# Advanced Electrical characterisation of high voltage 4H-SiC PiN diodes

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**Abstract.** This paper reports the design, the processing, the static characterisation, the switching behaviour and the high current stress test of 10 kV aimed 4H-SiC bipolar diodes. The actual breakdown voltage of the selected devices is between 7 kV and 8 kV. The switching characterisations show a good behaviour with a $t_{rr}$ of only 90 ns. No degradation was observed after the application of 10 000 high current pulses during the stress tests.

## Introduction

4H-SiC bipolar diodes are key devices for high voltage converters and smart grids applications [1]. Although the unipolar-bipolar limit remains to be defined, bipolar devices cannot be replaced by the unipolar counterparts when it comes to high voltage applications. This is a consequence of the high current injection capabilities of bipolar devices, which make them capable of higher surge current robustness.

In the frame of SuperGrid Institute (SGI), high voltage bipolar devices have been designed, fabricated and characterised.

## Device Processing

PiN diodes were fabricated by Ion Beam Services on $N^+$ substrates, using a 110 µm thick epilayer with a doping concentration of $7x10^{14}$ cm$^{-3}$. A cross-section of the PiN diode is shown in Fig. 1.

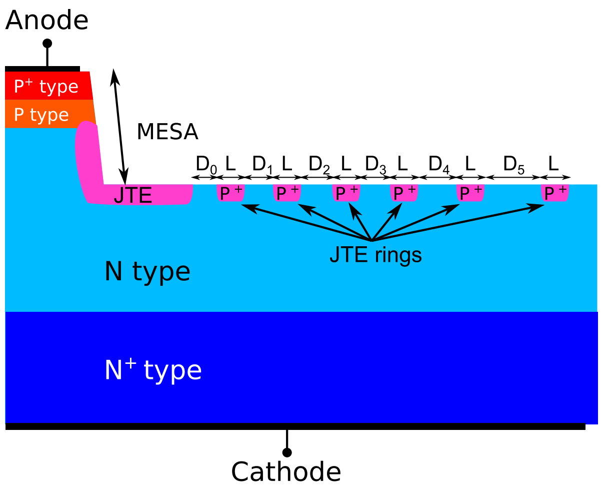


Fig. 1 – Schematic cross-view of the fabricated PiN diode.

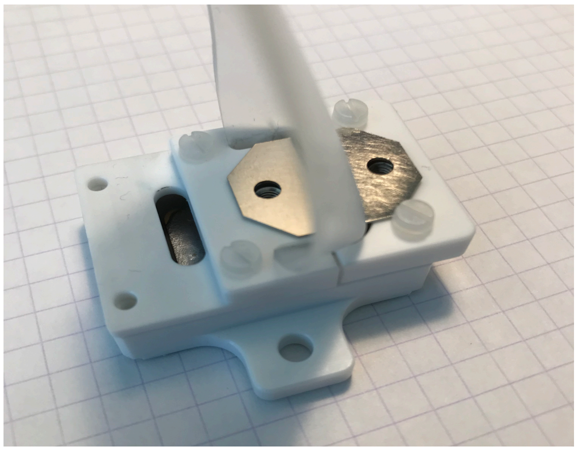

Fig. 2 – 10 kV capable packaging.

The edge termination of the PiN diodes includes MESA and Junction Termination Extension (JTE) 400 µm long surrounded by 6 JTE-rings with increasing spacing between them ($D_i$). The diode is squared with a length of 7.7 mm (0.6 $cm^2$) of radius curvature on the corners fixed to 600 µm. After characterising all devices at wafer level, the best ones were diced and packaged in a specific package developed by DeepConcept company [2] as shown in Fig. 2.

## Device Characterisation and Stressing

The characterisation and stress cycling is done as shown in figure 3. After a full static and switching characterisation, the device is mounted on the rig and is submitted to the stress protocol. The forward and reverse characterisation is done after 1, 10, 100, 1000 and 10 000 pulses of high current. At the end of the stress test, the electrical parameters of the devices are checked for any stress caused variation. Further tests can be done to analyse how much the robustness and reliability of the device has been affected.

