ALTERNATE OPTIMIZATION OF PROCESS PARAMETERS

by

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ABSTRACT

Optimization traditionally employs strategies of factorial design that have been shown to be lacking in efficiency. Research into evolutionary operation schemes, a more efficient technique, has been conducted and an alternative strategy for optimization proposed. The procedureis outlined and an application with the computer modeling program SUPREM II is discussed.

INTRODUCTION

In microelectronic engineering, as in all engineering disciplines, optimization of a system is a common goal. A specific example would be the determination of optimum processing parameters such as softbake temperature and time, exposure and development time on resolution on a photoresist line. While optimization is defined as perfection of a system, an engineer often has to optimize by determing when something is 'good enough' or acceptable.

Most bachelor degree programs teach the traditonal design of experiments techniques such as full and fractional factorial designs, which have been employed with good results. These methods follow an approach as shown below; [1,4]

1) Determine important factors (screening)
2) Factor modeling
3) Optimization of factors

Methods that follow this procedure can be inefficient in time and resources, when trying to optimize a system. This is caused by several reasons. Screening experiments require the factor relationships to be understood and elimination of an important factor can occur if the screening is performed in a factor space not near the optimum (i.e. the factor may only have a pronuounced effect in the area of the optimum). When conducting an optimization, the number of trials required is of exponential dependence. Therefore as the number of factors increases, the trials increases dramatically.

An alternative approach is the use of an efficient design strategy to optimize a system of factors. These methods are not seen as a replacemnt to good, sound ststistical experimental design techniques, only as a supplement to the engineer's tools. The sequential simplex method has been used successfully in the field of chemistry by several authors. S. N. Deming of the University of Houston, Houston, TX, has advocated its use in experimental designs. [1,3]

Sequential simplex optimization is an evolutionary operation (EVOP) technique. This technique will optimize a system of factors without having to determine the important factors and perform modeling beforehand. This will allow the inclusion of all factors thought to have a bearing on the performance of the system. The lattitude of each factor will be determined in the region of the optimum and then its importance can be determined. Also, for the same amount of factors the sequential simplex method requires less trials per iteration than the traditonal techniques.

TECHNIQUE

Sequential simplex optimization (SIMPLEX) can be described as a geometrical progression method of optimization. Its main function in the EVOP strategy is optimization. Modeling and screening can be handled by regression and statistical analysis techniques.

SIMPLEX is dependent on the concepts of systems theory,response surfaces and response functions. The systems theory concept states that a system of factors (inputs) is related to its output by an objective function. When SIMPLEX is employed it is not necessary to know the objective function. A response surface is generated from a response function upon which SIMPLEX works. Figure 1 is an example of a guassion type function plotted against its input factors. The response function should include all important observable outputs with proper weighting and tradeoffs assigned.

The response function is designed to produce the best combination of output factors, not an optimum of one of them. This is the area where the engineer must make decisions based upon prior knowledge of the process (objective function) and most important, deciding what outputs have to be taken into account. The age old question of "What do you want?" comes into play. This is often the hardest part of SIMPLEX. An example of a response function (R) as applied to dry etching follows;

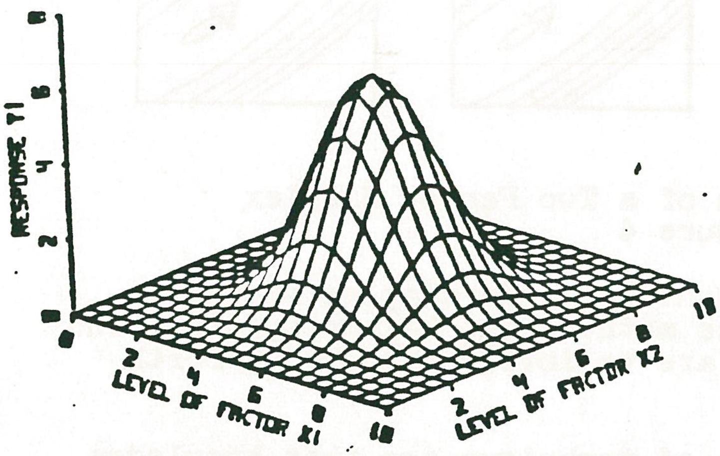
$$R = \frac{(\text{etch rate}) * (\text{selectivity})}{(\text{percent non-uniformity})}$$

