NASA/CR—2006-214257

Switching Characteristics of a 4H-SiC Based Bipolar Junction Transistor to 200 °C

Janis M. Niedra
QSS Group, Inc., Cleveland, Ohio

November 2006

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI Program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Reports Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include creating custom thesauri, building customized databases, organizing and publishing research results.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at *http://www.sti.nasa.gov*

- E-mail your question via the Internet to *help@sti.nasa.gov*

- Fax your question to the NASA STI Help Desk at 301–621–0134

- Telephone the NASA STI Help Desk at 301–621–0390

- Write to:
  NASA STI Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076–1320

NASA/CR—2006-214257

Switching Characteristics of a 4H-SiC Based Bipolar Junction Transistor to 200 °C

Janis M. Niedra
QSS Group, Inc., Cleveland, Ohio

Prepared under Contracts NAS3–98008 and NAS3–00145

National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

November 2006

Acknowledgments

This work was sponsored by the NASA Glenn Research Center under NAS3–98008 and NAS3–00145 with G.E. Schwarze as the Project Manager.

Level of Review: This material has been technically reviewed by expert reviewer(s).

Available from

NASA Center for Aerospace Information
7115 Standard Drive
Hanover, MD 21076–1320

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

Available electronically at http://gltrs.grc.nasa.gov

Switching Characteristics of a 4H-SiC Based Bipolar Junction Transistor to 200 °C

Janis M. Niedra
QSS Group, Inc.
Cleveland, Ohio 44135

Abstract

Static curves and resistive load switching characteristics of a 600 V, 4 A rated, SiC-based NPN bipolar power transistor (BJT) were observed at selected temperatures from room to 200 °C. All testing was done in a pulse mode at low duty cycle (~0.1 percent).

Turn-on was driven by an adjustable base current pulse and turn-off was accelerated by a negative base voltage pulse of 7 V. These base drive signals were implemented by 850 V, gated power pulsers, having rise-times of roughly 10 ns, or less. Base charge sweep-out with a 7 V negative pulse did not produce the large reverse base current pulse seen in a comparably rated Si-based BJT. This may be due to a very low charge storage time. The decay of the collector current was more linear than its exponential-like rise.

Switching observations were done at base drive currents (I_B) up to 400 mA and collector currents (I_C) up to 4 A, using a 100 Ω non-inductive load. At I_B = 400 mA and I_C = 4 A, turn-on times typically varied from 80 to 94 ns, over temperatures from 23 to 200 °C. As expected, lowering the base drive greatly extended the turn-on time. Similarly, decreasing the load current to I_C = 1 A with I_B = 400 mA produced turn-on times as short as 34 ns. Over the 23 to 200 °C range, with I_B = 400 mA and I_C = 4 A, turn-off times were in the range of 72 to 84 ns with the 7 V sweep-out.

Testing Circuits

A constant voltage source feeding a resistive load in the collector circuit was chosen to make up a most simple power side of the circuit. A nearby charged capacitor served well as the power source, since operation was with sub-microsecond pulses at no more than 0.1 percent duty cycle. The BJT itself was mounted to a temperature-controlled plate, with a thermocouple attached directly to the BJT. A general circuit diagram is provided in figure 1.

A fast rise, high voltage pulser is suitable for providing a very fast-rise current pulse to the base of a BJT. The DEI model HV-1000 is capable of pulse heights up to 850 V into a 50 Ω load at a low duty cycle, with a rise-time of 10 ns and durations up to 10 µs. Figure 2 shows the basic arrangement, omitting the required external high voltage supply and trigger pulser. Since the forward V_{BE} is only of the order of 10 V, good quality current pulses can be obtained into the base of the BJT. The duty cycle can be set as low as one pleases and about 0.1 percent was used.

A turn-off circuit was devised to accelerate the charge carrier sweep-out from the base region by providing a negative V_{BE} of about 7 V to terminate the collector current from its steady state value. In this way, turn-off transients comparable in duration, or even shorter, than the turn-on transients could be obtained. Such a circuit was implemented by adding a negative pulser (a DEI model HV-1000N) to the circuit in figure 2. A Zener diode was used to set the negative voltage level. The passive components in these circuits need not have a high power rating, due to the very low duty cycle.

