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ARTICLE *in* SOLID-STATE ELECTRONICS · MARCH 2004

Impact Factor: 1.5

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Solid-State Electronics 48 (2004) 491–493
SOLID-STATE ELECTRONICS
www.elsevier.com/locate/sse

Short Communication

Fast switch-off of high voltage 4H–SiC npn bipolar junction transistor from deep saturation regime

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Abstract

It has been demonstrated experimentally that the switch-off time of a high-voltage power (1.8 kV, 3.8 A) 4H–SiC bipolar junction transistor in the deep-saturation mode can be decreased from 200 to 25 ns by using an appropriate switch-off base signal. In such conditions, the switch-off time in the common-emitter configuration can be shorter than the switch-on time.

Keywords: Silicon carbide; Bipolar junction transistor; Fast switch-off

1. Introduction

In recent years, considerable progress has been made in developing power 4H–SiC-based bipolar devices: diodes, bipolar junction transistors (BJTs), and thyristors [1–3]. Static and transient characteristics of power (1.8 kV, 3.8 A) 4H–SiC npn BJTs with current gain β of about 30 at room temperature have been studied recently [4,5].

In all bipolar devices, the switch-off process is, as a rule, the slowest transient process limiting the highest achievable operation frequency. For power switching BJTs the problem of the switch-off time is especially important because the switch-on time becomes shorter, and switch-off time, by contrast, longer with increasing saturation level [4,6].

In this paper, we report for the first time on a strong decrease in the switch-off time of high voltage 4H–SiC npn BJTs in the deep saturation mode.

2. Experimental

1.8 kV, 3.8 A 4H–SiC BJTs were fabricated by Cree Inc., with a 20-μm-thick n^--collector layer doped to 2.5×10^{15} cm^{-3}, 1-μm p-base layer doped to 2.5×10^{17} cm^{-3}, and 0.75-μm n^+-emitter layer. The p^+-contact regions were formed in the base by aluminum implantation. The collector junction was terminated with a junction termination extension formed by boron implantation. The emitter-base configuration of 1×1.4 mm^2 devices had inter-digitized "overlayer" geometry, with base finger pitch of 23 μm and emitter finger width of 12 μm. The total length of the emitter fingers was 6 cm (total emitter area $S_E = 7.2\times10^{-3}$ cm^2, total collector area $S_C = 1.4\times10^{-2}$ cm^2). The base current gain β measured in the active mode at base current $I_b = 1$ A was equal to 20. For more details see Refs. [2,5].

The BJT was turned on in the common-emitter (CE) configuration by applying a long positive gate pulse. The characteristic BJT switch-on times were studied thoroughly in Ref [4]. The BJT was turned off by switching off the gate pulse or, alternatively, by applying a negative base current pulse.

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doi:10.1016/j.sse.2003.09.014

3. Results and discussion

The BJT switch off was studied in the deep saturation mode at base current $I_b = 1$ A, collector bias $V_0 = 250$ V, and collector load resistance $R_L = 50\ \Omega$. The saturation parameter $N = (\beta I_b - I_{C\,sat})/I_{C\,sat}$ [6], where I_b is the input base current, and $I_{C\,sat} \approx V_0/R_L$ is the saturated collector current. Hence, $N \approx 3$ for the given I_b, V_0, and R_L. It is noteworthy that the collector current density in this regime is 700 A/cm^2.

Curve 1 in Fig. 1a shows the decay of the base current during the conventional switch-off process. The total time of the base current drop is equal to 35 ns. The time dependence of the collector current I_C, which corresponds to this mode is represented by curve 1 in Fig. 1b. It is seen that the total time of the collector current drop is 200 ns.

As shown in Ref. [4], the total rise time of the collector current in the CE configuration in the active mode, which is equal to 130 ns, is defined by the $\beta C^*_{CB} R_L$ product, where C^*_{CB} is the effective collector–base capacitance. With N increasing, the total rise time of the collector current decreases, to become only 50 ns at $N = 4$ [3]. Hence, just the time of the collector current drop defines the limiting operation frequency.