The above equation will provide an increasing response as etch

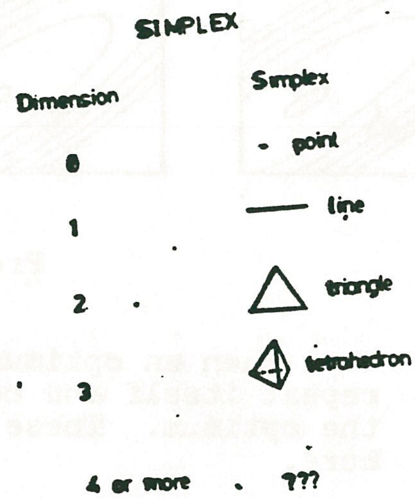
rate selectivity and percent non-uniformity improve.

Now that the basic parts of SIMPLEX, the simplex, response function and response surface, are in place, the progression of a simplex can be laid out.

A simplex is a geometric figure that has a number of vertices equal to the number of factors plus one. This is better understood by the graphical representation in Figure 2.



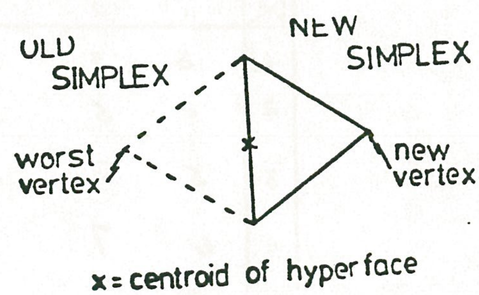
A Response Surface
Figure 1



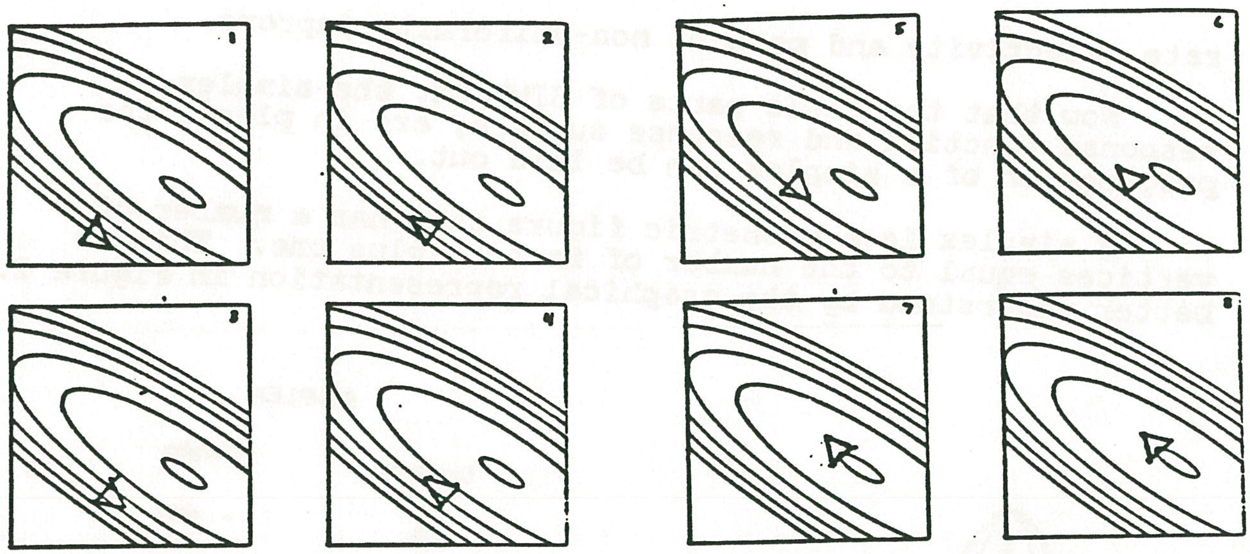
Simplexes
Figure 2

To start, an initial simplex is determined in the factor space. The placement and size can be arbitrary or can be influenced by knowledge or preference of the engineer. Next, the responses at each of the vertices are calculated and ranked in descending order. The worst vertex is discarded and a new vertex is generated by reflecting the rejected vertex through the centroid of the remaining hyperface. This is best understood by examining Figure 3.

