Degradation of the Output Characteristics of Junctionless Nanowire Transistors due to Negative Temperature Bias Instabilities

N. Graziano Junior¹, R. Trevisoli¹ and R. T. Doria¹
¹Electrical Engineering Department, Centro Universitário FEI, São Bernardo do Campo, Brazil
e-mail: sectecnologia@outlook.com

1. Abstract

In the present work, we have analyzed the degradation by NBTI (Negative Bias Temperature Instability) in junctionless nanowire transistors (JNTs). The study was performed through 3D numerical simulations considering JNTs with different doping concentrations (N_D = 5x10¹⁶ cm⁻³ and 1x10¹⁷ cm⁻³) as well as FinFETs whose results were considered as the reference. The analysis was done for transistors with different channel lengths between 20 nm and 100 nm biased at two different drain voltages. We obtained as a result the lower degradation by NBTI effect for JNTs device with higher doping concentration and higher drain voltage independently on the channel length.

Keywords- SOI, Junctionless, NBTI.

2. Introduction

The NBTI effect focuses on the reliability of the devices, especially for nanometric channel lengths [1]. This effect is associated with degradation of the gate dielectric of the devices along the time due to the presence of interface traps and is responsible for a degradation of the drain current (I_DS) and threshold voltage (V_TH) of the devices. Despite the NBTI degradation in MOS structures has been reported since the 60’s, the importance of studies related to this effect has increased inversely proportional to the reduction of transistors channel lengths. In ultimate technological nodes, this effect has the potential to become a great reliability problem due to its deleterious effects. The degradation of NBTI, which is a problem inherent in P-type transistors, is one of the most significant problems of reliability and constant concern in CMOS technology for channel lengths below 130 nm [2]. Specifically, NBTI causes a systematic degradation in the electrical parameters of the transistor such as drain current, transconductance, threshold voltage and capacitance.

With the reduction in the size of the devices for extremely small nodes, the electrical characteristics of the devices are degraded by the so-called short-channel effects, since the control of part of the channel region charges starts to be done by the source and drain depletion regions. So that, several new technologies have been developed to reduce the short channel effects of the devices and to provide better electrical characteristics for extremely small technological nodes. One of these recent technologies consists of Junctionless Nanowire Transistors (JNTs) [3], which present several different aspects in relation to the conventional MOS, due to the absence of doping gradients between source and drain in relation to the channel. The JNTs work analogously to SOI accumulation mode devices. However, this is not properly an accumulation mode device [3], since the majority of the current flows through the body and not closer to the surface as in the SOI accumulation mode transistors. However, up to now, the effect of NBTI on such devices has not been deeply studied. Thus, this work aims to analyze the influence of NBTI on the electrical characteristics of junctionless transistors with different concentrations of dopants and channel lengths. The results have been compared to the ones shown by inversion mode FinFETs.

3. Devices Characteristics

The simulated structures present gate length (L) of 20, 25, 30, 50, 80 and 100 nm, silicon thickness of 10 nm and gate oxide thickness of 2 nm. The buried oxide thickness is 100 nm. JNTs present a constant doping concentration from source to drain, which has been varied from 5x10¹⁶ cm⁻³ up to 1x10¹⁷ cm⁻³. In the case of FinFETs, the source and drain regions are doped with arsenic with a concentration of 5x10¹⁶ cm⁻³, whereas the channel presents a boron doping concentration of 1x10¹⁵ cm⁻³. All the simulations have been performed using Sentaurus TCAD [4] and models accounting for the carriers’ generation and recombination, mobility dependence on vertical and longitudinal electric fields and bandgap narrowing have been considered. It is worth mentioning that the simulated I_DS-V_GS curves without considering the NBTI effect have been validated to the ones from [5].

3. NBTI Analysis

Among the various intrinsic wear mechanisms that contribute to the eventual failure or shorten the life of a metal-oxide-semiconductor (MOS) transistor, we have the Negative Bias Temperature Instability (NBTI). This is perhaps one of the effects that has the greatest potential to harm the development of new devices, since it demonstrates direct relation with the decrease of the channel length, causing the degradation of the threshold and current characteristics of a device due to the accumulation of positive charges at the channel / dielectric interface of the port and the generation of positively charged interface states. The above-mentioned mechanism is thermally activated and not linearly dependent on the electric field in the gate oxide [6].

In Figure 1, the I_DS x V_GS curves of a cascade of
junctionless transistors with variable L are presented. As a rule, the longer the channel length, the lower the current (in module) for the same $V_{GS}$, until the device cuts off. From the curves shown, it can be noted that the $V_{TH}$ of the devices is reduced (in module) by reducing the channel length of the devices. This behavior is related to the increase in the influence of the short channel effects.

The on-state current of the devices has been extracted for a fixed $V_{GS} - V_{TH} = 1.0 \text{ V}$ neglecting the NBTI effect for all the devices as it can be seen in Figure 2. To extract the NBTI degradation in the $I_{DS}$ also shown in the curves of Figure 2, the device has been biased at a fixed voltage overdrive for $10^{3} \text{ s}$. As expected, when accounting for NBTI degradation, $I_{DS}$ is always smaller (in modulus) than the currents not submitted and this effect. This phenomenon is associate to the increase (in modulus) of $V_{TH}$ due to the presence of positive charges in the gate dielectric interface.

To analyze the NBTI influence, the threshold voltage variation ($\Delta V_{TH}$) has been obtained as a function of L for the different devices as shown in Figure 3. When comparing the results of devices with L higher than 30 nm biased in the same $V_{DS}$, we can conclude that JNTs devices have a lower degradation by NBTI effect, in relation to the FinFET devices. This can be explained by the smaller electric field shown by junctionless transistors with respect to FinFETs of similar dimensions [7]. The same conclusion can be taken when comparing JNTs with different $N_D$ as, when biased at same $V_{GS} - V_{TH}$ devices with higher $N_D$ are farer from accumulation regime, resulting in lower electric field.

![Fig.1. Drain current as a function of the gate voltage for JNTs with doping concentration of $5 \times 10^{18} \text{ cm}^{-3}$ and drain voltage of -0.05 V.](image1)

![Fig.2. Drain current as a function of the channel length for JNTs with doping concentration of $1 \times 10^{19} \text{ cm}^{-3}$ and drain voltage of -0.05 V.](image2)

![Fig.3. Degradation of the threshold voltage versus the channel length for JNTs and FinFETs with drain voltage of -0.05 V.](image3)

4. Conclusions

This work has shown, for the first time, the effect of the NBTI degradation on the drain current and threshold voltage variation of junctionless nanowire transistors with different doping concentrations. The results have been compared to the ones obtained for inversion mode FinFETs with similar dimensions at same bias. According to the results, JNTs presents lower NBTI degradation than FinFETs, which can be associated to the lower electric field. Additionally, the NBTI is lower for JNTs with larger doping concentration, since, for a fixed $V_{GS} - V_{TH}$, these devices are biased farer from accumulation regime and present lower electric field.

Acknowledgments

The authors thank the Brazilian funding agencies CAPES, CNPq and FAPESP for the financial support.

References