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Application of a New Method and Criterion for Analyzing Repetitive Surge Current in Commercial SiC Schottky Diodes

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Abstract. The repetitive peak forward surge current ($I_{F,RM}$) is a practically important parameter for SiC Schottky diodes, as it ensures reliable and robust circuit designs. However, there is no established method and criterion for this imperative parameter. Manufacturers predominantly provide the non-repetitive peak forward surge current value ($I_{F,SM}$) in datasheets, which is generally determined from derated measured peak currents that cause diode failures. Consequently, it is assumed that $I_{F,SM}$ enables diodes from various manufacturers with different structural designs to be compared in terms of their repetitive surge current performance. In this paper, we will demonstrate the need for a consistent criterion and a method to determine $I_{F,RM}$ by analyzing repetitive surge currents in representative commercially available SiC Schottky diodes. The analysis is based on a recently proposed method and criterion for the repetitive peak surge current in SiC Schottky diodes that ensures the junction temperature does not exceed the maximum device rating, which is 175°C for the commercially available devices analysed in this study.

Introduction

Silicon carbide Schottky diodes have become indispensable in modern power electronics due to their superior material properties compared to conventional silicon devices. Their wide energy gap, high critical electric field, and excellent thermal conductivity enable fast switching, low reverse recovery charge, and high efficiency operation at elevated voltages and temperatures [1, 2]. These characteristics make SiC Schottky diodes particularly attractive for applications in renewable energy systems, electric vehicles, and high-frequency power conversion, where energy efficiency, reliability, and compact form factors are paramount. A practically important parameter for ensuring the reliability of SiC Schottky diodes in such demanding applications is the repetitive peak forward surge current, $I_{F,RM}$. This parameter governs how devices perform under repeated surge or inrush conditions, such as those encountered during startup transients, short-circuit events, or highly dynamic load changes. However, despite its importance for robust circuit designs, no standardized method or criterion currently exists for specifying this imperative parameter. Manufacturers predominantly present the non-repetitive peak forward surge current, $I_{F,SM}$, in datasheets. When $I_{F,RM}$ values are provided by manufacturers, details regarding the criterion or method used to establish its value are not specified. As a result, variations in datasheet specifications among vendors make it difficult to meaningfully compare device robustness or to design circuits with reliable surge performance. Therefore, datasheet $I_{F,RM}$ values cannot be assumed to represent thermally safe repetitive operation, as they are not derived using a disclosed or standardized physical criterion. At present, the only standardized procedures for surge-current rating are defined by JEDEC for silicon rectifier diodes [3], and no equivalent standardized method exists for specifying repetitive surge current capability in SiC Schottky diodes.

To address this gap, a consistent criterion for determining $I_{F,RM}$ is required. Therefore, in this study, we perform a comparative analysis based on a recently proposed method and criterion for $I_{F,RM}$ in SiC Schottky diodes that ensures that the maximum junction temperature rating of 175°C is not exceeded [4]. In this way, the surge current capability is directly referenced to a fundamental thermal reliability limit. This was achieved using a comprehensive dataset comprising both TO-220 and TO-247 devices with blocking voltages of 650V, 1200V, and 1700V, and encompassing two structural types: merged PN Schottky (MPS) diodes and homogeneous-current Schottky barrier diodes (SBDs). By systematically evaluating repetitive surge currents in commercially available SiC Schottky diodes, this work demonstrates both the applicability and the necessity of the proposed method and criterion for determining $I_{F,RM}$. The analysis further highlights variations in vendor datasheet practices and establishes a standardized framework for assessing repetitive surge current capability in SiC Schottky diodes. As a result, this study provides researchers and circuit designers with a practical and reliable tool for benchmarking device performance and ensuring robust, thermally safe power-electronic designs.

