CoolSiC™ Automotive Discrete Schottky Diodes

Explanation of Datasheet Nomenclature

About this document

This application note provides an explanation of the nomenclature used in the datasheets of Automotive CoolSiC™ Discrete Schottky Diodes.

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Scope and purpose

This document aids the user to better understand the datasheet parameters, so as to be able to rightly judge the potentials and limits of the devices. It also enables the user to understand the specific setup and conditions under which the datasheet parameters are defined, which can be different in the end application.

Intended audience

Electrical engineers working on automotive power electronics.

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1 Introduction

Datasheets describe the relevant characteristics of the products under various operating conditions, which enable the user to judge the operating limits of the product. Infineon datasheets for CoolSiC™ Automotive Discrete Schottky Diodes are typically organized as follows:

- The front page with a summary of the key product parameters, description of the technology, its features, potential applications and pinning diagrams.
- Maximum ratings of major electrical, thermal and mechanical parameters.
- Thermal characteristics
- Electrical characteristics- both static and dynamic. It is to be noted that maximum values of the electrical characteristics are typically guaranteed by production tests. Some parameters, however, are only “verified by design/characterization”, as noted in the datasheets.
- Diagrams of the electrical characteristics and thermal impedances. It must be noted that all values in the characteristic diagrams are typical values, unless noted otherwise.
- Package outlines
- Revision history

1.1 Status of Datasheets

Datasheets are classified into the following three status depending on the state of development of the product.

- Target datasheet (version 1.x): contains data that is expected to be achieved, but may change during the development phase without any notice to the customer.
- Preliminary datasheet (version 2.x): contains data based on engineering samples, close to the final product. However, some data may still change during the remaining course of development, again, without notice to the customer.
- Datasheet (version 3.x): contains data based on the final product. Major updates in the datasheet are usually accompanied by the Product Change Notification (PCN) process.

1.2 Type designation

The part number of the diode contains information related to the part as shown in Figure 1. The first three letters indicate that the part is an Infineon (‘I’) automotive qualified (‘A’) diode (‘D’). The fourth letter (group-3) distinguishes between the two packages in which the part is available. The next two letters indicate the current class of the part, as will be explained in section 2.2. The letter in group-5 indicates the die attach type. Group-6 gives an indication of the blocking voltage class of the diode (explained in section 2.1). The last two letters indicate the diode technology.

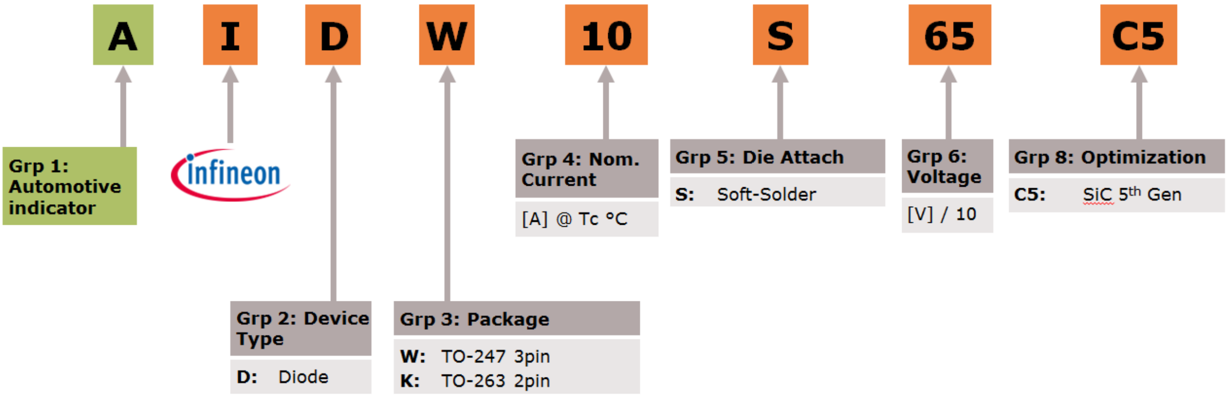


Figure 1: Type Designation for Automotive CoolSiC™ Diodes

1.3 Package Marking

Each part also contains a marking on its body for identifying the part number, and for production data. This is demonstrated in a specific example in the figure below. The package marking, also specified in the datasheet, is similar to the product name described in the previous section except that some characters such as the vendor, package indicator and die attach type, are removed. The production code indicates the part's compliance for a green product, the production lot, the year and calender week of manufacture. This makes it possible to trace the part to the production lot.

