The Anomalous Effect of Interface Traps on Generation Current in Lightly Doped Drain nMOSFET’s *

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The anomalous phenomenon of generation current \( I_{GD} \) in the lightly doped drain (LDD) nMOSFET measured under the drain bias \( V_D \)-step mode is reported. We propose an assumption of activated (A) and frozen (F) traps for the \( V_D \)-step mode: The A traps contribute to \( I_{GD} \) while the F process can make them lose the roles as generation centers. The A and F regions can form the F-A region. The comparison of the F and A regions decides the role of the F-A region. The experiments confirm the assumption.


In the reverse gated-diode structure, as the gate controls the region beneath the gate, the generation current \( I_{GD} \) flowing through the region due to defects can be controlled and measured. Therefore, the measurement method is used widely as a means of detecting interfacial deep-level defects in MOS structure\(^{[1–4]}\) for many different types of semiconductor process analysis. Therefore, a good understanding and control of this measurement are important in order to utilize it better. Verzi and Aum\(^{[5]}\) studied the mechanism of \( I_{GD} \). In Refs.\(^{[6,7]}\), the relationship of \( I_{GD} \) with drain bias \( V_D \) is discussed. Although lots of works have been carried out in this field, the relationship has not yet been comprehended completely so far. In this Letter, we examine the relation between \( V_D \) and \( I_{GD} \), and the impact of the interface trap on \( I_{GD} \) under the \( V_D \)-step mode.

When the substrate under the gate is accumulated, the main reverse current is the metallurgical junction current and it is low. When the gate voltage \( V_G \) approaches the flat band voltage \( V_{FB} \), the field-induced depletion region is formed. Consequently, the interface traps acting as the generation centers contribute to \( I_{GD} \) and then \( I_{GD} \) increases sharply. When \( V_G \) reaches the threshold voltage \( V_T \), the inversion layer is formed and then it shields the interface traps from the depletion region. Therefore, the traps lose the roles as generation centers and \( I_{GD} \) decreases dramatically. Then the peak of \( I_{GD} \) appears. The initial point of \( I_{GD} \) decreasing is the \( V_T \) point. \( V_T \) is the function of \( V_D \):\(^{[8]}\)

\[
V_T = \left( \frac{\alpha e_0}{\epsilon_0 e_{ox}} \right) \left[ -Q_{eff} \right. + \left[ 2e_0 e_{ox} qN_A (\psi_s + V_D) \right]^{0.5} \right] + \Phi_{ox} + \psi_s,
\]

where the parameters have the common meanings. From the equation we can conclude that the \( I_{GD} \) peak width expands with increasing \( V_D \) since \( V_T \) increases.

The devices used here are of surface channel. They were manufactured using a 90 nm process technology with a lightly doped drain (LDD) structure and a shallow trench isolation (STI) scheme. The gate oxides of all the devices were annealed in N\(_2\)O atmosphere after thermal growth. The gate has the length of \( L = 0.22 \mu m \) and the width of \( W = 2 \mu m \). The oxide thickness is 4 nm. HP 4156B, a high precision semiconductor parameter analyzer, was used to complete the tests. In the measurements, the source is floating and the substrate is grounded.

Figure 1(a) shows the \( V_D \)-single mode measurement. In this mode, \( V_G \) is swept with the fixed \( V_D \), and \( I_{GD} \) of certain \( V_D \) can be only measured one time. There is an interval time when \( V_D \) is changed. Figure 1(b) shows \( I_{GD} \) measured under the \( V_D \)-single mode. Note that the curves start to rise at \( V_G = V_{FB} \). \( V_{FB} \) is found to be about \(-0.2 \) V in Fig. 1(b). When \( V_D = 0.2 \) V, the curve shape is very sharp while when \( V_D = 0.4 \) V and \( V_D = 0.6 \) V, the shapes expand, and the reason is as mentioned above.

We propose a concept based on the above facts: The activated (A) traps can act as the generation centers, which can contribute to \( I_{GD} \). The A region where the A traps locate increases with increasing \( V_D \) and determines the width of the \( I_{GD} \) shape. Thus the results shown in Fig. 1 can also be explained: because the A region increases ordinarily from \( V_D = 0.2 \) V to 0.6 V, the widths of their \( I_{GD} \) shapes also increase ordinarily.

