Low magnetic field Impact on NBTI degradation

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Abstract

This article presents the effect of low magnetic field (B<10 mT) on both Negative Bias Temperature Instability (NBTI) stress and recovery. This effect is study on commercial power double diffused MOS transistors (VDMOSFET). We show that the degradation is less important when the magnetic field is applied. The dynamic of the degradation change and the relaxation is accelerated. These results can give useful insight for understand the NBTI degradation mechanisms. In addition, it's could be exploited to improve the VDMOS devices life time .

Keywords: NBTI, VDMOSFET, magnetic field, Helmoltz coil

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1. Introduction

For over four decades, scientists have been scaling devices to increasingly smaller feature sizes [1]. This trend is driven by a seemingly unending demand for ever-better performance and by fierce global competition. The steady complementary metal oxide semiconductor (CMOS) technology downscaling is needed to meet requirements on speed, complexity, circuit density, power consumption and ultimately cost required by many advanced applications. However, going to these ultra-scaled CMOS devices also brings some drawbacks such as reliability degradation and again effect.

According to ITRS 2011 [1] failure mechanisms that can influence CMOS devices in future are: Bias Temperature Instability (BTI), Time Dependent Dielectric Breakdown (TDDB) and Hot Carrier Injection (HCI).

Despite the many efforts (theoretical and experimental) to understand the physical mechanisms behind these degradations [2-3], the microstructure of trap induced degradations, remains unknown and is the subject of current debate. Nevertheless, a consensus has been established on creating traps in the oxide by TDDB degradation and in the oxide and at the interface by BTI and HCI. Also some studies agree on the nature of the microstructure associated with the created traps; "P_b center" in interface [4] and 'E' center 'in oxide [5]. These paramagnetic defects contain an unpaired electron in their orbital which can be sensitive to external applied magnetic field (*B*). Indeed, under the influence of an external magnetic field the unpaired electron in paramagnetic defects oriented its spin in a particular direction (spin up or spin down). Under this condition, only the electron with opposite spin can be trapped into these paramagnetic defects. Hence with applied external magnetic field we can control the orientation of unpaired electron and consequently the spin dependent recombination, trapping and tunneling into the defects..

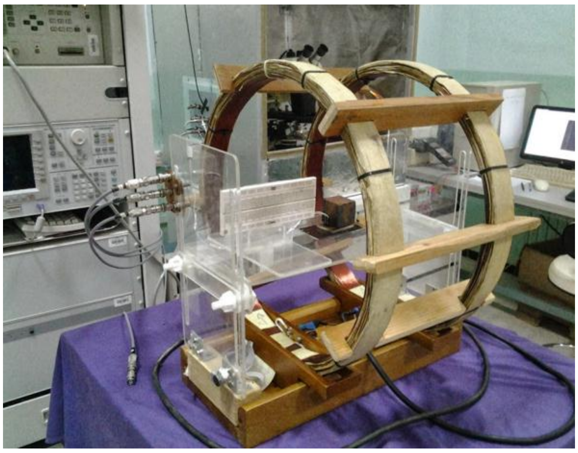

Fig. 1. Photo of a Helmoltz coil used to generate uniform magnetic field

In this article, we investigate the influence of NBTI on power commercial vertical double diffused transistor (VDMOSFET) under different intensities of magnetic fields. Our results show that both stress and recovery are affected by low magnetic field (< 10mT). This insight could help to understand NBTI mechanisms.

2. Devices and experimental setup

The devices investigated in this study are commercial N-channel VDMOSFETs BS108 encapsulated in TO-92[6].

The initial threshold voltage V_{th0} is extracted using the linear extrapolation method and found to be in the range [0.4-1.8V], the same as given by the manufacturer [6].

The devices are stressed using the constant voltage stress (CVS) which consist of applying a high constant voltage into the gate where the drain and the source are

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connected to the ground.

After obtaining curve I_{DS} (V_{GS}) of virgin transistor (without stress), a negative voltage stress is applied to the gate. During measurement phase, the drain current I_{DS} is monitored around V_{th} (at V_G=1.3V) with applied drain-source voltage (V_{DS}) of 50 mV, see fig. 2.

