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# Experimental Investigation of Electro-thermal Stress Impact on SiC-BJT's Electrical Characteristics

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**Abstract** — The aim of this study consists in investigating the effects of electrical and thermal stresses on SiC n-p-n bipolar junction transistors (BJTs). The stability of the electrical characteristics of BJTs is inspected under switching operation, DC operation, temperature cycling and continuous thermal stress up to 225°C. While switching operation and temperature cycling for several hours lead to significant changes at 25°C, the electrical characteristics were little degraded at high temperature. Besides, DC operation and continuous thermal stress did not result in significant degradation at all, both at room temperature and at high temperature.

**Key words** — BJT, Silicon carbide, electrical stress, thermal stress, stability.

## Introduction

Thanks to technological improvements in the SiC sector those last years, several SiC components (MOSFET, JFET and BJT) have reached maturity and the fabrication of very high power converter operating at high temperature has become possible. However, the stability of these components is still an issue, especially for high temperature applications, and is strongly dependent on the packaging. Ageing and reliability tests have already been performed on different SiC components, such as MOSFET [4][6], JFET [1][2] and BJT [3][5][7]. Since we considered BJTs as interesting candidates, we chose to study the stability of their characteristics on last generation components and subject them to a thorough ageing.

## Ageing and Measurement Resources

### *Ageing Resources*

In order to apply a thermal stress for a long time, transistors are placed on an aluminum block (100x60x35mm), with an Acim Jouanin heating cartridge (500W, 100mm long) inside. The temperature of the components is measured thanks to a type K thermocouple placed on their case and is controlled with a Jumo iTron16 PID controller. A Thermonics thermal conditioner (T-2500) has also been used in some tests for fast temperature cycling.

The electrical stress was applied between collector and emitter by laboratory power supplies, such as a

3.3kW Genesys 600-5.5 TDK-Lambda, in series with a resistive load.

### *Measurement resources*

The measurements have been made with an Agilent Curve Tracer (B1505).

## Components

The tests have been performed on 4H-SiC NPN power bipolar junction transistors supplied by TranSiC. During our experimentations, we used either BitSiC BT1206AB or BT1220AB, which have the same chip but with a larger die size for the BT1220AB. Both devices are packaged in TO258, rated at  $V_{ce0}=1200V$  and  $T_{jMAX}=250^{\circ}C$ . BT1206AB can only withstand  $I_{cMAX}=6A$  at  $T_j=25^{\circ}C$ , while BT1220AB handles 20A. According to the manufacturer, they are supposed to have a small on-resistance ( $<50m\Omega$ ).

## Measurements and Results

### *Description of experimental setups*

In order to compare ageing speeds, different stresses were applied and so different setups were used. Meanwhile, their  $I_{CE}-V_{CE}$  characteristics have been measured at short time intervals. Impacts of temperature on electrical characteristics both during tests and after (irreversible evolutions) have



been investigated. We observed the variation of electrical characteristics while applying:

- (S#1) only a 10 kHz electrical stress,
- (S#2) only a 150°C continuous thermal stress,
- (S#3) only temperature cycling (1°C/s) between 25°C and 150°C,
- (S#4) 4 temperature cycles between 25°C and 225°C,
- (S#5) 4 temperature cycles between 25°C and 225°C and a 10kHz electrical stress
- (S#6) 4 temperature cycles between 25°C and 225°C and a 3A DC stress.

#### S#1 First setup: 10 kHz electrical stress

Switching tests were performed with a 150Ω load and 500V source. A home-made current driver with an output current swing capability of 1A was used for driving the BJTs. For this setup, the output current was set to 400mA with a switching frequency of 10kHz and a duty cycle of 0.5, during 10 hours.

Low collector current rise and fall times ( $t_r = 150\text{ns}$ ,  $t_f = 180\text{ns}$ ) were recorded (Fig.1 and 2) for switching 3.3A at 500 V and were temperature-invariant, due to the “unipolar” nature of the SiC BJT device design.

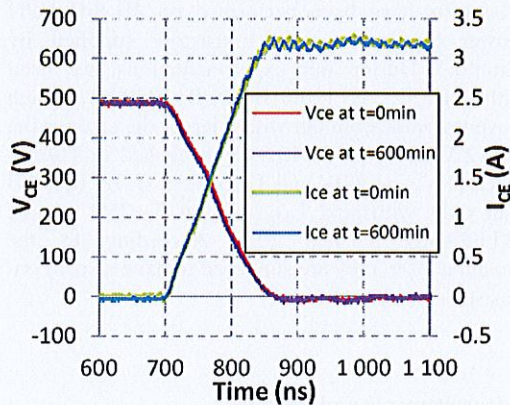


Fig.1: Collector current rise time before and after 10 hour switching tests.

