Design Guidelines for Schottky Rectifiers

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INTRODUCTION

Known limitations of Schottky rectifiers - including limited high temperature operation, high leakage and limited voltage range - can be measured and controlled, allowing wide application on switch mode power supplies.

Schottky rectifiers have been used in the power supply industry for approximately 15 years. During this time, significant fiction as well as fact has been associated with this type of rectifier. The primary assets of Schottky devices are switching speeds approaching zero-time and very low forward voltage drop (V_F). This combination makes Schottky barrier rectifiers ideal for the output stages of switching power supplies. On the negative side, Schottky devices are also known for limited high-temperature operation, high leakage and limited voltage range B_{VR}. Though these limitations exist, they are quantifiable and controllable, allowing wide application of these devices in switch mode power supplies.

High leakage, when associated with standard P-N junction rectifiers, usually indicates “badness,” implying poor reliability. In a Schottky device, leakage at high temperature (75 °C and greater) is often on the order to several mA, depending on chip size. In the case of Schottky barrier rectifiers, high-temperature leakage and forward voltage drop are controlled by two primary factors: the size of the chip’s active area and the barrier height (ϕB).

Design of a Schottky rectifier can be viewed as a trade off. A high barrier height device exhibits low leakage at high temperature, however, the forward voltage drop increases. These parameters are also controlled by the die size and resistivity of the starting material. A larger die will lower the V_F but raise the leakage if all other parameters are held constant. The resistivity of the starting material must be chosen in a range where the breakdown voltage (B_{VR}) is not degraded at the low end and the forward end of the resistivity range. Since a larger chip size is obviously more expensive, this is not the primary method for controlling these parameters. Chip size is usually set to a dimension where the current density through the die is kept at a safe level.

BARRIER HEIGHT (ϕB), A FACTOR

Vishay General Semiconductor produces two product lines of Schottky barrier rectifiers. One line is referred to as the “MBR” series, a high-temperature, low-leakage, relatively high V_F type of Schottky device with a high barrier height (ϕB). The second line is the “SBL” series, designed to operate at lower temperature (125 °C or less); however, while leakage current is higher, forward voltage drop (V_F) is significantly lower and they are designed with a low-ϕB barrier height. The low- ϕB-line SBL series uses a nichrome barrier metal with a barrier height of ϕB = 0.64 eV. The high-ϕB MBR series uses a nichrome-platinum barrier metal to achieve barrier height (ϕB = 0.71 eV). Both series are guard-ring protected against excessive transient voltages.

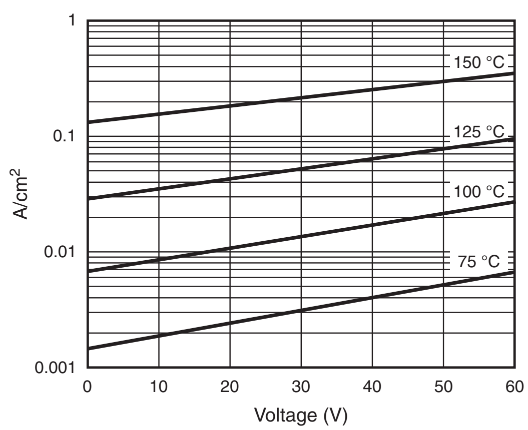

Figure 1.

Both the low and high-barrier-height Schottky devices are valuable in a variety of applications. When the true operating temperature of the Schottky rectifier exceeds 125 °C, the high-barrier-height series must be used to avoid thermal runaway.

This occurs when excessive self-heating of the rectifier causes large leakage currents, resulting in additional selfheating. The process becomes a form of positive thermal feedback and may lead to damage in the rectifier or inappropriate functioning of the circuit utilizing the device.

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Using a high-barrier-height (MBR) component prevents this anomaly, but sacrifices higher forward voltage. Operating the low barrier height (SBL) series at a junction temperature of 125 °C, a decision on the use of a low- or high-barrier-height Schottky device must be made.

