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**Irradiated HV Power MOSFETs working in linear zone: a comparison of electro-thermal behavior with standard HV products**

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**Introduction**

This paper studies the thermal instability phenomenon of irradiated HV Power MOSFET devices working in linear zone operating conditions and compares their electro-thermal behavior with standard products. Experimental results show that irradiated devices have more thermal instability than standard devices, therefore, they should be used carefully in these particular operating conditions.

In most of cases, Power MOSFETs are used in switching operating conditions where  $R_{DS(on)}$  is the key parameter to evaluate the device's performance. However, in some special cases, devices work in linear zone. A Power MOSFET works in linear zone when high-currents and high voltages are together applied to MOSFET terminals. Power MOSFETs are used in linear zone in some dedicated applications especially in automotive segment such as: standard topologies of audio amplifiers, linear DC-DC converters, DC fan controllers, electronic loads, current mirrors, smart fuses, etc... In many of these applications, typically, the LV Power MOSFETs are used. Furthermore, Power MOSFETs work in linear zone for a short period of time when they are used in switching conditions during the Miller region where high-currents and high voltages are together applied to MOSFET terminals. This means that the thermal instability must be also evaluated in applications where linear zone isn't the typical operating condition. Therefore, this phenomenon needs to be evaluated even during the slow switching process either in LV or, in particular, in HV Power MOSFETs when high inductive loads are driven. Considering a theoretical Power MOSFET FBSOA, linear zone is referred to that area delimited by maximum allowed dissipated power for different power pulse duration.

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# 1 Basic concepts

In linear zone, the Power MOSFET can be subjected to a thermal run-away process that could lead the device to fail. Failures are experimentally explained as a drain current focusing phenomenon (hot spots). Failures are generally localized in the center of the die, close to the source wire bonding. Owing to that, standard theoretical FBSOA does not exactly describe the safe area in forward-biased conditions since the red area portion is lost (see [Figure 1](#)). An analytical approach has been performed to describe this phenomenon. In linear zone (saturation region),  $I_D$  can be written as:

**Equation 1**

$$I_D = \frac{1}{2} \mu \frac{W}{L} c_{OX} (V_{GS} - V_{TH})^2$$

$c_{OX}$  is the gate oxide capacitance by unit area,  $W$  is the perimeter of the device,  $L$  is the length of the channel,  $\mu$  the mobility of the carriers in the channel and  $V_{TH}$  is the threshold voltage. Introducing the term  $K$  as:

**Equation 2**

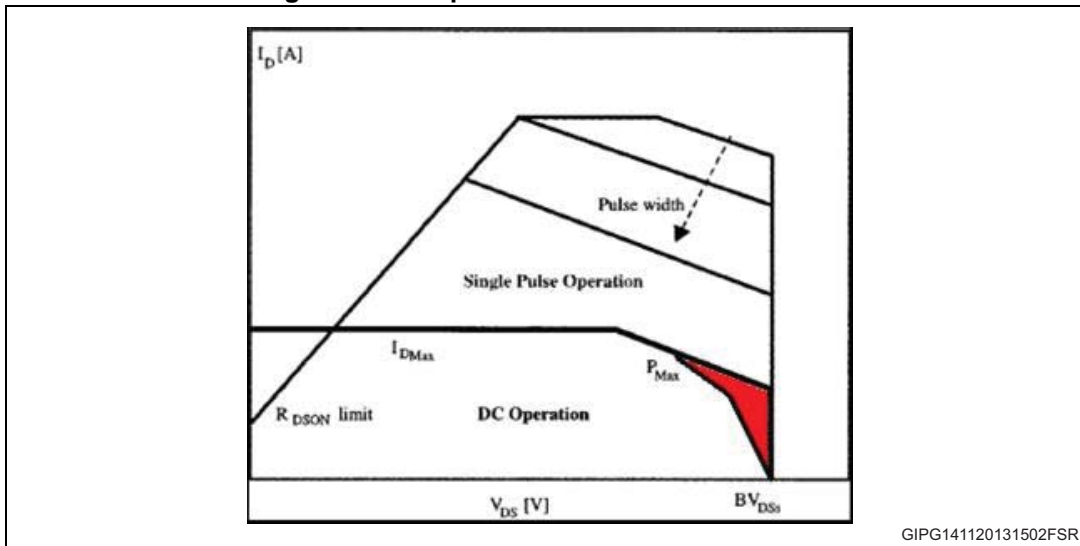
$$K = \frac{1}{2} c_{OX} \frac{W}{L} \mu$$