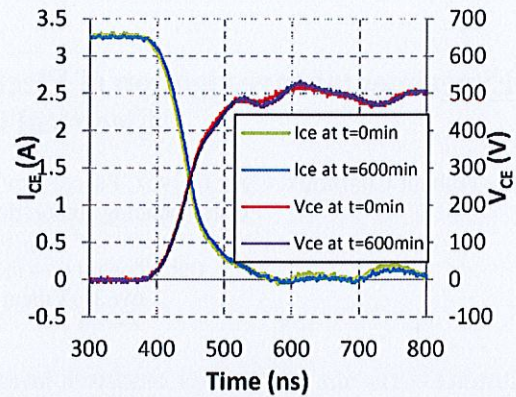


Fig.2: Collector current fall time before and after 10 hour switching tests.

From  $I_{CE}-V_{CE}$  characteristic curves at different base currents, the On-resistance can be extracted (Fig.3).

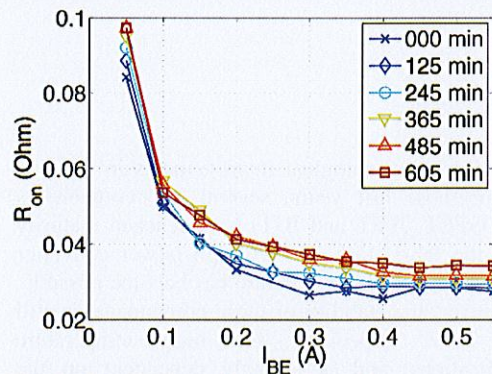


Fig.3: Evolution of the On-resistance versus base current during the switching tests. The colour of the curves becomes warmer with increasing time.

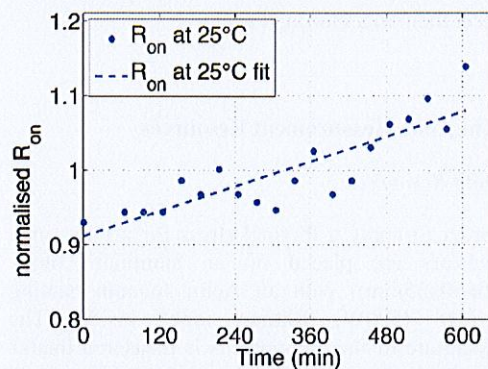


Fig.4: Evolution of the On-resistance normalised by its mean value versus time for a 400mA base current. The resistance increases by an average of 1.8% by hour.



Figure 4 shows the variation of On-resistance at  $I_B=400\text{mA}$  normalised by its mean value.

$$\frac{R_{on}}{\overline{R_{on}}}$$

After the switching tests, the On-resistance at  $I_B=400\text{mA}$  increased by 18%. (Fig. 4)

#### S#2 Second setup: 150°C continuous thermal stress

A second sample has been characterized before, during and after a 10-hour long continuous thermal stress at 150°C without any electrical stress. The On-resistance value increases continuously during the heating process (Fig. 6). After the thermal ageing, the On-resistance at 25°C decreased by 12% and its value at 150°C decreased by 3% (Fig. 5, 6 and 7), which is quite low.

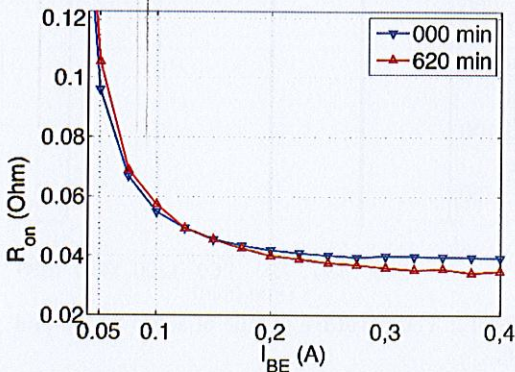


Fig. 5: Evolution of the On-resistance versus base current at 25°C, before and after a 10-hour long continuous thermal stress.

