Whitepaper

Trench Schottky Rectifier
functioning, benefits and use cases

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Named after the German physicist Walter Hans Schottky, the Schottky diode consists mainly of a metal-semiconductor interface. Because of its low forward voltage drop and its high switching speed it is widely used in a variety of applications, such as in power conversion circuits as a boost diode. The electrical performance of a Schottky diode is, of course, subject to physical trade-offs – between the forward voltage drop, the leakage current and the reverse blocking voltage. The Trench Schottky diode can be seen as a further development of the Schottky diode, expanding the limits of its planar counterpart. In this article the functioning and the benefits of Trench Schottky rectifiers are discussed.

An ideal rectifier will generally have a low forward voltage drop, a high reverse blocking voltage, zero leakage current and a low parasitic capacitance, facilitating a high switching speed. When considering the forward voltage drop there are two main elements: the voltage drop across the junction – PN junction in case of PN rectifiers and metal-semiconductor junction in case of Schottky rectifiers; and the voltage drop across the drift region. While the forward voltage drop across a PN junction is intrinsically determined by the built-in voltage and hence, mainly by the chosen semiconductor, the forward voltage drop across the metal-semiconductor interface in a Schottky barrier rectifier can be modified by the choice of the Schottky metal, with the Schottky barrier being the result of the difference between the metal work function and the electron affinity of the semiconductor.

By using Schottky metals with a low metal work function, the voltage drop across the metal semiconductor interface can be minimized. However, there is a trade-off between the forward voltage drop across the junction and the leakage current of the Schottky rectifier, as the level of the leakage current is also determined by the Schottky barrier and the electrical field across the metal semiconductor interface. In addition to this trade-off, the advantage of a low voltage drop across the junction can disappear when the thickness of the drift region is further increased in order to achieve a high reverse blocking voltage. This is the reason why the reverse blocking voltage of Schottky rectifiers is traditionally limited to well below 200V.

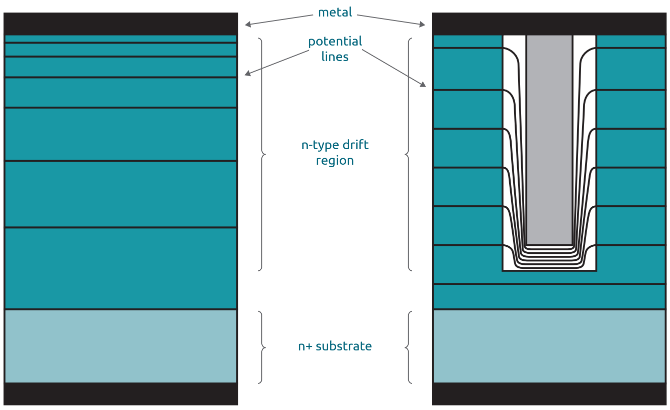

Figure 1: Equi-potential lines in a planar Schottky rectifier (left) and in a Trench Schottky rectifier (right) in reverse direction.

Given this explanation, one might ask how can the major advantage of Schottky rectifiers - i.e. a low voltage drop across the metal semiconductor interface - be preserved despite the demand for a low leakage current and a high reverse blocking voltage? Here, Trench rectifiers prove very useful.

The concept behind the Trench Schottky rectifier is termed 'RESURF' (reduced surface field). The RESURF effect is illustrated in Figure 1. In a planar Schottky rectifier the equi-potential lines are crowded near the top electrode resulting in a high electrical field near the surface. This results in a strong increase of the leakage current with increasing reverse voltage, and an early breakdown when the critical electrical field is exceeded near the surface.

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By etching trenches into the silicon and filling them with poly silicon – electrically separated from the drift region by a thin dielectric – the trenches act as a kind of field plate in the semiconductor, depleting the drift region in reverse direction and resulting in a flattened electrical field profile along the drift region. Therefore, the trench concept achieves a lower leakage current by relaxing the electrical field near the surface and producing a higher breakdown voltage compared to a planar device with the same epitaxial structure.