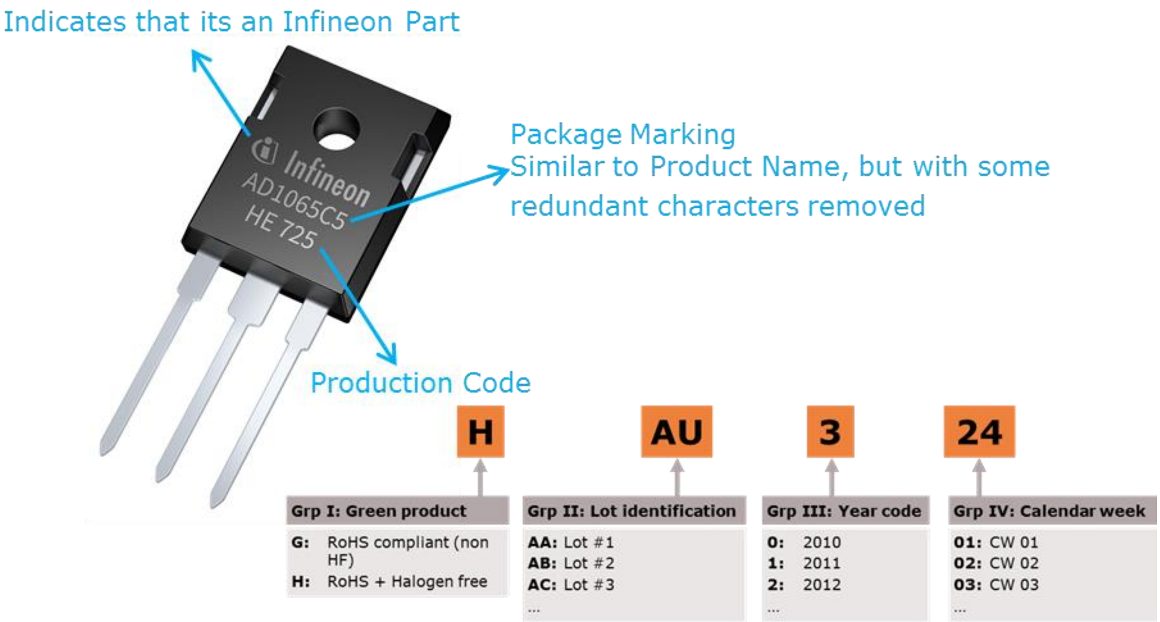


Figure 2: Package Marking for an example CoolSiC™ Diode

2 Maximum ratings

The maximum ratings specified in the datasheet shall not be exceeded in the application, even for short events. Violating these conditions lead to a drastic decrease of the device lifetime, and may lead to device failure.

2.1 Repetitive peak reverse voltage (V_{RRM})

The repetitive peak reverse voltage V_{RRM} is the maximum reverse voltage that can be repetitively applied to the diode without destroying it. These values shall not be violated in the application conditions, even for short transients. Therefore V_{RRM} has to be taken into account, while optimizing the stray inductance, or the switching speed of the complementary active switches.

2.2 Continuous forward current for $R_{thJC,max}$ (I_F)

Continuous forward current, I_F, gives an indication of the continuous current capability of the diode at specific cooling conditions, and also serves for the type designation. For a given case temperature T_C and the worst case thermal resistance (junction-case) $R_{thJC,max}$, I_F is the maximum continuous current for which the junction temperature does not exceed the maximum operating temperature specified in the datasheet.

The continuous forward current capability at different case temperatures and for different duty cycles is also given as a chart as shown in Figure 3. Duty cycle D =1 indicates that the current considered is continuous, and the diode does not get any time to cool down. I_F is higher at lower T_C as the temperature swing to reach T_j max is higher, and at lower duty cycles because the diode gets some time to cool down.