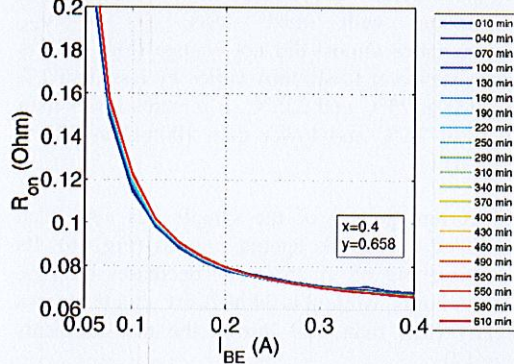


Fig. 6: Evolution of the On-resistance versus base current at 150°C, during a 10-hour long continuous thermal stress. The colour of the curves becomes warmer with increasing time. The variation is very slight.

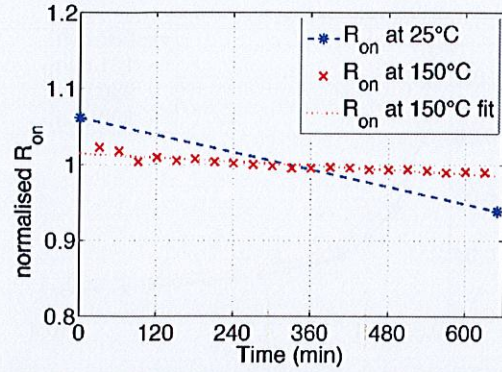


Fig. 7: Evolution of the On-resistance normalised by its mean value versus time for a 400mA base current. The resistance decreases by an average of 1.2% by hour at 25°C and by 0.3% by hour at 150°C.

Thus, almost no variations during the plateau at 150°C have been observed. The degradation at 25°C before and after heat stress may be due to the rapid increase and decrease in temperature (60°C/min). The next step of our work consists in observing the effect of temperature cycling on electrical characteristics.

#### S#3 Third setup: Temperature cycling

A third sample has been stressed by temperature cycling between 25°C and 150°C at a rising and falling speed of 60°C/minute, in order to observe the effects of temperature change. (Fig. 8)

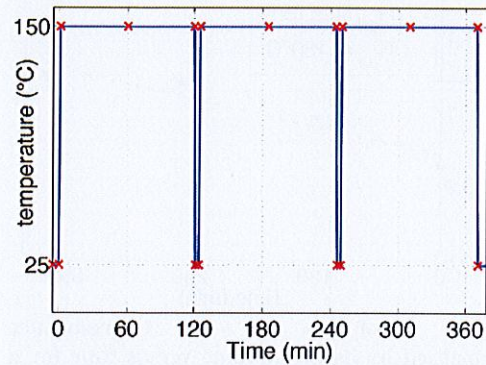
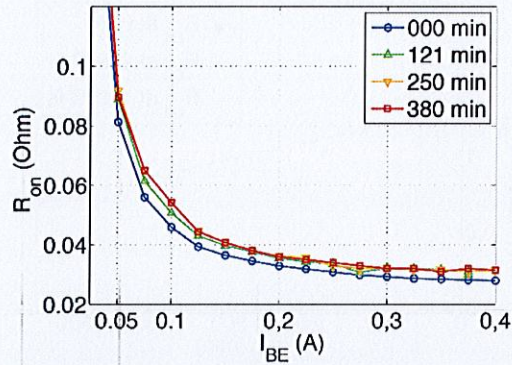


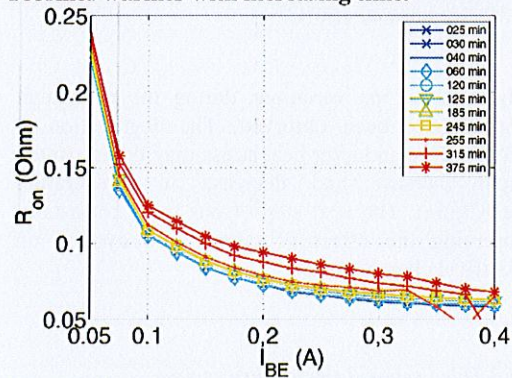
Fig. 8: Temperature profile of setup #3.

Figures 9 and 10 show the variation of On-resistance at 25°C and at 150°C. The sudden increase in the resistance value at  $t=120\text{min}$  and  $t=240\text{min}$  shows the effects of thermal cycling (Fig. 11). The overall increase after 6 hours of cycling is 13% and is approximately the same when measured at 150°C and at 25°C.