Surge Current Ratings and Reliability Considerations in SiC Schottky Diodes

In 4H-SiC Schottky diodes, the surge current capability constitutes a key parameter in assessing the robustness and long-term reliability in practical power electronic applications, which is specified in terms of both $I_{F,SM}$ and $I_{F,RM}$. The $I_{F,SM}$ parameter represents the maximum current a diode can withstand during a single short-duration high-current pulse, arising from fault conditions or inrush currents, such as charging of bulk capacitors and inductive load energization. By contrast, $I_{F,RM}$ specifies the maximum current permissible during repetitive, short-duration high-current pulses, which are typically encountered in electronic circuits during normal operation, such as switching transients or recurring fault conditions.

The $I_{F,SM}$ parameter is evaluated in the literature by progressively increasing the peak of a single surge-current pulse until device failure or a defined degradation criterion indicative of surge limit is reached, which is then derated to assure consistent functionality under specified conditions [5-9]. The evaluation is typically performed using a half-sine wave pulse of either 10ms duration at 50Hz or 8.3ms at 60Hz. The $I_{F,RM}$ parameter is evaluated under identical half-sine wave conditions; however, to ensure reliable operation and prevent cumulative thermal overstress, a peak surge current level below the destructive threshold defined by $I_{F,SM}$ is selected and applied repetitively with sufficient cooling intervals [10-13]. An important consideration for repetitive surge current events is their reliance on the time-dependent transient thermal impedance, which determines the cumulative junction-temperature rise when cooling between pulses is insufficient, ultimately becoming the dominant reliability constraint. However, under standardized test conditions with sufficient cooling intervals, the cumulative thermal effect is effectively mitigated.

Together, the $I_{F,SM}$ and $I_{F,RM}$ ratings provide critical benchmarks for the safe design and reliable operation of SiC Schottky diodes, as they define the operating limits and tolerance for both single-event and repetitive surge current conditions. While $I_{F,SM}$ sets the destructive single-event limit, $I_{F,RM}$ is practically important and serves as a critical parameter for circuit designers in preventing premature failure and ensuring long-term operation in practical applications. This practical importance is highlighted by experimental studies demonstrating that repetitive surge current stress can induce forward-voltage drift and progressive degradation in SiC Schottky-based devices, including JBS and MPS diodes, even when the applied current remains below the single-surge destructive limit. Reported mechanisms include stacking-fault-mediated bipolar degradation associated with minority-carrier injection in JBS/MPS structures [11], as well as aluminum metallization melting and electromigration driven by repeated high-current thermal stress [11, 13]. Therefore, these parameters are indispensable for ensuring device robustness in practical applications such as power converters, motor drives, and automotive systems, where surge currents frequently occur during switching, inrush, or fault conditions. Accordingly, it is essential that both $I_{F,SM}$ and $I_{F,RM}$ are clearly defined and supported by an appropriate method and criterion for SiC Schottky diodes, as each plays a critical role in device reliability.

Criterion for Repetitive Peak Forward Surge Current

Given the critical importance of the $I_{F,RM}$ parameter, the analysis within this paper is based on a recently proposed method and criterion for repetitive peak surge current [4]. The foundation of the proposed criterion is defined by the condition that the surge current pulse does not exceed the isothermal *I-V* characteristic measured at the device's maximum rated junction temperature, which is 175°C for commercially available devices [14-17]. This ensures that the junction temperature (T_j) of the packaged device remains within its specified thermal limit under repetitive surge current conditions. Figure 1 illustrates the method used in [4] by mapping the surge current measurements (loops) to the isothermal *I-V* characteristics measured at 175°C.