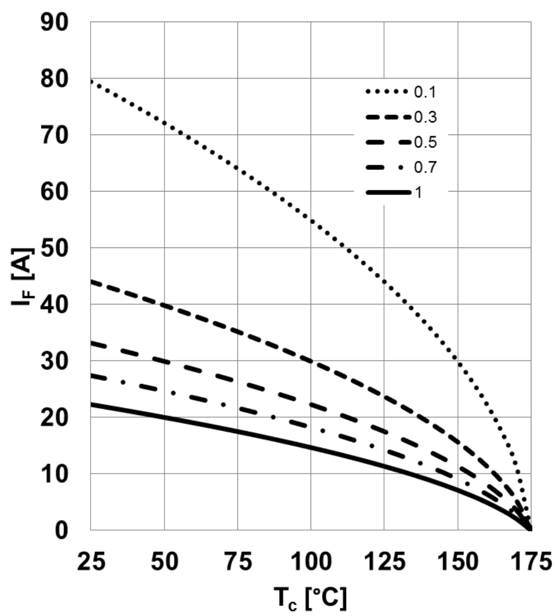


Figure 3: An example I_F =f(T_C) chart

It must be noted that this term I_F only takes into account the conduction losses and not the switching losses. Therefore, when the diode is switching, the forward current capability would be accordingly lower. Moreover, it is to be noted that this parameter has no meaning by itself, but only in conjunction with the T_C and $R_{thJC,max}$. This has to be kept in mind, especially when this parameter is used to compare different devices.

2.3 Surge non-repetitive forward current, sine half wave ($I_{F,SM}$)

The maximum peak current of a half sine wave that the diode can safely take in the forward direction is called the surge non-repetitive forward current $I_{F,SM}$. $I_{F,SM}$ is specified at case temperatures of 25°C and 150°C. The frequency of the sine wave is usually 50Hz (as the term originated for rectifier diodes, for which the grid frequency of 50Hz is relevant). This results in a time period of the half sine wave at 10ms. During such a current pulse, the diode junction temperature exceeds the maximum permissible temperature, and therefore, it is necessary to allow the chip sufficient time to cool before resuming normal operation.

While comparing the $I_{F,SM}$ values of devices from different vendors, it is important to pay attention to the period of the half sine wave, since some vendors specify at 8.3ms (i.e., grid frequency of 60Hz), which results in apparently higher values for $I_{F,SM}$.

2.4 Non-repetitive peak forward current, $I_{F,max}$

Non-repetitive peak forward current, $I_{F,max}$ is similar to $I_{F,SM}$, with the exception that the shape of the applied current waveform is rectangular instead of a sine wave, and the period is significantly shorter at 10µs. This value is specified only at $T_C = 25°C$.

2.5 I^2t value

The I^2t value, which specifies the surge current capability of the diode, is obtained by integrating the product of the square of the current half sine wave mentioned in section 2.3 and time. The below equation may be used to calculate this value, or to back calculate $I_{\mathrm{F,SM}}$ for a known i^2t value.

$$i^2t = \int_0^{10\mathrm{ms}} (\, I_{\mathrm{F,SM}} \cdot \sin t)^2 dt = 0.005 \cdot I_{\mathrm{F,SM}}^2$$

2.6 Diode dV/dt ruggedness

The diode dV/dt ruggedness is the maximum slope of the voltage waveform at which the diode could be dynamically switched. This is typically limited by the test setup, and not by the diode itself. Nevertheless, this value specified in the datasheet is the maximum value for the dv/dt that is guaranteed. This value is guaranteed upto a working voltage of 480V for a 650V diode and 960V for a 1200V diode.

2.7 Power dissipation (P_{tot})

This is the maximum power the device can dissipate at $T_C = 25°C$, so that the maximum permitted junction temperature of 175°C is not exceeded. P_{tot} is calculated as follows:

$$P_{\mathrm{tot}} = \frac{T_{\mathrm{vj,max}} - T_{\mathrm{C}}}{R_{\mathrm{thJC,max}}}$$

As $R_{thJC,max}$ is considered for determining this value, P_{tot} is a worst case value.

The value of P_{tot} at any case temperature other than 25°C can be determined from the $P_{tot} = f(T_C)$ graph given in the electrical characteristics diagrams section. An example graph has been shown in Figure 4. It can be seen that P_{tot} falls linearly with T_C and reaches 0 at 175°C, where it can not dissipate any power because the case temperature is already at the operating limit of T_j.