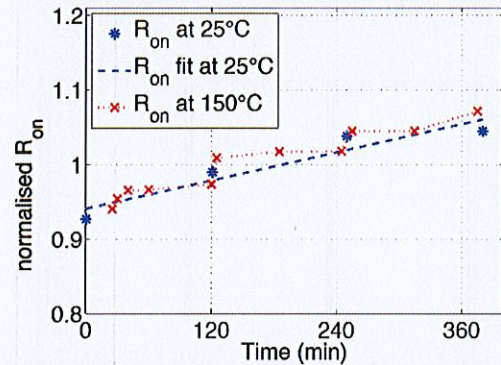




**Fig. 9:** Evolution of the On-resistance versus base current at 25°C, before, during and after a thermal cycling. The colour of the curves becomes warmer with increasing time.



**Fig. 10:** Evolution of the On-resistance versus base current at 150°C, during a thermal cycling. The colour of the curves becomes warmer with increasing time.



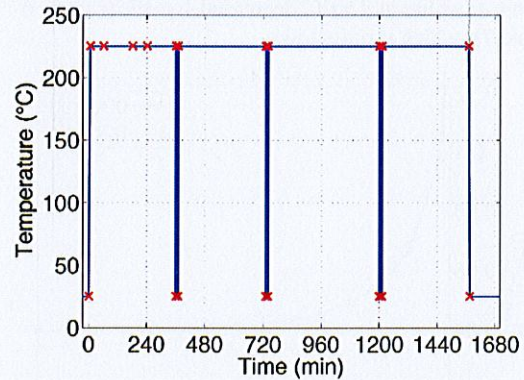
**Fig. 11:** Evolution of the On-resistance normalised by its mean value versus time for a 400mA base current. Blue stars are normalised  $R_{on}$  values at 25°C, blue dashed line is a fitted curve at 25°C and red dotted line with crosses as markers is normalised  $R_{on}$  values at 150°C. The resistance increases by an average of 2.2% by hour.

From these three experiments, different kinds of stress have been observed alone. Voltage switching and temperature switching have been far more

wearing than continuous stress. The next step of our work consisted in observing the combined effects of electrical and thermal stresses at a more challenging temperature.

#### *S#4 Forth setup: 225°C thermal stress*

The three last samples were placed together on the heating block, so we can assume that they were subjected to exactly the same 225°C heat stress for 26 hours. (Fig. 12) The temperature variation speed was lower than in previous test: 30°C/minute for the rising and 15°C/minute for the falling.



**Fig. 12:** Temperature profile of setup #4, #5 and #6.

One of them was subjected to no electrical stress (the forth setup) and can be used as a point of comparison with next tests. Its  $I_{CE}$ - $V_{CE}$  characteristics almost did not change (Fig. 13). Its On-resistance at  $I_B=400mA$  varies by less than 1% (Fig. 15) at 25°C and 225°C. It remains lower than 50mΩ at 25°C and lower than 100mΩ at 225°C (Fig. 14).

The current gain  $\beta$  of the sample has also been calculated during the ageing process (Fig. 16). Its value is about 65 at 25°C and decreases by 12% after 26 hours, while  $\beta$  is 34 at 225°C and decreases slightly (less than 4%) during the measurements (Fig. 17).

The small impact of temperature variations (at  $t=360min$ ,  $t=720min$  and  $t=1200min$ ) can certainly be explained by a compensation between the decrease noted at a constant stress (setup #2) and increase observed during temperature changes (setup #3). Moreover the temperature changes are smoother so the thermal cycling effects are probably lesser. In any case, the small overall On-resistance variation is very encouraging.



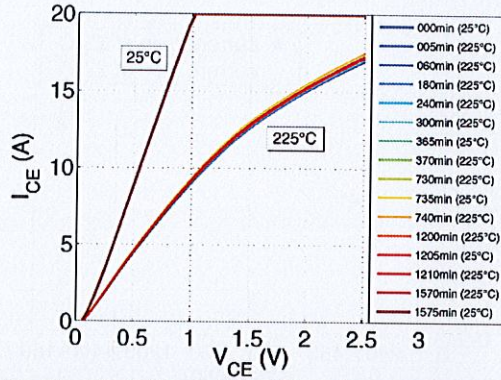


Fig. 13: Evolution of  $I_{CE}$ - $V_{CE}$  characteristics at  $I_{BE}=400\text{mA}$  with ageing. The colour of the curves becomes warmer with increasing time. The variation is very small.