Equation 1 can be rewritten as:

**Equation 3**

$$I_D = K(V_{GS} - V_{TH})^2$$

**Figure 1. Example of Power MOSFET FBSOA**



During the linear zone operating condition, when a power pulse is applied, the device warms, the junction temperature increases and  $I_D$  changes its value because the mobility of

the carriers in the channel and  $V_{TH}$  change their values. In particular, either  $\mu$  or  $V_{TH}$  decrease when the temperature increases. From the derivative of (equation 2) against T, the thermal coefficient, TC, of the device can be achieved by:

**Equation 4**

$$\frac{\partial I_D}{\partial T} = \frac{I_D}{K} \left[ \frac{\partial K}{\partial T} \right]_{V_{DS} = \text{const}} - 2\sqrt{K}\sqrt{I_D} \left[ \frac{\partial V_{TH}}{\partial T} \right]_{V_{DS} = \text{const}}$$

TC is the main thermal-electro parameter used to monitor the thermal instability phenomenon. In fact, in linear zone, the electro-thermal stability of each device is evaluated by considering a graph where TC is achieved versus  $I_D$ . In equation 4, the first term, depending on the derivative of K, tries to make TC negative while, vice versa, the second term, depending on the derivative of  $V_{TH}$ , tries to make the same coefficient positive. If the first one is higher than the second one, TC becomes negative and no failure occurs, vice versa, TC becomes positive and a thermal run-away phenomenon could occurs. However, even if TC is positive, the device could work in safety region. This depends on the capability of the whole die thermal system to catch the heat per unit area and time developed by the electrical power pulse. If the heat produced by unit time can be totally extracted from the device, then the Power MOSFET works in safety conditions. Otherwise, the heat increases the internal energy of the system causing a die temperature rise until T reaches the maximum allowable value (localized silicon) leading the device to fail.

## 2 Experiments, results and discussion

To evaluate the electro-thermal instability of irradiated HV Power MOSFETs working in linear zone and to compare their performance with standard devices, two different samples belonging to two different suppliers have been taken into account. Devices under testing have a breakdown voltage equal to 600 V, a standard threshold voltage with 50 A of nominal drain current in continuous mode when the ambient temperature is 25 °C. The only difference between irradiated and not irradiated devices is the irradiation process. To study the thermal behavior in linear zone of the devices under testing, thermal coefficients have been measured: 10 V V<sub>ds</sub>. TC has been achieved against the drain current fixing the V<sub>ds</sub> values to 10 V and considering two ambient temperature values: 25 °C and 75 °C. Testing has been fulfilled considering the worst conditions where the current isn't fixed by external equipment or controlled by a feedback, but it depends on the same transistor (open loop case) only. The graph in *Figure 2* and *Figure 3* takes into account TC versus I<sub>D</sub> for V<sub>ds</sub> = 10 V.