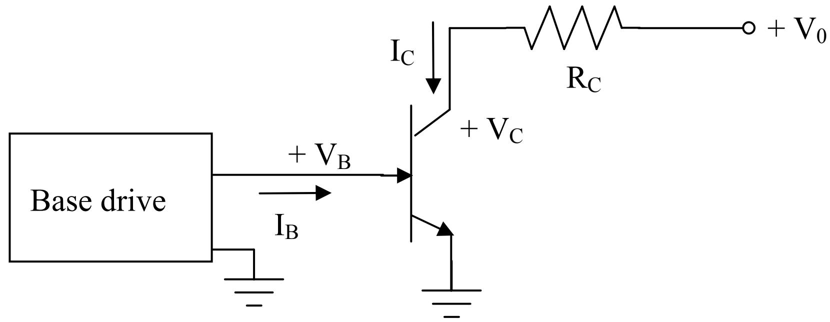

Figure 1.—Basic resistive load turn-on switching test circuit. Currents I_B and I_C are sensed by high-speed current transformers (Tektronix CT1 and CT2). Potential V_B is sensed by a 1 kΩ input impedance, fast-rise probe and potential V_C by a Tektronix 10X probe. R_C is a carbon composition resistor, normally set to 100Ω.

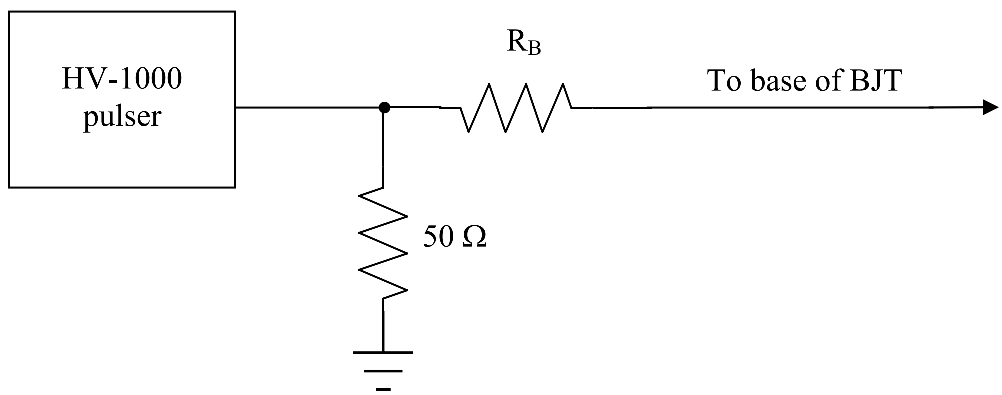

Figure 2.—Block circuit diagram for a pulsed constant current base drive. R_B values of 300 Ω to 1 kΩ were used.

Figure 3 provides a diagram of the combined circuit, used primarily for capturing the turn-off transient, once steady IC has been established by the positive base drive part. The two high voltage pulsers are timed by trigger signals from two channels of a delay trigger pulse generator, a Berkeley Nucleonics model 555. And the output from the HV-1000N overcomes that from the HV-1000 sufficiently to activate the Zener diode, thus setting the negative base drive level. This circuit was constructed with low power resistors and diodes for use at very low duty cycle only. Moreover, the model 555 was unable to gate the high voltage pulsers at duty cycles exceeding 10 percent. But using this somewhat elaborate setup, base voltage transition times, from positive to negative in less than 10 ns, could be achieved.