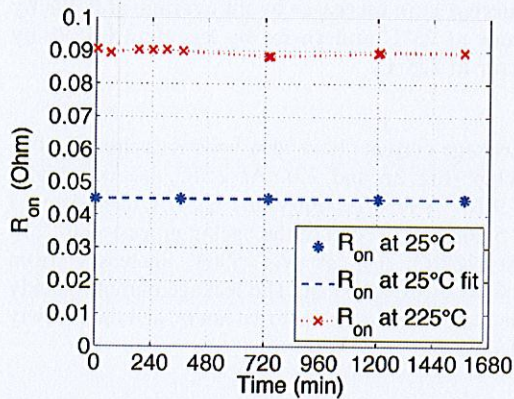


Fig. 14: Value of On-resistance versus time for a 400mA base current. Blue stars are  $R_{on}$  values at 25°C, blue dashed line is a fitted curve at 25°C and red dotted line with crosses as markers is  $R_{on}$  values at 225°C.

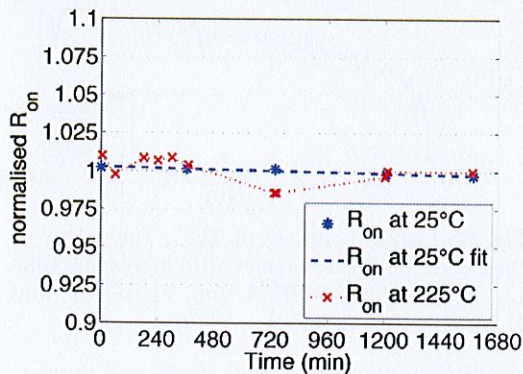


Fig. 15: Evolution of the On-resistance normalised by its mean value versus time for a 400mA base current. Blue stars are normalised  $R_{on}$  values at 25°C, blue dashed line is a fitted curve at 25°C and red dotted line with crosses as markers is normalised  $R_{on}$  values at 225°C. The resistance decreases by an average of 0.04% by hour.

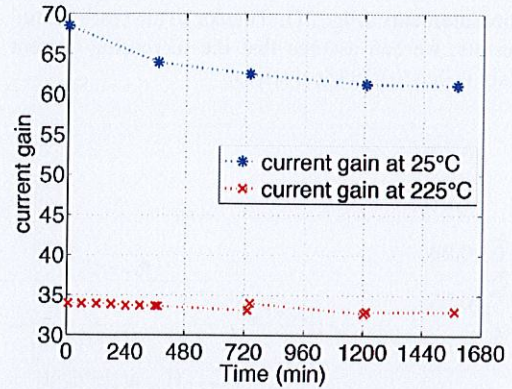


Fig. 16: Current gain ( $\beta$ ) versus time for  $I_B=200\text{mA}$   $V_{CE}=2.5\text{V}$ . Blue dotted line with stars as is  $\beta$  values at 25°C, red dotted line with crosses as markers is  $\beta$  values at 225°C.

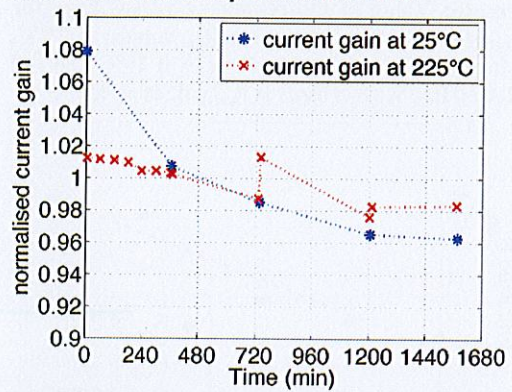


Fig. 17: Evolution of current gain ( $\beta$ ) normalised by its mean value versus time. Blue dotted line with stars as markers is  $\beta$  values at 25°C, red dotted line with crosses as markers is  $\beta$  values at 225°C. The current gain decreases by an average of 0.46% by hour at 25°C and by 0.15% by hour at 225°C.

#### S#5 Fifth setup: 225°C thermal stress and 10kHz electrical stress

The fifth device was subjected to an additional 10kHz electrical stress, with the same 500V source and 150Ω load as in previous test.

