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650V Rapid Diode
for Industrial Applications

IFAT IPC APS AE
Omar Harmon

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Author: Omar Harmon IFAT IPC APS AE

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1 Introduction

With the introduction of Rapid Diodes, Infineon Technologies enters the hyperfast fast high voltage silicon diode market. Based on ultrathin wafer technology, two families are released to cover different application requirements. Rapid 1 is used in low switching applications (up to 40 kHz) whilst the Rapid 2 is used in fast switching applications (up to 100 kHz). This application note was designed to show how the Rapid diode will improve the existing system solution for its targeted applications in terms of efficiency and soft reverse recovery behavior. The Rapid diode portfolio can also be found at the end of this application note.

2 Description of Technology and Product Family

Rapid diodes are based on ultrathin wafer technology, where wafer thickness and doping profile are optimized to achieve

1. Very low conduction losses (V_F)
2. Temperature stable conduction losses (V_F)
3. Low reverse recovery charge (Q_{rr})
4. Low peak reverse recovery current (I_{rrm})
5. High level of softness

Rapid 1 is forward voltage (V_F) optimized for lowest conduction losses thus, focuses on application switching up to 40 kHz. Rapid 2 meanwhile, is low Q_{rr} and reverse recovery time (t_{rr}) optimized ensuring that switching losses are kept to a minimum, and are therefore best suited for applications switching beyond 40 kHz.

2.1 Rapid Diode Trade-off Curve of V_F, Q_{rr}

Rapid 1 and Rapid 2 are P-i-N diodes that are categorized via a trade-off curve of V_F versus Q_{rr}. Rapid 1 has been optimized to offer low V_F, whilst the Rapid 2 offers low Q_{rr} to keep the switching losses to a minimum. This trade-off is determined by the plasma of excess charge carriers injected into the drift region of the diode. Increasing the plasma concentration to a P-i-N diode lowers the V_F through better conductivity. Consequently, more charge is present on to the device during the forward bias state. This charge then has to be removed first before it can block reverse voltage during reverse bias. More charge on to the device (then lower V_F), the longer it takes to remove them (higher Q_{rr}). This results in a higher Q_{rr} due to the fact that the t_{rr} of the diode will be longer. Figure 1 shows Rapid 1 and Rapid 2 V_F - Q_{rr} tradeoff.

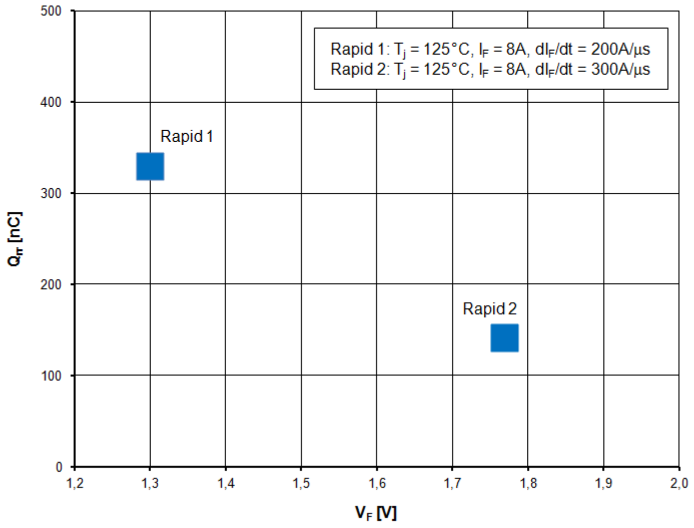


Figure 1: Trade-off V_F - Q_{rr} for Rapid 1 and Rapid 2

2.2 Relative Variation of Switching Parameters as a Function of Temperature

In order to have a very stable temperature behavior of the major electrical parameters, Rapid diodes have weak life-time killing implemented. Table 1 shows Rapid 2 and competitor switching characteristics at 125°C case temperature relative to switching characteristics at 25°C case temp. Rapid 2 is used in high switching frequency applications where switching characteristics are a very important parameter. Switching losses are kept to a minimum at elevated case temp, thanks to a small variation on switching parameters. In relative to Rapid 2, the competitor almost doubled their value of Q_{rr} and I_{rrm}. More comparison with another competitor is provided in the Application of Rapid Diodes section.