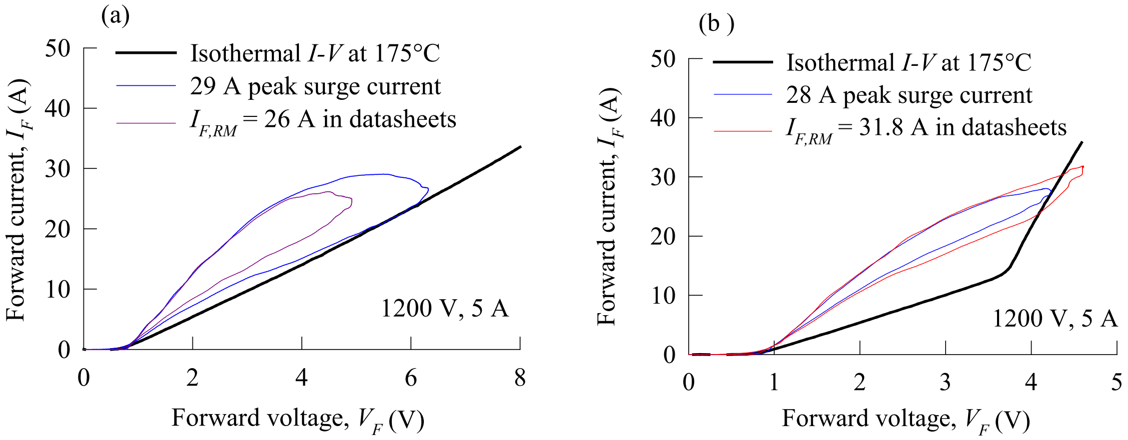

Fig. 1. Mapping of surge-current loops to isothermal *I-V's* at 175°C for vendor C (a) and vendor A (b).

Experimental Scope and Device Dataset

A comparative analysis was conducted across four commercial vendors (Vendors A–D) for both TO-220 and TO-247 packaging with the maximum temperature rating of 175°C. The devices include two structural types—merged PN Schottky (MPS) diodes, represented by Vendors A–C, and homogeneous-current Schottky barrier diodes (SBDs), represented by Vendor D—with TO-220 devices rated at 650V and 1200V and TO-247 devices rated at 650V, 1200V, and 1700V. This selection of vendors, package types, and voltage ratings establishes a representative dataset, allowing the proposed criterion to be systematically applied and the results benchmarked against the corresponding datasheet specifications.

Criterion-Based Analysis of Repetitive Surge Current Capability: TO-220 SiC Schottky Diodes

Assessment of Datasheet-Based Surge Current Specifications

Tables I and II summarize the surge-current data for the TO-220 SiC Schottky diodes from three commercial vendors (Vendors A–C), along with the corresponding comparative analysis. A key limitation in relying on commercial datasheets to assess the surge current capability of SiC Schottky diodes is that the $I_{F,RM}$ parameter is not always specified, as demonstrated by Vendor B in Table I. In such cases, it is common practice to approximate the repetitive surge current as 70% of the specified $I_{F,SM}$ value (0.7 $I_{F,SM}$ in Table I). However, the derated $I_{F,SM}$ values show poor correlation with the stated $I_{F,RM}$ values, signifying that $I_{F,SM}$ is not an adequate and reliable indication of $I_{F,RM}$ when it is not provided in datasheets. For Vendor A, the 650V devices exhibit an $I_{F,RM} / I_{F,SM}$ ratio of

0.66; however, at 1200V this ratio decreases significantly to 0.45, indicating a pronounced reduction in repetitive surge current capability with increasing blocking voltage. The devices from Vendor C show a wider range of $I_{F,RM}$ / $I_{F,SM}$ ratios at 1200V, ranging from 0.57 to 0.70. Thus, at 650V the only available determination is 0.66 (as Vendor B does not specify the $I_{F,RM}$ parameter), whereas at 1200V the ratios vary considerably between 0.45 and 0.70 across vendors. Therefore, in the absence of a standardized method for extracting $I_{F,RM}$, these variations illustrate the lack of consistency in the $I_{F,SM}$ derating criterion used to define the $I_{F,RM}$ parameter. Consequently, for vendors that do not report $I_{F,RM}$ values (e.g., Vendor B), reliance on datasheet specifications alone is problematic due to the inconsistencies observed across manufacturers. At 1200V, Vendor A specifies an $I_{F,RM}$ / $I_{F,SM}$ ratio of 0.45, whereas Vendor C reports ratios between 0.57 and 0.70 for devices with the same blocking voltage. This up to 55% variation in repetitive surge current capability across vendors demonstrates that datasheet $I_{F,RM}$ values are not based on a consistent criterion. Therefore, the absence of standardization and the observed variability further demonstrate that repetitive surge current capability cannot be reliably estimated by simply applying a universal de-rating of $I_{F,SM}$.