Its initial On-resistance was 40mΩ at 25°C (Fig. 18) and increased by 48% after 26 hours of ageing (Fig. 19). Thus the resistance varies on average by 1.8% per hour. This variation fits well with the 18% variation in 10 hours observed in the first setup.

The On-resistance at 225°C is about 105mΩ (Fig. 18) and almost did not change (Fig. 19).

The current gain  $\beta$  is about 60 at 25°C and increased slightly (6% after 26 hours) while  $\beta$  is 30 at 225°C and its variation range is 5% during the



measurements (Fig. 21). Thanks to the forth setup results, we can assume that the increasing current gain is due to electrical stress.

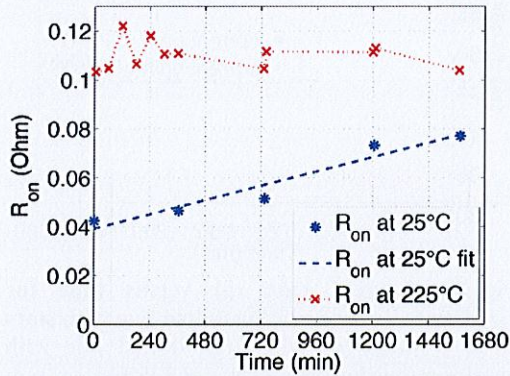


Fig. 18: Value of On-resistance versus time for  $I_{BE}=400\text{mA}$ . Blue stars are  $R_{on}$  values at  $25^\circ\text{C}$ , blue dashed line is a fitted curve at  $25^\circ\text{C}$  and red dotted line with crosses is  $R_{on}$  values at  $225^\circ\text{C}$ .

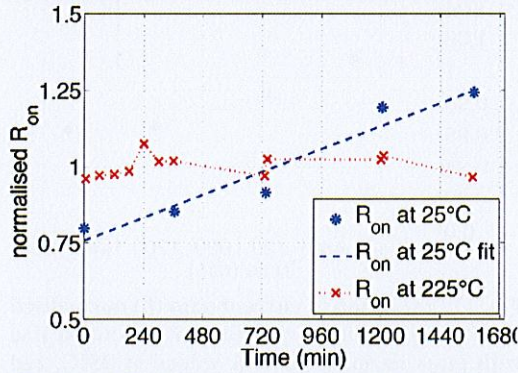


Fig. 19: Evolution of the On-resistance normalised by its mean value versus time for  $I_{BE}=400\text{mA}$ . Blue stars are normalised  $R_{on}$  values at  $25^\circ\text{C}$ , blue dashed line is a fitted curve at  $25^\circ\text{C}$  and red dotted line with crosses is normalised  $R_{on}$  values at  $225^\circ\text{C}$ . The resistance increases by an average of 1.8% by hour at  $25^\circ\text{C}$  and varies by less than 0.07% by hour at  $225^\circ\text{C}$ .

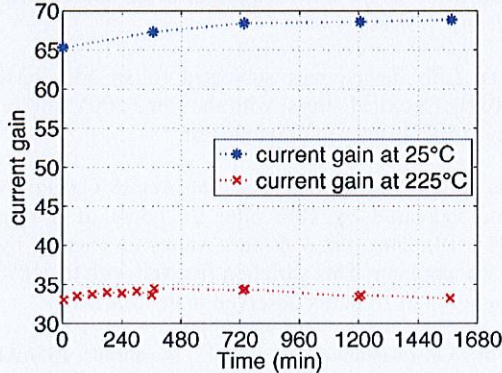


Fig. 20: Current gain ( $\beta$ ) versus time for  $I_B=200\text{mA}$   $V_{CE}=2.5\text{V}$ . Blue dotted line with stars is  $\beta$  values at  $25^\circ\text{C}$ , red dotted line with crosses is  $\beta$  values at  $225^\circ\text{C}$ .

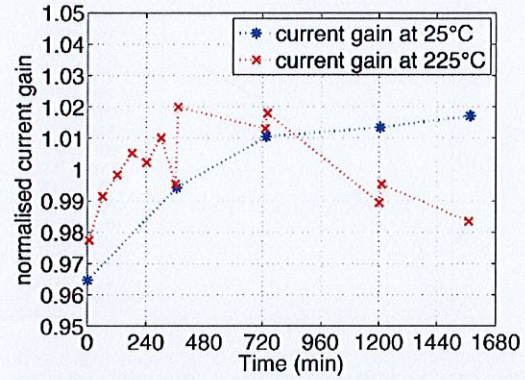


Fig. 21: Evolution of current gain ( $\beta$ ) normalised by its mean value versus time. Blue dotted line with stars is  $\beta$  values at  $25^\circ\text{C}$ , red dotted line with crosses is  $\beta$  values at  $225^\circ\text{C}$ . The current gain increases by an average of 0.2% by hour at  $25^\circ\text{C}$  and varies by less than 0.15% by hour at  $225^\circ\text{C}$ .

