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Critical Modeling Issues in Negative Bias Temperature Instability

Tibor Grasser* and Ben Kaczer°

* Christian Doppler Laboratory for TCAD at the Institute for Microelectronics, TU Wien, Austria
° IMEC, Leuven, Belgium

I. INTRODUCTION

Negative bias temperature instability (NBTI) has been known for more than forty years but has attracted growing attention during the last couple of years. After a relatively long period where the reaction-diffusion theory [1, 2] reigned more or less undisputedly as the dominant explanation, a growing number of authors have recently voiced their doubts regarding its validity. In particular, whether NBTI is due to interface states and/or oxide charges is amongst the most controversial issues at the time. This recent controversy has also been fueled by the introduction of new fast measurement techniques, which are capable of monitoring degradation and recovery in the microseconds regime, and the realization that the traditionally employed constant bias stress does not provide enough knobs to probe this intricate phenomenon. Rather, it is now understood that a good understanding can only be developed by studying the degradation response to dynamic bias conditions. Based on a thoroughly chosen set of experimental data we evaluate and benchmark the bulk of the existing models, highlight their shortcomings and develop a model which delivers promising results.

II. EXPERIMENTAL

In order to estimate device lifetimes, constant bias and temperature stress is conventionally employed which is either terminated at predefined times to determine the degradation [3] or monitored on-the-fly [4]. Unfortunately, such a setup has also traditionally been used for the development of models. Recently it has been recognized that these models fail to explain a number of features visible only under dynamic boundary conditions. Examples are the log-like recovery which covers at least twelve decades in time, the strong bias sensitivity particularly to positive biases, a marked duty-factor dependence, the presence of possibly two contributions (e.g., oxide and interface charges), and the initial log-like vs. the long term power-law-like behavior.

III. REACTION-DIFFUSION THEORY BASED MODELS

The reaction-diffusion model is the prime example of a model which can not cover much more than constant bias stress. Particularly striking is that the model predicts recovery to occur over four decades in time and its general inability to reproduce recovery characteristics. Furthermore, the model predicts bias-independent recovery, in stark contrast to experimental data. Numerous attempts have been made to salvage the model by considering different diffusion constants in the oxide and poly-layers, consideration of the oxide/poly interface, explicit dimerization of hydrogen, and dispersive transport [5]. Nonetheless, only rather poor benchmark results can be obtained by all these model variants and we must conclude that NBTI is not controlled by diffusion.

IV. DISPERSIVE-REACTION-RATE MODELS

Although models assuming a dispersion of the defect creation rate could be considered special cases of RD theory, they are markedly different as in these models diffusion plays no role. These models have been shown to be able to reproduce data obtained by charge-pumping measurements during both stress and recovery, which is conventionally interpreted as given by interface states [6].

V. HOLE TRAPPING MODELS

In order to explain the broad distribution of time scales and the bias dependence observed during both stress and recovery, various hole trapping models have been suggested. However, a critical analysis reveals that, although some of these models can produce excellent fits under certain circumstances, their underlying microscopic explanation is either missing or questionable. For instance, the detailed hole trapping model developed by Tewksbury [6, 7] is based on elastic hole trapping into pre-existing traps, which in modern ultra-thin dielectrics gives maximum time constants in the millisecond regime only.

VI. COMBINED MODELS

Reaction-diffusion theory based models and dispersive-reaction-rate models are frequently combined with hole trapping models to improve the quality of the prediction [6, 8]. However, these models do not take the frequently observed correlation between the created interface states and the oxide charges into account [9]. In consequence, they often fail to reproduce the temperature and voltage dependence of the overall degradation behavior.

To overcome the above mentioned issues, we have recently suggested a model where holes are inelastically trapped into deep states which in turn acts as a catalyst to interface state generation [10].

VII. CONCLUSIONS

We have thoroughly analyzed existing NBTI models and identified a number of serious shortcomings, implying that the physical assumptions underlying existing models cannot be correct. Based on these results we suggest a new model which delivers promising results.

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