POZNAN UNIVERSITY OF TECHNOLOGY ACADEMIC JOURNALS
No 76 Electrical Engineering 2013

Mohamed Ali SHABAN*
Yousef ETTOMI*

STUDY OF ELECTRO-THERMAL STRESS OF IGBT DEVICES

The aim of this paper is to present a new approach which consists to correlate or coupled the functional and electrical stress with temperature. This approach can be extremely useful in the predicting the stressing effect and the impact of IXGH-IGBT I-V characteristics on circuit degradation. Moreover, this new approach significantly improves such parameters likes (threshold voltage V_{th}, collector saturation current, the stress and enhanced collector leakage current) and provides new capability for use this power device IXGH-IGBT in an actual circuit environment and modules. We also explain the physical reasons behind the improvement obtained using functional electrical stress on the IGBTs for IXYS constructor with temperature. Moreover, the forward blocking capability of IXGH-IGBT under a coupled Functional - Electro stress at high temperature was analyzed using simulation. This paper gives a straight comparison in term of the stress for improving the switching speed of IGBT device. This study is essential to ensure product reliability and to the evaluation of hot carrier reliability in the early stages. Furthermore, our reliability study permits us to improve the implantation of the device in a circuit, as well as its use in industrial operating conditions. The need for good simulator (Spice, Spice) to carry out a reliability study is pointed out in this paper.

1. INTRODUCTION

The Insulated Gate Bipolar Transistor or IGBTs are metal oxide-semiconductor field effect transistors (VDMOS) driven bipolar transistor. It is the most widely used semiconductor power device. It has been successfully used in a variety of switching applications such as motor drives and appliance controls because of its superior characteristics: lowon- state voltage drop, high switching speed, high current density and high blocking capability. Furthermore, modern IGBTs seem to be susceptible of achieving ultra-low on state power loss and turn off loss as well as extending the boundary of the IGBTs safe operating area (SOA). Using devices such as for the motor drive part, it allows a good trade –off between the switching speed, the on-state voltage drop and the ruggedness [Trivedi 97]. In the last decade, the search for an ideal power switch also demands that it can be used at high temperature without significant degradation in its performance. Although early

* Higher Institute of Electricity, Libya.

reports showed that the IGBT at high temperature has been studied with the conclusion that it cannot be successfully used at temperature of 200°C because an increased leakage current [3]. For this reason, we try more to study the behavior of IXGH-IGBT for IXYS constructor under functional –electro-thermal stress which are able to perform the conduction characterization of power IGBTs devices and to determine the effect of this coupled stress on the package of IGBT (chopper circuit). A cross-sectional diagram indicating voltages and currents is shown in Fig. 1.