**Figure 2. Comparison between standard and irradiated HV Power MOSFETs: TC curves vs. I<sub>D</sub> (supplier 1)**

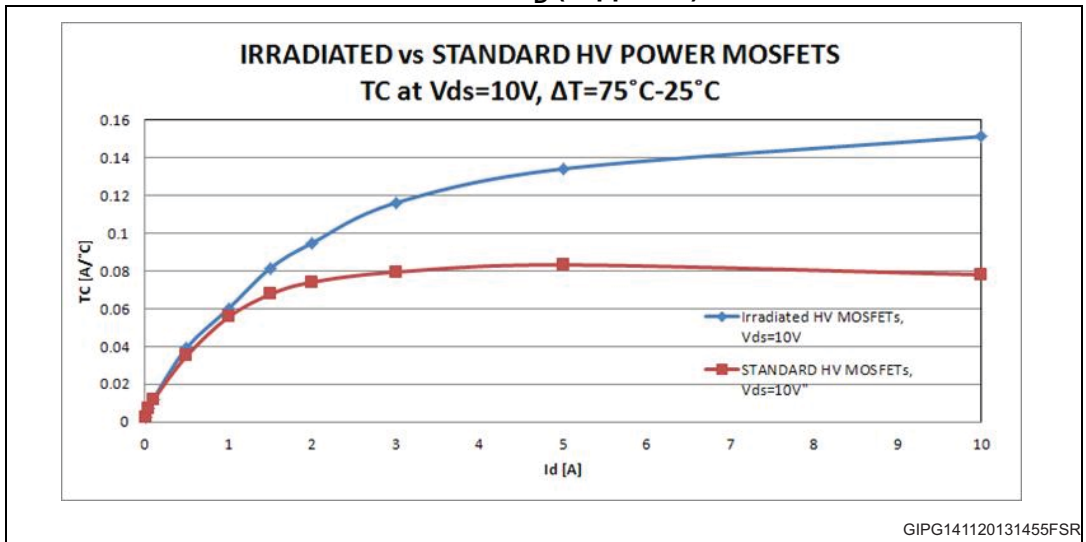
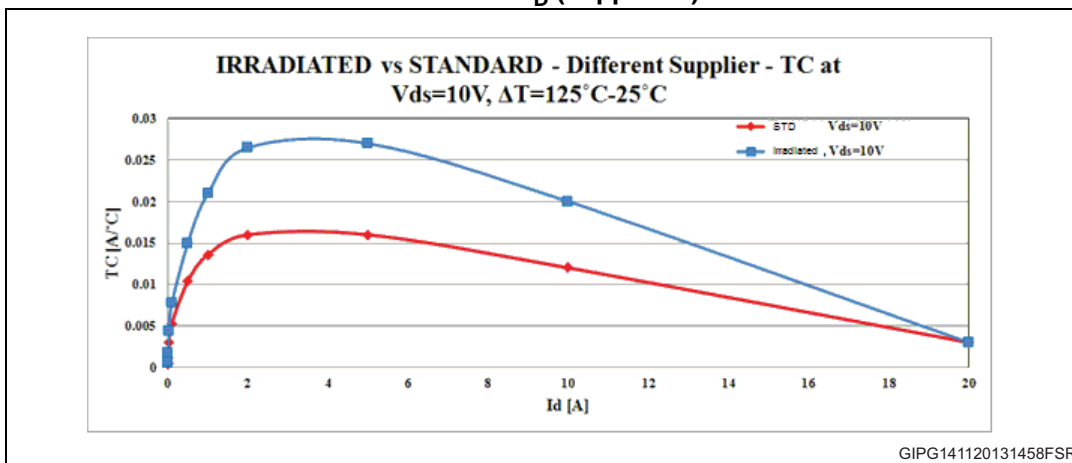
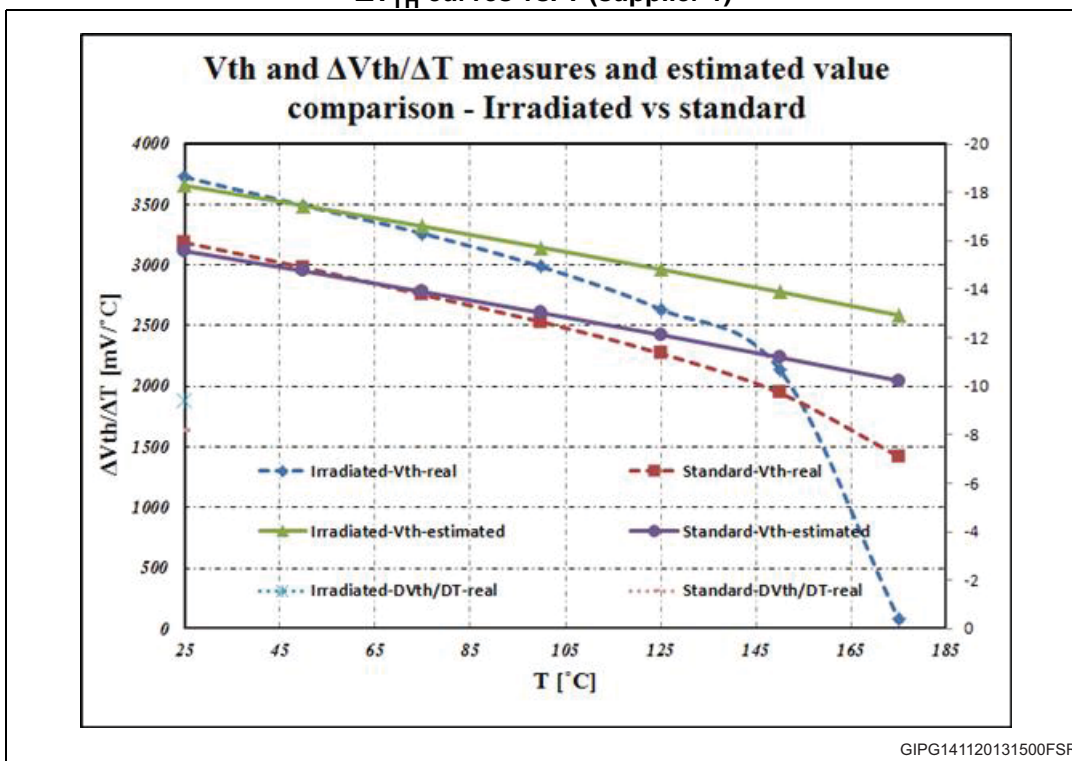