Leakage currents have also been measured for this setup (Fig. 22 and 23). At  $25^\circ\text{C}$ ,  $I_{CE}$  is initially  $3.9 \cdot 10^{-10}\text{A}$  for  $V_{CE}=500\text{V}$  and  $I_{BE}=0\text{A}$ , and becomes  $2.5 \cdot 10^{-9}\text{A}$  at the end of the ageing process (Fig. 22). At  $225^\circ\text{C}$ ,  $I_{CE}$  at  $V_{CE}=500\text{V}$  increases from  $1.8 \cdot 10^{-8}\text{A}$  to  $4.7 \cdot 10^{-6}\text{A}$ . The leakage current quickly increases within the first two hours, and then slowly decreases.

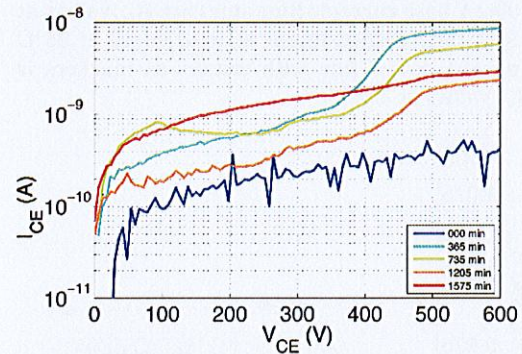


Fig. 22: Leakage current at  $25^\circ\text{C}$ . The colour of the curves becomes warmer with increasing time.  $I_{CE}$  is initially  $3.9 \cdot 10^{-10}\text{A}$  for  $V_{CE}=500\text{V}$  and  $I_{BE}=0\text{A}$



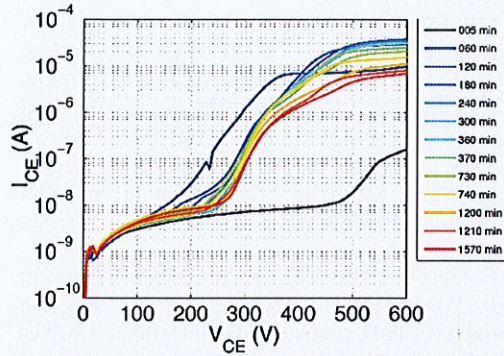


Fig. 23: Leakage current at 225°C. The colour of the curves becomes warmer with increasing time.

*S#6 Sixth setup: 225°C thermal stress and DC stress*

Besides the thermal stress, the sixth device was subjected to a 3A DC electrical stress.

Its initial On-resistance was 42mΩ at 25°C and 95mΩ at 225°C (Fig. 24) and increased by less than 1% after 26 hours (Fig. 25).

The current gain with DC stress almost follows the same variation as in the previous setup. It increases by 12% at 25°C and varies by less than 6% at 225°C (Fig. 27). At 225°C, it seems that electrical stress and thermal ageing compensate each other.

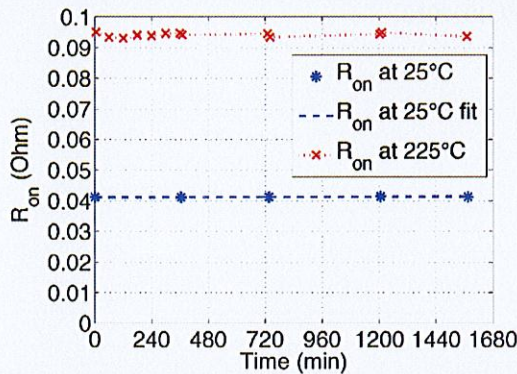


Fig. 24: Value of On-resistance versus time for a 400mA base current. Blue stars are  $R_{on}$  values at 25°C, blue dashed line is a fitted curve at 25°C and red dotted line with crosses as markers is  $R_{on}$  values at 225°C.