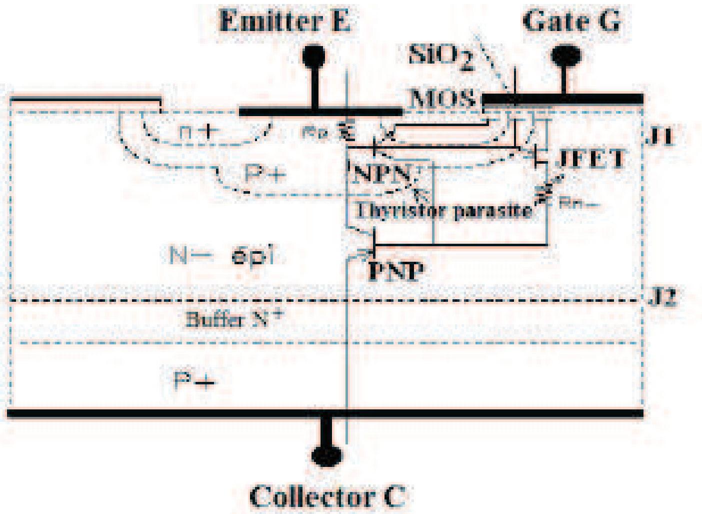

Fig. 1. Cross-sectional diagram indicating voltages and currents

2. HOT CARRIER STRESS

Hot carrier in IGBTs occurs due to the high power dissipation caused when current flows through a region with a high electric field. This dissipation power results in self heating and raises the working at high temperature. Since IGBTs are used in high current conditions, the high current leads to the redistribution of charge and the electric field within the device. The increased charge density leads to a higher peak electric field [8]. Thus, when electrons and / or holes gain energy in an electric field, they can be injected onto the oxide to become oxide-trapped charge, they can drift through the oxide, causing gate current; they can create interface-trapped charge, and can generate photons as illustrated in Fig. 2. Hot carrier lead to a series of undesirable’s device behavior modifications. Not and Dit lead to threshold voltage changes and mobility degradation which will investigate in this paper. Hot carrier can be classified to the main failure of an IGBT [7].

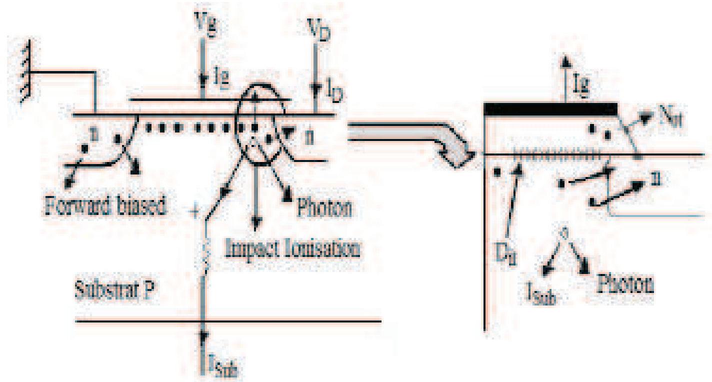

Fig. 2. Various effects produced by hot carriers [4]

3. A FULLY COUPLED FUNCTIONAL-ELECTRO THERMAL STRESS

The conducted work represents a contribution to the discussion of fully coupled Functional-Electro–Thermal stress on IGBT device characteristics for IXYS constructor. This contribution allows researches the capability of investigating thermal imbalances between IGBTs family as well as its use in industrial operating conditions.

A. Static mode

The main part of the static operating mode is based on the implantation of IXGH-IGBT for IXYS constructor under functional stress: chopper circuit see Fig. 3.

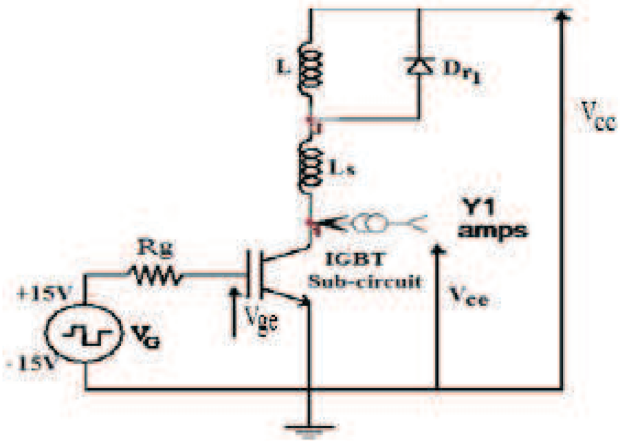

Fig. 3. Chopper circuit used for stressing the IGBT [5]

Prim alary, the IXGH-IGBT was stressed at low and high collector voltage for the temperature value +27°C to 400°C in order to understand the origin of enhanced hot carrier stress damage. Comparing the DC current simulation results (see Fig. 4) obtained with IXGH-IGBT subjected to functional electro- thermal stress for low and high collector voltage with the gate bias Vg = +15 V. As can be seen in Fig. 4, as the supply collector voltage Vcc scales down, the collector current drops more quickly. Consequently, the gate bias adjusted to *V Vcc* 2 *ge* = shown to correlate with peak degradation in device I-V characteristics and can be considered the worst case DC stress conditions. In this case, both holes and electrons are injected together into the oxide [7].