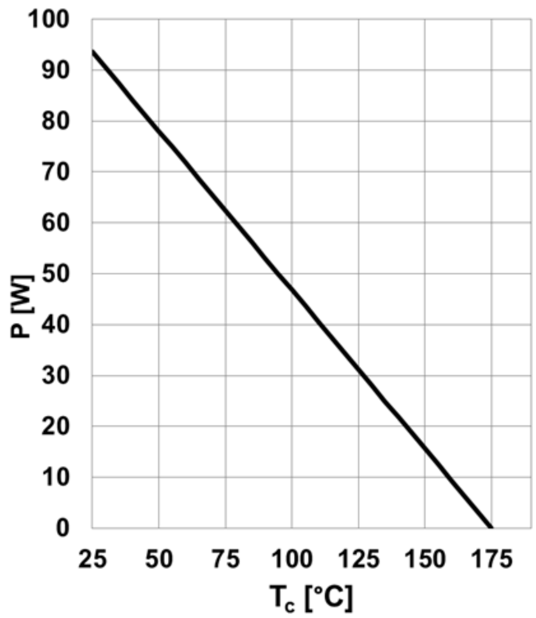


Figure 4: An example $P_{tot} = f(T_C)$ graph

2.8 Operating temperatures (T_j)

This value refers to the maximum value of the junction temperature that is permitted for the device. In reality, it is the temperature at a virtual junction which is in the centre of the active area. For dimensioning the converter and cooling system, care must be taken to not exceed these values. From the reliability and lifetime point of view, the expected lifetime of a power semiconductor is higher at lower operating junction temperature.

2.9 Storage temperature (T_{stg})

This defines the temperature range over which the devices can be stored. For more information please refer to (1) and (2).

2.10 ESD

The robustness of the diodes to Electrostatic Discharge (ESD) impulses is given by two parameters:

1. Human Body Model (HBM): This test reproduces the case of an electrostatically charged human being handling a device, and accidentally discharging his electrostatic charge into the device. This test, performed as per AEC-Q100-002 (3), is depicted below.

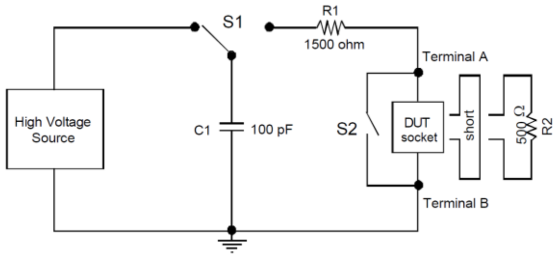


Figure 5: Setup for the Human Body Model as per AEC Q100-002 (3)

Basically, a high voltage source charges a 100pF capacitor, and then discharges the device through a 1.5kΩ resistor. The discharge voltage is increased until the device is destroyed and this maximum voltage is specified in the datasheet.

2. Charged Device Model (CDM): This test reproduces the discharge of the electrostatically charged device (DUT) into a conductive surface. This test is described in AEC-Q100-011 (4), and below figure shows the test setup.

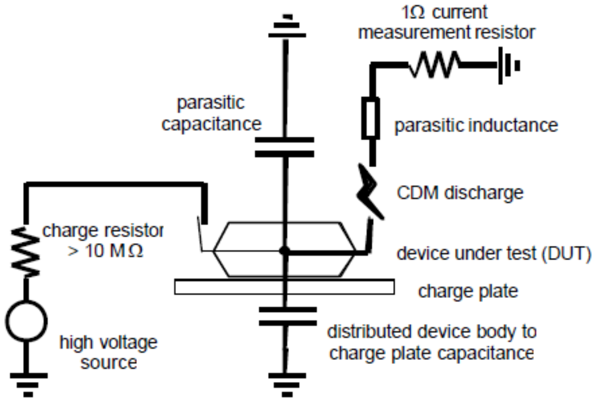


Figure 6: Setup for the Charged Device Model as per AEC Q100-011 (4)

The device is electrostatically charged by contacting one or more of the pins with a charged plate, to a certain potential, and then discharging it into a 1Ω resistor. The maximum voltage until which the device can sustain is noted in the datasheet.

2.11 Soldering temperature (T_{sold})

This is the maximum permitted temperature during the soldering process to which the devices may be subjected to for a maximum of 10s. Only wave soldering is permitted for through-hole packages such as TO-247, and this T_{sold} applies at the tip of the leads, i.e., 1.6mm (0.062 inches) away from the case. For TO-263, reflow soldering is permitted and T_{sold} applies anywhere on the whole package.

