Datasheet

Stress Engineering

Synopsys TCAD Services

Overview

Stress engineering is mandatory to meet the performance targets of leading-edge CMOS technology and is now extending to strained SiGe channels and hybrid orientation of NMOS and PMOS devices. This involves a large number of possible device configurations for exploring and optimizing MOSFET performance, which can only be investigated efficiently with the help of TCAD. Yet, the complexity of stress effects, ranging from the impact of stress on process simulation to 3D effects and drain current enhancement in the quasi-ballistic transport regime of nanoscale transistors, makes TCAD simulation a challenging task.

Synopsys TCAD Services offers a range of services to address device optimization and process integration issues in stress engineering. Examples include adding mechanical stress and advanced classical or Monte Carlo device simulations to customer process flows, exploring new structures and processes, and extending simulator capabilities using, for example, the physical model interface.

Introduction

Stress, crystallographic orientation, and channel material engineering offer many degrees of freedom to optimize device performance within the given device window. TCAD allows for an efficient assessment of the different configurations, as illustrated in Figure 1, which shows a typical 3D mechanical stress simulation, and in Figure 2, where the effect of high stress and quasi-ballistic transport on the $I_{d,sat}$ gain is demonstrated. Current stress engineering approaches rely on a large number of stress techniques: etch stop layer, dual stress liner, stress memorization techniques, embedded source/drain SiGe pockets, and layout proximity effects. With regard to crystallographic orientations, the current focus is on <110> and <100> channel orientations for (100) NMOSFETs, and combinations of <110> and <100> channel directions with (110) and (100) PMOSFETs, while strained SiGe is being considered as a new channel material for PMOSFETs. Given so many options for implementing stress engineering, TCAD is an efficient and cost-effective tool for exploring and optimizing the device performance enabled by the various stress sources, unorthodox crystallographic orientations, and new channel materials.

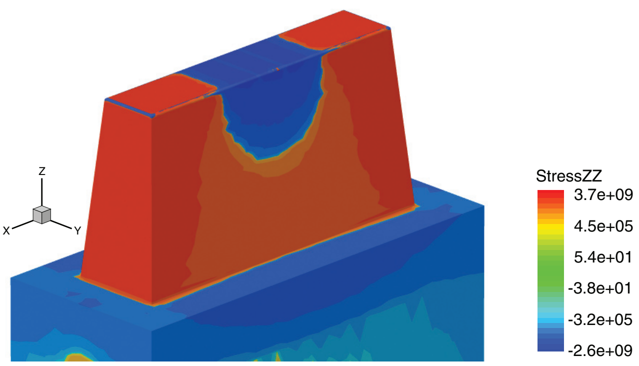

Figure 1: Stress component normal to the gate interface in the Si body of the MOSFET.

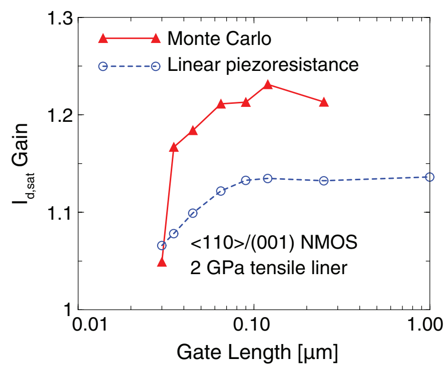

Figure 2: Scaling of the stress-induced on-current gain.