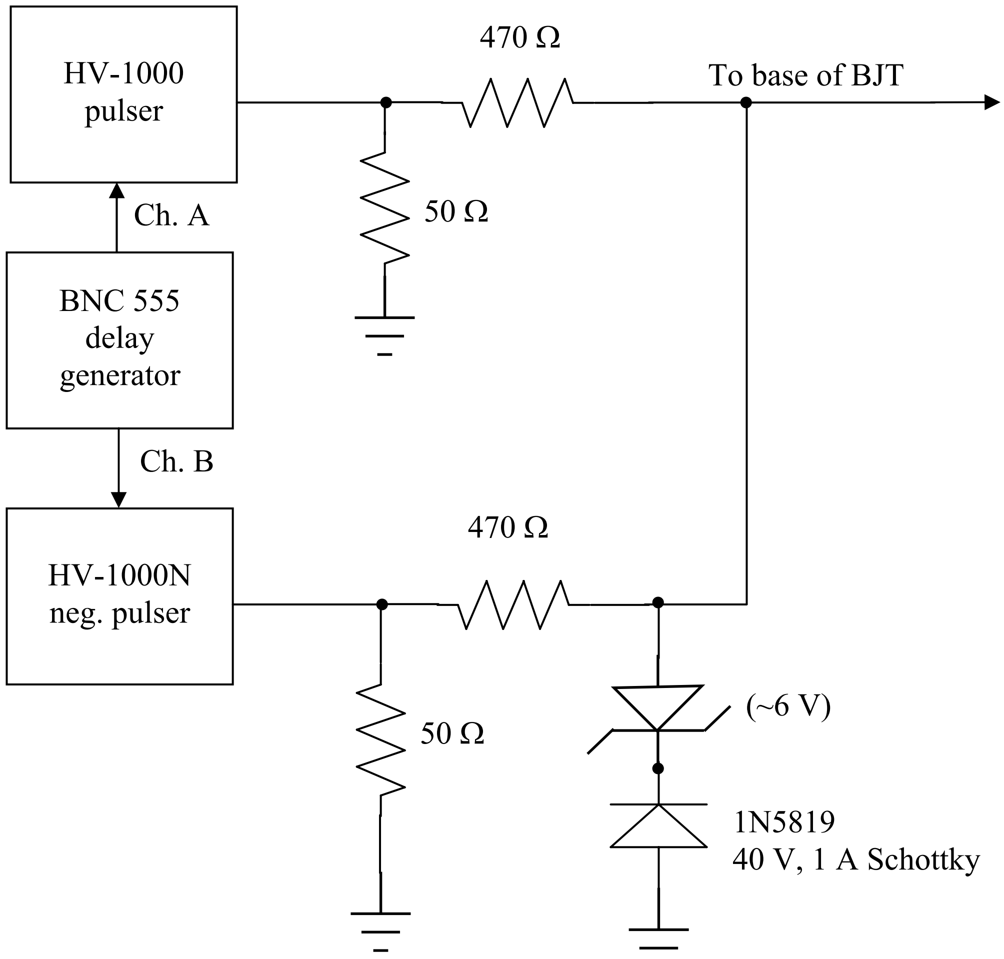

Figure 3.—Block circuit diagram of a pulsed constant voltage base sweep-out drive added to the constant current base drive of figure 2. The reverse V_{BE} is set by the Zener diode. The delay generator provides timed gating pulses, Channels A and B, to the positive and negative high voltage pulsers.

High Temperature Switching Data Overview

The data in table I presented below shows the amount of base drive needed to get acceptable switching at selected temperatures and load currents for the SiC-based BJT labeled as P2. This data was taken using the constant current base drive mode, primarily because it is easier to set the current to a given value. The values of currents indicated are their steady state values, reached typically in less than a microsecond.

At the 0.1 percent duty cycle used, no temperature rise above ambient of the BJT's case could be resolved. The case was, however, fastened to a BN substrate to provide good heat conductivity. An estimate of the switching loss of 10^{-4} J per on-off cycle thus gives an estimate of an average power loss of only 0.1 W. Device temperature rise can then be estimated from either the specific heat (range 0.3 to 1.0 J/(g K)) or the thermal conductivity (range 2 to 5 W/(cm K)) of SiC. Assuming a chip 1 mm thick and

3 mm on side, either estimate gives a temperature rise less than 1 K. Hence it seems safe to assume that the junction temperature is within a degree or so of that of the case in these pulse measurements.

TABLE I—SWITCHING DATA, WITH 100 Ω LOAD RESISTOR AND –7 V BASE SWEEP-OUT

(a) Data at 23 °C

I_B (mA)	I_C (A)	V_0 (V)	$\tau_{IC, ON}$ (ns) (10 to 90%)	$\tau_{IC, OFF}$ (ns) (10 to 90%)
400	4.0	402	80	84
300	"	402	116	
200	"	402	198	
100				
400	3.0	308	65	74
300	"	308	92	
200	"	308	156	
100	"	304	>370	
400	2.0	208	49	64
300	"	206	71	
200	"	206	116	
100	"	204	288	
400	1.0	106	34	
300	"	106	45	
200	"	104	70	
100	"	104	162	

(b) Data at 150 °C

I_B (mA)	I_C (A)	V_0 (V)	$\tau_{IC, ON}$ (ns) (10 to 90%)	$\tau_{IC, OFF}$ (ns) (10 to 90%)
400	4.0	410	90	72
300	"	410	132	
200	"	408	248	
400	3.0	308	74	63
300	"	306	103	
200	"	308	181	
100	"	306	>361	
400	2.0	206	56	57
300	"	206	78	
200	"	204	125	
100	"	202	334	
400	1.0	106	36	
300	"	106	49	
200	"	104	76	
100	"	104	170	

TABLE I—Concluded.

(c) Data at 175 °C

I_B (mA)	I_C (A)	V_0 (V)	$\tau_{IC,\ ON}$ (ns) (10 to 90%)	$\tau_{IC,\ OFF}$ (ns) (10 to 90%)
400	4.0	408	94	73
300	"	406	133	
200	"	406	249	
100	"	>402	>360	
400	3.0	308	74	64
300	"	306	104	
200	"	306	176	
100	"	>306	>373	
400	2.0	206	55	57
300	"	206	79	
200	"	204	128	
100	"	204	334	
400	1.0	106	36	
300	"	106	47	
200	"	104	75	
100	"	102	171	