Device	**Relative Value at Tc = 125°C**		
	t_{rr}	Q_{rr}	I_{rrm}
Rapid 2	= 0.9 x t_{rr} _25°C	= 2.2 x Q_{rr} _25°C	= 1.5 x I_{rrm} _25°C
Competitor	n.a.	= 4.0 x Q_{rr} _25°C	= 2.5 x I_{rrm} _25°C

Table 1: Relative Variation of Switching Parameters as a Function of Temperature

3 Application of Rapid Diodes

Major home appliances, UPS, welding and solar applications are designed typically to operate at low switching frequencies. Conduction losses dominate switching losses at lower switching frequency operation. Rapid 1 is suitable in these applications especially if the switching frequency is less than 40 kHz.

For PFCs operating in continuous conduction mode (CCM), which is widely used in high power, high efficiency applications, and operate in hard switching at high switching frequencies, the Rapid 2 is best suited. This is due to the low Q_{rr}, which minimizes switching losses therefore maximizing system efficiency. Table 2 lists the target applications for the Rapid diodes.

Target Application	Topology	Rapid
UPS	PFC	Rapid 1 or 2
Solar Inverters	PFC	Rapid 1 or 2
Home Appliance	PFC	Rapid 1
Welding	PFC + TTF	Rapid 2
Telecom	PFC	Rapid 2
Server	PFC	Rapid 2
PC Power	PFC	Rapid 2

Table 2: Rapid 1 and Rapid 2 Target Applications

In this section, Rapid 1 and Rapid 2 static and dynamic characteristics will be compared to competitor diodes commonly found in the market. Rapid 1 is focused more on low conduction losses while Rapid 2 is focused on the switching characteristics. The final result will show how the Rapid diode improved the existing system solution.

3.1 Rapid 1 Static and Dynamic Performance

Rapid 1 is optimized for lowest conduction losses, the major power loss on application with switching frequency up to 40 kHz. The following section will validate Rapid 1 static and dynamic characteristics against competitors.

3.1.1 Rapid 1 V_F curve, I_{rrm}, and Q_{rr}

Rapid 1 advancement in thin wafer technology helps to maintain a stable V_F over temperature. Figure 2 shows a 30A/650V rated Rapid 1 tested against two 30A/600V low V_F competitor diodes commonly found especially in the Asian solar market. It is visible that Rapid 1 has the lowest V_F against the competitors. This corresponds to have the lowest conduction losses across the junction temperature. It also shows Rapid 1 V_F is less dependent on junction temperature compared to competitors.

