The Role of the Parasitic BJT Parameters on the Reliability of New Generation Power MOSFET during Heavy Ion Exposure

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I. INTRODUCTION

In this paper we briefly describe an experimental study of the role of the parasitic transistor on the charge generation phenomenon observed during the impact of heavy ions on medium voltage power MOSFET [1-5]. We observed that new generation power MOSFETs reveal, during single event impact, a premature damage of the gate structure before a typical burnout occurrence. The damage is related to the activation of the parasitic BJT but hasn’t to be interpreted as a damage of the drain structure. The damage is detected by an increase of the gate leakage current, but can’t be confused as a typical gate rupture event. Although the gate leakage current seems to recover its original value, the damage is irreversible and leads the gate oxide to the breakdown when the device is subsequently biased. The experimental procedure showed that in this damage mechanism the activation of the parasitic BJT plays a relevant role, so the generated charge and the device robustness could be influenced by the epitaxial parameters.

II. THE ROLE OF THE BJT

In order to study the role played by the parasitic BJT we performed a comparison between two specifically constructed prototypes having different epitaxial regions. Both of them have the typical surface lay-out used in 250V VDMOSFET. We used also two analogous diode structures obtained by not performing the source diffusion technological step during their construction. The main parameters of the tested devices are reported in Table.1.

<table>
<thead>
<tr>
<th>MOSFET TYPE</th>
<th>SURFACE LAY-OUT</th>
<th>EPI-LAYER THICKNESS</th>
<th>DIODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>SAME</td>
<td>HIGH</td>
<td>D(_A)</td>
</tr>
<tr>
<td>B</td>
<td>SAME</td>
<td>LOW</td>
<td>D(_B)</td>
</tr>
</tbody>
</table>

TABLE 1: The prototypes tested

Irradiation experiments had been performed at the Laboratori Nazionali di Legnaro – INFN – ITALY, to best simulate the interaction with cosmic rays we have chosen, for the experiments, ions of bromine at 250 MeV [6, 7].

In Fig.1 the comparison between the mean value of the charge generated by the A-type prototype and by its analogous diode D\(_A\) is reported as a function of the bias voltage. The surplus of charge generated by the MOSFET is attributed to the activation of its parasitic BJT. The A-type MOSFET exhibits gate damages during the exposure for a bias voltage applied \(V_{DS} = 75\) V at the point marked by a star point in the Fig.1. The corresponding diode D\(_A\) didn’t show any damage up to the maximum blocking voltage. It is worth to outline that diode D\(_A\) had on its surface the gate structure like the corresponding MOSFET. The diode robustness proves the crucial role played by the parasitic transistor in the failure mechanism detected in the MOSFET. The comparison of the equivalent drain charges versus the bias voltage, obtained for the two prototypes with different epi-thickness under the same irradiation conditions, is reported in Fig.2.

![FIG.1: Charge vs voltage bias, A-type MOSFET and D\(_A\) diode](image1)

![FIG.2: Charge vs voltage bias, A-type and B-type MOSFET](image2)

The generated charge for the devices with smaller thickness is larger than the other devices. The amount of the generated charge is proportional to the current peak of the corresponding pulse, which largely depends on the activation of the parasitic BJT that takes place during the impact with the energetic particle. In this situation the BJT operates in a dynamic condition that is very similar to the high field base push out operation. As a matter of fact the impacting particle causes the formation of a high density electron holes plasma that extends within the epilayer for a depth equal to the range of the particle. In this plasma region the electric field is very small and the
applied external voltage $V_{DS}$ distributes between the body junction and the drift region, i.e. the portion of the epitaxial not covered by the plasma region. The voltage $V_{CB}$ across this drift region can be expressed as [8]:

$$V_{CB} = \frac{q}{2e} \left( \frac{W_v - W_{CIB}}{N_v} - \frac{J_C}{q \cdot v_{lim}} \right)$$

(1)

Where $J_C$, $v_{lim}$, $W_{CIB}$, $W_v$ and $N_v$ denote the collector current density, the carriers saturation velocity, the width of the plasma region, the width and the doping concentration of the epitaxial region, respectively. During the impact $W_{CIB}$ is fixed and depends only on the range of the impacting particle, moreover the local current density $J_C$ depends on the amount of the generated charge and then mainly on the LET of the particle. So that at a fixed biasing voltage the voltage across the drift region, $V_{CB}$, is larger for the MOSFET with the thicker epitaxy and consequently the voltage across the junction becomes smaller. As this junction operates in avalanche conditions the amount of the charge generated by impact ionization becomes much smaller for the thicker device as it is shown in Fig. 2. The reduction of the generated charge results in a lower sensitivity to gate damage of the thicker devices as it is shown in Table 2 that reports the drain voltage at which gate damages are observed for the A- and B-type MOSFETs.

<table>
<thead>
<tr>
<th>MOSFET TYPE</th>
<th>EPI-LAYER THICKNESS</th>
<th>$V_{DS}$ DAMAGE VOLTAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>HIGH</td>
<td>75-80V</td>
</tr>
<tr>
<td>B</td>
<td>LOW</td>
<td>180-185V</td>
</tr>
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</table>

**TABLE 2:** The damage voltage

**III. THE FAILURE MECHANISM**

The device gate damage at $V_{DS} = 0$V is evidenced by the increase of the gate leakage current thus indicating that the gate oxide is involved. This is confirmed by 3-D Atlas simulations, not reported here for brevity, that evidences the formation of a large electric field across the gate oxide over the channel region during the particle impact.

Regarding the drain structure it is worth to outline that no Single Event Burn-out was observed during the experiments. As a matter of fact the post-irradiation electrical measurements didn’t reveal a drain structure damage. In all irradiated samples no drain leakage effects are present, independently of the epi-layer thickness.

In Fig.3.a) a representative comparison of the $I_{DSS}$ leakage curves before and after irradiation of a structure under study is presented. In order to evidence no drain leakage mechanism, in Fig.3.b) a plot obtained in a different experiment that reveals a drain damage is reported. The failures of the DUTs have been always accompanied by an appreciable increase in the gate leakage, thus demonstrating that the failures are due to a gate oxide damage. Although the gate leakage seems to recover its original value, the damage is irreversible and leads the gate oxide to the breakdown when the device is subsequently biased. However, this damage hasn’t to be interpreted as a SEGR occurrence.

![Fig.3: $I_{DSS}$ leakage curves: a) no Drain structure damage; b) Drain structure damage](image)

The damage mechanism is related to the high charge generated, in fact, the two structures generates a similar amount of charge at the failure point.

The above considerations suggest that the gate damages can be attributed to contemporaneous presence of a large amount of charge due to the activation of the parasitic BJT and a large electric field across the gate oxide that cause trapping of holes into the oxide.

**IV. ACKNOWLEDGEMENTS**

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