BARAS : Novel and Highly Efficient Simulation System for Process Control Sweeping and Statistical Variation

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1. Necessity of an Automatic Simulation System

For the realization of today's miniaturization and low voltage drive of ULSIs, it has become much more important to understand and predict the effect of process variations on device performance. Predicting the quantitative effect of every process variation on device characteristics has following advantages: In designing, required performance range can be appropriately specified, and in manufacturing, when some device characteristics is out of specification, processes to control can be feed-forwarded for proper production. In order to realize this by utilizing simulations, it would be crucial for the simulation system to have a user-interface with ease of operation and an efficient data processing ability based on the actual process parameter distribution of the manufacturing equipments. There are some simulation tools[1-3] which enable above tasks. However, they have difficulty in handling mask shape variations and in utilizing actual process distributions which do not follow Gaussian.

We have developed BARAS, the automatic simulation system capable of very efficient process control sweeping, statistical variation analysis and output data processing, which has functions for producing input data files automatically and has an easy-to-use GUI (Graphical User Interface). Furthermore, BARAS has succeeded in reducing CPU time drastically by utilizing moment expansion method and enabled Monte Carlo simulations based on real process parameter variations.

2. The Automatic Simulation System BARAS

2.1. Overviews of the System

To simulate the characteristics of a MOS device based on actual process variations, first, an impurity profile is calculated from the actual process recipe by the well-calibrated process simulator, and then device characteristics are simulated using the result of the process simulation under specified bias conditions. In BARAS, users set a series of process data, and then sweep conditions or distributions of any process parameters with very simple operation, in the original process input window. BARAS produces automatically all the input data files corresponding to the conditions and actual distributions, and then submits them to the process simulator and to the device simulator. From the result of the device simulation, the threshold voltage Vth, the saturation current Ids and the subthreshold swing S are extracted and stored automatically in a database. Users can see all the specified data and mean values, variations and standard deviations of them in the form of tables and graphs with easy GUI operations.

2.2. Novel Features of BARAS

BARAS produces input data files depending on different process parameter values according to users' specifications. The followings are the novel features of BARAS.

(1)Sweeping mask dimension parameters Predicting the effect of variations of gate length and sidewall width is also very significant and one of the novel features of BARAS. However, these values cannot be swept automatically in the known tools because changing such parameters affects the shape of other masks, and it is extremely difficult to auto-mesh considering impurity distributions and mask shapes. By adding attribute information to masks, BARAS can infer the MOS device structures and with this information, effects between masks are automatically considered when values are changed. We also have developed an original auto-mesher utilizing empirical knowledge resulting in efficient and practical mesh generation.

(2)Monte Carlo simulations based on actual distributions Distributions of actual process parameters do not necessarily follow typical distributions such as Gaussian. Even for this case, BARAS can perform Monte Carlo simulations based on the actual process parameter distributions different from the known tools.

(3)Drastic reduction in simulation number and CPU time for Gaussian distributions There are many cases that variations of process parameters follow the Gaussian distribution. In this case, it is possible to obtain the standard deviation of device characteristics from differential values of calculated device characteristics on process variations and the variation of each process. Using this moment expansion method, when n parameters vary, standard deviation of device characteristics can be extracted by calculating only $2*n$ times, while Monte Carlo simulation needs calculation of order of nth power. For example, when there are three parameters to vary, at least 1,000 (3rd power of 10) calculations are needed for Monte Carlo simulation. On the other hand, our method needs six (2*3) calculations. In this case, it is possible to reduce CPU time to about 1/160.

3. Design Specification by BARAS

BARAS was applied to investigate the effect of process parameters on device characteristics and to specify required *Vth* ranges on deep half-submicron N-ch MOS devices. Investigated were N-ch MOS devices such as High, Middle and Low according to their *Vth* value.

Confirming that the process variation follows Gaussian distribution, we applied moment expansion method mentioned in 2.2(3). In the case of N-ch MOS device, process parameters which affect *Vth* are gate length (*Lgate*), Vth ion implantation dosage (*Vth-II*), thickness of gate SiO2 (*Tox*) and width of sidewalls (*SW*). First, we obtained center values and process parameter variations on our manufacturing equipments. Table 1 shows these values for a High Vth MOS device. From this, standard deviation was set on these four process parameters with our original process editor. BARAS produces eight input data files by sweeping ±10% on every specified process parameter and submits them to a 2D process simulator. From the result of the process simulation and specified biases, BARAS produces input data files for a 2D device simulator and submits them for computation. Users can see contributions of every process parameter on device characteristics with very easy operations on GUI. Table 2 shows the effect of all the process parameters on *Vth* (variation) and its ratio for the High Vth MOS device. In case of this device, standard deviation (σ) of *Vth* is predicted to be 17.3mV. Shown in Fig.1 is the plot of the effect of all the process parameters on *Vth* for High, Middle and Low Vth MOS devices to their *Vth* ranges specified as 3σ. This result shows that the effect of *Tox* is crucial for the High Vth MOS device. On the other hand, Lgate highly effects on *Vth* in the Low Vth MOS device enabling to pinpoint the process parameter to control for reducing the *Vth* variation.

4. BARAS evaluation

BARAS achieved to cut the tedious and long work of more than ten days to less than one day's work, which consists of preparing input data files for process variations and sweeping conditions, and handling large amount of output data. Because of this laborious work for input data preparation, the accurate and detailed predictive simulation was usually impossible without the development of BARAS. BARAS is in practical use for more than twenty months in house and has high evaluation from all the users.

5. Summary

We have developed BARAS, an automatic simulation system for process parameters control sweeping and analyzing process variations having a very easy and simple GUI handling, by which any process parameters can be swept and the result of simulations can be displayed in tables and graphs very efficiently. BARAS succeeded to reduce more than ten days' work to less than one day's work, and what is more is that it made possible to obtain very accurate device characteristics variation based on actual process variation and to feed-forward it for performance control.

References

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Table 1 Center values and standard deviations for High Vth MOS

process	center value	σ(st.devi.)
Lgate(μm)	0.45	0.0253
Vth-II(keV)	4e+12	3.69e+11
Tox(nm)	10.0	0.2067
SW(μm)	0.14	0.014

Table 2 Effect of High Vth MOS process parameters on *Vth*

process	variation [V^2]	ratio(%)
Lgate	5.94e-5	19.9
Vth-II	1.16e-5	3.9
Tox	2.28e-4	76.2
SW	1.03e-11	0.0
σ *	1.73e-2[V]	-

(*) Total standard deviation, i.e., the square root of the sum of each process variation.

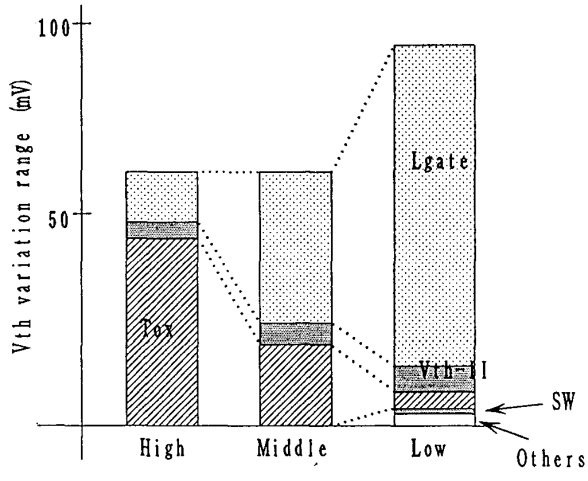

Figure 1 Effect of process parameters on Vth for High, Middle and Low Vth MOS to their *Vth* ranges specified as 3σ