Statistical Process Control**, which mimic the development of human's intuition to weave out the complications and improve life.

PhoeniX R MODULE collects and analyzes process's data (thus, not only the end results) to determine if a correlation is relevant and therefore useful. **By collecting data from samples at various points within the process, variations in the recipe that may affect the quality of the end product can be detected and corrected.**

**PhoeniX R is a customized module which will be constructed based on the Client's process's parameters.**

Among other propriety, PhoeniX R MODULE estimates the process's tolerance, and the error's margin of the process's parameters. Harvesting on these results PhoeniX R MODULES “brainstorms” new recipes which may hint a breakthrough in process's efficiency.

In DRIESO project, one main goal is to speed up the development process. The process's speed is a combination of etch time and cleaning time. Up till now, attention was only paid to minimize the pollution during etching, and little attention was paid to the cleaning's procedure itself.

PhoeniX R MODULE has been used to investigate the cleaning procedure, and managed to reduce the cleaning time up to 40%\(^1\).

Illustration 5: Blue: standard cleaning process's duration. Yellow: optimized cleaning process's duration

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\(^1\) Besides investigating the cleaning's process parameters, PhoeniX R Module has also been applied to investigate the etch process parameters such as facet width and selectivity. The data analysis are available in the DRIESO DOE Analysis (Reference: DRIESO DOE Analysis v2, October 2006, Jan Bos)
**PhoeniX wxRieApp**

For a beneficial communication, ideas need to be visualized.

*PhoeniX wxRieApp is the visualization of PhoeniX R MODULE’s ideas, and the PhoeniX Living Database’s memories.*

In PhoeniX wxRieApp, the user fills in the geometrical values of the required etch’s profile. Subsequently, the user appoints if the proposed recipe should optimize the cleaning’s process, or the etch’s process.

Depending on the models available in the R MODULE, a set of solutions is presented if such a solution could be found. Selecting a result gives a visualization of the optimized result. If the input is outside the region where the model is valid, the application will signal that there is no possible solution.

**Example:**

An etch hole of 15um deep is required where a mask thickness of 5um is available.

The application calculates a recipe and finds equipment settings where the selectivity is 5.6.

This is OK for the proposed mask thickness because 5x5.6um is 28um.

This simulation is done in the screen-shoot below.
If we now only have 2um mask thickness available, the 15um depth will not be reached because 2x5.6um is 11.2um.

The simulation is done again with the 2um mask thickness as an input parameter.

PhoInX wxRieApp finds a new recipe with selectivity 8.5, which is now sufficient for the required etch depth.

The relevant simulation is illustrated in the screen-shoot below.
The previous examples are conducted with the accompanying PhoeniX R MODULE to work on the input geometrical data. The PhoeniX wxRieApp does not necessarily need the access to the archives in the database to execute the task. Hence it can be referred as the “offline mode” of PhoeniX wxRieApp.

However, if for the comparison purposes, one requests to find another variant of the recipe from the archives, then PhoeniX wxRieApp has to switch to the “online mode”.

The same input geometrical data can be used by PhoeniX wxRieApp to search for the relevant recipe from the archives in the database. PhoeniX wxRieApp browses all historical data directly to search for the most suitable process schemes.

Whether the SEM images or any other bitmaps which correspond to the obtained recipe would be available or not, PhoeniX wxRieApp will execute the recipe to create a mathematical etch profile in the Viewer Window. Thus the Viewer is never blank if a recipe were to be found.

When the SEM image or a bitmap is available with the obtained recipe, the image will be projected on the mathematical etch profile calculated internally by the wxRieApp.

The illustration below shows an archived recipe obtained from the PhoeniX Living Database.
Illustration 6: PhoeniX wvRieApp “online mode”. Etch-Profile Viewer: the purple track-line represent the mathematical profile, whilst the yellow track-line represents the archived profile.
Conclusion:

A new approach towards process development has been introduced into the Micro System Technology market place. This approach has been applied successfully on an Alcatel Deep Reactive Ion Etching machine for a Silicon Dioxide etch process. The overall process duration has been cut down to 50%, while the same quality of etching is maintained. This achievement exceeds the preliminary expectations.

This significant breakthrough is realized because of the wholesome synergy between the solid mathematical approach of PhoeniX R Module, and the extensive process's expertise of the engineers in the consortium.

Introduce the PhoeniX Design of Experiments tools into your cleanroom and design environment to considerably reduce your production time to market.

PhoeniX wxRieApp and PhoeniX R Module will support you to reduce the operational cost, and to speed up the product development.

The other PhoeniX Foundry products; “The Living Database”; form the solid foundation from which these design applications will obtain their data.

Furthermore, PhoeniX Plan and Management software gives a new life to the process data by using them for project planning, and to validate the machine operations to predict the maintenance requirements.

Together, the PhoeniX Design and Database Software move your Cleanroom towards the next breakthrough in productivity.

References

1. Eindverslag DRIESO Concept1, October 2007, Mirthe Wehrmeijer, LioniX BV
2. PhoeniX B.V. Presentation, July 2007, Niels Olij, PhoeniX BV
3. DRIESO DOE Analysis v2, October 2006, Jan Bos, PhoeniX BV