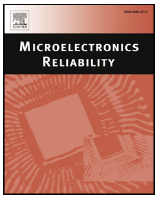
Microelectronics Reliability 87 (2018) 106–112

Contents lists available at ScienceDirect

Microelectronics Reliability

journal homepage: www.elsevier.com/locate/microrel



New NBTI models for degradation and relaxation kinetics valid over extended temperature and stress/recovery ranges

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ARTICLE INFO

Keywords:
FDSOI
CMOS
Fast measurement
Temperature
Recovery
Stress
$Vg_{recovery}$
NBTI
Compact model
Reliability

ABSTRACT

In this paper we present NBTI stress and recovery effects measured on PFET devices issued from various FDSOI technologies. NBTI degradation and recovery subsequent to DC stress are measured at the µs time scale. After in-depth analysis of temperature and stress/recovery bias effects, we propose new NBTI models for degradation and recovery kinetics including temperature, Vg_{stress} and $Vg_{recovery}$ dependencies. These models are finally validated on different technologies and various experimental conditions.

1. Purpose

NBTI is a major reliability issue for industry due to its impact on circuit performance [1], especially on nodes beyond 40 nm. Over the last 40 years, many attempts to model stress and relaxation have been published, but until now there are still discussions regarding the physical origins of defect generation [2–6]. Until the development of fast measurement techniques, the recoverable component of V_{th} drift was largely underestimated which in turn reduces the accuracy of reliability models for short stress times. Combining the new observations based on fast measurements, we propose new NBTI models with extended applicability ranges in terms of stress time, temperatures and stress/recovery bias.

2. Experimental

Samples used in this study are PFETs from the 28 nm FDSOI node. The equivalent oxide thickness in inversion of the high-k/Metal Gate stack is 1.7 nm [7]. NBTI DC stresses at different stress voltages were performed in a wide range of temperature from −40 °C to 300 °C, and were followed by recovery phases at 0 V, or slightly positive voltage. Typical fast Id-Vg curves measured within 10 µs are illustrated in Fig. 1 and were further used to extract V_{th} drifts [8].

Fig. 2 reports the ΔV_{th} variations with stress time for a given stress voltage and for various temperatures. As illustrated on the graph, a simple power law is not able to fit the whole range of $\Delta V_{th}(t)$ variations, especially for short stress time, and even when focusing on longer stress time, the power law exponent thus obtained would depend on temperature.

The corresponding relaxation traces following the stress of Fig. 2 are reported in Fig. 3. Two dynamics are clearly evidenced especially at low temperature conditions. Consequently, trying to fit experimental results with a simple logarithmic behavior is not suitable, especially for the first milliseconds of recovery.

It turns out that, considering a wide range of temperature, and ΔV_{th} acquisitions starting at the µs scale, simple fitting equations such as power law for stress and pure logarithmic behavior for recovery are not satisfactory.

In addition, Arrhenius plots of ΔV_{th} during stress (resp. recovery) are reported in Fig. 4 (resp. Fig. 5) for different stress times (resp. recovery times). Although an activation energy of 0.12 eV is found for the stress phase, ΔV_{th} measured during the relaxation phase could not be modeled by a simple Arrhenius law over the considered temperature range.

Therefore, in order to build a compact model able to reproduce the $\Delta V_{th}(t)$ variations for a wide range of temperatures and characteristic times down to the µs regime, more complex models have to be developed.

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https://doi.org/10.1016/j.microrel.2018.04.009
Received 8 August 2017; Received in revised form 11 April 2018; Accepted 11 April 2018

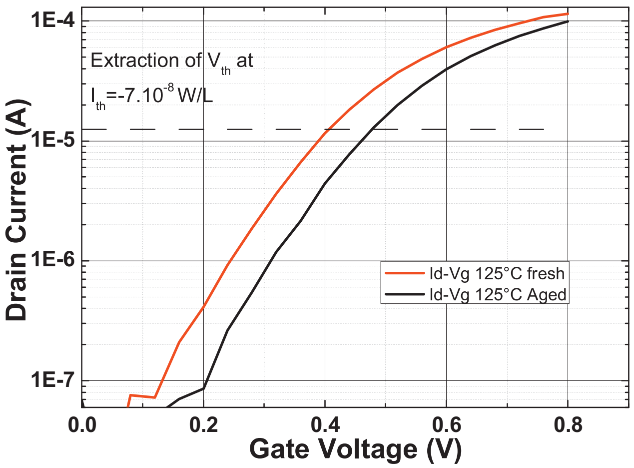

Fig. 1. Fresh and aged fast Id-Vg curves measured at 125 °C.

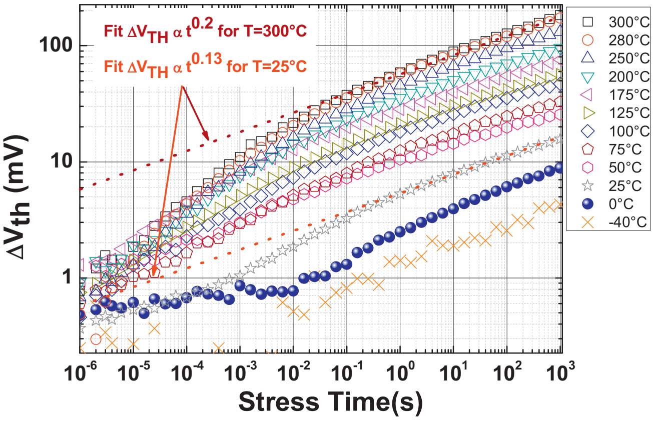

Fig. 2. ΔV_{th} vs stress time obtained during DC stress performed at several temperatures from 300 to −40 °C with the same DC stress voltage (measurement delay 10 µs).

