Recovery of Negative and Positive Bias Temperature Stress in pMOSFETs

Ph. Hehenberger*, H. Reisinger°, and T. Grasser•

* Institute for Microelectronics, TU Wien, A-1040 Wien, Austria

° Infineon Technologies, D-81739 München, Germany

• Christian Doppler Laboratory for TCAD at the Institute for Microelectronics, TU Wien, A-1040 Wien, Austria

***Abstract*— Based on the asymmetric recovery behavior observed following negative and positive bias temperature stress in pMOSFETs, various stress tests with different stress times, oxide electric fields, and oxide thicknesses were performed. In contrast to NBTI, where the relaxation of the threshold voltage often follows a logarithmic behavior, PBTI stress reveals no logarithmic recovery. Notable relaxation after PBTI stress instead appears to happen later but faster. This asymmetry is more pronounced at harsher stress conditions, e.g. increasing stress time and oxide electric field. This can be explained by the different relative measurement windows for NBTI and PBTI, which depend on the stress time and the oxide electric field. A closer analysis of the recovery yields the spectra of capture and emission time constants of the underlying defects. We analyze the dependence of these spectra on the stress time and the oxide electric field, where the emission times of the defects are shifted towards smaller times for higher oxide electric field.**

Introduction

Already decades ago the semiconductor industry discovered reliability issues such as the bias temperature instability (BTI), which happens when the gate of a heated metal-oxide-semiconductor field effect transistor (MOSFET) is biased while keeping the other contacts grounded [1, 2]. The degradation of device parameters, such as the threshold voltage V_{th} or the mobility, finally limits the operating lifetime of the transistor [3, 4]. This issue has become more important with decreasing device sizes and higher operation temperatures and has caused a considerable debate on the underlying physics and its consequences. Motivated by [5], the apparent differences in relaxation behavior of negative and positive BTI (NBTI and PBTI) on pMOSFETs are studied.

Although PBTI on pMOSFETs is technologically not as important as NBTI, it provides a valuable probe of the underlying physical degradation mechanism. The most intriguing observation is that both negative and positive bias stress create positive charges in the oxide [5]. While degradation built up during PBTI stress is about a factor two smaller than that built up during NBTI, up to medium stresses the degradation also recovers in a similar fashion. NBTI shows nearly perfect logarithmic relaxation when stressed up to $-6.5\,\mathrm{MV/cm}$ for $100\,\mathrm{ks}$, but deviations are found for higher stress fields ($E_{\mathrm{ox}} = -8\,\mathrm{MV/cm}$), depicted in the top of Fig. 1. It appears that the strong relaxation in the initial phase ranging from $1\,\mu\mathrm{s}$ to about $100\,\mathrm{ms}$ slows down to finally saturate. This saturation level is often called "permanent component" in contrast to the already recovered component [5, 6]. After [7] this permanent component follows a power-law. However, when comparing these two cases (low vs. high field) for PBTI, other effects become visible. Moderate PBTI stress ($6\,\mathrm{MV/cm}$) yields a constant recovery rate per decade, comparable to the case of NBTI with $E_{\mathrm{ox}} = 6\,\mathrm{MV/cm}$. In contrast, for high-field PBTI stress the recovery is first delayed and then pronounced.

I. Experimental Setup

NBTI/PBTI stress at $125\,^{\circ}\mathrm{C}$ were performed using the fast-V_{th} method of [8]. PMOSFETS from a standard $90\,\mathrm{nm}$ CMOS process with plasma-nitrided oxide (around $6\,\%$ of nitrogen) with three different oxide thicknesses ($t_{\mathrm{ox}} = 1.8\,\mathrm{nm}, 2.2\,\mathrm{nm}$, and $5.0\,\mathrm{nm}$) and geometries of $W/L = 20\,\mu\mathrm{m}/0.12\,\mu\mathrm{m}, 20\,\mu\mathrm{m}/0.12\,\mu\mathrm{m}$, and $20\,\mu\mathrm{m}/0.24\,\mu\mathrm{m}$, respectively, were used.

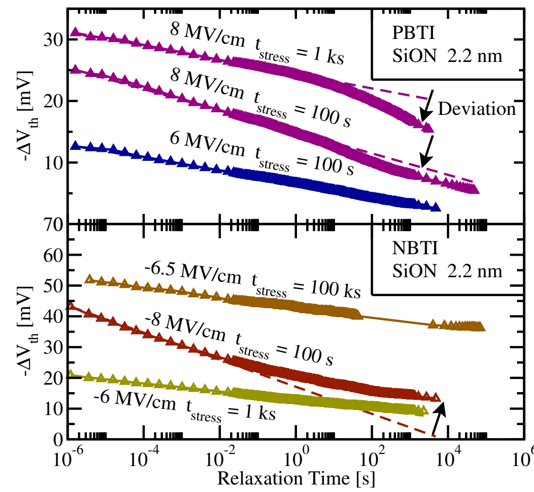

Fig. 1. Samples with an oxide thickness of $2.2\,\mathrm{nm}$ stressed using various NBTI/PBTI-conditions from $100\,\mathrm{s}$ up to $10\,\mathrm{ks}$. Depending on the type of stress, there is either no deviation from a logarithmic recovery behavior, a deviation downwards (PBTI) or upwards (NBTI). While for weak NBTI/PBTI-conditions ($E_{\mathrm{ox}} = \pm 6\,\mathrm{MV/cm}$ and $t_{\mathrm{stress}} = 100\,\mathrm{s}$) a logarithmic fit of the relaxation is possible, this is not the case for the other heavier stress conditions.

II. Schematic Recovery Behavior

In order to be able to discuss our experimental results we summarize our key findings first. The complete recovery trace after BTI stress is schematically depicted in the top left of Fig. 2. Unfortunately, the full features are rarely visible, compare with the curve of $E_{\mathrm{ox}} = -8\,\mathrm{MV/cm}$ and $t_{\mathrm{stress}} = 100\,\mathrm{s}$ in Fig. 1.

Actually, the monitored relaxation characteristics after typical BTI stress is limited in range. While for PBTI only the upper section of the whole relaxation curve is visible, it is the lower section for NBTI. Within these sections τ_{A} and τ_{B} depend on the curvatures and mark the transition between the initial and the late phase of the recovery. Using the curvature to detect a change of the relaxation we will analyze the recovery following PBTI versus NBTI stress.

III. Extraction Routine

The determination of the curvature following bias temperature stress is displayed in Fig. 3. First, each relaxation of V_{th} is referred to its initial $V_{\mathrm{th,0}}$ and is plotted as ΔV_{th} as a function of $\log(t)$. The first decades as well as the last decade in time are used to fit the experimental data with a logarithm of the form $a + b\log(t)$, giving the initial and long term recovery behavior. Eventually, the intersection of the two fits results in the "kink point" τ_{A} or τ_{B}.

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