The following procedure has been developed to provide an analytical method of selecting the most efficient Schottky barrier device for a given application.

CALCULATING THE BARRIER HEIGHT (ϕB) OF SCHOTTKY RECTIFIERS

Calculating the barrier height of a Schottky rectifier where ϕB is not given is a straightforward process. The following two equations will yield an excellent engineering approximation of the barrier height, ϕB:

ϕB = (- KT/q) LN (J/R x T) *(1)*

$J_0 = I_0$ / active area (cm^2)
ϕB = barrier height (eV)
K = Boltzmann's constant = 8.62 x 105 eV/°K
T = ambient temperature in degrees Kelvin
J_0 = current density at zero volts
R^* = Richardson's constant = $112/cm^2k^2$
I_0 = forward current at zero volts

To solve equation (1), the current density J_0 (equation (2)) must be found first:

$J = I_0$ / active area $(cm^{2)}$ *(2)*

Vishay General Semiconductor provides the active area of its Schottky die in its product literature. If a manufacturer does not supply this information, decapsulating the device under question and measuring it with a precision caliper can provide an approximation of the active Schottky area, assuming 90 % of the total chip area is active.

Total die area x 0.9 = active area *(3)*

The calculation of I_0 is done graphically (figure 2.). A minimum of three low-current room-temperature forward voltage drop V_F measurements are needed. This data is graphed on semi-log paper (figure 2.) where the vertical axis (log scales) is the current and the horizontal axis (linear scale) is the measured V_F When these points are graphed, the result should be a true straight line. If the graph curves downward (see the dotted line on the left side of figure 2.), it indicates that the lowest measurement current is being affected by the rectifier's room temperature leakage. In this case, the current level at which the V_F measurements are taken should be increased to "swamp" out the contribution of low level leakage on the measurement. If the current levels are raised excessively, the series resistance of the device in question will influence the measurements. This causes a downward curve as represented by the dotted line on the right side of figure 2. Again, the results should yield a true straight line.

The point where the line intercepts the vertical axis is the current at zero Volts (I_0). J_0 is then calculated:

$J_0 = I_0$ / active area (cm^2) *(2)*

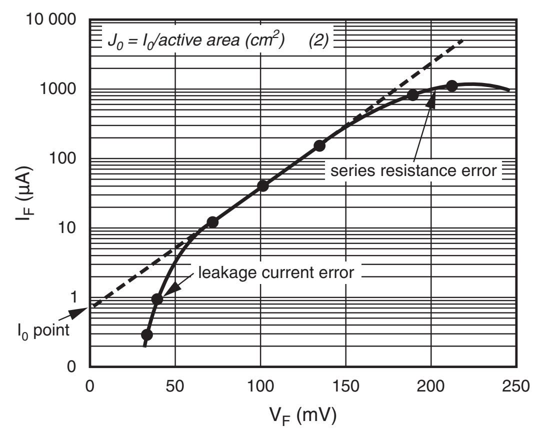

Figure 2. Calculation of J_0 (current density at zero Volts)

This result is then placed into the first equation:

ϕB = (- KT/q) LN (J_0/R x T^2) *(4)*

The results of the calculation are usually in the range of 0.6 eV to 0.8 eV. Results well outside this range indicated either a defective rectifier, measurement, or calculation error.

SELECTING EFFICIENT SCHOTTKY DEVICES

Normalized graphs of the low (SBL) and high (MBR) barrier height processes are provided. The vertical axis on all graphs is in Amperes per square centimeter (A/cm^2). The horizontal axis provides forward voltage drop for the low and high barrier parts. Two additional graphs have the horizontal axis labeled for reverse voltage (V_R) for both the low and high barrier series. The graphs for the low barrier (SBL) series parts have curves for operation at 75 °C, 100 °C, and 125 °C.