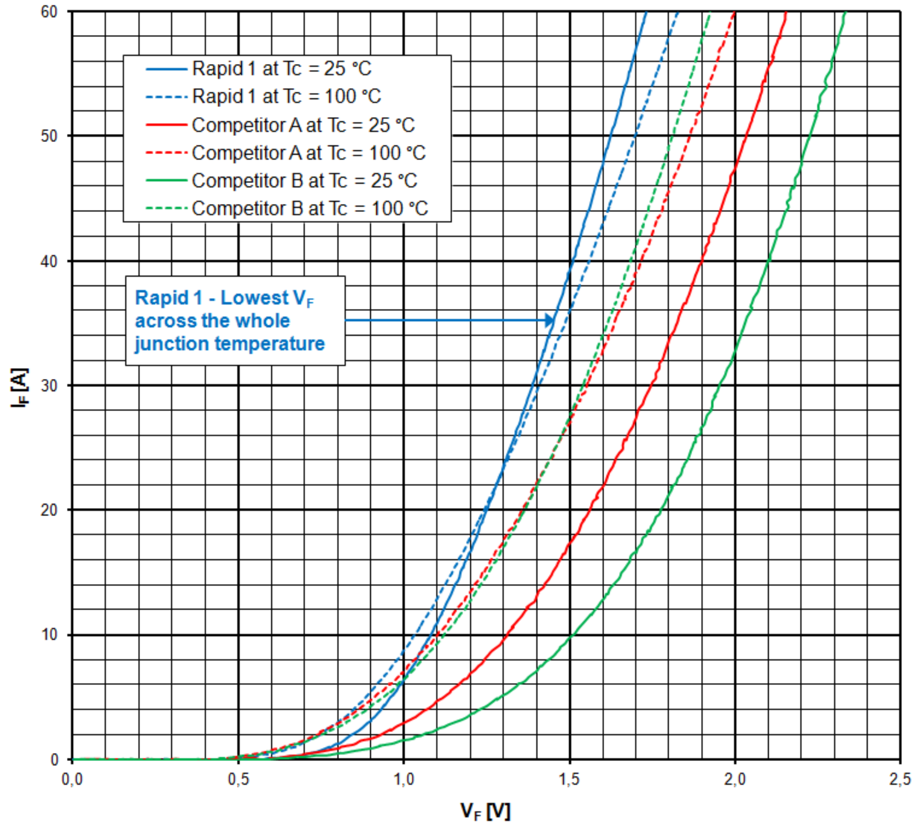


Figure 2: Diode Forward Voltage vs. Forward Current over Temperature

Next we test the switching performance of these three devices. A double pulse test fixture is used to measure the maximum I_{rrm}, Q_{rr} and see how this will affect the power switch turn-on losses ($E_{on(switch)}$). Figure 3 shows a double pulse circuit.

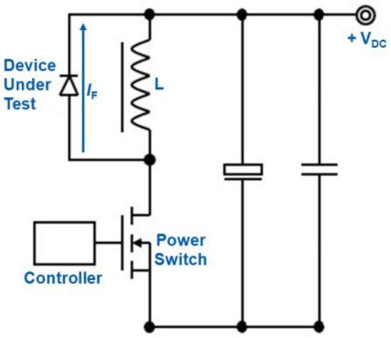


Figure 3: Double Pulse Test Circuit

Table 3 shows the measured test results of Rapid 1 with the competitors.

Device	V_F [V]	I_{rrm} [A]	Q_{rr} [nC]	$E_{on(switch)}$ [mj]
Rapid 1	1.406	14.99	861.2	1.019
Competitor A	1.550	19.22	712.7	1.016
Competitor B	1.542	22.74	772.3	1.019

Table 3: Diode and $E_{on(switch)}$ Test Result. I_D=30A, T_j=100°C

From figure 2, Rapid 1 clearly shows it has the lowest V_F compared to the competitors. This will translate into lower conduction losses essential in high power and low switching frequency application. Thanks to a low I_{rrm}, E_{on} of the power switch is kept to a minimum therefore minimizing the electrical and thermal stress on the power switch. Rapid 1 therefore combines low V_F for lower conduction losses and low I_{rrm} to reduce E_{on} of the power switch therefore increasing overall efficiency, with the additional benefit of having a 650V breakthrough voltage.

3.2 Rapid 2 PFC Tests

To validate the switching performance of Rapid 2, the device will be evaluated and then compared with competitors on a PFC test board. A hard-switched CCM PFC circuit with an output power capability of 800W is used as a test platform, as shown in figure 4. The test platform input voltage can be varied from 110 V_{AC} to 220V_{AC} and the output voltage (V_{OUT}) of the PFC is 400V_{DC}. Tests are done in a 25°C ambient temperature. A “plug and play” approach is used to test the diodes.

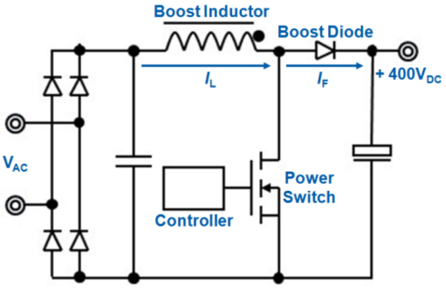


Figure 4: PFC Circuit

3.2.1 PFC Reverse Recovery Waveform and Efficiency Result

The waveforms shown in figure 5 show an 8A/650V rated Rapid 2 boost diode reverse recovery characteristics compared with some 8A/600V low Q_{rr} version competitors. As shown the boost diode is conducting 5.6A forward current (I_F). After 20ns, the diode starts to divert this forward current to the power switch by turning-on the power switch. After 6ns, boost diode forward current has been diverted to the power switch. The boost diode undergoes reverse current conduction at a rate of 2000A/µs di_F/dt. Reverse current conduction starts after 26ns then peaks down to a maximum reverse current, I_{rrm}, and then back to zero.

