Integrated Statistical Process and Device Simulation System with Automatic Calibration using Single-Step Feedback and Backpropagation Neural Network

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1. Motivation

An integrated simulation system that combines process and device simulation is developed in Submicron Development Center of AMD to address the following issues:

1. The manufacturing data is fundamentally statistical. It is difficult to measure exact values for each parameter in every process steps, and single data point is simply insufficient to justify any decision.
2. A high order of data accuracy is required for fine-tuning an established fabrication process.
3. A high degree of flexibility and out-of-spec prediction ability is required for process development.
4. Fast ramp-up time for process control demand minimum engineering calibration effort.
5. Development engineer need full flexibility to modify process flow, process parameter, as well as underlying device physics models.

These require combination of statistical approach, device physics modeling and a series of data processing techniques. The unique features are discussed in the following section.

2. Methodology

Statistical Distribution Function

In order to closely reflect the different data distribution in the real manufacturing environment, data in arbitrary format and distribution profile is allowed to be entered, stored and processed. Data can be entered in array of data points, arbitrary function description, or standard statistical description. Immediately after entry, each input data will be converted into a statistical distribution function (SDF) before the actual processing. A statistical distribution function is simply a fixed dimension list of parameter value in the order of population percentile. All data, however, will be stored in a central database together with the SDF organized following process flow and electrical measurement step for other applications' access. In the simulation system, each result, including intermediate result, will be a SDF. SDF, rather than a single data point, is considered as the elementary data type (i.e. single data point is anonymous).

The system accepts data of 3 different types:

1. Process parameter (e.g. furnace temperature, deposition time)
2. In-line measurement (e.g. gate oxide thickness, poly CD)
3. electrical data (e.g. Vth, Idef)

Single-Step Feedback Automatic Calibration

In a statistical simulation, the simulation step is repeated many times. Each repetition will randomly select one value from each input SDF, process the input values with the corresponding physical or device model, and obtain a value for each output SDF. Two different run modes are defined: the calibration run and the prediction run. In the calibration run, purpose is to use existing data for neural network training (automatic calibration).

Instead of completing the whole simulation in each single simulation repetition, gathering the intermediate output values in all simulation steps and perform neural network training all at once, this system employs *single step feedback* to perform the calibration, i.e. each single simulation step is considered as the final step for its own statistical simulation run.

Using this scheme, the interaction between different simulation steps can be minimized and the propagation of simu-

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lation error will be terminated.

Backpropagation Neural Network with Levenberg-Marquardt Approximation

Neural network is used to adjust the model with real measurement data for the following advantages:

1. One single implementation can be used to map multiple functions of vastly different characteristics without lose of accuracy and extrapolation ability.
2. Neural network can respond to changes in its environment in its operation, i.e. adaptive. In addition, the weight of time factor can be easily adjusted to reflect the stability of the real environment.

Levenberg-Marquardt approximation is employed to improve the training performance and accuracy.

3. Merits

1. The simulation system has the flexibility to fully utilize all available measurement data to improve the simulation accuracy.
2. The system is fundamentally statistic. The distribution profile is automatically calculated for each result and intermediate result. SDF allows data in any arbitrary distribution profile.
3. Single-step feedback and neural network mapping support automatic calibration. Hence, model for previous technology can be used to simulate new technology with minimum silicon run.
4. Engineer is allowed to flexibly modified the process flow, process parameter, simulation model as well as replace any dataset or SDF with his own. The system will report parameter variation, process interaction, and electrical test windows in a statistical distribution manner and help to pin point the source of each changes.

4. Application Example

In the following example, all production lots of a single product with electrical test carried out in a 2-week period were used for the correlation run. No engineering tuning of the simulation model was employed. The correlation functions were used for prediction run to all production lots of the same product in the following week. The predicted electrical data were then compared to the real measured data. Percentage error results of selected parameters is given in the following table:

Device	**Parameter**	**Percentage Error**
PMOS	Vth (V)	1.220%
	Vsat (V)	1.694%
	Gm (mA/V)	0.173%
	Isat (mA)	0.163%
NMOS	Vth (V)	1.829%
	Vsat (V)	3.700%
	Gm (mA/V)	0.094%
	Isat (mA)	0.638%
	Std. Dev. Gm	4.027%

For those WET parameters that were defined by measurements in the linear region, a superb accuracy of less than 1% error (in most cases around 0.1-0.2% error) was obtained. This performance is no question the best that can be expected from a simulation tool with automatic calibration. And for those WET parameters that were defined by the measurements in the exponential region, the accuracy of less than 5% error (in most cases around 1-2% error) is also considered satisfactory.

As the tool is based on statistical simulation, a complete output distribution, rather than a single value, is obtained. The comparison of the standard deviation for the Gm indicates that the prediction for the distribution of the whole data set is reasonably accurate.