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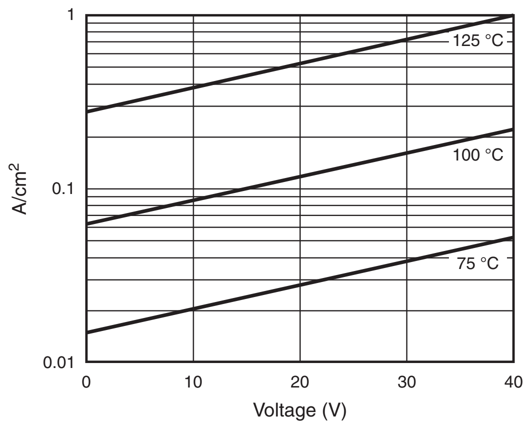

Figure 3. Voltage vs. Die Area Leakage Barrier Height = 0.64 V

These curves may be used in two ways. If the die size, barrier height, temperature and forward current (I_F) are known, V_F can be graphically calculated. Using the leakage curves, and knowing the reverse voltage (V_R) to which the device will be subjected, it is possible to find the leakage current. Conversely, if the circuit parameters are set, the curves will provide the die size in A/cm^2 equations, making it possible to analytically select either a low or high-barrier-height rectifier for maximum circuit efficiency. Most Schottky rectifiers are used in switch mode power supplies.

To select a Schottky rectifier that yields maximum efficiency, it is necessary to determine the "duty cycle equilibrium point", or the duty cycle point at which both a low- and high-barrier-height part will dissipate precisely the same amount of power:

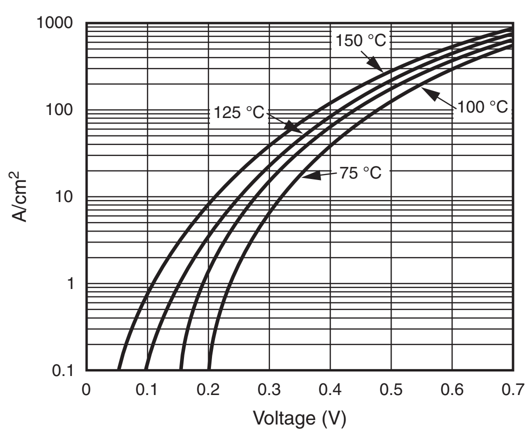

Figure 4. Die Area Current vs. Forward Voltage Drop Barrier Height = 0.71

$D\,(P_{df}\phi BL) + (1 - D)(P_{dr}\phi BL) + =$
$D(P_{dr}\phi BH) + (1 - D)(D_{dr}\phi BH)$ (1)

$P_{dt} = P_{df} + P_{dr}$ (2)
$P_{df} = I_F \times V_F$ (3)
$P_{dr} = I_R \times V_R$ (4)

D = duty cycle forward conduction
$1 - D$ = duty cycle reverse blocking
I_F = forward current
I_R = reverse current
P_{df} = power dissipation in forward
P_{dt} = power dissipation in reverse
P_{dt} = total power dissipation
V_F = forward voltage drop
V_R = reverse voltage
ϕBL = low barrier height
ϕBBH = high barrier height

The following is an example of the use of this equation:

Given the need for a 30 V Schottky capable of operating at 10 A, the choice is between a SBL1040 (ϕB = 0.64) or a MBR1045 (ϕBH = 0.71). These two devices were chosen for convenience in this example because of their equal die size (0.0477 cm^2 active area).

The equilibrium point must be calculated for 75 °C, 100 °C, and 125 °C. For demonstration purposes, only the 75 °C equilibrium point will be calculated in the same manner. The reverse leakage (I_R) and forward voltage drop (V_F) are derived from graphs 1 through 4 using the temperature, die size and ϕB given above.