This process, rejecting and reflecting the worst vertex, is continued until the simplex centers itself upon an optimum. Figure 4 shows how a progression might take place.



Reflection of Simplex
Figure 3



Progression of a Two Factor Simplex
Figure 4

When an optimum is encountered, the simplex starts to repeat itself and convergence methods can be employed to find the optimum. These methods are to involved to bring forth here.

Advantages to this type of technique are that knowledge of the objective function is not required, it is rather simple to follow once the reponse function is defined because the calculations to determine the next test point (vertex) and it can save time and resources. The last point can be illustrated by a comparison with a commonly used factorial approach. Using a two level factorial design as an example, Figure 5 shows the required number of trials for k factors and n iterations. As can be seen, SIMPLEX can save a significant amount of time.

SIMPLEX

k \ n	1	2	3
1	3	4	5
2	4	5	6
3	5	6	7
4	6	7	8

(k+n+1)

FACTORIAL METHODS

k \ n	1	2	3
1	2	4	8
2	4	8	16
3	6	12	24
4	8	16	32

$(k)(2)^n$

Simplex vs. Factorial
Figure 5

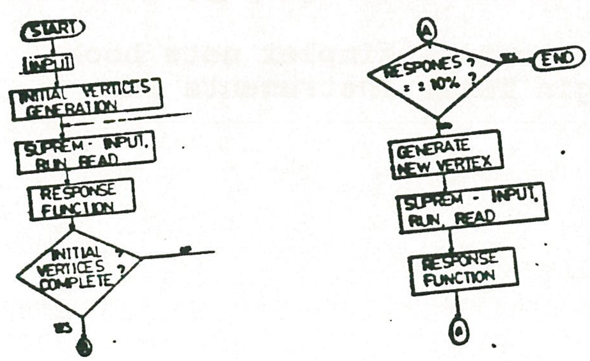
Disadvantages to the SIMPLEX are that it does not provide a good data base, due to the lower number of iterations. This is offset by the fact that a database is later generated when the system is modeled in the optimum region. Besides, the data is not needed most times from a non-productive region. Secondly, SIMPLEX is not applicable to all processes. A process that has relatively quick turn around and low setup is the best. For example, applying SIMPLEX to diffusion process that uses propogation delay as a response, would not be a acceptable because the amount of processing and time required to obtain a reponse. A factorial approach with many variations would work better, providing numerous results at once.

APPLICATION

The optimization of the predeposit and drivein times of a diffusion, with the sheet resistance and junction depth as the response factors was investigated. SUPREM II was employed as the objective function. It is a modeling program developed at Stanford University, that predicts diffusion profiles given the process paramters. It is used in the design of devices as well as their processes.

When designing a process, these parameters usually have their values defined. Therefore, SIMPLEX was employed to determine the predeposition and drive-in times to provide the desired combination of junction depth and sheet resistance.

The advantage of using this technique is that no internal changes have to be made to SUPREM II, as might be required by other methods. Also, it is relatively easy to make changes to the program, such as changing the response function, which is based upon the sheet resistance and the junction depth. The program follows the procedure put forth previously. The flow of the program is shown in Figure 6.



Program Flowchart
Figure 6

The logic is complete and the program is about fifty percent complete. At this writing, there are some 'bugs' with setting up the SUPREM II input file. Also, there are some other file handling problems and difficulty running SUPREM II from another program.

CONCLUSION

The principles of SIMPLEX have been brought forth and applied to a modeling program, SUPREM II. The logic for the SUPREM II oprimization has been drafted.

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