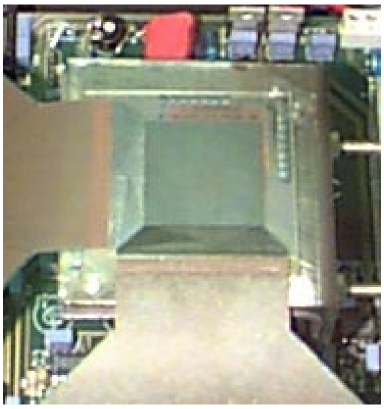
FACULTY OF APPLIED SCIENCES

Department of Electronics
and Information Systems

a-SiN:H X – Ray Sensor

Igor A. Popov



Promotor: Prof. Dr. Ir. A. Van Calster
Thesis submitted for obtaining the
Degree of Doctor in Applied Sciences

Academic year 2000

Planning of experiment.

As can be seen the problem of optimisation of a-SiN:H thin film with respect to structural and electrical requirements is indeed quite complex. There are tens of characteristics to be measured. Many of them require certain substrate material, certain thickness of the films an so on. This means that for characterisation of a-SiN:H deposited under certain set of PECVD parameters one will need more than one deposition[1] . And here is the question of PECVD parameters. Our PECVD reactor has 6 independently controlled parameters - Pressure in the deposition chamber, RF power (frequency is fixed at 13.56 MHz), Substrate table temperature, 3 independent gas flows - all of which influence the properties of the deposited film. In order to see the influence of the each parameter at least at first order approach one would take minimum three settings for each parameter. This leads to 3^6= 729 possible combinations/needed experiments. Thus amount of needed depositions grows even more.

Historically this problem of huge number of experiments needed is dealt with quite simple - by limiting the number of parameters one will work with and limiting the number of film characteristics one wishes to optimise. This selection - what parameters will not be varied and to which values they will be set - is made on the base of technological experience and analysis of published experimental data. Such an approach is very successful but does not answer one question: Are the films deposited under current parameters set really as good as can be or it is just a local minimum?

Answering such question is of crucial importance in this work. As was mentioned the goal of this work is production of the stable film which meets electrical requirements. This means that we want to be able to change as many deposition parameters as possible during the experiments. And on the other hand we want to control (be able to measure) as much of film properties as possible. One of the possible answer to our concern is the system of experimental design.

Dr. Taguchi's System of Experimental Design[2] [33][3] is aimed to the decreasing of the number of experiments needed for optimisation of one or another characteristics of a product. It is based heavily on the concept of orthogonal arrays which are used for assigning experiments. Such an orthogonal array allows drastically decrease the number of experiments while observe the influence of particular process parameter level during the change of every other parameter. In a way this is what one could call "screening experiments". Firstly, with the help of SED one understands how the given property of the product is influenced and how strong this influence is for every process parameter. Based on this date outcome of the experiment with any process parameters set is predicted. Secondly, process parameters levels are chosen so as to get best result.

Area of application of the SED is very wide and still expanding, so more orthogonal arrays are coming in use. Just to demonstrate the power of the SED, let's get back to our PECVD process: 6 independent parameters with 5 levels each (for higher confidence in curves) lead to 5^6 = 15625 depositions. With the use of L_{25} (6 parameters, 5 levels) orthogonal array number of experiments is as low as 25. Obviously, good things always come together with bad. Wherever SED will work correctly for the given task depends strongly on inter influence of process parameters. Fortunately, PECVD of Si based thin films is the area where SED works. ELIS-TFCG/IMEC has a history of successful application of SED in a optimisation of SiO_xN_y dielectric films [32,34]. This gives certain level of confidence that SED is applicable in the case of a-SiN:H thin films as well.

There is another aspect to the problem of dealing with huge volumes of experimental data - finding the optimal decision. Flatly, it is finding the global minimum in N-dimensional space where the working surface is superposition of M surfaces (N and M are the number of process parameters and product properties under optimisation respectively). There are two approaches to such a problem: (i) the use of brute force what means going through the all possible parameter sets looking for the best; (ii) the use of some heuristic algorithm which will allow to find the best solution in much shorter time. In my opinion the second approach is much more efficient and as algorithm of search for the optimum "Taboo Search" [35] must be selected. Just a few remarks why:

The main request to any search algorithm one would use in technology is that such algorithm should be able to find "global" minimum on the search surface "even" if there are more than 1 minimum. Historically, the Simulated Annealing method was widely used for technical problems. Being very simple and easy to implement it has major disadvantage - the tendency to converge into the local minimum rather than into global. This disadvantage is inherited with descent strategy of search in which search always moves in the direction of improvement. Thus the result of the search is strongly dependant on the starting point and search surface. Random "moves" implemented in SA can not taken as a cure.

Taboo Search is a recently developed search algorithm which is aimed at always reaching the global minimum. "Taboo" does not really involves any references to the religious or moral considerations, instead it keeps itself busy with imposing and removing certain restriction to guide the search process all over the search surface, looking for the true and only global minimum. There are few kinds of restrictions and rules which allow to utilise much more information provided by SED than traditional SA method.

- Taboo search keeps history, meaning that the new use of the move which lead to the current situation will be forbidden for *n*-iterations even if it appears to lead to the best results - thus search is pushed to the new regions instead of oscillating around local minimum;

- When operating in N-dimensions TS will introduce penalties of frequently used process parameter, meaning that if the current state was reached by changing parameter *k*, next state will be reached without changing parameter *k*, even if it appears to lead to the best results;

- If all the "positive moves" are under some kind of taboo, search will take "negative" moves. Yet the use the "aspiration" may take place at this stage. Aspiration allows to decide on the direction of the current move and/or, if the best move is under taboo, whether or not this taboo can be overridden. Aspiration set of rules can be easily build on the base of Contribution Ratio derived from SED results. In case of SA use this information would be wasted.

- Randomisation[4] can be easily introduced into TS as running search few times with random starting points.

Use of the System of experimental Design together with Taboo Search for the optimisation of a-Si alloys is very effective. Description of the developed software for use in PECVD process optimisation can be found in the Appendix A.

[1] To be totally correct this number of depositions must be multiplied by number of runs one needs to get the statistical data that allows to say that films deposited under current conditions have certain properties and these properties are reproducible from substrate to substrate, from run to run.
[2] Further in text we will refer to the System of experimental design as SED.
[3] The volume I of the ref.33 devoted to the application of SED and volume II discusses the mathematical basis of SED.
[4] Concession to the SA adepts