SuperLLD3 Series of 600 V Low-loss Fast-recovery Diodes

Tetsuhiro Morimoto
Taketo Watashima
Masaki Ichinose

1. Introduction

At present, societal problems such as global warming and environmental disruption are diverse, and the conservation of resources is often called for. Reducing power consumption, increasing efficiency and simplifying the circuitry to achieve a smaller size and fewer components are important considerations for electronic equipment. Also, the switching power supplies installed in electronic equipment are advancing toward lower power consumption, higher efficiency, higher frequency, and lower noise emission.

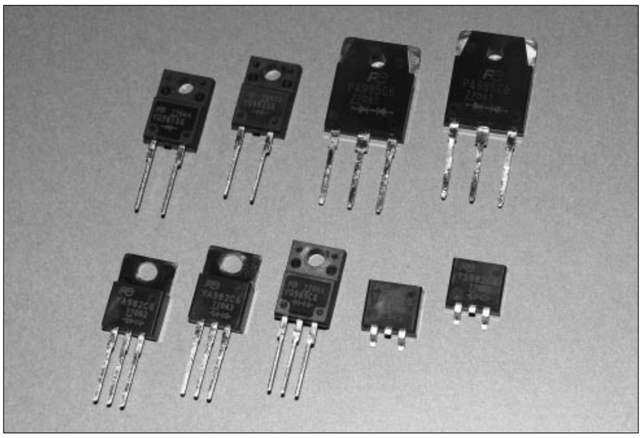
Fuji Electric has commercialized and developed a product line of various diodes, including low-loss fast-recovery diodes (LLD) and Schottky barrier diodes (SBD), as rectifying diodes suitable for various applications to power supplies.

This paper presents an overview of the newly developed SuperLLD3 series of 600 V low-loss fast-recovery diodes intended for use primarily in power factor correction in switching power supplies. (See Fig. 1.)

2. Suitable Applications and Requirements of the SuperLLD3 Series

In electronic equipment that uses commercial power supplies, a rectification circuit for AC-DC conversion is often utilized in the input rectification part. This circuit generates a distorted current waveform and is the source of harmonic component current, causing such problems as malfunction and decreased longevity of the electronic equipment and a lower power factor of the supplied power. Meanwhile, legal regulations in each country mandate the suppression of harmonic components, and a power factor correction circuit is added to comply with these regulations. As described above, the trend toward higher efficiency of power supplies is intensifying, and therefore a power factor correction circuit is absolutely essential for achieving higher efficiency and lower power loss in the system overall. The power factor correction circuit has a circuit configuration as shown in Fig. 2, and uses either a non-continuous inductance current method (current discontinuous mode) or a continuous inductance current method (current continuous mode) as the control method. Of these control methods, the current continuous mode is used mainly for high output power supplies. With this method, since the MOSFET (metal-oxide-semiconductor field-effect transistor) is made to ON during forward conduction of the diode, the forward current of the diode will be forcibly reverse-biased, and the problem of suppression of switching loss that accompanies the reverse recovery phenomenon of a diode must be considered.

Fig.1 Exterior view of SuperLLD3 series of 600 V low-loss fast-recovery diodes



Moreover, suppression of the forward loss of a diode must also be considered in order to increase the output and reduce the size of a power supply. Accordingly, in addition to reducing the reverse recovery time (t_{rr}), it is also important to reduce the forward voltage (V_F) of a diode. Thus, a LLD is needed that achieves higher speed than Fuji Electric's conventional SuperLLD1 series specialized for high-speed (short t_{rr}) and also has a lower V_F.

Figure 3 shows an example of the loss analysis results of a diode and MOSFET in a current continuous mode power factor correction circuit. The MOSFET accounts for two-thirds of the total loss, which is an extremely large percentage, and the turn-on loss which accounts for approximately half of this loss is largely affected by the reverse recovery characteristics of a diode. Thus, a diode that is higher speed and achieves a