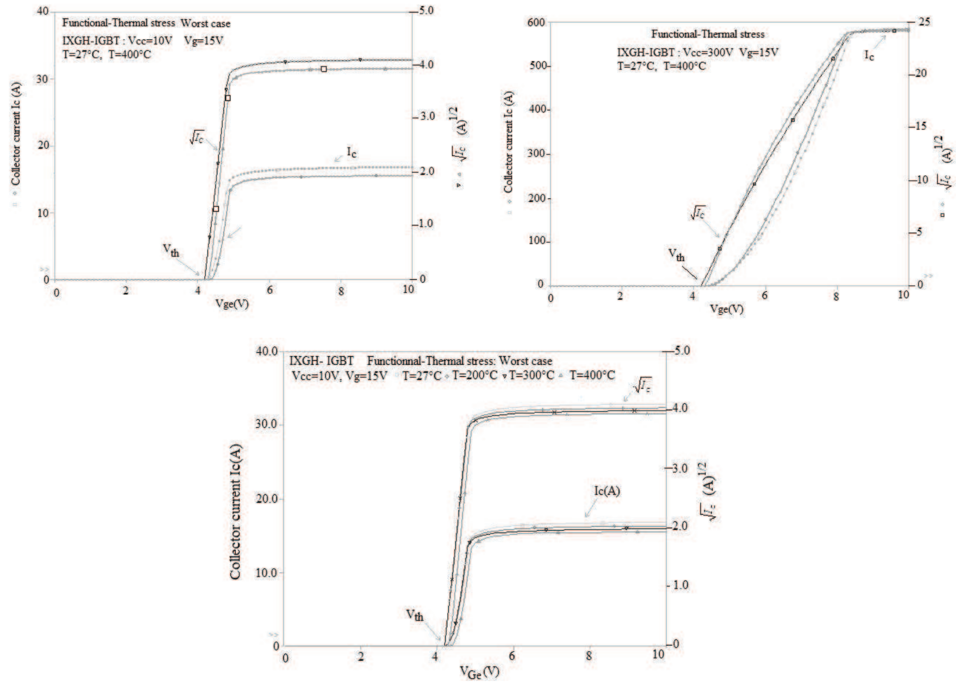

Fig. 4. Collector current and square root collector current versus gate voltage for IXGH-IGBT

In this section, the electrical parameter Vth is evaluated for IXGH-IGBT aged by electro-functional stress at temperature range of 27°C to 400°C. This later is determined by plotting *C I* versus Vge and extrapolating the curve to zero collector current illustrated in Fig. 4. As observing in I-V characteristics IC = f (VGE) ANF in Fig. 5, the threshold voltage Vth of the IXGHIGBT device increase as temperature increase upper than 300°C. When the IGBT is stressed, the interface states create acceptors levels, a degradation lead to electron capture and accumulation of negative charge in these states, and increase the doping level of the channel. These result an increase of Vth (see eq.1).

$$V_T = \left[\phi_{ms} - \frac{Q_f}{C_{OX}} \right] + 2\psi_B + \frac{\sqrt{4\xi_S q N_A (\psi_B)}}{C_{OX}} \tag{1}$$

where: Φ_{ms} - potential difference between metal work function and the semiconductor work function, Q_f - fixed –oxide charge, Ψ_B - Substrate voltage, N_A - substrate doping (zone P), C_{OX} - thin oxide capacitance .Thus, it is therefore easier to turn on the IGBT at high temperature upper than 300°C.