Figure 2(a) shows the \( V_D \)-step mode measurement. In this mode, the bias is always applied to the drain,
and there is no interval time during the process of one $V_D$ jumping to another $V_D$. Figure 2(b) plots the curves of $I_{GD}$ measured under the $V_D$-single mode. Although $V_D$’s are still 0.4 V and 0.6 V, the rising edges of their curves shift rightwards compared to Fig. 1(b), the array is in file and the shape widths decrease. This situation is very different from the $V_D$-single mode. For understanding this situation well, we might as well assume that, since the bias is always applied to the array is in file and the shape widths decrease. This situation is very different from the $V_D$ single mode.

According to the assumption, as $V_G$ is swept at $V_D = 0.2$ V, the interface traps are activated. When the gate voltage sweeping is stopped, the A region of $V_D = 0.2$ V transforms into the F region, and cannot contribute to $I_{GD}$ during the next $V_D = 0.4$ V measurement. It is indicated that the curve of $V_D = 0.4$ V in Fig. 2 does not rise from $V_{FB}$, but from a point somewhat rightward and that $I_{GD}$ is almost zero at the range between $V_G = -0.2$ V and 0.1 V, where the curve peak of $V_D = 0.2$ V appears. However, the A region of $V_D = 0.4$ V is created around the F region and then the F-A region is formed. Since the A region of $V_D = 0.4$ V is larger than the F region, the F-A region shows the feature of A. However, the F region shields a part of the A region. Thus the equivalent A region of the F-A region is smaller than that at $V_D = 0.4$ V under the $V_D$-single mode, indicated by the fact that the width of curve shape of $V_D = 0.4$ V in Fig. 2 is smaller than that in Fig. 1. The explanation is also suitable for the case of $V_D = 0.6$ V in Fig. 2. From Fig. 3, it can be seen that the curve of $V_D = 0.6$ V under the $V_D$-single mode covers the curves of $V_D = 0.2$, 0.4 and 0.6 V under the $V_D$-step mode. The falling edges of $V_D = 0.6$ V under the $V_D$-single mode and that under the $V_D$-step mode show superposition, indicating that the trap region is activated once under the $V_D$-single mode while it is activated more times under the $V_D$-step mode.

Fig. 1. (a) The schematic diagram of $V_D$ single measurement mode and (b) $I_{GD}$-$V_G$ at different $V_D$ under the $V_D$ single mode.

To certify our assumption, we measure $V_D = 0.6$ V and $V_D = 0.6$ V under the $V_D$-step mode. If the assumption is reasonable, the F region due to the first $V_D = 0.6$ V is the same as the A region of the second $V_D = 0.6$ V, the formed F-A region shows neither the A’s feature nor F’s feature and $I_{GD}$ of the second...
$V_D = 0.6$ V should be zero. The experimental result is presented in Fig. 4(a), which confirms our assumption.

Further, the case that the F region is larger than the A region is observed under the $V_D$-step mode. Figure 4(b) shows the experimental results, in which $V_D$ steps from 0.6 V to 0.2 V by $-0.2$ V. After measurement, the A region of $V_D = 0.6$ V turns to be the F region. Afterwards, the A regions of $V_D = 0.4$ V and $V_D = 0.2$ V and the F region form the F-A region. Since the F region is larger than the A region of $V_D = 0.4$ V and $V_D = 0.2$ V, the F-A region is equivalent to the F region. Thus, on the contrary to the A region, they make $I_{GD}$ negative peaks. Moreover, the greater the $V_D$ value is, the more negative the $I_{GD}$ peak is, as shown in Fig. 4(b).

In summary, under the $V_D$-step mode, our gated-diode experiments on the n-channel LDD MOSFETs show that the $I_{GD}$ curves are different from those under the $V_D$-single mode. We propose that the A traps act as the generation centers while the F process can make them lose the roles under the $V_D$-step mode. The A and F regions can form the F-A region. The comparison of the F and A region decides the role of the F-A region and influences $I_{GD}$.

References