Fig.2 Power factor correction circuit and operation waveforms

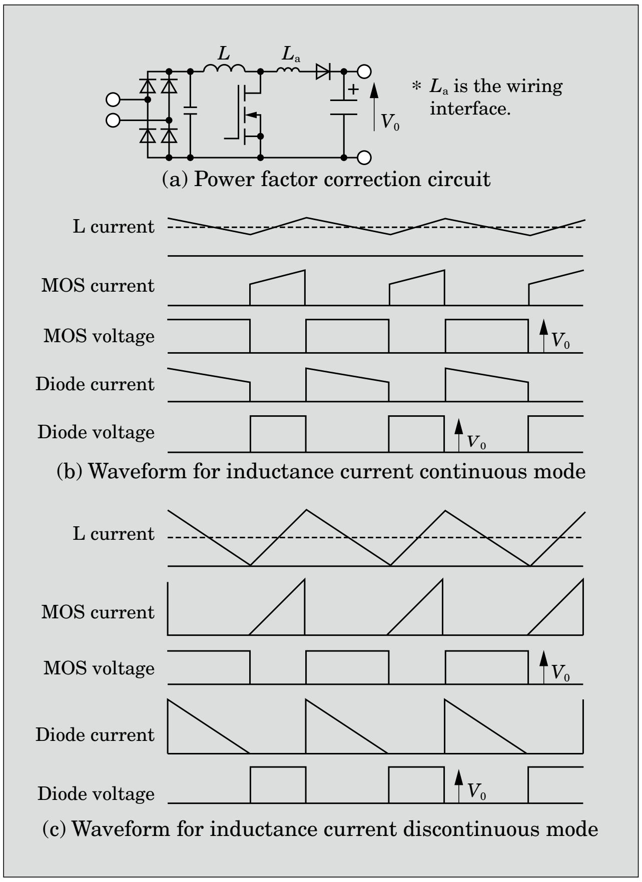
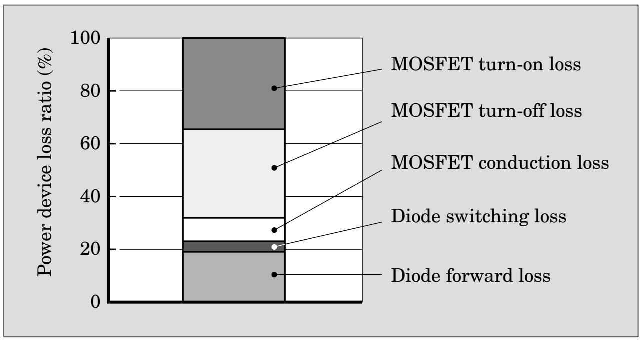


Fig.3 Simulation of loss generated in power devices of current continuous mode power factor correction circuit



lower V_F than Fuji Electric's conventional SuperLLD1 device is needed in order to reduce the MOSFET turn-on loss. The newly developed SuperLLD3 realizes a 25% shorter t_{rr} and a 20% lower V_F than the SuperLLD1.

3. SuperLLD3 characteristics and application example

The V_F-t_{rr} trade-off correlation of the newly developed SuperLLD3 and the conventional SuperLLD1 and SuperLLD2 are compared for 10 A devices as shown in Fig. 4. The SuperLLD3 is significantly improved compared to the V_F-t_{rr} trade-off line of the SuperLLD1

Fig.4 V_F-t_{rr} trade-off correlation

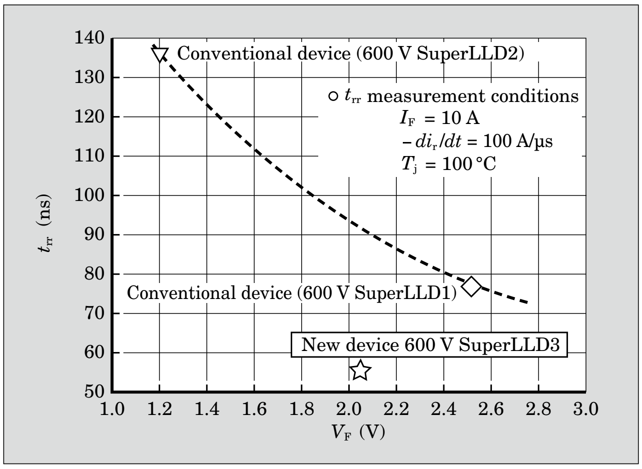
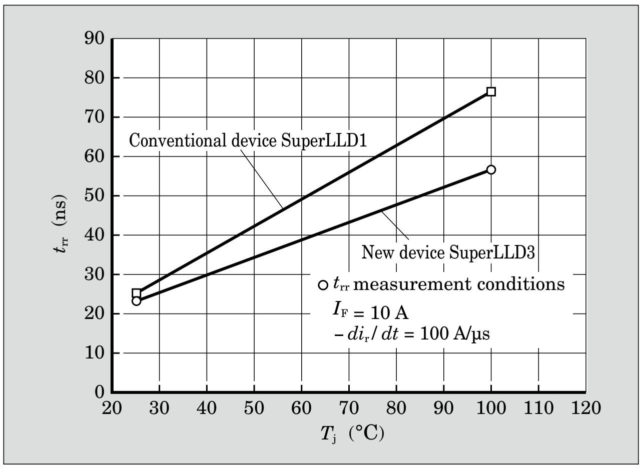