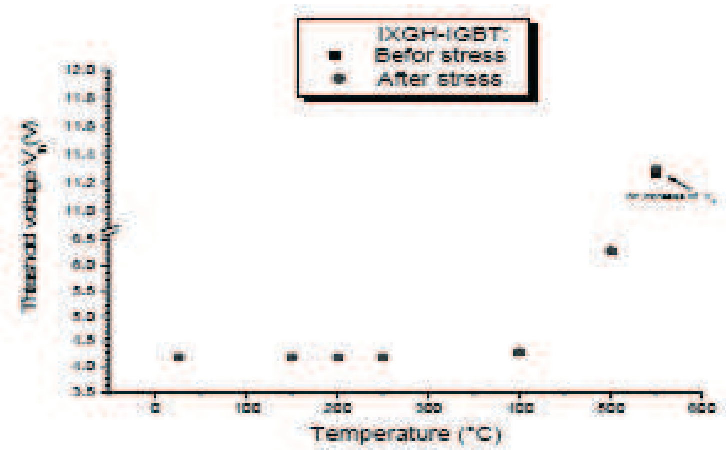

Fig. 5. Threshold voltage as versus temperature for IXGH-IGBT

As can be seen from Fig. 5, the effect of temperature on I-V characteristics has been shown to be significant in many instances: when the temperature is small to 250°C, no appreciable change in threshold voltage, this later is less affected by the gate voltage. Nevertheless, when the temperature increase up to 300°C, the applied stress results a positive shift in threshold voltage which indicates a greater effect of the interface traps charge that of the oxide. Additionally, the IXGH-IGBT successfully withstands an applied thermal stress of 300°C. Moreover, as shown in Fig. 6, the breakdown voltage decreases when the temperature increase which reflect on security surge of the power device.

As shown in Fig. 7, it is clear that the leakage current ICES rise gradually with increasing collector voltage until that avalanche breakdown point is reached. Furthermore, it is worth noting that the leakage current was found to exceed 100A value only when, the temperature was raised to 200°C. Thus, the IXGH-IGBT can be operated at temperature up to 200°C without excessive power loss in blocking mode.

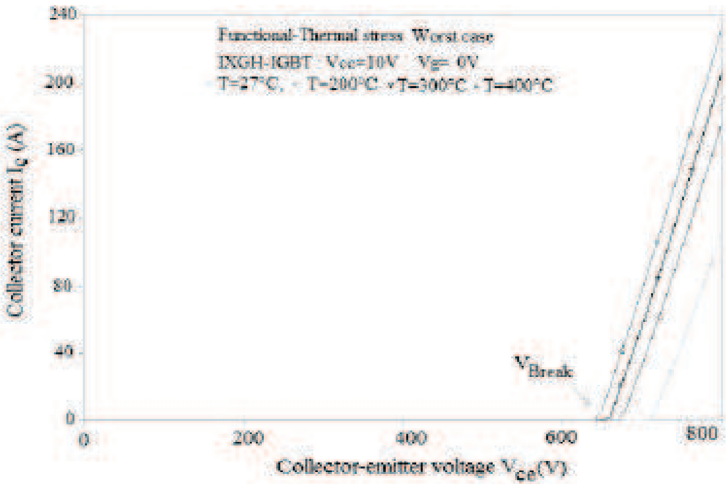

Fig. 6. Breakdown voltage for 27°C to 400°C

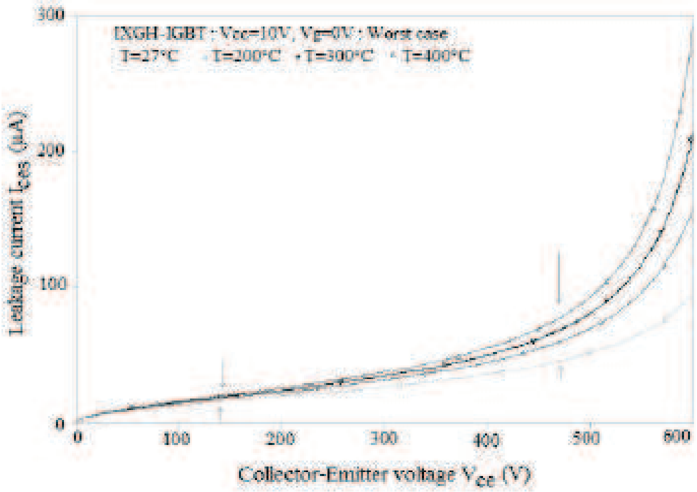

Fig. 7. Enhanced collector leakage current factor FICES vs collector emitter voltage

