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Impact of NBTI Stress on VDMOSFET Regions

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Abstract: In this paper, we investigate the impact of negative bias temperature instability (NBTI) degradation on both channel and drain regions, of commercial power double diffused MOS transistor (VDMOSFET), using capacitance-voltage method (C-V). We report that the degradation is important at channel (drain) region in p-channel VDMOSFET (n-channel VDMOSFET). That means that the phosphorus doped region (n-type) is more sensitive to NBTI stress.

Keywords: NBTI, C-V, VDMOSFET regions

1. INTRODUCTION

The power double diffused MOS transistor (VDMOSFET) has gained popularity and become the dominant device in high frequency switching applications [1], [2]. The extensive work on reliability of VDMOSFETs has been investigated under various degradations, such as total ionization dose [3], [4], hot carrier [5] and a phenomenon named negative bias temperature instability (NBTI) [6]–[9]. NBTI is the most serious reliability problem in modern CMOS technologies. Also, this degradation is an important issue in power VDMOSFET. Indeed, increased electric fields and elevated chip temperatures are frequently approached during the routine operation of power devices in automotive and industrial applications. So the NBTI degradation in power VDMOSFET is of importance as well. However, reliability studies of VDMOSFETs are complicated due to the different regions which constitute this device, such as the channel and the drain regions as shown by Fig. 1 for a p-channel VDMOSFET. NBTI could degrade both of these regions and influence the VDMOSFET parameters.

Typical VDMOSFET reliability investigations are routinely used, such as current-voltage (I-V) methods and charge pumping (CP) technique [6]. However, these techniques cannot give separate information about the degradation of the different regions which constitute the VDMOSFET. I-V methods measure the influence of both channel and drain regions degradation on drain current (I_{DS}). While CP is only able to characterize oxide and interface traps above the drain region and in part of the channel. It is unable to characterize the channel region close to the source which determines the threshold voltage (V_{th}) and I_{DS} in a VDMOSFET.

The Capacitance-Voltage (C-V) technique was introduced by Mileusnic et al [10] as an interesting technique to separate the interface (ΔN_{it}) and oxide-traps (ΔN_{ot}) in channel and drain regions of VDMOSFET devices. However, we should note, that to the best of our knowledge, there is no work that addresses the impact of NBTI on VDMOSFET regions. In this paper, using the C-V technique characterization, we analyze the impact of NBTI degradation on channel and drain regions of both n- and p-channel VDMOSFETs. We show that the degradation is important in n-type region (phosphorus doped region).

Fig. 1. Cross sectional view of the different regions of a p-channel VDMOSFET cell.

2. DEVICES AND EXPERIMENTAL SETUP

The VDMOSFET devices investigated in this study are commercial p-channel IRF9530N and n-channel IRF510 transistors encapsulated in TO-220. The device's gate oxide thickness is around of 100 nm. The measurement/stress/measurement (MSM) sequences have been performed using a fully automated experimental setup including a sensitive Agilent HP4156C for the application of a voltage stress, an Agilent 4284A precision LCR meter for C-V characterization and an Agilent 16440A SMU/pulse generator selector to switch between stress and measurement. The devices are stressed up to 4800 s by applying negative voltage of -50, -55 and -60 V for IRF9530N transistor and -40, -60 and -65V for IRF510 transistor. The stress is followed by a recovery at zero voltage ($V_G = 0$). The stress temperature is 27°C (room temperature). The experimental setup for the capacitance gate-source (C_{GS}) measurement by the C-V technique is shown in Fig 2. The gate and source of the VDMOSFET transistor are connected to the terminals V_{High} and V_{Low} of the LC-meter. This later can perform frequency measurements from 20 Hz to 1MHz. The capacitance measurements at high frequency as function of the gate voltage (V_G) are performed by superimposing to the continuous bias voltage a sinusoidal signal with amplitude of 25mV and frequency of 1MHz. The measurement acquisition is carried out via a GPIB bus connected to a computer in which a LabView application is installed.

Fig. 2. The experimental setup for the capacitance gate-source (C_{GS}) measurement by the C-V technique

3. RESULTS AND DISCUSSION

Fig. 3 illustrates the extraction of threshold voltage shift (ΔV_{th}) using $C_{GS}(V)$ characteristics in both channel and drain region on p- and n-channel devices. We note that V_{th-ch} correspond to channel-region threshold voltage, the capacitance at V_{th-ch} is denoted C_{th-ch} . $V_{th-drain}$ in the Fig. 3 corresponds to the drain-region threshold voltage obtained by extrapolating the lower knee on the left-hand (right-hand) side of $C_{GS}(V)$ characteristics in IRF510 (IRF9530N) transistor.

Fig. 3. Extraction of threshold voltage shift induced by NBTI stress using $C_{GS}(V)$ characteristics, (a) in n-channel VDMOSFET, (b) in p-channel VDMOSFET.

The extraction results of ΔV_{th} at channel and drain regions are given in Fig. 4. It is obviously clear that the degradation is higher at the drain region rather than the channel region for n-channel VDMOSFET IRF510 transistor. The situation is inverted for p-channel VDMOSFET IRF9530N (the channel region is more degraded compared to the drain region).

Fig. 4. Threshold voltage shift induced by NBTI at the channel and drain regions extracted using $C_{GS}(V)$ characteristics, (a) for n-channel VDMOSFET IRF510, (b) for p-channel VDMOSFET IRF9530N.

From the above observations, we could summarize that the n-type regions (phosphorus doped regions) are more sensitive to NBTI stress. This result is in agreement with the previous reported work. Indeed, it has already been pointed out that NBTI is observed in both n- and p channel transistors [11]–[15]. However, the instability is more severe in the p-channel transistor (n-type doped region) rather than in the n-channel transistor (p-type doped region). It can be seen in Fig. 3 and Fig. 5, respectively the C_{GS} curve shifts and stretches out in the negative voltage direction for p-channel IRF9530N and n-channel IRF510 transistors.

Fig.5. $C_{GS}(V)$ characteristics, (a) at the channel region of p-channel VDMOSFET (IRF 9530). (b) at the drain region of n-channel VDMOSFET (IRF 510)

Both oxide and interface traps induce negative shift of ΔV_{th} in p-channel transistor (n-type doped region). Contrary to the n-channel transistor (p-type doped region), interface and oxide traps induce positive and negative shifts of ΔV_{th} , respectively. All curves are shifted parallel toward negative voltage. This indicates that the oxide traps are dominating these regions (n-type doped regions). We should note that, all $C_{GS}(V)$ characteristics of different stress voltage have the same behaviours (not all shown here).

Since our result shows that the n-type regions (phosphorus doped regions) are more sensitive to NBTI stress, we could interpret this result using the model described by Tsetseris [16]. This model suggests that the hydrogen released easily from P–H complexes in the depletion region of an n-type (rather than B–H complexes in the p-type region) under NBTI stress conditions and then it is driven by the electric field to the interface and oxide. Thus hydrogen interacts with the defect precursors and leads to generate the oxide and interface traps. However more investigation is needed to clarify this issue.

4. CONCLUSION

The impact of negative bias stress on the channel and drain regions of commercial power double diffused MOS transistor (VDMOSFET) are characterized using the gate-source capacitances $C_{GS}(V)$. Our results indicate that the n-type regions (drain regions in n-channel VDMOSFET and channel region in p-channel VDMOSFET) are more sensitive to NBTI stress. This result is speculated due to the fact that the hydrogen released easily from P–H complexes (existing at n-type region) rather than B–H complexes (existing at p-type region).

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