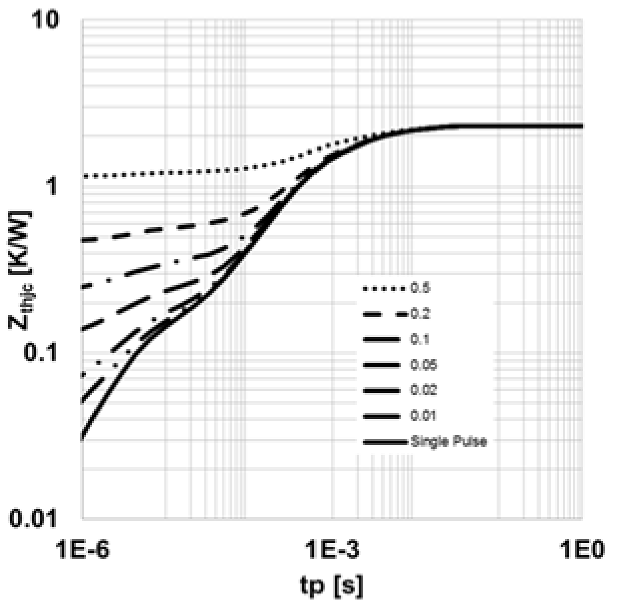
2.12 Mounting Torque (only for TO-247 devices)

TO-247 devices are recommended to be mounted on a heatsink with the help of M3 or M4 screws. It is crucial to apply the right amount of torque while mounting the parts. An inadequate torque results in ineffective contact between the case and the heatsink. On the other hand, if the torque is too high, the package will deform or lift away from the heatsink resulting, again, in poor contact. Therefore, appropriate mounting torque should be applied to minimize the contact thermal resistance, and avoid any damage to the device (1). The maximum torque that could be applied for mounting is provided in the datasheet.

3 Thermal Characteristics

3.1 Diode thermal resistance, junction - case / ambient (R_{thJC} / R_{thJA})

The steady-state thermal behaviour of the device is characterized in terms of the thermal resistance R_{th}. Depending on which point is taken as the reference, there are two thermal resistances of interest to the designer. R_{thJC} is the thermal resistance between junction and case, whereas R_{thJA} is that between junction and ambient. R_{thJC} is a characteristic of the device and is provided as typical and maximum values. For designing the thermal system, the maximum value of R_{thJC} has to be taken into account. R_{thJC} is measured according to the JEDEC JESD-51-14 standard (5). R_{thJA}, on the other hand, depends not only on the device itself, but also on the customer specific system design. Typically, the system (thermal interface material, heatsink) is the dominating contributor to this resistance. The R_{thJA} value provided in the datasheet is for the case where the device cooling pad is in still air as described in JEDEC JESD-51-2 standard (6). This value is meant to give an indication if the devices are ambient-rated, i.e., suitable for use without any cooling. All CoolSIC™ Automotive diodes are not ambient-rated.



i	1	2	3	4
r_i [K/W]	8.68E-01	2.44E-01	9.13E-02	5.67E-01
T_i [s]	3.70E-04	9.34E-03	3.66E-06	2.05E-03

Figure 7: An example Z_{th} characteristic diagram, along with the foster model coefficients.

To assess the dynamic thermal behavior, the thermal impedance Z_{thJC} curves provided in the datasheet are interesting (an example is provided in Figure 7). These curves show the response of the system to different pulse lengths t_P and duty cycle D. Also provided are the coefficients of the so called foster model. These parameters represent an imaginary thermal network consisting of a series connection of ‘N’ parallel R-C networks, and as such, owe no physical relation to the actual thermal stack of the device. These parameters are obtained by fitting a curve to the measured or simulated Z_{th} behavior over time, and can be used to obtain the Z_{thJC} as a function of time, using the following equation.

$$Z_{\mathrm{thJC}}(t) = r_1 \cdot \left[1 - e^{-\frac{t}{t_1}}\right] + \cdots + r_4 \cdot \left[1 - e^{-\frac{t}{t_4}}\right]$$

The constants are provided in the datasheet such that the time constants usually are increasing, and can be used to understand the thermal response of the system to different pulse lengths. The junction temperature of the diode can be calculated as:

$$T_{\mathrm{j}}(t) = P_{\mathrm{loss}}(t) \cdot Z_{\mathrm{thJC}}(t) + T_{\mathrm{C}}(t)$$

where, $P_{\mathrm{loss}}(t)$ is the power loss in the diode.