In order to clarify more the forward blocking capability of IXGH-IGBT under a coupled Functional-Electro stress with temperature, the stress and temperature enhanced collector leakage current factor FICES defined as the ratio:

$$F_{ICES} = \frac{I_C \big| V_{ge} = 0(T = 400^0 C\ )}{I_C \big| V_{ge} = 0(T = 27^o c)} \tag{2}$$

As shown in Fig. 7, as the temperature rise, the enhanced factor is further increased up to 110 V. The temperature effect becomes more significant at lower Vcc. Furthermore, as shown in Fig.8.a, the IXGH-IGBT aged under functional-thermal stress presents an intersection point which corresponds to zero temperature coefficients.

$$\frac{dV_{CE}}{dT} = 0 \Leftrightarrow I_C = \frac{-\alpha}{\beta} \tag{3}$$

Under this current value, the IXGH presents a positive temperature coefficient β where the collector current increase when the temperature increase. Upper this value IXGH-IGBT presents a negative temperature coefficient α. This, clarify the rise of collector current when the temperature decreases (see equ. 4):

$$\frac{dV_{CE}}{dT} = \alpha + \beta * I_C \tag{4}$$

This is decisive factor for safe parallel operation especially at high operating temperature in order to get a minimal current dc rating. In contrast, in the worst case where Vcc = 10 V, the curve in Fig. 8-b clearly exhibit a positive temperature coefficient for the whole temperature range.

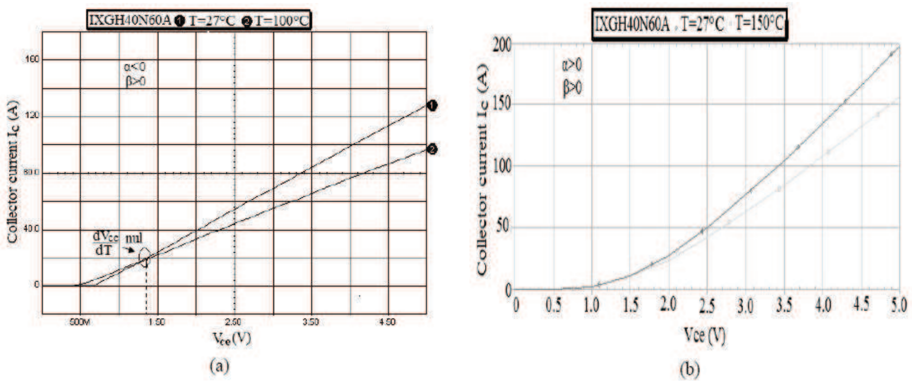

Fig. 8. Collector current versus collector–emitter voltage for IXGHIGBT

In order to clarify more the effect of hot carrier stress induced IGBT degradation and to examine the relation between linear current degradation and the gate voltage, the stress cycle were performed by driving the gate voltage. As shown in Fig. 9 for IXGH-IGBT, the saturated collector current decrease, thus the term G decrease. This degradation indicates interface state creation influencing channel carrier mobility which is due to enhanced carrier scattering in the channel. The saturated collector current for an IGBT is given by:

$$I_C = (\beta + 1)\mu \frac{w}{2L} C_{ox} (V_{GE} - V_{th})^2 = G(V_{GE} - V_{th})^2 \tag{5}$$