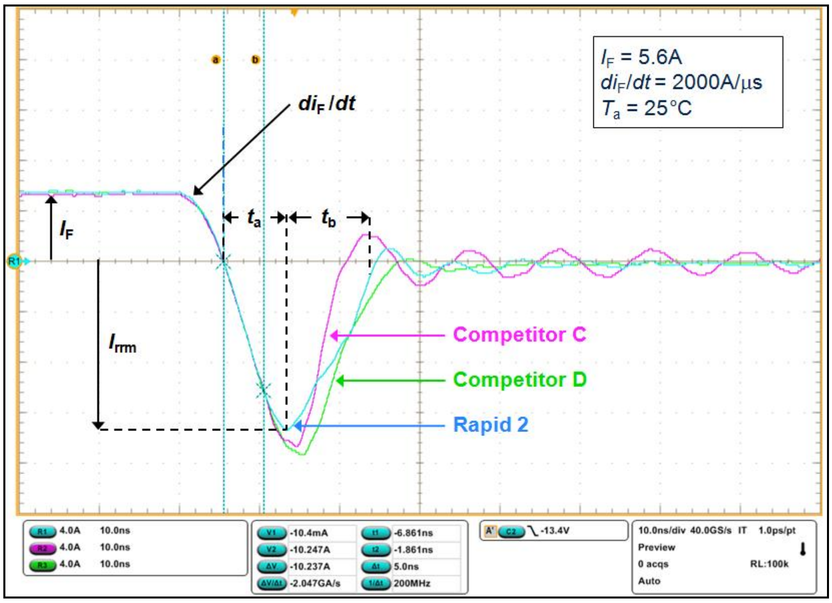


Figure 5: Boost Diode Reverse Recovery Waveforms and Test Circuit

As shown in Figure 5, Rapid 2 has the lowest I_{rrm} compared with the competitors thus minimizing power switch E_{on} losses. Soft recovery of Rapid 2 is also visible where recovery current during t_b is longer than t_a.

Figure 6 shows PFC efficiency comparison at $115V_{AC}$ and $230V_{AC}$ input voltage over the entire load range in a 25°C ambient. Having a good compromise between V_F and Q_{rr}, Rapid 2 shows a better efficiency from light to mid load while maintaining good efficiency at full load compared to competitors.

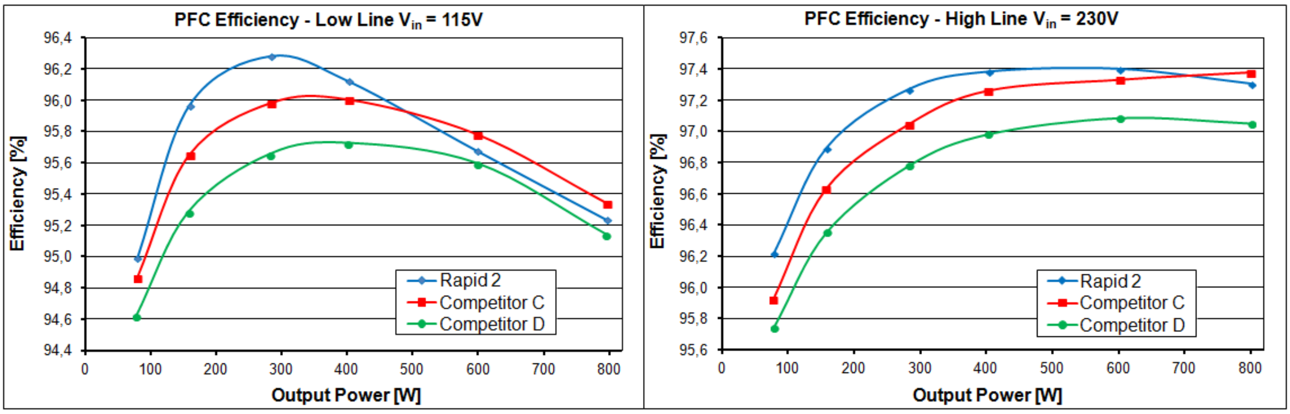


Figure 6: Efficiency vs Output Power at 115VAC and 230VAC

3.2.2 Rapid 2 Electrical Parameters Stability

As stated previously, Rapid diodes have very stable temperature behavior on the major electrical parameters. In table 4, competitor C and D increases switching parameters more than Rapid 2 when junction temperature is elevated. In relative to Rapid 2, competitor C and D doubled their value of Q_{rr} and t_{rr} respectively. Rapid 2 tends to have lower switching losses at increased junction temperature therefore cooler operation and ultimately higher reliability and extended lifetime for the end application.

