Modeling of Hot-carrier Degradation: Physics and Controversial Issues

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Introduction to the topic:
Over the last years, hot carrier-degradation modeling has evolved from simple empirical models to a more detailed understanding of the microscopic physics involving single- and multiple-carrier processes. Unfortunately, a detailed description of the physics requires knowledge of the carrier energy distribution function which can only be obtained from a solution of the Boltzmann transport equation. Most models in use today employ simplified solutions based on the average energy or, even more dramatic, the electric field, while in the ultimate simplification it is tried to capture the physics using closed analytic expressions. Although computationally more efficient, these approaches are inevitably inaccurate, even though their limitations might not be that obvious when a limited range of bias conditions, temperatures, and channel-lengths is investigated.
The essential peculiarities of hot-carrier degradation (the localization of the damage, change of worst case conditions in scaled devices as compared to long-channel counterparts, and the temperature behavior) suggest that the proper modeling of the phenomenon should rely on carrier transport. Channel carriers interact with Si-H bonds at the interface, thereby producing interface states. Additionally, charge trapping/detrapping processes in the oxide bulk can also contribute to the degradation. This dictates that an accurate description of the microscopic mechanisms of defect creation has to be integrated into the model. Finally, charged states distort the electrostatics of the device and act as additional scattering centers, which degrade the mobility. We will discuss the required ingredients for a hot-carrier degradation model which aims at covering and linking all the levels related to this effect. A careful study of the various models published, highlighting their range of validity as well as the resulting implications for lifetime prediction will also be given. A particular focus will be put on controversies in hot-carrier degradation understanding and modeling. For instance, the question whether the bulk oxide states contribute to the damage and how they are linked with hot-carrier degradation recovery will be posed.

Structure of the tutorial
1. Hot-carrier degradation: introduction and main peculiarities
2. Physical mechanisms behind the phenomenon
3. Physics-based modeling of hot-carrier degradation
4. The modeling paradigm which integrates all the levels of the effect: carrier transport, microscopic mechanisms of defect creation, and modeling of degraded devices
5. Open issues (contribution of bulk oxide traps, recovery, temperature behavior)
6. Conclusions

Who should attend
In this tutorial an overview of physical hot-carrier degradation models and a discussion of their limitations will be given. Also the controversial issues related to this detrimental phenomenon will be discussed, forming thereby the precursors for future investigation. This tutorial should be of interest to reliability engineers working on hot-carrier degradation and related phenomena (BTI, TDDB) as well as for anyone interested in this topic.

Biography of tutorial speaker
Stanislav Tyaginov was born in Leningrad (now Saint-Petersburg) in 1978. He received his MSc degree in physics (specialization: the physics of semiconductors) in 2002 and his doctoral degree in physics in 2006 (his PhD was devoted to the problem of the impact of insulator thickness non-uniformities on MOS tunnel structure characteristics). He has been working as a post-doctoral researcher at A.F. Ioffe Physical-Technical Institute (Saint-Petersburg, Russia). Starting from January 2008 he has also been employed as a post-doctoral researcher at the Institute for Microelectronics, TU Wien. His scientific interests include the modeling of hot-carrier degradation and TDDB as well as tunneling phenomena in MOS devices.