Where the term G is given as:

$$G = (\beta + 1)\mu \frac{W}{2L} C_{ox} = G(V_{GE} - V_{th})^2 \tag{6}$$

Determining the square root of equ (5) yielding:

$$\sqrt{I_C} = f(V_{GE}) = \sqrt{(\beta + 1)\mu \frac{Z}{2L} C_{ox}} (V_{GE} - V_{th}) \tag{7}$$

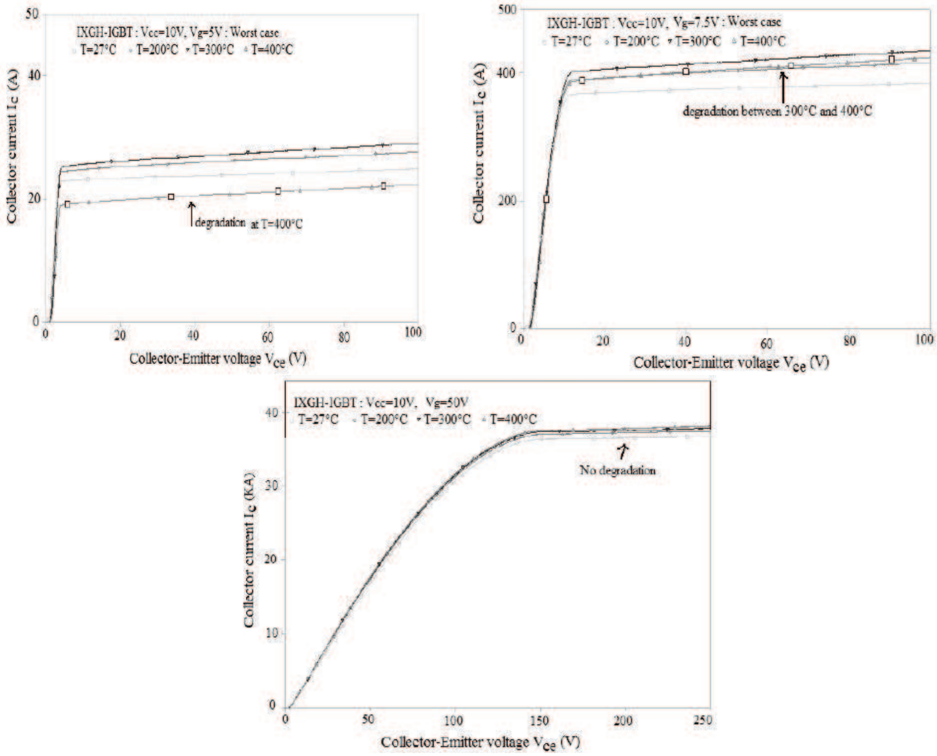

Fig. 9. Collector current versus temperature for IXGH-IGBT

B. Dynamic mode

From the correlation between electrical and thermal stress, the subthreshold current, current gain βPNP, fall time tf, and turnoff time can be extracted and their dependence on IGBT behaviour determined.