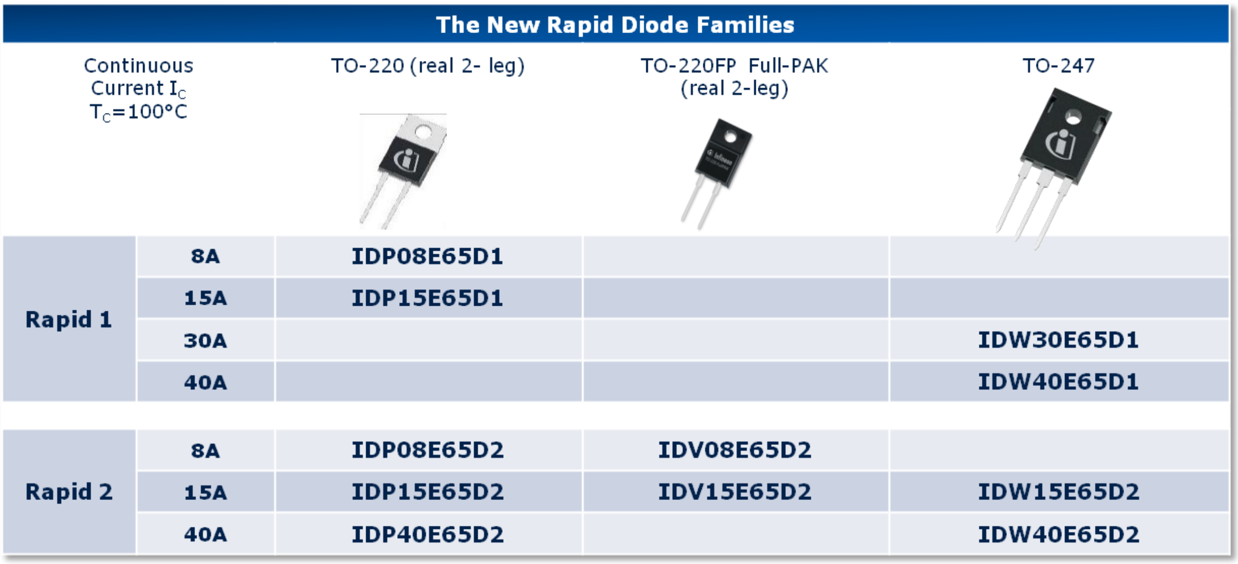
Device	**Relative Value at T_c = 125°C**		
	t_{rr}	Q_{rr}	I_{rrm}
Rapid 2	= 0.9 x t_{rr} _25°C	= 2.2 x Q_{rr} _25°C	= 1.5 x I_{rrm} _25°C
Competitor C	n.a.	= 4.0 x Q_{rr} _25°C	= 2.5 x I_{rrm} _25°C
Competitor D	= 2.1 x t_{rr} _25°C	= 3.3 x Q_{rr} _25°C	= 1.5 x I_{rrm} _25°C

Extracted from datasheet, conditions differ for different devices

Table 4: Relative Variation of Switching Parameters as a Function of Temperature

4 Portfolio

Rapid diode product naming will include package type, continuous current capability, “65” for the voltage class (divided by 10) and “D1” for Rapid 1 and “D2” for Rapid 2. Figure 7 shows the portfolio of Rapid diode.



The New Rapid Diode Families

	Continuous Current I_C T_C=100°C	TO-220 (real 2- leg)	TO-220FP Full-PAK (real 2-leg)	TO-247
Rapid 1	**8A**	**IDP08E65D1**		
	15A	**IDP15E65D1**		
	30A			**IDW30E65D1**
	40A			**IDW40E65D1**
Rapid 2	**8A**	**IDP08E65D2**	**IDV08E65D2**	
	15A	**IDP15E65D2**	**IDV15E65D2**	**IDW15E65D2**
	40A	**IDP40E65D2**		**IDW40E65D2**

Figure 7: Portfolio Rapid Diodes

5 Summary

Through characterization and application measurements, Rapid diodes have shown how existing solutions can be improved through better overall system efficiency, softer diode reverse recovery and ultimately higher system reliability. This is the result of low and stable static and dynamic characteristics, soft recovery and an additional 50V breakthrough voltage.

6 References

[1] “Fast IGBT and Diode technologies achieve Platinum Efficiency Standard in commercial SMPS applications”; Davide Chiola, Erich Griebl, APEC 2013