Table I. Comparison of surge-current data for TO-220 SiC Schottky diodes from three different vendors.

Vendor	V_B (V) / I_F (A)	$I_{F,SM}$ in datasheets (A)	$I_{F,RM}$ in datasheets (A)	0.7 $I_{F,SM}$ (A)	$I_{F,RM}$ / $I_{F,SM}$
A	650 / 10	70	45.9	49	0.66
	650 / 16	100	65.9	70	0.66
	650 / 20	126	83	88.2	0.66
	1200 / 5	70	31.8	49	0.45
	1200 / 10	120	54.2	84	0.45
B	650 / 10	82	n.a.	57.4	n.a.
	650 / 16	124	n.a.	86.8	n.a.
	650 / 20	142	n.a.	99.4	n.a.
	1200 / 5	59	n.a.	41.3	n.a.
	1200 / 10	99	n.a.	69.3	n.a.
	1200 / 20	198	n.a.	138.6	n.a.
C	1200 / 5	46	26	32.2	0.57
	1200 / 10	71	47	49.7	0.66
	1200 / 20	130	91	91	0.70

Criterion-Based Determination of Repetitive Surge Current Capability

To illustrate the importance of the recently proposed criterion for specifying repetitive surge current, the peak surge current (I_{peak} in Table II) was measured at T_j=175°C and T_c=25°C following the same surge current measurement method in [4]. To establish a tolerance margin, I_{peak} is derated to 90% so that the repetitive surge current is defined as $I_{F,RM}$ (175°C) = $0.9I_{peak}$. In Table II, these values for the repetitive surge current are benchmarked against the available $I_{F,RM}$ specifications in datasheets. The comparison shows that using $0.9I_{peak}$ yields $I_{F,RM}$ values in good agreement with most $I_{F,RM}$ specifications reported in manufacturer datasheets. Nonetheless, in the case of Vendor A, the datasheet $I_{F,RM}$ value for one 1200V diode is slightly overrated, whereas the datasheet values for all three 650V diodes are consistently underrated. This trend is further illustrated in Fig. 1, which maps surge-current loops to isothermal *I–V* characteristics at 175°C for representative 1200V/5A devices from Vendor C (Fig. 1a) and Vendor A (Fig. 1b). For Vendor C (Fig. 1a), the datasheet $I_{F,RM}$ of 26A lies below the measured peak surge current (I_{peak}=29A), while the criterion-based estimate ($0.9I_{peak}$=26A) aligns exactly with the datasheet value, indicating an accurate specification. In contrast, for Vendor A (Fig. 1b), the datasheet $I_{F,RM}$ of 31.8A exceeds both the measured peak surge current (I_{peak}=28A) and the criterion-based estimate ($0.9I_{peak}$=25A), indicating an overrated specification. For the Vendor A 1200V/5A TO-220 diode, the datasheet $I_{F,RM}$ of 31.8A exceeds the criterion-based value of 25A derived from measurements at T_j = 175°C. This indicates that the datasheet permits repetitive surge operation beyond the thermally defined limit of the device. In this case, the commonly assumed approximation $I_{F,RM} \approx 0.7\ I_{F,SM}$ would yield 49A, nearly double the thermally constrained value, illustrating that $I_{F,SM}$-based derating can significantly overestimate safe repetitive operation.

The ratio $I_{F,RM}$ (175°C)/$I_{F,SM}$ in Table II shows that the repetitive surge current typically lies between 60–90% of the non-repetitive surge current, reflecting how much of the single-event surge capability can be safely sustained under repetitive conditions at the maximum junction temperature of 175°C. This approach also captures vendor- and voltage-dependent variations, with certain high-voltage devices exhibiting reduced margins (0.36–0.41). This variability among vendors and devices illustrates that device-specific behavior must be accounted for, and that a simple universal derating of $I_{F,SM}$ is insufficient for reliably determining $I_{F,RM}$. Therefore, even in the presence of variation among vendors and devices, the proposed method provides a consistent framework for determining $I_{F,RM}$ with a safety margin that ensures adherence to the device's maximum thermal limits.