4 Electrical Characteristics, Static

4.1 DC blocking voltage (V_{DC})

The minimum voltage the device is guaranteed to block at 25°C under static conditions, such that the leakage current I_R is below the limit specified as the test condition, is called the DC blocking voltage represented by V_{DC}. Note that this is not an avalanche rating.

4.2 Diode forward voltage (V_F)

Practical diodes result in a voltage drop when they conduct current, which results in conduction losses. This forward voltage drop has to be as low as possible, and is therefore an important parameter while selecting diodes. The datasheet specifies the forward voltage drop at the continuous forward current, I_F which was discussed in section 2.2. These values are specified for two temperatures, 25°C and 150°C. The pulse length of the current injected during this test is kept as minimum as possible to prevent discrepancy due to self heating.

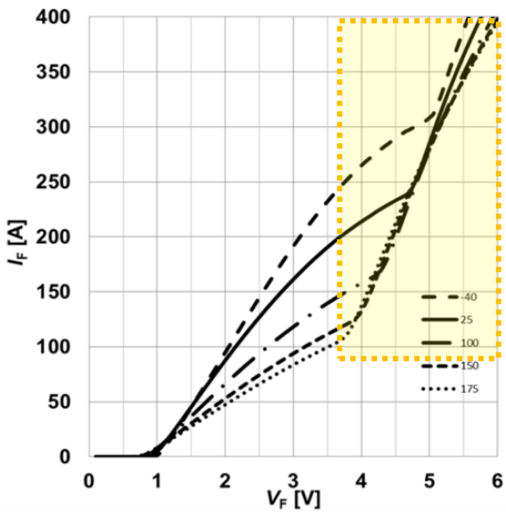


Figure 8: An example showing the forward voltage of the diode as a function of the current

The plot of V_F as a function of I_F is also given in the datasheet, as reproduced in above figure. CoolSiC™ diodes are Merged p-n Schottky (MPS) diodes which means that they are schottky diodes, but with small p-n islands which come into action only at high currents, which results in conductivity modulation (i.e., holes also contribute to the conduction) resulting in reduced voltage drop at higher currents (usually over 5 times the nominal current). This can be confirmed from the branching behavior of the curves (see highlighted region). This behavior results in a higher surge current capability for the MPS diodes. At higher temperatures, these p-n islands come into action sooner, i.e., at lower currents.

4.3 Reverse current, I_R

Practical power devices allow a small amount of current through them while blocking voltage, which is called as the reverse current or leakage current, I_R. This is because, at a temperature beyond absolute-zero, electrons always possess some energy which can result in some of them crossing the schottky metal barrier. The number of electrons crossing the barrier, indirectly the leakage current, is usually dependent on the bandgap of the base material, the technology, die size and process tolerances, apart from the blocking voltage itself. These values are specified at the rated DC blocking voltage specified in section 4.1, at 25°C and 150°C. As electrons acquire higher energies at higher temperatures, it becomes easier for them to overcome the schottky barrier,

and therefore, leakage current increases with temperature. The dependency of I_R on the blocking voltage is given in the electrical characteristics diagrams.

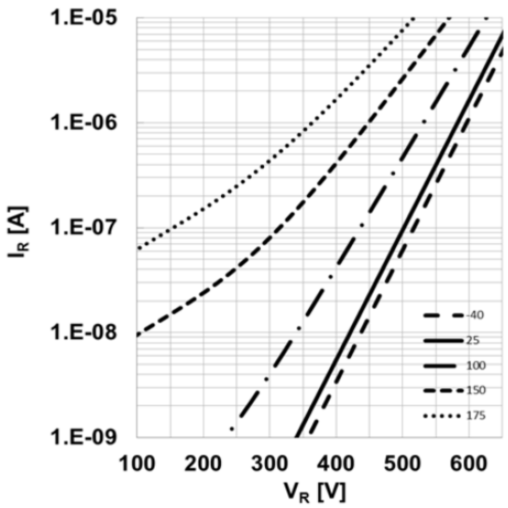


Figure 9: An example showing the reverse leakage current of the diode as a function of the reverse voltage

It is to be noted that the leakage current specified with the V_{DC} parameter in section 4.1 corresponds to the maximum value of I_R at 25°C.

