Study of Total Dose Effects in Power VDMosfets

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Outline

- Introduction
- Experimental and Devices
- Total Ionising Dose Effects on VDMOSFETs:
  - Threshold voltage variation during irradiation and annealing
  - Interface traps generation
  - Drain-Source Breakdown Voltage Degradation
- Conclusions
Introduction

The possibility of using commercial devices in radiation environments is subordinated to the successfully verification of its radiation reliability.

To qualify a device the first step is to evaluate its intrinsic tolerance to Total Ionising Dose (TID).

In this work we have studied the total dose effects on power MOSFETs used in a DC-DC converter for radiation harsh space environments.
Experimental and Devices

The device used through this work are Vertical Drain Power MOSFETs (VDMOSFETs); their characteristics and the experimental details are listed in the following table:

<table>
<thead>
<tr>
<th>Name</th>
<th>$V_{DS, \text{max}}$ (Vgs=0)</th>
<th>$V_{GS}$ during radiation</th>
<th>Max Dose (Si)</th>
<th>Dose Rate Rad(Si)/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>30V-MOSFETs</td>
<td>$V_{DS, \text{max}} = 30 \text{ V}$</td>
<td>$V_{GS} = 7.5 \text{ V}; 0 \text{ V}$</td>
<td>100 [krad]</td>
<td>7.5; 1.2</td>
</tr>
<tr>
<td>55V-MOSFETs</td>
<td>$V_{DS, \text{max}} = 55 \text{ V}$</td>
<td>$V_{GS} = 12 \text{ V}; 0 \text{ V}$</td>
<td>100 [krad]</td>
<td>7.5; 1.2</td>
</tr>
<tr>
<td>200V-MOSFETs</td>
<td>$V_{DS, \text{max}} = 200 \text{ V}$</td>
<td>$V_{GS} = 12 \text{ V}; 0 \text{ V}$</td>
<td>100 [krad]</td>
<td>7.5; 1.2; 0.12;</td>
</tr>
<tr>
<td>400V-MOSFETs</td>
<td>$V_{DS, \text{max}} = 400 \text{ V}$</td>
<td>$V_{GS} = 12 \text{ V}; 0 \text{ V}$</td>
<td>100 [krad]</td>
<td>7.5; 1.2;</td>
</tr>
</tbody>
</table>

$V_{ds, \text{max}}$’s are the drain-source breakdown voltage
Max Doses (Si) are the cumulated doses referred to Silicon.

All the devices are provided by ST Microelectronics (Catania, Italy)
Radiation Source

$^{60}$Co Gamma source:
- Owned by CNR and hosted at INFM-Legnaro
- Usually devoted to polymerization and degradation of polymers induced by radiation
- Present activity 2000 Ci ($7.4 \times 10^{13}$ Bq)
- Maximum dose rate: 0.9 krad/sec in the xy plane

The irradiation was performed by gamma-ray with dose rate ranging from 0.12 to 7.5 rad/sec.

Total accumulated dose were ranging from 1 krad to 100 krad
TID effect: $I_{ds}$-$V_{gs}$ curves shift

$I_{ds}$-$V_{gs}$ during and after irradiation for MOSFETs with $V_{ds,max}=30$ V

Notice the shift to lower $V_{gs}$ values after irradiation and the subthreshold slope variation during annealing at room temperature
Gated diode measurements confirm the increase of interface traps density after irradiation.

\[ V_d = 400 \text{ mV} \]

Source and bulk are not connected.
Gate capacitance during irradiation

200V-MOSFETs
f=100 kHz

Gate capacitance measurements confirm positive charge trapping into the gate oxide.
To summarize: threshold voltage shift