Figure 3. Comparison between standard and irradiated HV Power MOSFETs: TC curves vs.  $I_D$  (supplier 2)



In the above graph it is possible to notice that, considering both suppliers, the TC curve in the irradiated device is higher (around double) therefore, the irradiated MOSFETs have a thermal instability respect to standard ones in linear zone. These results can be explained measuring the decrease of the threshold voltage against the temperature as shown in the following graph (it is referred to [Figure 2](#)).

Figure 4. Comparison between standard and irradiated HV Power MOSFETs:  $V_{TH}$ ,  $\Delta V_{TH}$  curves vs. T (supplier 1)



In irradiated devices, the decrease of the threshold voltage versus the temperature is higher, in fact: 13 mV/°C between 25 °C and 150 °C, while in standard devices, it is around -10 mV/°C between 25 °C and 150 °C. If  $\Delta V_{TH}/\Delta T$  is higher, TC rises as well and, as

explained in equation 4, during the linear zone working conditions, the device has more thermal instability.

### 3 Conclusions

This paper has evaluated the thermal instability phenomenon of irradiated HV Power MOSFET devices working in linear zone operating conditions comparing their electro-thermal behavior with standard products and by considering two different suppliers. A theoretical study of the phenomenon (the introduction) has been followed by an experiment: measuring the thermal coefficients of two samples in identical devices. The former includes irradiated devices while the latter includes standard devices. Results show that irradiated transistors have a higher thermal instability, in fact both the threshold voltage derating and defectiveness of interface densities are higher than those in standard ones. Higher levels of interface states in the irradiated transistors are related to the same irradiation process.

### 4 References

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## 5 Revision history

Table 1. Document revision history

Date	Revision	Changes
03-Dec-2013	1	Initial release.

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