At Nexperia, a portfolio of Trench Schottky rectifiers has been developed and launched with a voltage range of 45-100 V (PMEG*T family). These devices achieve a well-balanced trade-off between the forward voltage drop Vf and the leakage current IR. Exemplarily, the Vf-IR trade-off for 60V products is shown in Figure 2. In this figure, the leakage current at maximum reverse voltage is plotted against the forward voltage drop at maximum forward current at 125°C. For comparison reasons, some Trench and planar Schottky rectifiers from two other manufacturers are plotted in this graph. For a given forward voltage drop the Nexperia product shows the lowest leakage current.

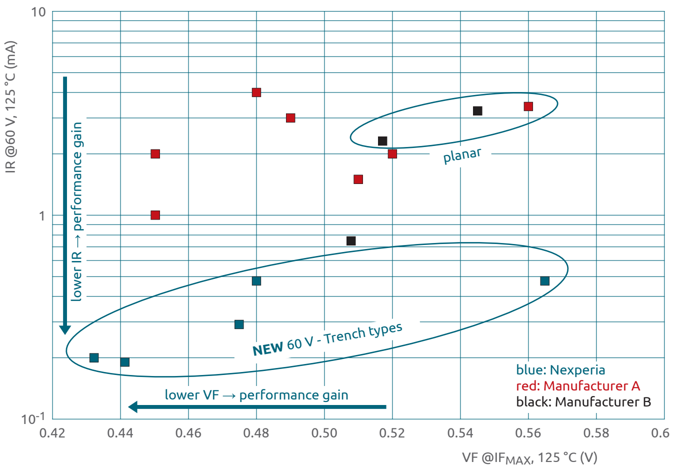


Figure 2: IR-Vf trade-off at maximum reverse voltage and maximum forward current at 125°C.

The lower leakage current of Trench Schottky rectifiers compared to their equivalent planar counterparts with a comparable forward voltage drop shows the Trench devices have a wider safe operating area of these devices. Therefore, in applications where higher ambient temperatures have to be tolerated, for example, automotive, the Trench Schottky rectifiers are a suitable choice since they are more robust against thermal runaway – the instability which occurs when the increase of the dissipated power caused by the leakage current of the rectifier is faster than the heat dissipation through the thermal resistance of the system.

The equivalent circuit diagram of a Trench Schottky rectifier is shown in Figure 3. Besides the usual parasitic capacitance given by the Schottky contact there is a second parasitic capacitance caused by the electrode and the thin dielectric in the trench structures. This means that per unit area the total parasitic capacitance of a Trench Schottky rectifier is higher than its planar counterpart. This must be considered for each particular application. In designs where the switching losses dominate the total losses it may be better to use planar Schottky rectifiers despite their higher leakage current or higher forward voltage drop because of their lower parasitic capacitance. In applications where the forward voltage drop or the leakage current are the dominating factors for total losses, Trench rectifiers should be used.

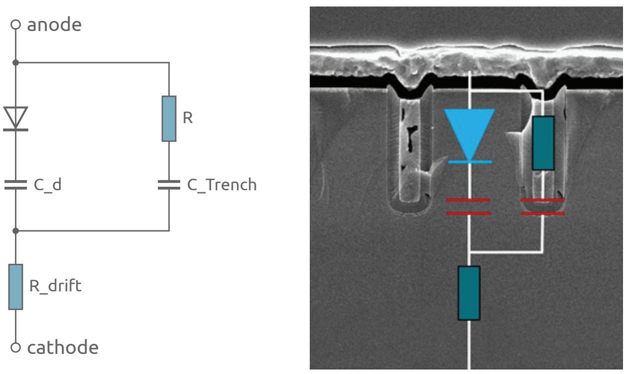


Figure 3: Equivalent circuit diagram of a Trench Schottky rectifier. The circuit elements are highlighted in the device cross section.

The equivalent circuit diagram also manifests itself in the switching behavior of the device, which is characterized by reverse recovery measurements. Such measurements are carried out by biasing the rectifier in a forward direction, then switching the device into a reverse condition. Due to the stored charge in the device (represented by the parasitic capacitance in the equivalent circuit) which must be first removed before the diode blocks, a so-called reverse recovery current of the rectifier occurs. The ramp reverse recovery measurement for a Trench Schottky rectifier and its planar counterpart with comparable die size is shown in Figure 4. In this measurement, the current has been ramped down with a rate of 100A/µs. The magnified area of the graph reveals the larger reverse recovery current and the longer reverse recovery time of the Trench rectifier compared to its planar counterpart, as a result of its higher parasitic capacitance, (as illustrated in Figure 3). The ramp reverse recovery measurement also reveals that the ringing caused by the Trench rectifier tends to decay faster than the planar device. A reason for this can be found again in the equivalent circuit diagram of the Trench rectifier. The additional RC-element in the circuit helps to suppress the generated ringing. Therefore, in EMC-sensitive applications it may be sensible to use Trench rectifiers rather than planar ones.

