Experimental study on the effect of the gate oxide thickness and the epitaxial layer resistivity on the reliability of low blocking voltage power VDMOSFET during heavy ion exposure

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I. INTRODUCTION

In this paper we present an experimental study of the effect of the gate oxide thickness and the epitaxial layer resistivity on the reliability of low voltage power VDMOSFET to sustain single event effects caused by the impact of heavy ions.

When an heavy ion impacts on a power MOSFET, it produces an amount of ionization space charge along its trajectory through the device depending on the energy loss in the several layers of the device. If the N-drain/P+-body junction is reverse biased, an intense electric field is present in the depletion region of this junction. The interaction between the ionization charge and the high electric field generates a current spike, due to a charge amplification mechanism, which can cause a device malfunction or permanent damage. In the worst case a failure event is ascribed to the activation of the parasitic transistor of the structure (Single Event Burnout) \cite{1, 2, 3} or to the gate oxide dielectric breakdown (Single Event Gate Rupture) \cite{4, 5, 6, 7}.

We have experimentally noticed that low blocking voltage power MOSFET's are subject to the activation of the parasitic bipolar transistor and the failure mechanism is related to a damage in the gate oxide layer. Although the gate leakage current seems to recover its original value, the damage is irreversible and may lead the gate oxide to the breakdown when the device is subsequently biased.

The physics of these phenomena are not well known yet and in order to gain more insights we have studied the influence of the N-drain epitaxial layer and the gate oxide thickness on the SEE reliability of a medium voltage power VDMOSFET. The prototypes employed in the first experimental session have been specifically constructed, starting a typical commercial 100V VDMOSFET lay-out, by using three different thickness of the gate oxide layer (tab.1). In the second experimental session, in order to investigate the influence of the epitaxial layer resistivity, we constructed two others more different prototypes with different epi-layer resistivity, but with identical gate structure and layout, with parameters and sizes which are typical for 100 blocking voltage devices (tab.2).

II. EXPERIMENTAL SET-UP

The DUTs were kept in their blocking (OFF) state during irradiations at varying gate and drain biases ($V_{GS}$ less or equal to 0V, $V_{DS}$ positive). The schematic of the circuit is shown in Fig. 1. The DUT is biased at the drain and gate terminals by means of external voltage sources, and the current pulse is collected by the two transmission lines with decoupling capacitors. The charge generated during an ion impact produces a current transient that is detected by a fast sampling oscilloscope (Tektronix TDS7104, a four channels, 10Gsamples/sec and 1GHz bandwidth scope). The time scale of the current pulses is of the order of a few nanoseconds, hence the circuitry was adapted to the impedance of the cables (50\ohm).

The DUTs were exposed to $^{79}$Br (250 MeV) beam. At this energy, the ion range is sufficient to ensure the penetration into the active layers of the device. In order to detect failure events, the gate and drain leakage currents have been continuously monitored. The device is declared failed when a conspicuous increase of the gate-source or drain-source leakage current occurs. To characterise the tested devices, each current waveform has been classified on the base of three parameters: the current peak, the total charge (obtained by integrating the waveform) and the decay time. A scatter plot was employed to represent each waveform by a point in a two- or three-dimensional space.

<table>
<thead>
<tr>
<th>TYPE</th>
<th>EPITAXIAL LAYER</th>
<th>GATE OXIDE THICKNESS</th>
</tr>
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<tbody>
<tr>
<td>A</td>
<td>SAME</td>
<td>$T_{OXA}$</td>
</tr>
<tr>
<td>B</td>
<td>SAME</td>
<td>$T_{OXB} = T_{OXA} \times 0.9$</td>
</tr>
<tr>
<td>C</td>
<td>SAME</td>
<td>$T_{OXC} = T_{OXA} \times 0.68$</td>
</tr>
</tbody>
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\textit{TAB.1: The prototypes tested (first session)}

<table>
<thead>
<tr>
<th>TYPE</th>
<th>GATE LAYOUT</th>
<th>EPI-LAYER RESISTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>SAME</td>
<td>LOW</td>
</tr>
<tr>
<td>E</td>
<td>SAME</td>
<td>HIGH</td>
</tr>
</tbody>
</table>

\textit{TAB.2: The prototypes tested (second session)}
with the aim of identifying the possible mechanisms involved in the experiment starting from the plot shape.

III. STATISTICAL ANALYSIS

To obtain a compact information of the acquired data, a statistical analysis was employed to determine gamma-like probability distribution functions (PDFs) that best describe the charge distributions for each value of $V_{DS}$ and $V_{GS}$, and the dependence of their statistical moments on the bias voltages was then studied. Information of the acquired data, a statistical analysis was employed to determine gamma-like probability distribution functions (PDFs) that best describe the charge distributions for each value of $V_{DS}$ and $V_{GS}$, and the dependence of their statistical moments on the bias voltages was then studied [8].

In fig.2 we report the comparison of the equivalent drain charges versus the bias voltage, obtained for the three prototypes A, B and C under the same irradiation conditions. The device failure is related to a damage of the gate oxide layer and the correlated damage voltage depends on the oxide thickness. Further, the figure shows that the charge generated is quite insensitive to the gate oxide thickness.

Due to a major oxide thickness, the prototypes D and E are less subject to a gate oxide damage. The failure mechanism is attributed to an avalanche interaction between the plasma filament and the intense electric field in the depletion region of the reverse biased n/epi-p+/bulk junction. The higher charge associated to the current pulses generated by this avalanche mechanism damages the drain structure and a burnout can occurs.

The fig.3 shows the comparison of the drain charges, generated by the avalanche mechanism, versus the bias voltage, obtained for the two prototypes D and E. The differences in the charge generated are ascribed to the dependence of the electric field peak, at the interface between the p’ region and the n’ epi-layer, on the epi-doping concentration.

IV. ACKNOWLEDGMENT

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