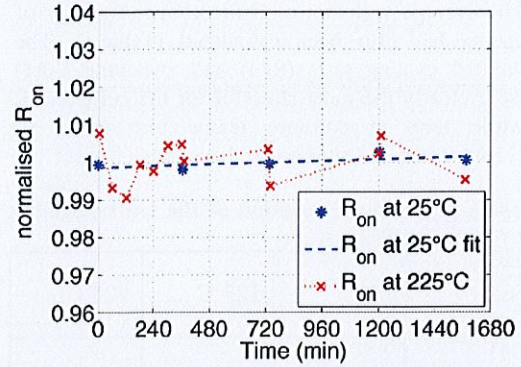


Fig. 25: Evolution of the On-resistance normalised by its mean value versus time for a 400mA base current. Blue stars are normalised  $R_{on}$  values at 25°C, blue dashed line is a fitted curve at 25°C and red dotted line with crosses as markers is normalised  $R_{on}$  values at 225°C. The resistance varies by less than 0.04% by hour at 25°C and by 0.07% by hour at 225°C.

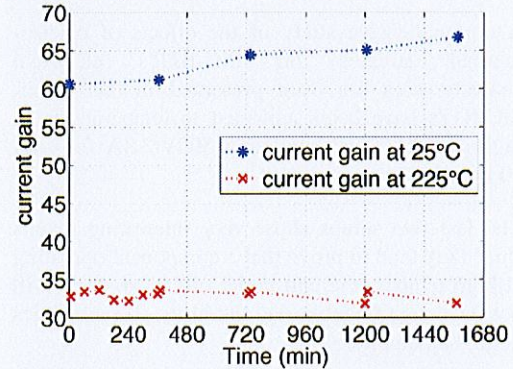


Fig. 26: Current gain ( $\beta$ ) versus time for  $I_B=200\text{mA}$   $V_{CE}=2.5\text{V}$ . Blue dotted line with stars as markers is  $\beta$  values at 25°C, red dotted line with crosses as markers is  $\beta$  values at 225°C.

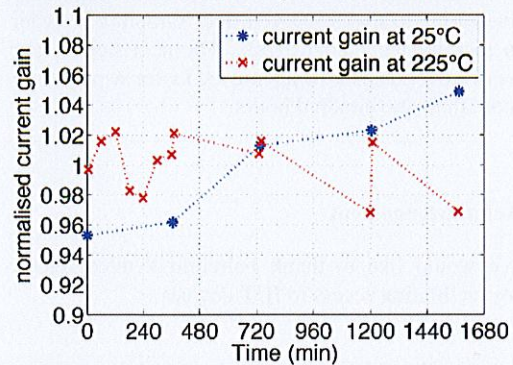


Fig. 27: Evolution of current gain ( $\beta$ ) normalised by its mean value versus time. Blue dotted line with stars as markers is  $\beta$  values at 25°C, red dotted line with crosses as markers is  $\beta$  values at 225°C. The current gain increases by an average of 0.36% by hour at 25°C and varies by less than 0.15% by hour at 225°C.



The average variation of On-resistance by hour of ageing has also been calculated (Table 1). The thermal cycling tests (S#3) and switching (S#1) were clearly the most stressful for the component, while tests at constant temperature (S#2) or constant current (S#6) do not have much impact.

**Table 1: Average variation of the On-resistance by hour for each setup.**

$\frac{\Delta R_{on}}{R_{on}} / \Delta t$ (in %/h)	25°C	125°C	225°C
S#1	1.8		
S#2	-1.2	-0.3	
S#3	2.2	2.2	
S#4	-0.04		-0.04
S#5	1.8		<0.07
S#6	<0.04		<0.04

## Conclusion

A comprehensive study of the effects of electro-thermal stresses on SiC-BJT's electrical characteristics has been presented in this paper. SiC-BJTs have been subjected to temperatures as high as 225°C and switching 500V/3.3A for over 10 hours.

The last two setups show very interesting results since they tend to prove that a component operating at high temperature and under electrical stress will not have significant variations in its characteristics at high temperature.

Besides, we noted that the changes were relatively significant during the early hours of aging, so we made more measurements at the beginning of each of our tests. However, we think it would be interesting to make an even finer sampling in order to identify more than trends. The next step of our work also consists in ageing BJTs for a period of more than one hundred hours.

## Acknowledgment

We would like to thank Fairchild Semiconductor for facilitating access to BJT devices.

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