Fig.5 t_{rr} temperature dependence



and SuperLLD2. The reverse recovery time t_{rr} is suppressed by approximately 25% compared to the SuperLLD1, and this is effecting in reducing switching loss during high frequency operation.

Next, Fig. 5 shows the temperature dependence of trr. With the SuperLLD3, the t_{rr} temperature change rate is smaller than for the SuperLLD1, and thus for high temperature operation, the switching loss is considered to be less temperature dependent.

Figure 6 shows the results of a comparison of the forward characteristics of the SuperLLD3 and the SuperLLD1. The SuperLLD3 has forward characteristics that are approximately 20% lower than the SuperLLD1 at high temperature (100 °C), thereby enabling a reduction in forward loss. Table 1 shows the results of comparing the characteristics of the SuperLLD3 and the SuperLLD1. Next, in order to verify the effect of the SuperLLD3 that achieves higher speed operation and lower V_F, an evaluation was carried out with an actual current continuous mode power factor correction circuit. The evaluated power supply had an output of 390 W (390 V/1 A) and the switching frequency was 65 kHz.

Table 2 shows the measured temperature rise and conversion efficiency of the diode and MOSFET when mounted in the SuperLLD3 and SuperLLD1, respectively. The diode and MOSFET were evaluated using separated heat sinks. Due to a significantly lower V_F and a higher speed t_{rr}, the temperature rise of the diode mounted on the SuperLLD3 was approximately 11 °C lower than in the case of the SuperLLD1. Moreover, the MOSFET's drain current, which affects the turn-on loss that accounts for approximately one-third of the loss, is reduced due to application of the SuperLLD3, and thus the temperature rise of the MOSFET was also suppressed. Application of the SuperLLD3 enables a reduction in the total temperature rise of the diode and MOSFET, and an approximate 1% improvement in conversion efficiency.

Fig. 6 Comparison of 600 V 10 A LLD forward characteristics

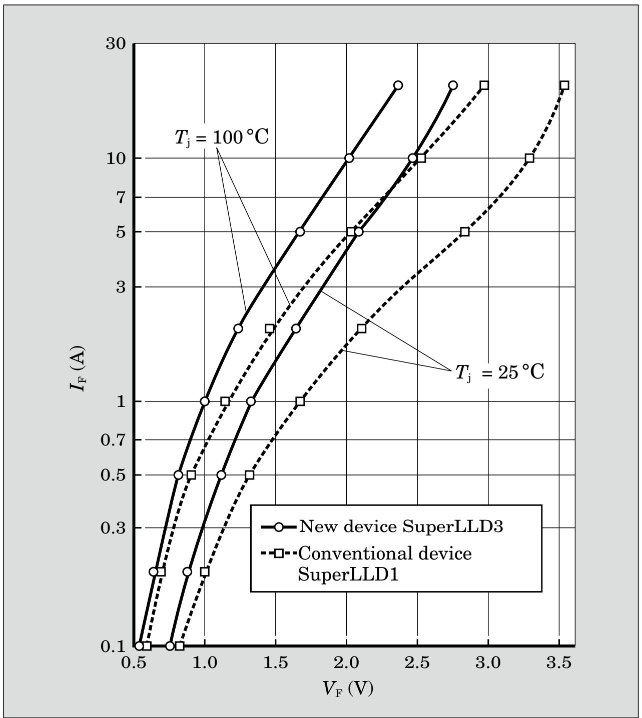


Table 1 Comparison of SuperLLD3 and SuperLLD1 characteristics (actual measured values)