For the low-barrier-height SBL1040:

$P_{dr} = V_R \times I_R = Watts$ (4)
$30\ V \times (1.9 \times 10^{-3}\ A) = 0.057\ W$
$P_{dr} = I_F \times V_F = Watts$ (3)
$10\ A \times 0.46\ V = 4.6\ W$

For the high-barrier-height MBR1045:

$P_{dr} = V_R \times I_R = Watts$ (4)
$-\ 30\ V \times (1.43 \times 10^{-4}\ A) = 4.29 \times 10^{-3}\ W$
$P_{df} = I_F \times V_F = Watts$
$10\ A \times 0.565\ V = 5.65\ W$

Solving for the equilibrium point at 75 °C:

LOW BARRIER **HIGH BARRIER**

$(D \times P_{df}\phi BL) + [(1 - D) \times P_{dr}\phi BL] = (D \times P_{df}\phi BH) + [(1 - D) \times P_{dr}\phi BH]$
$(D \times 4.6\ W) + [(1 - D)\ 0.057\ W] = (D \times 5.65\ W) + [(1 - D)\ 0.00429\ W]$
$0.05271 = 1.1027 \times D$
$D = 0.0478$
$D\ \% = 0.0478 \times 100$
Duty cycle equilibrium point, D - 4.78 %

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Switching loss is assumed to be equal on both sides of the equation and thus ignored. This procedure is then repeated for 100 °C and 125 °C. After calculating the equilibrium point for 100 °C and 125 °C, the results are:

DUTY CYCLE EQUILIBRIUM	
TEMPERATURE	**POINT %**
75 °C	4.78 %
100 °C	15.93 %
125 °C	52.42 %

The results of these calculations are graphed in figure 6. To the left of the equilibrium curve, the high-barrier-height MBR1045 is most efficient; to the right of the equilibrium curve, the low barrier-height SBL1040 is more efficient. This is easy to understand because the high-barrier-height part exhibits lower reverse power loss and at a low duty cycle more time is spent in the reverse mode.

With the duty cycle higher than the equilibrium point, the part spends a larger percentage of time in the forward mode, and the low-barrier-height type part has a lower V_F and the forward power losses are reduced.

With knowledge of the application, including expected duty cycle and temperature, it is possible to choose the most efficient Schottky barrier rectifier, constructing a graph similar to figure 5.

It is thus easy to graph the duty cycle versus temperature, as in figure 6., and by knowing the application (expected duty cycle and temperature), make the intelligent choice of the most efficient Schottky rectifier for the application in question.

This analysis technique enables the design engineer to make an efficient and cost-effective choice of Schottky rectifier in duty-cycle-based systems. In addition, light has hopefully been shed on the difference in design philosophies between the low- and high-ϕB style of Schottky rectifiers.

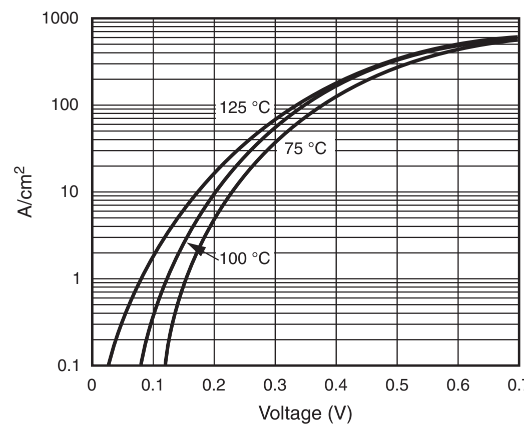

Figure 5. Die Area Current vs. Forward Voltage Drop
Barrier Height = 0.64

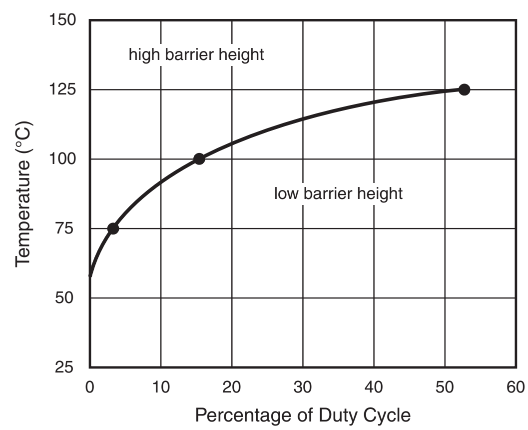

Figure 6. Duty Cycle Equilibrium MBR1045 vs. SBL1040