This protocol is applied without and under various intensities of the magnetic field (3, 5, 8 and 10mT) and varying stress voltage (V_S = -10, -15 and -20V) for 800 seconds. Then, a relaxation for 1200 seconds at zero gate voltage (V_G=0). The stress temperatures are set to 27°C (room temperature).

The measurement/stress/measurement protocol is illustrated in the fig. 2. The applied uniform magnetic field is generated using a homemade Helmholtz coil with a diameter of 44 cm, which is able to generate a maximum magnetic field of 10mT, (see fig. 1). The generated magnetic field is controlled using a high voltage power supply controlled by computer. The magnetic field is limited to 10 mT due to the heating of Helmholtz coil.

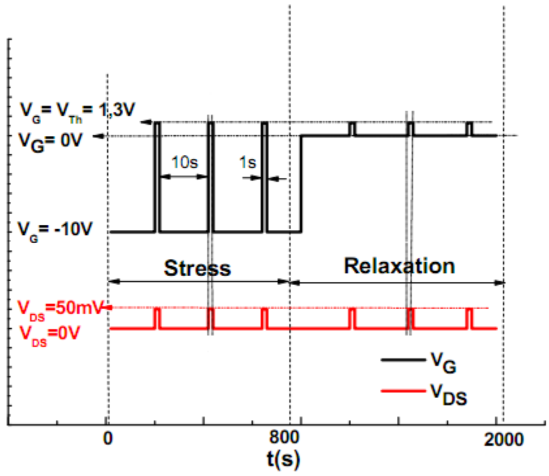


Fig. 2. Timing diagram of voltages applied to the VDMOSFET under NBTI stress by "CVS" technique

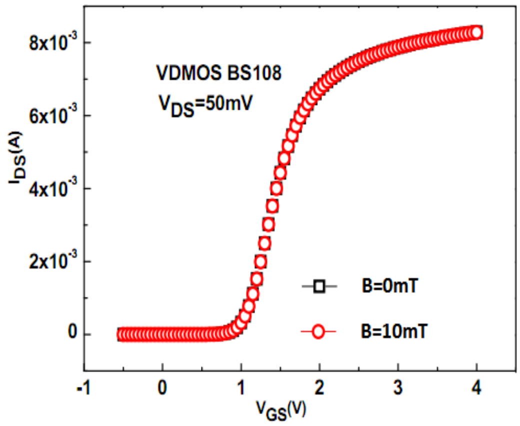


Fig. 3. Virgin I_{DS} (V_{GS}) characteristics with and without magnetic field.

3. Results

3.1. Magnetic field impact on virgin devices

In order to check the influence of the magnetic field on virgin VDMOSFET devices (BS108), we measured I_{DS} (V_{GS}) curves on virgin devices without and under magnetic field; the result is shown in fig. 3. A negligible effect of the magnetic field on the curve is observed. This negligible effect is probably due to the deviation of electrons by the magnetic field.

3.2. IDS current degradation

Fig. 4(a) and Fig 4(b) show I_{DS} current evolution with time during stress and relaxation (V_G=0V) phases with and without magnetic field. The decreasing of I_{DS} current during the stress is due to both pre-existing and generation of traps at the interface and in the oxide [4-5]. While during the relaxation period, the I_{DS} current tend to return to its initial state. This behavior is observed for all stress tensions with and without magnetic field.

