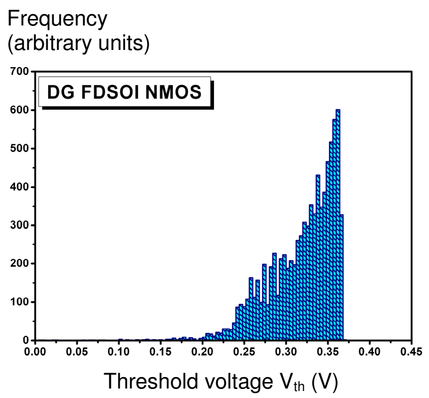
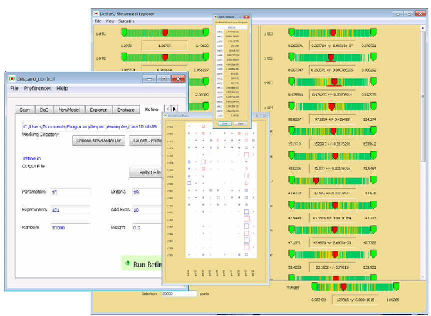
HIESPANA – HIERARCHICAL SIMULATION OF NANOELECTRONIC SYSTEMS FOR CONTROL OF PROCESS VARIATIONS



Simulated frequency distribution of the threshold voltage of a double-gate fully-depleted SOI NMOS transistor. In the simulations, the influence of variations of the lithography process leading to variations of the gate length was considered.



GUI of the DesParO software package for parameter analysis and optimization.

Goals of the HIESPANA Project

Increasing influence of variations on the performance of devices and circuits

With the transition from micro- to nanoelectronics, further scaling of devices and systems encounters challenges due to approaching basic physical limitations.

Besides the difficulties in reaching nominal performance figures, variations become increasingly important, as they could lead to enlarged fractions of devices and circuits being out of specifications. This holds not only true for ultra-large-scale integration (“More Moore”), e.g. for memories or high-performance processors, but also for analog and high-voltage devices with relaxed scaling (“More-than-Moore”).

Characterization and optimization by means of simulation

The systematic investigation of process variations utilizing experimental methods only is limited. In contrast, simulation in principle allows comprehensive and cost-efficient study of variations. Using process and device simulation, electrical characteristics of devices for a given process technology and set of parameters can be determined. Based on this, circuit parameters can be extracted which allow characterization of the properties of the circuit. Alternatively, this can also be achieved by tightly integrated hybrid device and circuit simulation. When now considering variations on process level, by using simulation it is possible to quantify the influence of these variations on device, circuit, and system level.

In conclusion, simulation has the strong potential to characterize and minimize the influence of variations. This is highly relevant for the optimization of the manufacturing process for nanoelectronic devices and systems.

Overview of HIESPANA

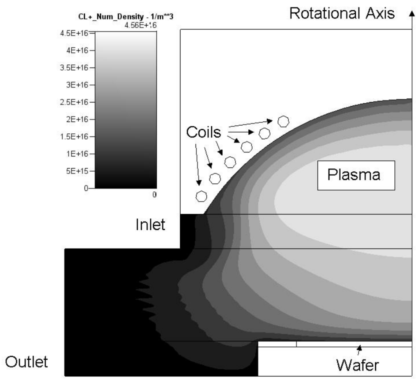
For exploiting the potential of simulation for dealing with variations, a hierarchical simulation approach is mandatory. Within HIESPANA five Fraunhofer Institutes cooperate on the development of such an approach. The simulation chain spans from process and device modeling via circuit simulation to system simulation. In other words, simulation starts with a detailed description of devices on nano-scale (using high-resolution numerical grids) and – by using appropriate interfaces between the simulation levels – ends up by modeling of the entire system on macroscopic level.

To this end, we develop predictive physical models which are capable of delivering nominal data as well as variations. Furthermore, tight integration of the simulation modules is carried out. For analyzing the simulation results (e.g. for studying sensitivity, robustness, and reliability, for optimization, for data extraction and reduction), powerful algorithms are developed and implemented.