<table>
<thead>
<tr>
<th>Dose [krad]</th>
<th>Time [s]</th>
<th>Threshold Voltage [V]</th>
</tr>
</thead>
<tbody>
<tr>
<td>10^{-1}</td>
<td>100</td>
<td>10^{-1}</td>
</tr>
<tr>
<td>10^{-2}</td>
<td>10</td>
<td>1.5</td>
</tr>
<tr>
<td>10^{-3}</td>
<td>1000</td>
<td>3</td>
</tr>
<tr>
<td>10^{-4}</td>
<td>10000</td>
<td>3.5</td>
</tr>
<tr>
<td>10^{-5}</td>
<td>100000</td>
<td>10^{-1}</td>
</tr>
<tr>
<td>10^{-6}</td>
<td>1000000</td>
<td>1.0</td>
</tr>
<tr>
<td>10^{-7}</td>
<td>10000000</td>
<td>1.5</td>
</tr>
<tr>
<td>10^{-8}</td>
<td>10000000</td>
<td>3</td>
</tr>
<tr>
<td>10^{-9}</td>
<td>10000000</td>
<td>3.5</td>
</tr>
</tbody>
</table>

- Dose: 10^{-1} to 10^{-8} krad
- Time: 10^0 to 10^{7} s
- Threshold Voltage: 10^{-1} to 3.5 V

- Vgs = 0 V
- Vgs = 12V (Worst Case)

Annealing

Irradiation

Vgs = 12V (Worst Case)
Threshold voltage shift versus dose rate

Dependence of the threshold voltage shift on dose rate for 200V-MOSFETs.

The $V_{th}$ shift is measured at 50krad(Si); during irradiation at $V_{gs}=12V$. 
Output Characteristics: 200V MOSFETs

The $\Delta V_{ds,\text{max}}$ drop between pre- and post-irradiation measurement is around 80V.
Output Characteristics: 400V - MOSFETs

After radiation
\[ \Delta V_{ds,max} = 5 \text{ V} \]

→ In 400V-MOSFETs such difference is very small (being only 1% of the pre-irradiation value)

→ The accumulation of positive charge in the field oxide produces a local enhancements of the electric field.
We summarize in the following table the variations of the MOSFET threshold voltage after 100 krad(Si) and $10^6$ s annealing time:

<table>
<thead>
<tr>
<th>$V_{gs}$ during experiment</th>
<th>$\Delta V_{th}$ shift After 100 krad(Si)</th>
<th>Residual $\Delta V_{th}$ after 100 krad(Si) and Annealing time: $10^6$ s</th>
</tr>
</thead>
<tbody>
<tr>
<td>30V-MOSFET</td>
<td>1.4 V</td>
<td>0.6 V</td>
</tr>
<tr>
<td></td>
<td>0.7 V</td>
<td>0.3 V</td>
</tr>
<tr>
<td>55V-MOSFET</td>
<td>2.2 V</td>
<td>------</td>
</tr>
<tr>
<td></td>
<td>1.3 V</td>
<td>-------</td>
</tr>
<tr>
<td>200V-MOSFET</td>
<td>2.4 V</td>
<td>1.4 V</td>
</tr>
<tr>
<td></td>
<td>1.2 V</td>
<td>0.7 V</td>
</tr>
<tr>
<td>400V-MOSFET</td>
<td>3 V</td>
<td>2 V</td>
</tr>
<tr>
<td></td>
<td>1.5 V</td>
<td>0.7 V</td>
</tr>
</tbody>
</table>
Conclusions

- We have studied the effects of cumulative radiation dose on the DC characteristics of power MOSFETs for a prototype DC-DC converter.
- A large threshold voltage variation is observed after gamma-irradiation.
  - due to a positive trap charging which can be partially recovered over time periods of a week or so.
- Radiation induced $V_{th}$ shifts are much reduced under low dose rate exposure.
  - in space environment, small $V_{th}$ shifts are expected also for several krad’s radiation doses.
- The residual effect of radiation damage is the accumulation of oxide defects at gate oxide interface, which slows down the ON-OFF switching speed of the transistors.
- Depending on technology VD Power MOSFETs may show large drain-source breakdown voltage drop after irradiation
  - 200 V MOSFETs features 35% shift