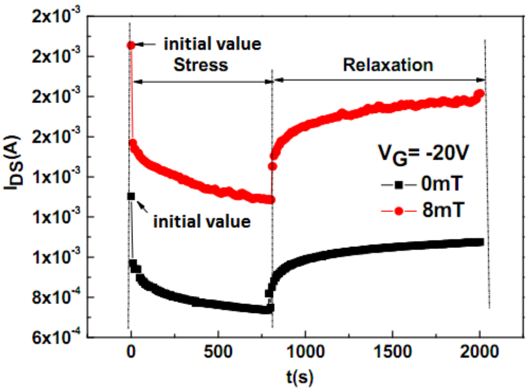
3.3. Impact of magnetic field on NBTI threshold voltage shift

The threshold voltage shift (ΔV_{th}) evolution during the stress and relaxation for different voltages of stress, are shown in fig. 5. ΔV_{th} degradation increases with time and with the increase of the voltage stress. This is a consequence of traps creation. During stress, the evolution of ΔV_{th} follows approximately a power law with time (ΔV_{th} α t^n), see fig. 5. At the beginning of the relaxation phase (a few seconds after the stress voltage is removed), ΔV_{th} has a tendency to return quickly to the initial state then continues slowly. The above behaviors are reported by several authors [7-8]

In fig. 6, we compare the degradation of the threshold voltage obtained for stress without and under different magnetic fields. Note that ΔV_{th} is obtained using relation (1):

$$\Delta V_{Th} = \frac{I_{DS} - I_{DS_0}}{I_{DS_0}} \left(V_{GS} - V_{th_0}\right) \qquad (1)$$

(a)



(b)

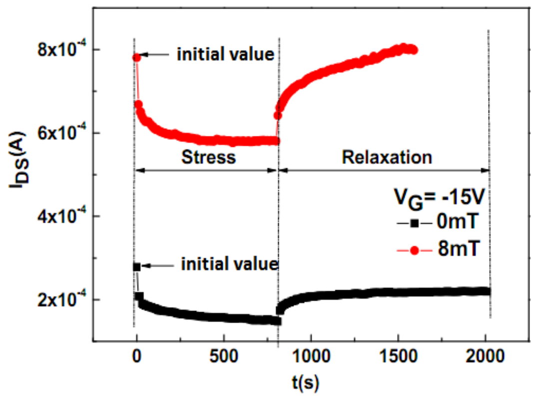


Fig. 4. I_{DS} as a function of stress time at (a) V_G=-20V and (b) V_G=-15V for B=8mT

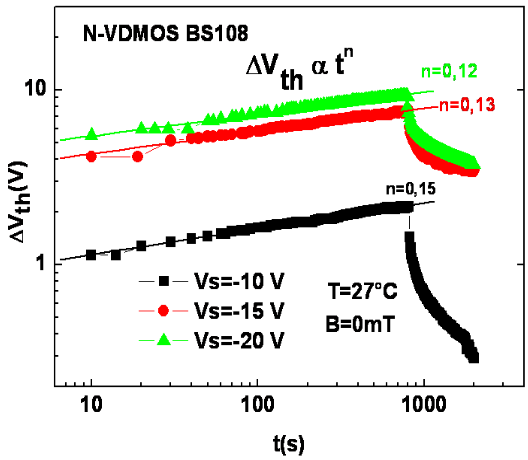


Fig. 5. ΔV_{Th} as a function of stress time for different stress conditions

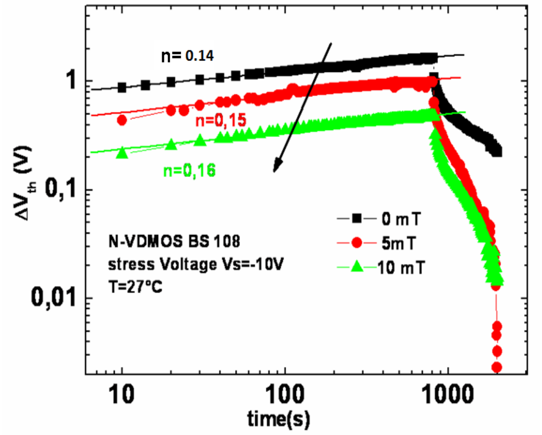
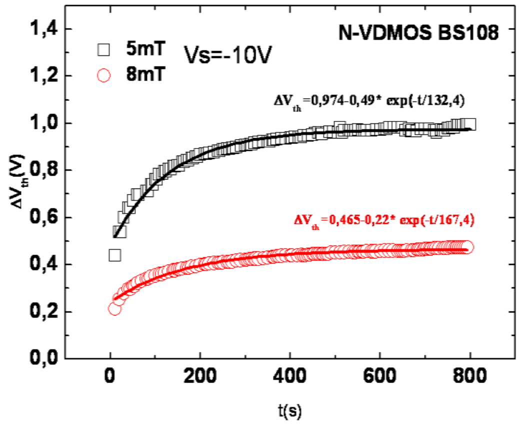