5 Electrical Characteristics, Dynamic

In traditional Si PiN diodes, minority charge carriers (holes) contribute to conduction. However, when the diode has to be turned off, these holes have to be removed. As holes have a lower mobility than electrons, this process takes some time, resulting in reverse recovery. In SiC schottky diodes, on the other hand, conduction is only due to majority charge carriers, i.e, electrons. As a result, when they turn-off, there are no holes which have to be extracted, resulting in a reverse-recovery free switching behavior. However, there is a small current over-shoot which appears in the reverse direction, which is purely due to the junction capacitance which has to be charged before the device can start blocking. This has to be done each time the diode is turned off resulting in dynamic losses.

Therefore, reverse recovery energy E_{rec} is not specified for SiC diodes, unlike Si diodes. Instead, the junction capacitances, capacitive charge and capacitive energies are specified which give an indication of the dynamic losses.

5.1 Total Capacitance (C)

When the diode is blocking voltage, there is region in between the p- and n- regions where the charges are not mobile, due to the counter electric field. This region is called the depletion region, which acts like a dielectric separating the conductive p-n regions. This in effect, acts like a capacitor. The value of this capacitance is inversely proportional to the width of the depletion region. The width of the depletion region itself increases with blocking voltage, which makes the capacitance an exponential function of the blocking voltage, i.e., C=f(V_R). This dependence is is given in the datasheet electrical characteristic diagrams (e.g., see below figure), and the values for the capacitance are specified at three values of blocking voltage: 1V, 3V and 600V. All the capacitance values are measured at 1MHz and 25°C.

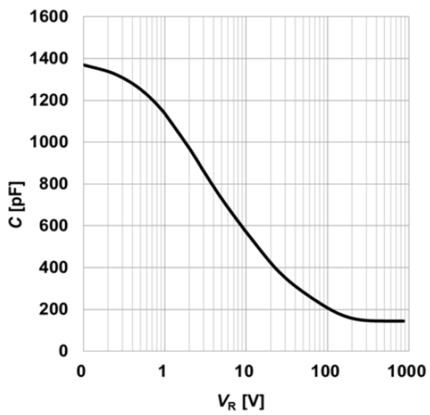


Figure 10: An example showing the junction capacitance as a function of the reverse voltage

5.2 Total capacitive charge (Q_C)

The total capacitive charge is obtained by integrating the curve C=f(V_R) over voltage as below:

$$Q_C = \int_0^{V_R} C(V_R).dV_R$$

For 650V diodes this integration is performed between 0-400V, and for the 1200V diodes between 0-800V.

It is to be noted that these values are independent of the speed (di_F/dt) at which the diodes are made to switch (depending on the complementary active switch) and temperature, as shown in Figure 11. This independency

gives SiC schottky diodes an added advantage over Si diodes where the dependency on $\mathrm{d}i_{\mathrm{F}}/\mathrm{d}t$ and temperature is significant.

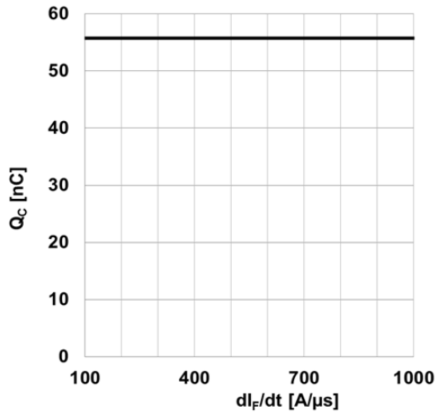


Figure 11: An example showing the stored charge in the junction capacitance as a function of the switching $\mathrm{d}i_{\mathrm{F}}/\mathrm{d}t$