Table II. Repetitive peak surge current, $I_{F,RM}$ (175°C), based on a recently proposed criterion for TO-220 SiC Schottky diodes for three different vendors.

Vendor	V_B (V) / I_F (A)	Peak surge current for T_j=175°C and T_c=25°C, I_{peak} (A)	$I_{F,RM}$ (175°C) = $0.9 I_{peak}$ (A)	$I_{F,RM}$ in datasheets (A)	$I_{F,RM}$ (175°C)/ $I_{F,SM}$
A	650 / 10	55.4	50	45.9	0.71
	650 / 16	96.3	87	65.9	0.87
	650 / 20	113.4	102	83	0.81
	1200 / 5	28	25	31.8	0.36
	1200 / 10	54.9	50	54.2	0.41
B	650 / 10	80.5	72	n.a.	0.88
	650 / 16	108.9	98	n.a.	0.79
	650 / 20	94.7	85	n.a.	0.60
	1200 / 5	27.1	24	n.a.	0.41
	1200 / 10	55.1	50	n.a.	0.50
	1200 / 20	164	148	n.a.	0.75
C	1200 / 5	29.1	26	26	0.57
	1200 / 10	56.6	51	47	0.72
	1200 / 20	101.3	91	91	0.70

Criterion-Based Analysis of Repetitive Surge Current Capability: TO-247 SiC Schottky Diodes

Assessment of Datasheet-Based Surge Current Specifications

The comparative analysis was extended to TO-247 SiC Schottky diodes, which are widely used in high-power, high-temperature applications owing to their superior thermal and current-carrying capabilities, thereby providing an important benchmark for evaluating surge current behavior across different vendors. Tables III and IV summarize the surge-current data for the TO-247 SiC Schottky diodes for three commercial vendors (Vendors A, B, and D), along with the corresponding comparative analysis.

The comparison in Table III highlights distinct vendor-dependent practices for specifying $I_{F,RM}$, demonstrating a lack of consistency in how manufacturers define the repetitive surge current capability, as reflected by the wide variation in $I_{F,RM} / I_{F,SM}$ ratios (0.42–0.90) across vendors and voltage classes. Moreover, the commonly assumed derating of $I_{F,SM}$ by 0.7 does not align with datasheet values for $I_{F,RM}$, leading in some cases to overestimation (e.g., Vendor A, 1700V) and in others to underestimation (e.g., Vendor D, 1200V). For 1200V/20A TO-247 devices, Vendor B specifies an $I_{F,RM} / I_{F,SM}$ ratio of 0.42, while Vendor D reports a ratio of 0.90, highlighting more than a twofold discrepancy in repetitive surge current capability for devices with identical ratings. These discrepancies, as observed in the TO-220 analysis, demonstrate that a simple universal derating of $I_{F,SM}$ is insufficient for reliably determining $I_{F,RM}$, since in some cases this approach can be misleading and may result in operation beyond the device's thermal limits.

Table III. Comparison of surge-current data for TO-247 SiC Schottky diodes from three different vendors.

Vendor	V_B (V) / I_F (A)	$I_{F,SM}$ in datasheets (A)	$I_{F,RM}$ in datasheets (A)	0.7 $I_{F,SM}$ (A)	$I_{F,RM}$ / $I_{F,SM}$
B	650 / 20	103	n.a	72.1	n.a
	1200 / 20	190	80	133	0.42
A	1700 / 25	180	117	126	0.65
D	650 / 20	145	128	101.5	0.88
	1200 / 20	156	140	109.2	0.90
	1700 / 25	177	151	123.9	0.85