Item		Condition	New device SuperLLD3	Conventional device SuperLLD1	Units
V_F	25 °C	I_F = 10 A	2.5	3.3	V
	100 °C		2.0	2.5	V
t_{rr}	25 °C	I_F = 10 A, $-di_r/dt$ = 100 A/μs	23	25	ns
	100 °C		57	77	ns
I_{RP}	25 °C		1.2	1.2	A
	100 °C		1.75	1.74	A

Table 2 Temperature rise and efficiency of SuperLLD3 and SuperLLD1

Item		New device SuperLLD3	Conventional device SuperLLD1	Units
Efficiency		88.16	87.17	%
Temperature rise of case	Diode	35.7	46.8	°C
	MOSFET	50.4	52.9	°C

Conditions: 390 W (390 V, 1.0 A output), 65 kHz

4. SuperLLD3 Design Measures[1]

Figure 7 shows the basic structure of a planar type diode. The LLD uses a lifetime killer diffusion process to achieve higher speed operation.

As an example of LLD design considerations, Fig. 8 shows the correlation between V_F and t_{rr} at

Fig.7 Cross-section of LLD chip

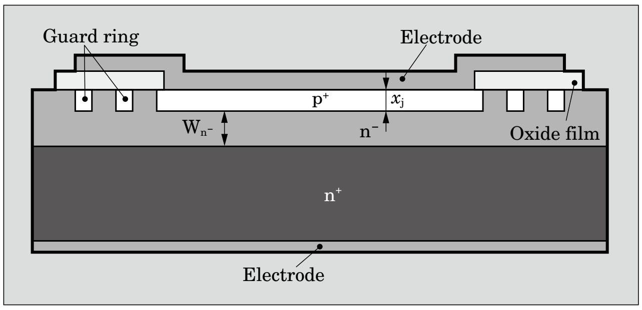


Fig.8 V_F-t_{rr} trade-off correlation

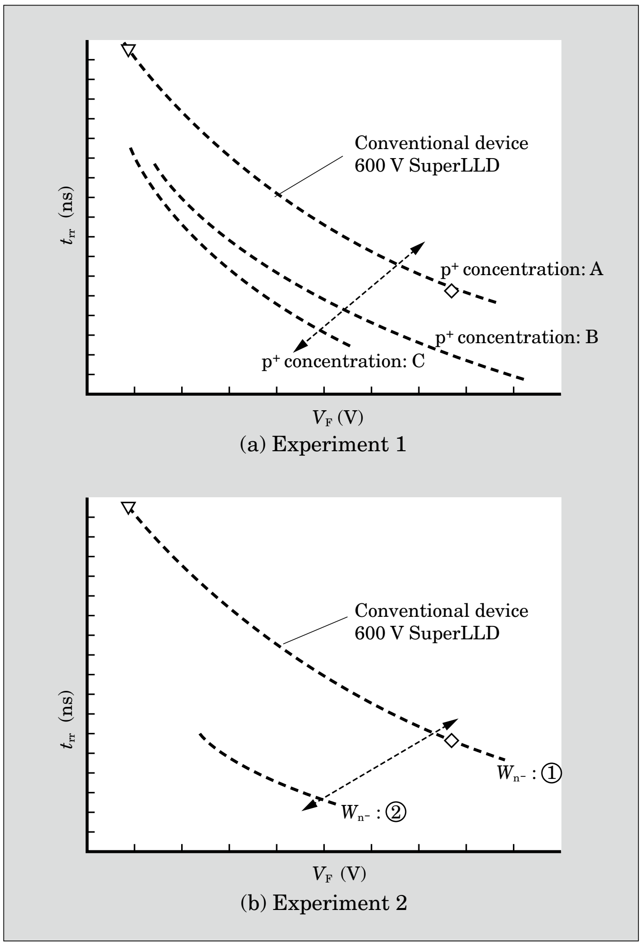
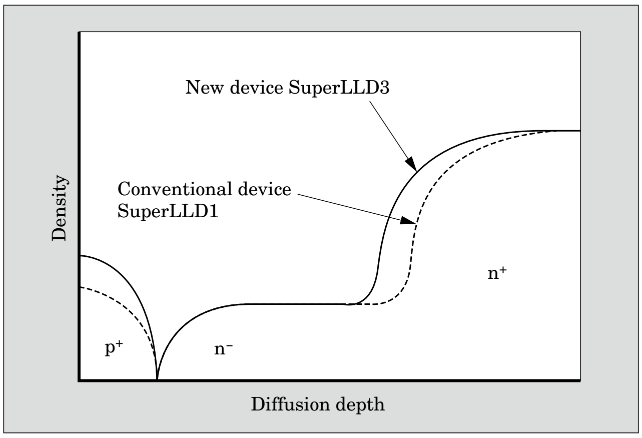