Fig. 6. Comparison of ΔV_{th} with and without the application of a magnetic field at Vs = -10V

(a)



(b)

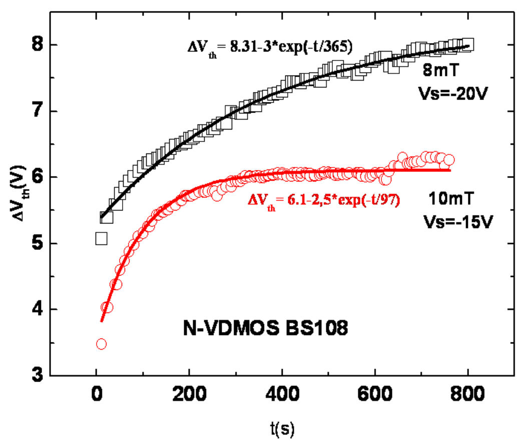


Fig. 7. ΔV_{th} as a function of stress time under different magnetic field

Regarding the above experimental results, we can note three important observations: the degradation is less important under stress with magnetic field, the dynamic of stress without magnetic field differs from the one with magnetic field, and the recovery (relaxation) is accelerated in the presence of magnetic field. These effects are observed and reproductive for all stress voltages used in the present work. In addition, the same observations are reported by H.TAHI et al for behaviors another VDMOSFET device (IRF 9530) at 27°C and 80°C [9].

The degradation of ΔV_{th} decreases under magnetic field. One possibility for decreased ΔV_{th} under magnetic field is diminishing of the contribution of paramagnetic defects (P_b center at the interface and E' center in the oxide) to the degradation under the effect of a magnetic field. Indeed, the application of a magnetic field allows the orientation (polarization) of the unpaired electrons of paramagnetic defects and free electrons of the conduction band of the substrate (silicon). This reduces the trapping of electrons by the paramagnetic traps, according to the Pauli exclusion theorem which stipulates that the electrons can not be in the same location (same energy state) in the same quantum state [10]. Therefore, some paramagnetic defects generated by stress become electrically inactive under magnetic field (we say that they are electrically transparent). In addition, the dynamic of stress changes with the application of a magnetic field. Indeed, the evolution of ΔV_{th} with time, without magnetic field, follows a power law, (see fig.5). However, this power law can not fit the evolution ΔV_{th} under magnetic field. An exponential law is found to fit the best than the power law (see fig. 7) [11-12]. We think that the exponential evolution is the sign of the creation of non-paramagnetic traps. However, further investigations are needed to confirm this hypothesis, for example the comparison of ΔV_{th} extracted using the electrical methods (contribution of all paramagnetic defects and non-paramagnetic) with the characterization using the spin paramagnetic resonance (SPR) (contribution of paramagnetic defects, only).

Moreover, under magnetic field, the degradation ΔV_{th} relaxes quickly compared to the one when no magnetic field is applied i.e. the threshold voltage shift with the application of a magnetic field tends to return quickly to the initial state. Therefore, the application of a magnetic field could be beneficial to extend the life time of MOS devices.

3. Conclusion

The experimental results show that in the presence of magnetic field during stress, the degradation is reduced and the relaxation is accelerated i.e. stress and recovery phases are affected by the magnetic field. We think that this result may contribute to understanding the physical mechanisms behind the degradation of MOS transistors and help to provide technological solutions to reduce the effect of degradation and increase the life time of VDMOS devices. Therefore, it is worth to study other kind of degradation and more investigations are needed to clarify this issue.

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