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TCAD Optimization Based on Task-Level Framework Services

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Abstract

This paper presents the integration of an external optimizer into the VISTA TCAD framework. A collection of task-level framework services is used by the optimizer to request the execution of process flow and device simulation tasks. All aspects of tool control and simulation data management are taken care of by these services, allowing for an easy implementation of a variety of task-level applications such as sensitivity analysis tasks, optimization, and RSM extraction. An example shows the calibration of MINIMOS' mobility parameters.

1. Introduction

The automatic optimization of semiconductor devices by means of computer simulation requires the repeated execution of multistep process flows to compute a set of response variables as functions of a set of control variables. For example, the implant dose and energy are chosen as control variables to optimize the LDD implant of an n-channel MOSFET, with the response variables being the drive current $I_{D,max}$ and the substrate current $I_{B,max}$, and the goal is to minimize $I_{B,max}$ and to maximize $I_{D,max}$. Finding the optimum design involves two independent tasks: the *selection* of sampling points in the design space, and the *evaluation* of the design at these points. The former is provided by an optimization algorithm, i.e., the optimizer, which, in general, determines the location of sampling points from the results of previously evaluated points in an iterative fashion until an optimum is reached. The latter returns response values for given input settings, obtained, e.g., by running a process flow simulation for each evaluation, or by using a previously established response surface model (RSM) of the process. The operations required to determine the responses as functions of the settings are not relevant to the optimizer. They can be treated as being hidden inside of a black box that takes care of executing the appropriate tasks to produce the desired outputs.

In the present work, the Vienna Integrated System for TCAD Applications (VISTA) [1] provides a collection of task-level services for the definition and simulation of process flows, catering to an external optimization tool that acts as a client and uses these services to evaluate and optimize the design. An evaluation may lead to the start of simulation tools, the computation of a response surface model, or simply the retrieval of a previously computed result; from the client's point of view, all these cases are identical.

2. Framework Service Layer

The service layer provides access to a set of high-level framework services based on VISTA's simulation flow representation [3]. It allows for the creation, modification, and execution of process flow instances, the submission of tasks for execution, the retrieval of responses, and the persistent storage of results. Automatic split generation and scheduling minimize the number of simulator runs required for iterative as well as parallel optimization techniques. Independent split branches are executed simultaneously over the network to quickly obtain results.

The service layer is implemented in VISTA's extension language VLISP, a superset of XLISP. An instance of a process flow together with its run-time data is called an *experiment* and is represented by a VLISP object. Table 1 gives examples of available services to create and manipulate experiments.

Service	Description
`Define Experiment`	Defines experiment attributes, e.g., process flow, initial wafer, etc.
`New Experiment`	Creates new instance of existing experiment.
`Edit Step Parameter`	Modifies parameter values at step in process flow.
`Submit Experiment`	Requests execution of process flow or retrieves previously computed results.
`Inquire Step Data`	Returns responses, current wafer data, etc.

Table 1: Examples of framework services to create and access experiments.

By means of these services, high-level TCAD applications like design-of-experiments (DoE), sensitivity analysis, and optimization can be conveniently implemented with all tool invocation details, etc., hidden.

3. Framework – Optimizer Interface

When an optimization task is initiated by the framework, an *agent* is assigned to the optimizer tool, which establishes a connection between the task-level services and the optimizer. The agent is realized as a VLISP object. It takes care of passing messages between the optimizer and the framework by means of a callback-based, asynchronous connection, allowing for the execution of multiple optimization tasks at the same time. Fig. 1 shows the interaction between the optimizer agent and the service layer on the one hand, and between the agent and the external optimizer on the other hand. The framework passes a description of the model to the optimizer, defining the model's type and its control and response variables. During the course of the optimization, the optimizer requests the evaluation of the model for a certain set of control values by sending a message to the framework. Messages between the optimizer and the framework rely on VISTA's operating-system independent standard-input/standard-output redirection capabilities. Depending on the internal operation of the optimizer, evaluation requests may be sent synchronously, or a number of requests may be sent at a time. Upon termination of the optimization, the result found and diagnostic information are passed back to the framework.