Criterion-Based Determination of Repetitive Surge Current Capability

The comparison illustrated in Table IV reinforces the vendor-dependent variability in repetitive surge current specification. As in the previous case, the peak surge current (I_{peak}) was measured at T_j=175°C and T_c=25°C, and then derated to $0.9I_{peak}$ to specify the repetitive peak surge current, $I_{F,RM}$ (175°C). These values were then benchmarked against the datasheet specifications where available. Overall, Table IV confirms the same trends identified for the TO-220 packaged devices: vendor- and voltage-dependent variations exist, and datasheet specifications may either underrate or overrate actual surge current device performance. For example, Vendor A specifies an $I_{F,RM}$ value for its 1700V/25A diode that is greater than the measured I_{peak}, even though the latter was obtained at the device's maximum junction temperature. For Vendor A's 1700 V / 25 A TO-247 diode, the datasheet $I_{F,RM}$ of 117A exceeds the criterion-based value of 104A obtained at T_j = 175°C. Similarly, for Vendor D's 650V/20A diode, the datasheet $I_{F,RM}$ (128A) exceeds the measured peak surge current at 175°C (99A), again indicating disagreement with a thermally constrained definition of $I_{F,RM}$. This implies that the device could repeatedly sustain surges beyond its rated thermal limit. A similar issue is observed for Vendor D's 650V/20A diode, where the datasheet $I_{F,RM}$ likewise exceeds the measured I_{peak}, again suggesting repetitive operation beyond safe thermal limit. By contrast, applying the proposed method—first determining the maximum surge current that can be handled within the 175°C junction temperature limit, and then derating this value by 10%—ensures that $I_{F,RM}$ remains below the destructive threshold and maximum device ratings. Furthermore, the observed variation in the $I_{F,RM}$(175°C)/$I_{F,SM}$ ratio highlights the device-specific thermal behavior arising from structural design, blocking voltage, and current ratings. In this case, the results confirm the need for a standardized method and criterion to ensure that repetitive surge current capability is defined within the thermal limits of the device.

Table IV. Repetitive peak surge current, $I_{F,RM}$ (175°C), based on a recently proposed criterion for TO-247 SiC Schottky diodes for three different vendors.

Vendor	V_B (V) / I_F (A)	Peak surge current for T_j=175°C and T_c=25°C, I_{peak} (A)	$I_{F,RM}$ (175°C) = $0.9I_{peak}$ (A)	$I_{F,RM}$ in datasheets (A)	$I_{F,RM}$ (175°C)/ $I_{F,SM}$
B	650 / 20	85	77	n.a	0.75
	1200 / 20	88	79	80	0.42
A	1700 / 25	115	104	117	0.58
D	650 / 20	99	89	128	0.61
	1200 / 20	121	109	109.2	0.70
	1700 / 25	172	155	123.9	0.88

Summary

The repetitive peak forward surge current ($I_{F,RM}$) is a critical reliability parameter for SiC Schottky diodes, as it defines safe operation under repeated surge events and ensures robust circuit designs. Despite its importance, no standardized method or criterion currently exists, and manufacturers typically report only the non-repetitive peak forward surge current ($I_{F,SM}$), which is based on destructive single-pulse measurements and provides limited guidance for repetitive operation. In this study, we perform a comparative analysis based on a recently proposed criterion for determining $I_{F,RM}$, where the measured peak surge current at T_j=175°C and T_c=25°C (I_{peak}) is derated by 10% ($0.9I_{peak}$) to maintain operation within the device's maximum thermal limit of 175°C. Analysis across multiple vendors and voltage classes shows that this approach yields $I_{F,RM}$ values that are largely consistent with datasheet specifications, while avoiding the inconsistencies associated with unstandardized reporting or reliance on a universal derating of $I_{F,SM}$. The results demonstrate that the proposed criterion provides a reliable and broadly applicable specification for $I_{F,RM}$, enabling meaningful benchmarking across vendors, ensuring compliance with maximum thermal ratings, and supporting robust, thermally safe circuit designs. These findings highlight the lack of standardization in current datasheet practices and establish the importance of adopting a unified measurement method for repetitive surge current capability in commercial SiC Schottky diodes.

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