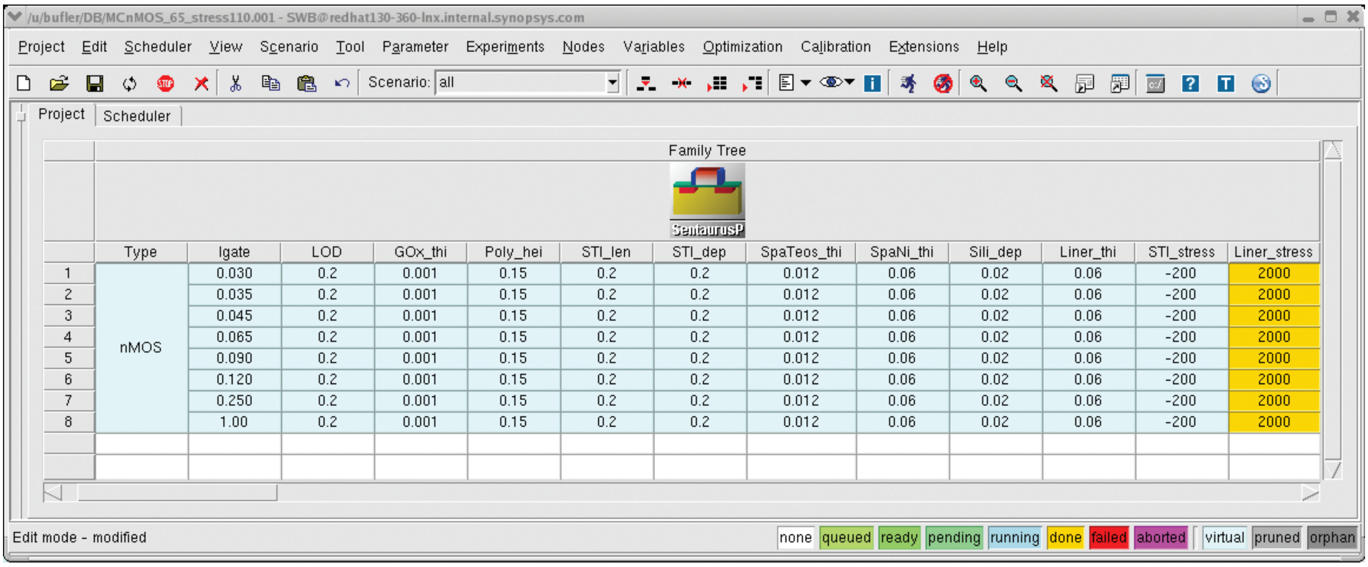

Figure 3: Mechanical stress simulation part of a Sentaurus Workbench setup covering stress, process and Monte Carlo device simulation.

TCAD Stress Engineering

The complexity and level of sophistication of the TCAD approach to stress engineering depend on specific customer needs. For example, 3D effects may significantly influence the channel stress and typically vary with changes in geometry. If large numbers of geometry and stressor configurations are to be simulated, 3D process and device simulation can involve considerable computational resources. In some cases, 3D mechanical stress simulation can be combined with 2D process and device simulation where a constant averaged stress is used in device simulation.

Another topic of interest is the sensitivity of dopant diffusion to stress since this effect critically impacts the amount of gate overlap [1]. Furthermore, high stress and short channels are not well described by uncalibrated drift-diffusion simulation with the standard linear piezoresistance model. Here, Monte Carlo device simulation [2] can be integrated in a Sentaurus Workbench project (see Figure 3) for accurate investigations and as reference for the selection and calibration of the appropriate mobility model in faster classical device simulation. Possible choices depend on the configuration with respect to stress sources and crystallographic orientations, and include the second-order piezoresistance model, the Intel hole mobility model, and the corresponding electron-valley repopulation model.

Summary of TCAD Services in Stress Engineering

- Extension of customer process flows with stress and advanced device simulation
- Implementation of new advanced device simulation models using, for example, the physical model interface (PMI)
- Exploratory simulation studies of unorthodox crystallographic orientations and stress sources
- Performing complete stress optimization for a given customer technology

[1] I. Martin-Bragado *et al*., “Anisotropic dopant diffusion in Si under stress using both continuum and atomistic methods,” in *12th International Workshop on Computational Electronics (IWCE)*, Amherst, USA, pp. 8–9, October 2007.

[2] F. M. Bufler, A. Tsibizov, and A. Erlebach, “Scaling of Bulk pMOSFETs: (110) Surface Orientation Versus Uniaxial Compressive Stress,” *IEEE Electron Device Letters*, vol. 27, no. 12, pp. 992–994, 2006.

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