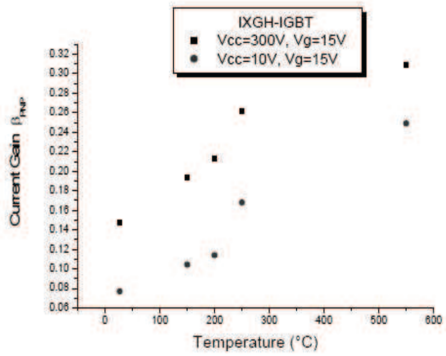

Fig. 10. Subthreshold current be for and after stress temperature for IXGHIGB

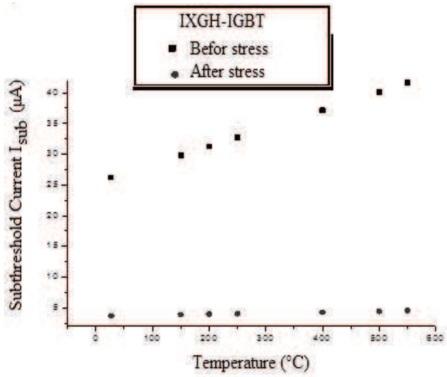

Fig. 11. Current gain ß$_{PNP}$ as versus for IXGH-IGBT

As can be seen from Fig. 10, the degradation of subthreshold current at a given gate Vg < Vth, mean there will be more subthreshold current flow in IGBT unstressed than in a stressed device. Although, it will know that, the current gain ßPNP increase with increasing temperature [Baliga 87]. Nevertheless, our results show that current gain ßPNP is less important in IGBT stressed than in an unstressed device (see Fig. 11). Furthermore, we can notice, that the fall time tr and carrier lifetime τ has been improved. These later affect greatly the switching speed of the device.

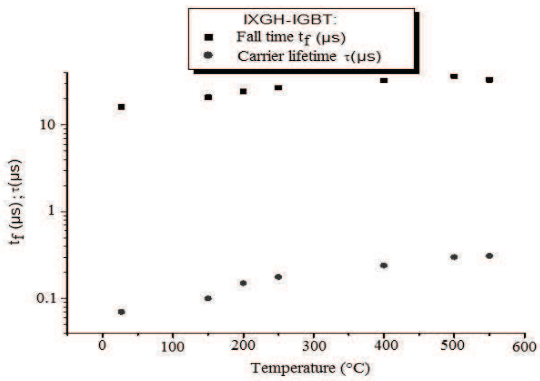

Fig. 12. Fall time t$_r$ and carrier lifetime τ as versus temperature for IXGH-IGBT

4. CONCLUSION

The key improvement in our numerical study is the inclusion of the effect of compensation which has been shown to be of great importance of IXGH-IGBT under electrical and thermal stress. Thus, the presented work extends the range of the use of IXGH-IGBT in industrial operating conditions. In this paper; the main conclusions which can be made from the present reliability study are:

– It was demonstrated that the IXGH-IGBT can safely operate at temperature larger than 300°C. This feature makes the IXGH40N60A extraordinarily well suited for applications in which high temperature than 200°C.
– Our results clearly notice an increase in threshold voltage after stress. This increase indicates a greater effect of the interface traps charge than that of the oxide.
– It was further claimed that the drop in the static saturation current is due to degradation of the effective channel mobility as a result of enhanced surface scattering by stress induced interface trap charges.
– For the discussion of our results, the electrical stress can compensate the thermal stress by improvement of such parameters of IGBT device like: tf, current gain ßPNP, lifetime τ and the breakdown voltage.
– Also the decrease in turn-off time with increasing temperature results of decreasing current gain i.e. a larger portion of the collector current is carried by the Mos channel current which can be turned much.

REFERENCES

[1] Jayant Baliga B., Modern power devices, Schenectady, New York: General Electric Company; 1987, December .
[2] S.Clemente, A.Dubhashi, and B.Pelly, " Improved IGBT process eliminates latch-up and yields higher switching speed – Part-I "; Power Conversion Intell.Motion, vol.166, n0.10, pp. 8-16, October.1990.
[3] R.Constapel and J.Korec, in ISPSD'94 pp117-121 (1994).
[4] Tahui Wang and al, " A comprehensive study of hot carrier stress-induced Drain leakage current degradation in thin-oxide n-Mosfet", IEEE Trans. Electron Devices, Vol.46, N09, pp 1877-1882, September 1999.
[5] Brian D. Buractay, "Basic optimization methods", PP (47-90), Edward Arnold (publishers), 1985.
[6] V.A. Strove," The Algorithm for alleviating overloads using Pseudo-inverse method" paper from Moscow power engineering institute, 1991.
[7] A.M, Sassoon "combined use of the Powell and fletcher-powerll nonlinear programming method for optimal load flow", IEEE, PAS, Vol.88, 1999, pp.1580.