(d) Data at 200 °C

I_B (mA)	I_C (A)	V_0 (V)	$\tau_{IC,\ ON}$ (ns) (10 to 90%)	$\tau_{IC,\ OFF}$ (ns) (10 to 90%)
400	4.0	408	94	72
300	"	408	135	
200	"	408	241	
400	3.0	308	74	65
300	"	306	107	
200	"	304	181	
100	"	>302	>373	
400	2.0	204	56	58
300	"	204	78	
200	"	204	126	
100	"	204	340	
400	1.0	106	36	
300	"	106	49	
200	"	104	77	
100	"	104	169	

Summary of Observations

The data tables indicate that collector current turn-on transition times of 100 ns, or less, can be readily achieved with a 4 A current and a 100 Ω resistive load. This, however, requires a 400 mA base drive current step, at which the V_{BE} steadies out to roughly 10 V, with 4 A of collector current flowing. As expected, this turn-on time is sensitive to the base drive and the load currents, with only a slight sensitivity to temperature, from 23 to 200 °C. If the load current is lowered, then similar times can be obtained at a lower base drive. Here the externally measured case temperature is thought to be a good measure of also the junction temperature, because of the very low duty cycle pulse mode and the rather low switching loss per on-off cycle.

An abrupt base turn-off was implemented by sending a negative voltage pulse to the base to overcome the positive base current pulse. Due to the low base charge storage time in this SiC device (crystal defects?), there was no need to limit the reverse base current. Without emitter junction reverse breakdown data, about 7 V was thought to be conservative. This was sufficient to give collector current decay times of the same order as its rise times. Faster times may be possible, depending on the emitter breakdown characteristics. Also, clamping the base voltage to the emitter level would certainly elongate the turn-off time. Although zero level clamping seems difficult with the pulsers, data points for a plot below a 1 V level may be feasible by omitting the Zener diode in figure 3. This has not yet been done.

The setup shown in figure 3 produces a collector current turn-off waveform that is nearly linear in time, whereas its turn-on waveform approximates closer to exponential. This makes for a difference in the switching losses when calculating these from formulas to approximate the waveforms.

Although the P2 device can switch up to at least 1.6 kW at 200 °C in a low duty cycle pulse mode, thermal conductance to case is expected to significantly reduce its capability at say 50 percent duty cycle. The estimation of junction temperature rise for a given average power dissipation in the device is problematic, at best. An experimental attempt will be described in another report.

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	November 2006	Final Contractor Report

4. TITLE AND SUBTITLE	5. FUNDING NUMBERS
Switching Characteristics of a 4H-SiC Based Bipolar Junction Transistor to 200 °C	WBS 423799.03.01 NAS3–98008 NAS3–00145
6. AUTHOR(S) Janis M. Niedra	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) QSS Group, Inc. 21000 Brookpark Road Cleveland, Ohio 44135	8. PERFORMING ORGANIZATION REPORT NUMBER E–15540
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546–0001	10. SPONSORING/MONITORING AGENCY REPORT NUMBER NASA CR—2006-214257

11. SUPPLEMENTARY NOTES

Project Manager, Gene E. Schwarze, Power and Propulsion Division, NASA Glenn Research Center, organization code RPE, 216–433–6117.

12a. DISTRIBUTION/AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE
Unclassified - Unlimited Subject Category: 33 Available electronically at http://gltrs.grc.nasa.gov This publication is available from the NASA Center for AeroSpace Information, 301–621–0390.	

13. ABSTRACT *(Maximum 200 words)*

Static curves and resistive load switching characteristics of a 600 V, 4 A rated, SiC-based NPN bipolar power transistor (BJT) were observed at selected temperatures from room to 200 °C. All testing was done in a pulse mode at low duty cycle (~0.1 percent). Turn-on was driven by an adjustable base current pulse and turn-off was accelerated by a negative base voltage pulse of 7 V. These base drive signals were implemented by 850 V, gated power pulsers, having rise-times of roughly 10 ns, or less. Base charge sweep-out with a 7 V negative pulse did not produce the large reverse base current pulse seen in a comparably rated Si-based BJT. This may be due to a very low charge storage time. The decay of the collector current was more linear than its exponential-like rise. Switching observations were done at base drive currents (I_B) up to 400 mA and collector currents (I_C) up to 4 A, using a 100 Ω non-inductive load. At I_B = 400 mA and I_C = 4 A, turn-on times typically varied from 80 to 94 ns, over temperatures from 23 to 200 °C. As expected, lowering the base drive greatly extended the turn-on time. Similarly, decreasing the load current to I_C = 1 A with I_B = 400 mA produced turn-on times as short as 34 ns. Over the 23 to 200 °C range, with I_B = 400 mA and I_C = 4 A, turn-off times were in the range of 72 to 84 ns with the 7 V sweep-out.

14. SUBJECT TERMS	15. NUMBER OF PAGES
4H-SiC bipolar junction transistor; High temperature; Switching times; Base charge sweep-out	12
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102