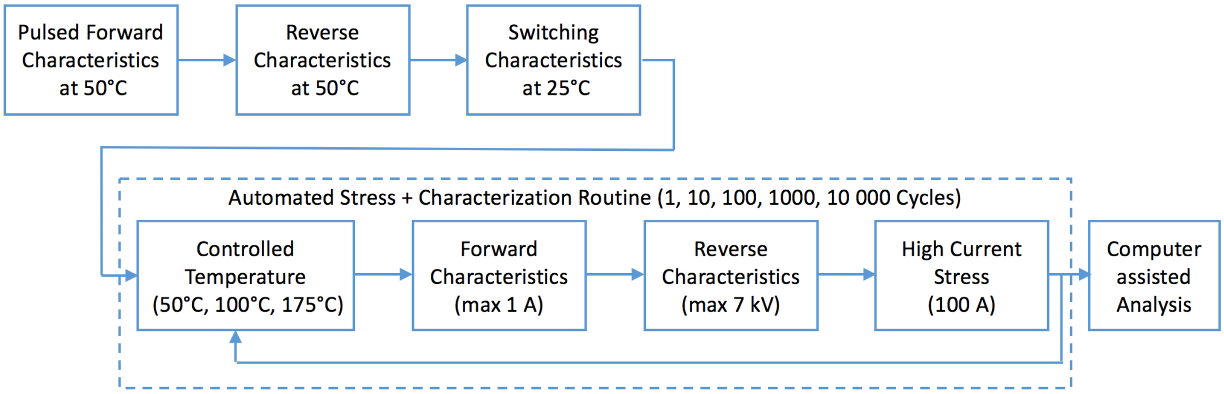


Fig. 3 – The specific characterisation procedure including the stress test that has been applied to the diodes.

The full characterisation and stress automated rig is fully described in [3]. The current capabilities have been doubled and the reverse bias voltage is now limited to 8 kV.

**Static Characteristics.** Forward and reverse characteristics of the diode are shown in Fig. 4 and Fig. 5 respectively. The measurements have been carried out at 50°C, 100°C and 175°C. The presented device has a threshold voltage of 3 V at 1 A, a dynamic resistance of 69 mΩ and a breakdown voltage of 6.8 kV.

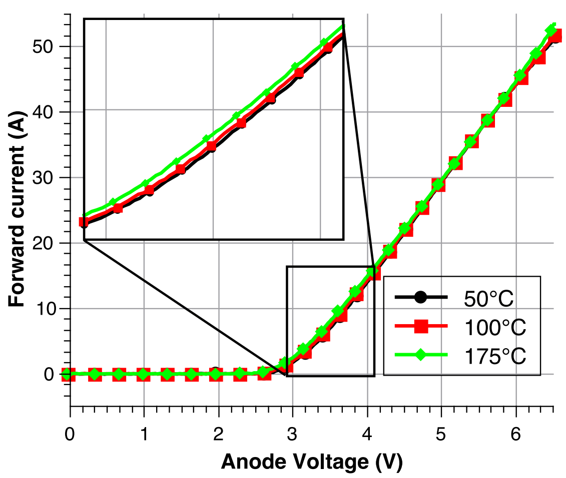


Fig. 4 – Pulsed (50 µs) Forward Characteristics of the SGI 4H-SiC PiN diode.