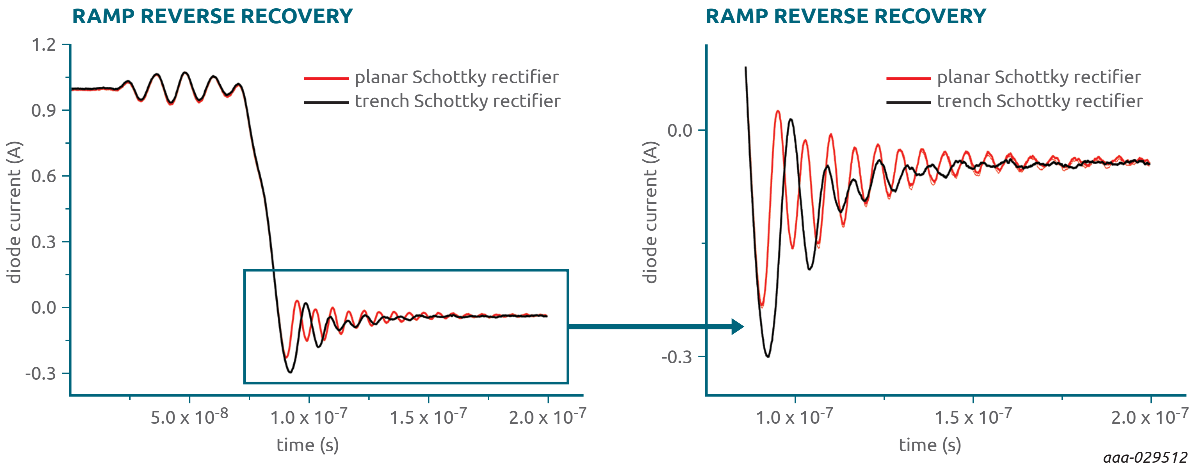
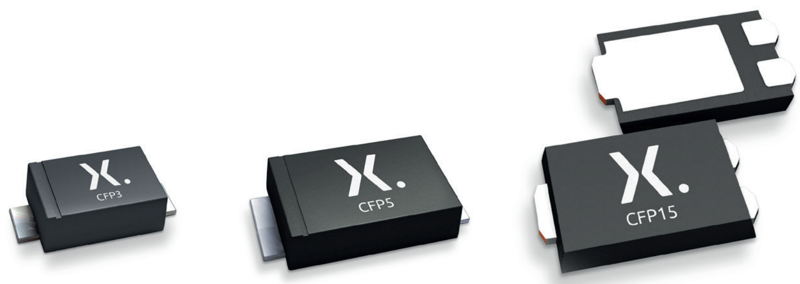


Figure 4: Ramp reverse recovery measurements on Trench and planar rectifiers. 100A/µs ramp.



CFP3 (SOD123W)
2.6 x 1.7 x 1.0 mm*
$R_{th(j-sp)}$ = 18 K/W

CFP5 (SOD128)
3.8 x 2.5 x 1.0 mm*
$R_{th(j-sp)}$ = 12 K/W

CFP15 (SOT1289)
5.8 x 4.3 x 0.78 mm*
$R_{th(j-sp)}$ = 3 K/W

Figure 5: Nexperia Trench Schottky rectifiers in clip-bonded FlatPower packages

*Body size (l x w x h)

In summary, the following can be stated from an applications standpoint: Trench rectifiers are the correct choice if a better trade-off between forward voltage drop and the leakage current is required, provided that the application can tolerate the higher parasitic capacitance. At the same time, the additional RC element in the equivalent circuit helps to suppress potential ringing during the switching of the device making Trench rectifiers the preferred choice in EMC-sensitive applications. Trench rectifiers should also be selected in high power density applications where the ambient temperature is elevated since they are more robust against thermal runaway effects.

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