New Technique to Improve Response-Surface-Method Model Fitting Accuracy for Process Technology and Device Design Optimization

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- Abstract -

Statistical analysis techniques – Experiment Design (ED) and Response-Surface-Method (RSM) – have traditionally been employed to conduct and analyse real-world experiments. [1] ED and RSM provide a systematic and efficient framework for conducting a minimum number of experiments while gaining a maximum amount of information from the experimental results. Recently, ED and RSM have been applied to computer "experiments" involving integrated processing, device and circuit simulations. [2] These simulations typically require extensive amounts of CPU time and involve a huge number of input parameters. For processing technology and device design optimization, the goal is to determine a set of input parameters which produce the desired output device and circuit specifications. Rather than conduct an inefficient investigation involving a lengthy series of full computer simulations, ED is used to sparsely sample the input parameter space, and RSM is used to calculate the coefficients of approximating functions for the various output parameters over the entire range of the input parameter variations. These analytical functions are then used to find an optimal point where all of the design specifications are met. They are also used to produce statistical distributions of responses with respect to input parameter variations.

In general, RSM utilizes a fitting function which is a first-, second-, or higher-order polynomial of the input parameters. The fitting accuracy may be improved by transformation of the inputs and/or outputs. We have developed a technique to determine possible improving transformations of the input parameters. The approach is based on an experimental design known as a Central-Composite-Faced (CCF) design. A CCF design for two input variables is shown in figure 1. Each circle in the figure represents an experiment where the input parameters are set to values within the range of interest: $+1$ is highest, -1 is lowest. For each input parameter, a characteristic ratio is extracted from the experimental results. This characteristic ratio is used to select parameters in a transformation family (modified Box-Cox transformation, for example). In many cases, transformation of the inputs produces an approximating function which fits the experimental data much more closely than the classical RSM model.

We employ a system which we have developed to automatically conduct computer simulation experiments. This system calculates the experiment design array, performs the series of coupled process and device simulations, extracts the output parameters from the simulation results, and analyzes the results. For each experiment, values of selected input variables are substituted into the input decks which are then submitted to the process and device simulators. Process simulations are performed for three cross-sections of an MOS transistor, and the results are combined together and used as input for the two-dimensional device simulator.

An example of the approach is illustrated in figures 2-5. In this example, a blanket threshold-adjust implant dose, and the gate oxidation temperature are varied. These variations produce the several channel region doping profiles shown in figure 2. The fitting function which was found for the extracted threshold voltage is shown in figure 3. This fitting function shows a sub-linear response along the dose axis. 9 experimental points were used to calculate this fitting function. In order to evaluate the fitting accuracy, all of the experiments over an 8×8 grid of input parameter variations were conducted. The difference between the 64 extracted threshold voltage values and the fitting function is shown in figure 4. Transformations were automatically found for the two input variables, and a fitting function involving these transformed variables was found. The difference between the 64 extracted threshold voltage values and the transformed fitting function is shown in figure 5. The fitting accuracy (rms error) is improved by a factor of about 5 over the unrefined case. This drastic improvement of the fitting accuracy of this approach over the classical RSM technique will result in a major reduction in the overall optimization cycle time.

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[1] G.E.P. Box, W.G. Hunter and J.S. Hunter, *Statistics for Experimenters: An Introduction to Design, Data Analysis, and Model Building*, John Wiley and Sons, New York 1978.

[2] A.R. Alvarez, B.L. Abdi, D.L. Young, H.D. Weed, J. Teplic and E.R. Herald, "Application of Statistical Design and Response Surface Methods to Computer-Aided VLSI Device Design," *IEEE Trans. on Computer-Aided-Design*, vol. 7, no. 2, Feb. 1988, 272-288.

Fig. 1 A Central-Composite-Faced Experimental design. Each circle in the figure represents an experiment where the variables x_1 and x_2 are set to values within the range of interest: +1 highest, −1 is lowest.