5.3 Typical capacitance stored Energy (E_C)

The plot of the energy stored in the junction capacitance of the diode as a function of voltage is given in the datasheet. This is obtained by integrating the product of V_R and $C=f(V_R)$ curve (discussed in section 5.1) as follows:

$$E_C = \int_0^{V_R} C(V_R).V_R.dV_R$$

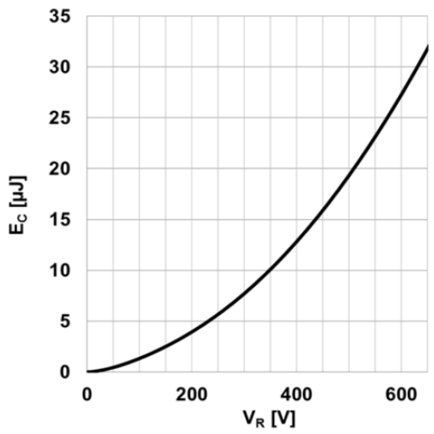
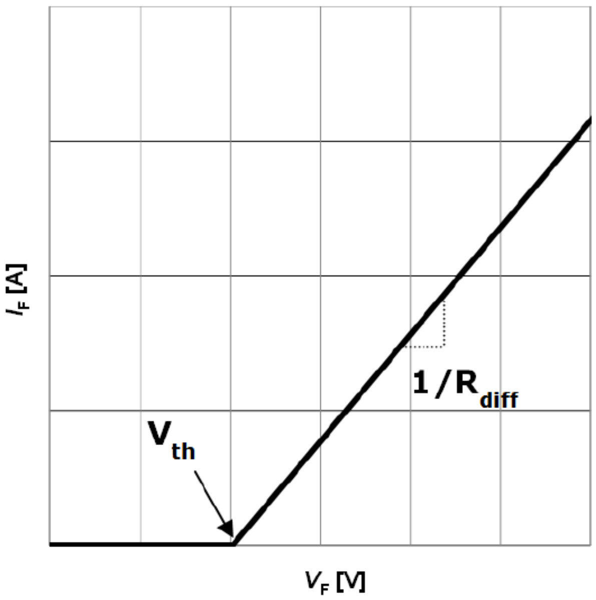


Figure 12: An example showing the stored energy in the junction capacitance as a function of the reverse voltage

5.4 Simplified forward characteristic model

For calculating the conduction losses in the diode, it is useful to have approximate behavioral equations to describe the forward voltage drop V_F as a function of the current I_F and the junction temperature, T_j. This is provided in the last part of the datasheet.



$$V_F = V_{th} + R_{diff} \cdot I_F$$

$$V_{th} = A \cdot T_j + B \text{ [V]}$$

$$R_{diff} = C \cdot T_j^2 + D \cdot T_j + E \text{ } [\Omega]$$

A =	-0.000921384	[V/°C]
B =	1.037044918	[V]
C =	3.19648E-07	[Ω/(°C)^2]
D =	1.84813E-05	[Ω/°C]
E =	0.010216049	[Ω]

Figure 13: An example simplified forward characteristics model

As shown in Figure 13, V_F is approximated as a straight line whose slope is given by the inverse of a 'differential resistance' R_{diff}, and an offset or threshold voltage (V_{th}). The equation of the line would then be:

$$V_F = V_{th} + R_{diff} \cdot I_F$$

where, V_{th} and R_{diff} are dependent on the junction temperature as follows:

$$V_{th} = A \cdot T_j + B \text{ [V]}$$

$$R_{diff} = C \cdot T_j^2 + D \cdot T_j + E \text{ } [\Omega]$$

where A, B, C, D and E are coefficients dependent on the device and are given in the datasheet.

It is to be noted that this model yields typical values, and not maximum values for V_F. Therefore, the use of this model has to be restricted to only power loss calculation and not for dimensioning the power semiconductors. Furthermore, this model is valid at I_F only upto 2 times the rated nominal current of the diode. As such, it does not represent the surge current operation mode.

5.5 Package Outlines

The outline and all mechanical dimensions of the package are specified in the datasheet. This can also be accessed from the official website of Infineon (7).

5.6 Revision History

This indicates the version, date of release of the datasheet. Any changes in the released datasheets will be documented here.

6 References

1. Recommendations for Assembly of Infineon TO Packages. *Additional Information, R 3.0, 2017-04-01, Infineon Technologies.*
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Revision history

Document version	Date of release	Description of changes
Revision 1.0	25.07.2018	First Release- A Pai
Revision 1.1	14.09.2018	Minor corrections in section 1.1, 2.2 and 2.8

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