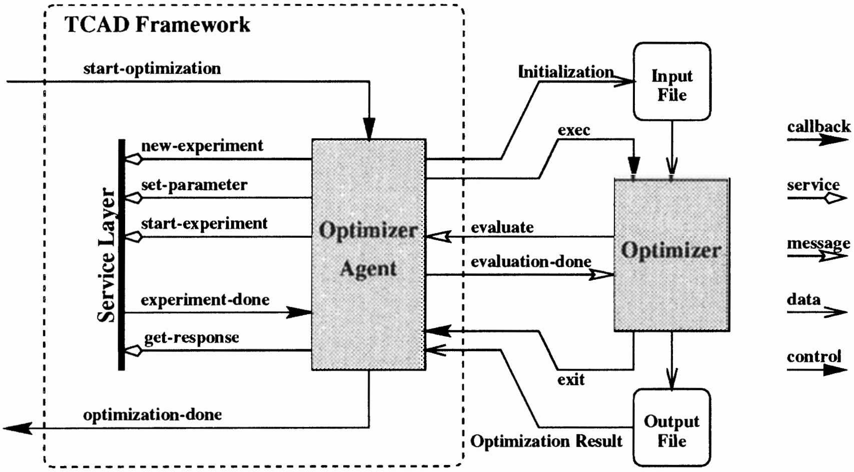

Figure 1: Communication between the service layer, the optimizer agent, and the external optimizer.

4. Application Example

To verify the feasibility of the approach presented above, the MINIMOS [4] mobility model equation parameters were calibrated using p-channel data from devices fabricated with a retrograde n-well, salicided dual-gate CMOS process. The calibration was done using nonlinear least-squares optimization to adjust physical model parameters to minimize the errors between calculated and experimental values. The two-dimensional doping profile was determined experimentally [2]. Process and device simulation were performed by the TCAD framework upon request of the optimizer. With the calibrated mobility parameters, MINIMOS simulation accurately reproduces experimental I-V data over a wide range of biases and lengths. The width of all the simulated and measured devices is 64 μm, the oxide thickness (t_{ox}) is 72.7 Å. The polysilicon gate doping concentration (N_p) is equal to 2.7×10^{19} cm^{-3} as determined from gate capacitance measurement with the device biased in the inversion region. Fig. 2 shows measured and simulated results for the linear region currents for three gate lengths. Good agreement is found in all regions of bias for all three lengths.

5. Conclusion

Using an external optimizer as a client in the simulation environment separates the evaluation of the *model* to be optimized from the optimization task, thereby effectively liberating the optimizer from dealing with tool invocation intricacies, error handling provisions, and user interface requirements. Different optimizer tools can be used,

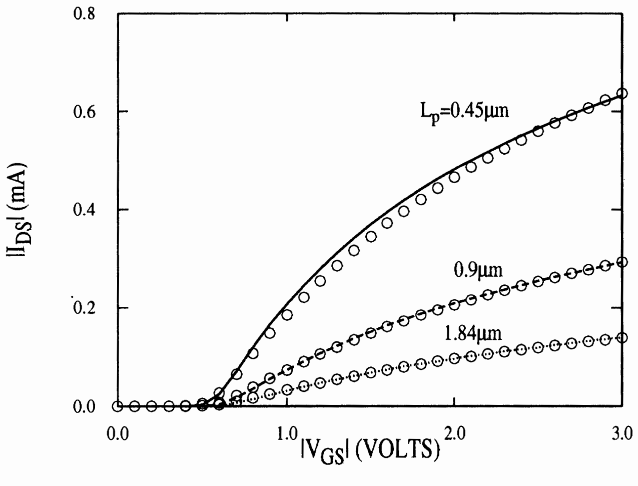

Figure 2: Comparison of measure and simulated I–V characteristics in the linear region ($V_{DS} = -50$ mV) for three gate lengths ($L_p = 0.45$, 0.9 and 1.84 μm).

as they access the evaluation services in a standardized way. Other task level applications such as sensitivity analysis or RSM generation can be easily implemented using the services presented. The framework's parallel execution and split generation capabilities provide fast responses to multiple model evaluation requests.

6. Acknowledgment

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