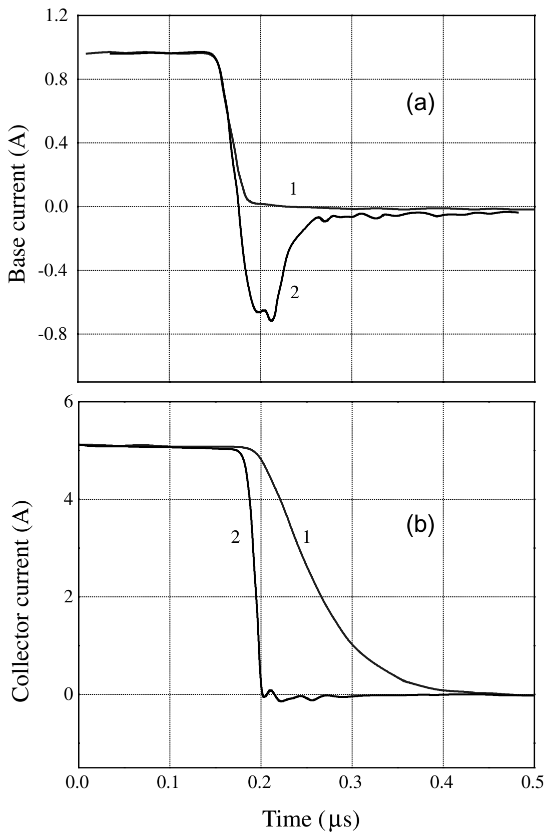

Fig. 1. Time dependences of (a) base current and (b) collector current during the switch-off process for a high-voltage (1.8 kV, 3.8 A) 4H–SiC BJT in the deep saturation mode. Curve 1 show the base and collector current waveforms in the conventional switch-off mode, when the base current decreases to zero. Curve 2 show the base and collector current waveforms in the mode with appreciable switch-off reverse base pulse.

The switch-off time, Δt_{off}, can be made shorter by applying a negative base pulse in the switch-off process (curve 2 in Fig. 1a and b). For the case shown in Fig. 1 ($I_b^+ = 1$ A, $I_C = 5$ A, $N = 3$), the minimum $\Delta t_{off} = 25$ ns is reached at $I_b^- \approx 0.7$ A. The time dependence of the base current (curve 2 in Fig. 1a) is virtually not affected by the collector bias V_0 and this dependence has just the same form across the whole range of V_0 variation, from 0 to 250 V.

The time dependence of the base current in the switch-off process (curve 2 in Fig. 1a) is qualitatively similar to that of the current waveform in measurements of the reverse current recovery for p–n junctions [7,8]. Minority carriers (electrons) are removed from the base by the negative base current. It is very interesting to note that the collector current becomes zero when a considerable charge of non-equilibrium electrons and holes exists in the base. Comparison of curve 2 in Fig. 1a and b readily shows that a noticeable base current is observed approximately 120 ns after the break of the collector current.

It is noteworthy that the drastic shortening of the switch-off time leads to a remarkable decrease in energy loss per switching cycle and an increase in the maximum operation frequency of switching power SiC BJTs.

4. Conclusion

The switch-off time of a power high-voltage (1.8 kV, 3.8 A) 4H–SiC BJT in the deep saturation mode can be decreased from 200 to 25 ns by applying an appropriate switch-off base signal. In such conditions, the switch-off time in the CE configuration is shorter than the switch-on time. The decrease in the switch-off time makes it possible to diminish remarkably the energy loss per switching cycle and results in higher possible maximum operation frequency of switching.

Acknowledgements

This work was funded by the Office of Naval Research MURI program, contract # N00014-95-1-1302, monitored by Dr. John Zolper. At All-Russia Electrotechnical Institute and Ioffe Institute this work was supported by Russian Foundation for Basic Research (grant N02-02-16496).

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