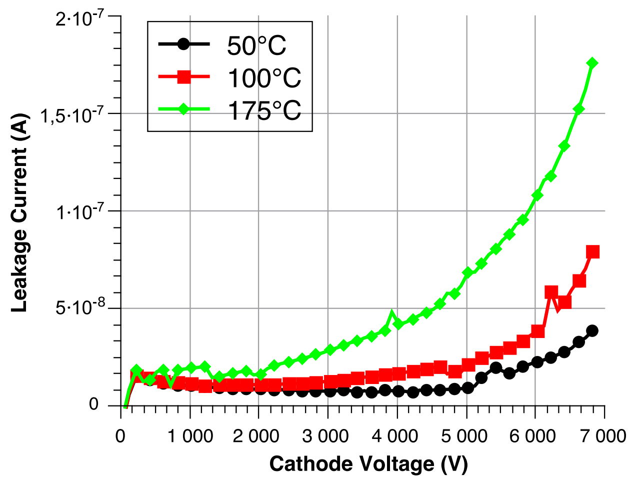


Fig. 5 – Reverse Characteristics of the SGI 4H-SiC PiN diode.

**Switching Measurements.** Double Pulse Tests (DPT) [4,5] have been achieved on unstressed components. The DPT circuit was adapted to high voltage switching. The high voltage controlled switch (15 kV 1200 A) is supplied by Comeca [6]. It is a serial and parallel assembly of IGBTs.

Fig. 6 shows the turn-off measurement for two forward currents. The constant di/dt obtained in the first phase of the turn-off show the quality of the DPT circuit.

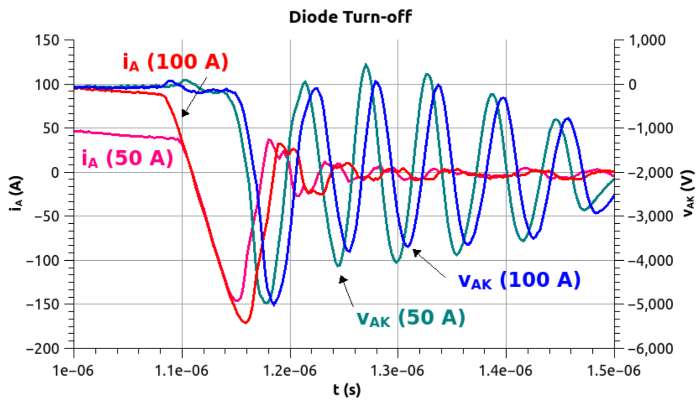


Fig. 6 – DPT turn-off measurements for different forward current $i_F$ (50 A and 100 A) for a reverse applied voltage $V_R$=2.0 kV. The di/dt is clearly constant during the turn-off first phase with is classical in PIN turn-off.

Fig. 7 shows the turn-off measurement for three reverse applied voltage. The maximal reverse voltage $V_{RM}$ reaches 6.8 kV.

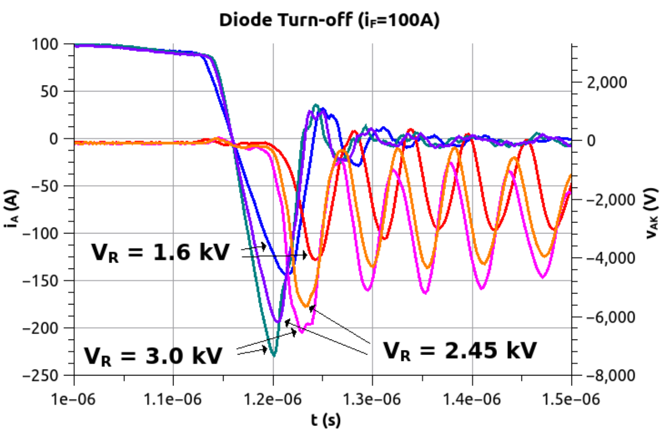


Fig. 7 – DPT turn-off measurements for different reverse applied voltage $V_R$ (1.6 to 3.0 kV) for a forward current $I_F$=100 A.

The fabricated bipolar diodes show good switching performances with $t_{rr}$ about 90 ns at 100 A and 2 kV.