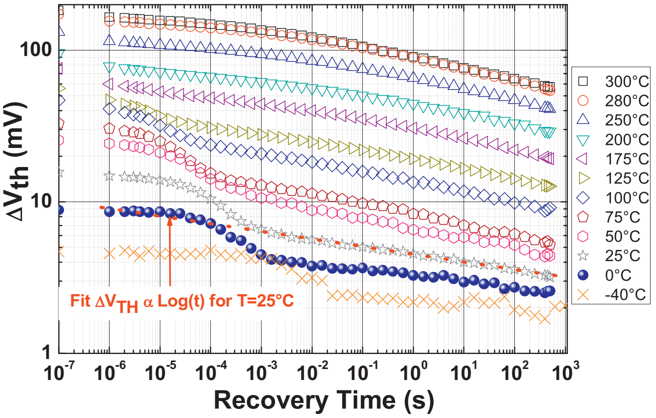

Fig. 3. Relaxation measurement following the stress reported in Fig. 2.

3. Review of NBTI stress models

In the literature, different NBTI models have been developed and proposed by different groups. They are based on different physical assumptions and are obtained by different experimental and analytical approaches.

Among them, the DP/DR model applied to NBTI reliability by Denais and Huard [9–11], consists of a decomposition of the NBTI degradation into a permanent component (DP) and a recoverable component (DR). The recoverable component is attributed to the trapping/detrapping of holes in the oxide while the permanent component comes from Si—H bond breaking following a dispersive reaction-limited mechanism [12,13].

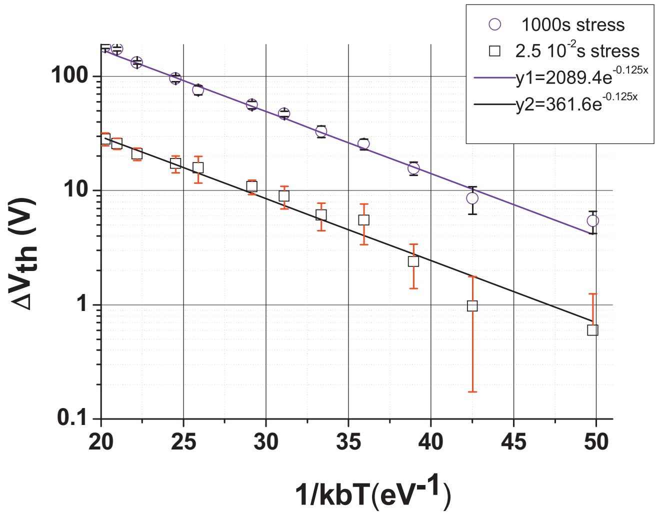

Fig. 4. Arrhenius plot of ΔV_{th} as obtained for the stress phase for the same DC stress at 0.025 s and 1000 s stress times. In the inset, x stands for 1/kbT.

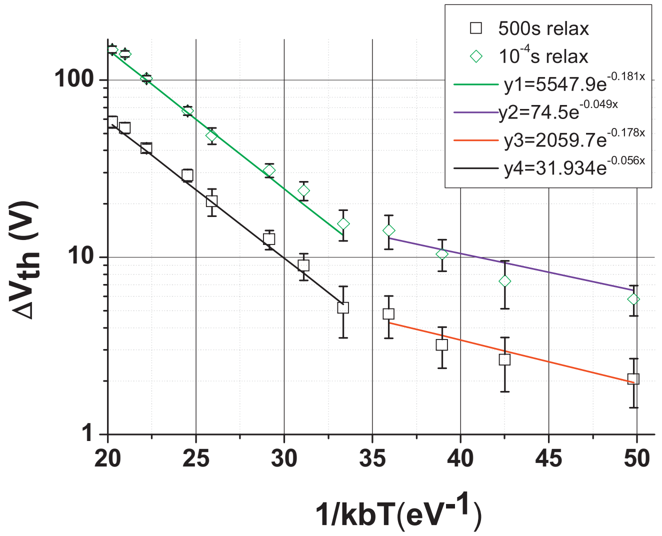

Fig. 5. Arrhenius plot of ΔV_{th} as obtained during the recovery phase at 0.1 ms and 500 s recovery times. In the inset, x stands for 1/kbT.

A model proposed by Grasser and Kaczer [14,15] in which a permanent and a recoverable component are also considered where the recoverable component could be a consequence of the interface state hydrogen re-passivation [16] or coming from the neutralization of trapped charges [13]. On the other hand, the permanent component could be related to unpassivated interface states [13] and to deep hole traps [17].

TTOM approach proposed by Mahapatra et al. [18–20], includes three different components to model the stress and relaxation behaviors. It has proven to be able to model various features of NBTI [19,20]. Using a double interface reaction-diffusion model and a transient trap occupancy model (TTOM), they are able to model the generation and recovery of interface traps. Moreover, they modeled hole trapping/detrapping in preexisting traps with an empirical stretched exponential as well as the higher bulk trap generation.

These three models provide interesting description of the physical