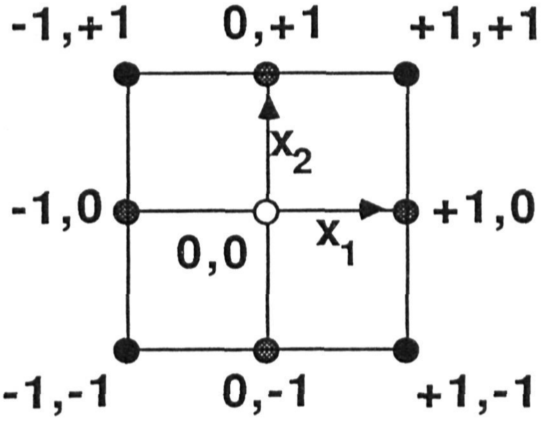

Fig. 2 Five of the nine channel region doping profiles produced by a CCF design for the two input variables: dose of threshold-adjust implant, and gate oxidation temperature.

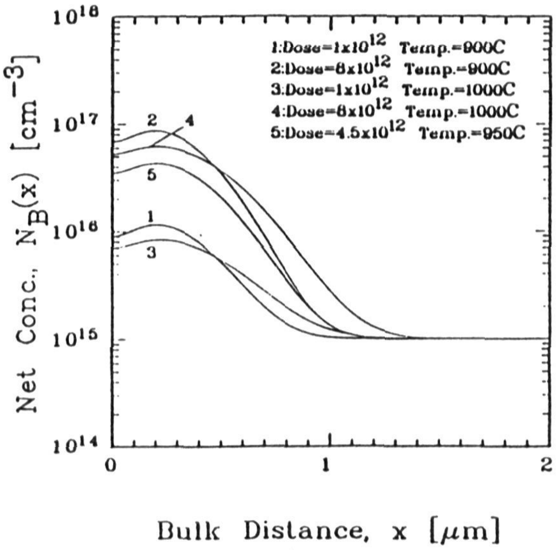

Fig. 3 The function which was fit to the nine extracted threshold voltage values from the results of the CCF experimental design, plotted over the entire range of input parameter variations.

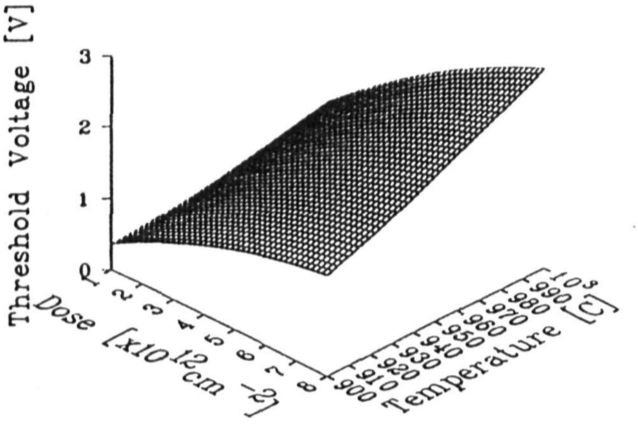

Fig. 4 The error between the fitting function and extracted threshold voltage values at 64 points in the input parameter space.

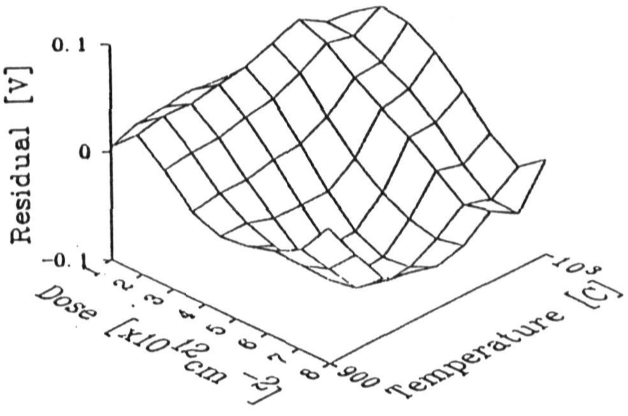

Fig. 5 The error between the fitting function in transformed input variables and extracted threshold voltage values at 64 points in the input paramter space. The error is reduced by a factor of about 5 (rms value) over the untransformed case.