The Fraunhofer simulation modules provide interfaces to third-party tools, e.g. to tools from Synopsys, Cadence, or TU Vienna.

Process and device simulation

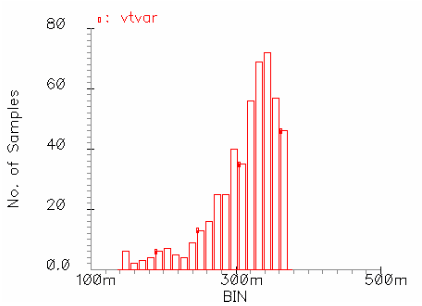
Within process simulation, physical-based models are used to determine the geometry (e.g. using the simulators Dr.LiTHO and ANETCH for modeling of lithography and etching) and doping of devices, including variations, caused e.g. by variations of process parameters. Subsequent device simulation and compact model extraction allow investigation of circuit performance and its variations. In effect, this concept allows transfer of variations from process to circuit and system level.



Equipment simulation of an etching reactor carried out to determine variations of the etch rate across the wafer. The figure shows the concentration of chlorine ions.

Circuit simulation

On circuit level, compact models of the integrated devices are used to analyze circuit block characteristics. Since these compact models are nonlinear in nature the variations of the extracted model parameters due to the considered process variations will exhibit non-normal density functions both for normal and non-normal distributions of process parameters. Therefore add-on tools have been developed that allow the simulation of random variables with arbitrary probability density functions.

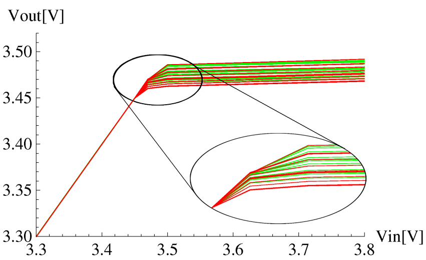


Generated random numbers following a given non-symmetrical probability density function.

System simulation

Based on the circuit netlists, model cards, and parameter distributions, a behavioral model on system level is generated. This allows fast simulation of the system and extraction of statistics regarding the output quantities of interest.

Furthermore, parameters being relevant for system behavior can be identified with sensitivity analysis, and their influence on the output quantities can be studied without the need to perform costly Monte Carlo simulations.



Input-output characteristics of an overvoltage protection circuit with model parameter variations. Green: original system, red: symbolic approximation.

The software Analog Insydes allows reduction of the behavioral model preserving the symbolic parameters. Model order reduction here significantly reduces simulation times. Though, keeping the system parameters preserves information regarding relevant dependencies of the system for the design process.

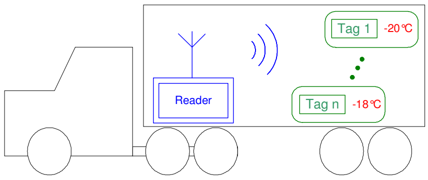
Algorithms and integration

The third-party tools Minimos-NT (TU Vienna) and Spice3 (Univ. Berkeley) have been integrated into the simulator MECS (Univ. Cologne / SCAI). In this way, tightly coupled circuit and device simulation is enabled. Instead of standard compact models (e.g. Spice3 BSIM), some fully discretized devices (Minimos) can be used for increasing accuracy of results. For analyzing parameter variations of the process-device-circuit chain, the DesParO software tool is used. The extended linear solver package SAMG speeds up simulators on different levels.

Demonstrator

The demonstrator where the hierarchical simulation procedures and concepts are applied is a passive UHF sensor transponder that combines RFID technology with smart sensors to create new applications for modern transponder technology. Requiring no batteries, an operating range of several meters can be achieved.

The extended range enables new implementations in many applications like monitoring the cooling chain for medical transports, food chain management, or health care.



Possible application for the sensor transponder.

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Fraunhofer Project HIESPANA
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