Table 3 600 V SuperLLD3 absolute maximum ratings and electrical characteristics

Device type	Package	Chip composition	Absolute maximum ratings V_{RRM} (V)	$I_{o\,(max)}$ (A)	I_{FSM} (A)	Electrical characteristics V_{FM} (V) (T_j = 25 °C)		I_{RRM} (μA) $V_R = V_{RRM}$	t_{rr} (ns) I_F = 0.1 A, I_R = 0.2 A, I_{rec} = 0.05 A	$R_{th\,(j-c)}$ (°C / W)
YA981S6R	TO-220AB	Single	600	8	40	3.0	I_F = 8 A	25	26	2.50
YG981S6R	TO-220F	Single	600	8	40	3.0	I_F = 8 A	25	26	4.50
TS982C6R	T-pack (S)	Twin	600	16	40	3.0	I_F = 8 A	25	26	1.50
YA982C6R	TO-220AB	Twin	600	16	40	3.0	I_F = 8 A	25	26	1.50
YG982C6R	TO-220F	Twin	600	16	40	3.0	I_F = 8 A	25	26	2.00
YA982S6R	TO-220AB	Single	600	10	50	3.0	I_F = 10 A	30	28	2.00
YG982S6R	TO-220F	Single	600	10	50	3.0	I_F = 10 A	30	28	3.50
TS985C6R	T-pack (S)	Twin	600	20	50	3.0	I_F = 10 A	30	28	1.25
YA985C6R	TO-220AB	Twin	600	20	50	3.0	I_F = 10 A	30	28	1.25
YG985C6R	TO-220F	Twin	600	20	50	3.0	I_F = 10 A	30	28	1.75
PA985C6R	TO-3P	Twin	600	20	50	3.0	I_F = 10 A	30	28	1.50

100 °C when the densities of three types of p^+ layers (A < B < C) and the lifetime killer diffusion density were varied. Similarly, the figure also shows the correlation between V_F and t_{rr} at 100 °C when the thicknesses of two types of n^- layers (① > ②) and the lifetime killer diffusion density were varied. From Fig. 9, it can be seen that by increasing the densities of the p^+ layers and decreasing the thickness of the n^- layers, t_{rr} can be made faster and V_F can be lowered. Based on these considerations, the density and diffusion depth of the p^+ layers, the lifetime killer diffusion density and the n^- layers were optimized, and as shown in Fig. 9, the SuperLLD3 series was commercialized with a higher density and shallower diffusion depth profile design than in Fuji's conventional LLD series.

Fig.9 Diffusion profile



5. SuperLLD3 Series

Table 3 lists the absolute maximum ratings and electrical characteristics of the SuperLLD3. The rated current is from 8 to 20 A, and the package is either a TO-220AB, a TO-3P, a fully-insulated mold type TO-220F, or a surface mount type T-pack (S).

6. Postscript

An overview of Fuji Electric's newly developed SuperLLD3 series has been presented above. This series has sufficient performance for application to current continuous mode power factor correction circuits, and is also effective in applications to the secondary rectification in a high-output power supply where high working voltage, high speed and low V_F characteristics are required. In the future, the power supply trends toward higher output and smaller size through harmonic current driving are expected to continue, and even lower power loss and lower noise emission will be required for the diodes used in such power supplies. Fuji Electric intends to continue to improve the characteristics and quality of high-speed diodes, including LLDs, SBDs and the like, and to expand its product lineup and provide even more effective products to the market.

References

(1) Onishi. Y. et al. Analysis on Device Structure for Next Generation IGBT. Proceedings of the 10th ISPSD. 1998. p.85-88.