**High current Stress.** The repetitive high current used to stress the devices were 10 ms half-sine pulses with 100 A peak. After 10 000 pulses at different temperatures, static measurements are carried out to plot the evolution of different electrical parameters ($V_{th}$, $R_{on}$). The extracted data are given in the following table.

Tab. 1 – Dynamic resistance and threshold voltage of the diode for different temperatures.

| Temperature (°C) | Dynamic resistance (mΩ) | | Threshold voltage @ 0,5 A (V) | |
|---|---|---|---|---|
| | before | after | before | after |
| 50 | 513 | 503 | 2,93 | 2,94 |
| 100 | 526 | 530 | 2,87 | 2,88 |
| 175 | 616 | 609 | 2,76 | 2,76 |

The forward and reverse characteristics before and after the 10 000 high current pulses are shown in Fig. 8 and Fig. 9 respectively. It seems that stressing the device doesn't alter its forward performance.

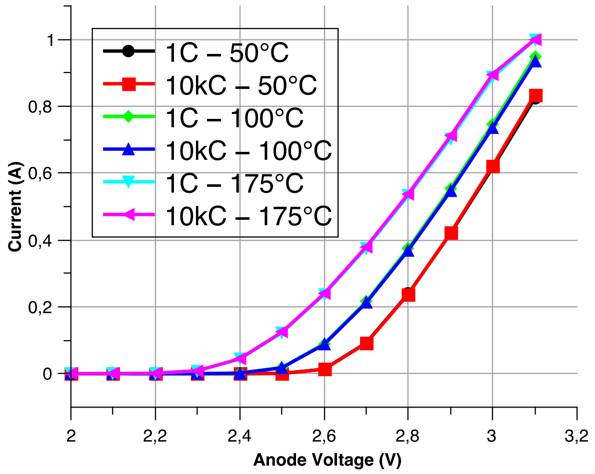


Fig. 9 – Forward characteristics at increasing temperature after stress.

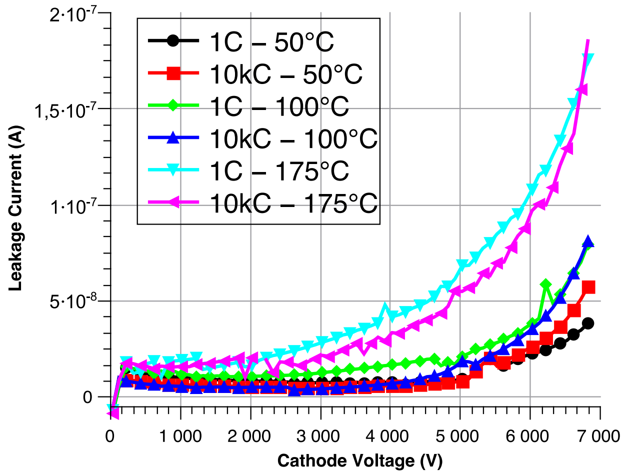


Fig. 10 – Reverse characteristics at increasing temperature after stress.

Neither the resistance, nor the threshold voltage seem to be affected by the high current stress. Whereas the reverse characteristics seems to be improved by the cycling at higher temperature. The leakage current is lower after the cycling for 100°C and 175°C, but at this stage it can not be attributed to the stress itself. The effect may be as well a consequence of high temperature stress during a long time, which could relieve mechanical stress and affect the trapped charge at the interface between oxide and JTE. Further tests are necessary to determine the origin of the leakage current improvement. Nevertheless, the stress has almost no effect on the device, which is an indicator of its outstanding robustness.

## Summary


The actual blocking voltage is 80% of the 10 kV aimed breakdown voltage. Static and switching characteristics show good performances. According to the results, it seems that there is no degradation of the static electrical characteristics after stress. The slight improvement of the leakage current is not necessarily an effect of high current, but can be a consequence of high temperature stress. In the future studies, higher current levels will be used for stress tests and the effect on both static and switching performance will be analysed.



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