6th Generation Power MOSFET Super FAP-E^{3S} Low Q_g Series

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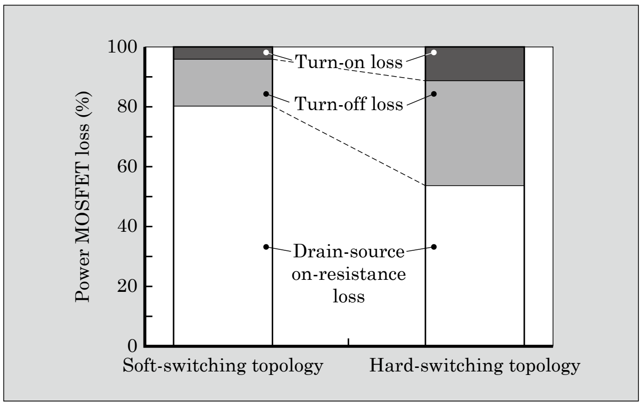
1. Introduction

In recent years, efforts to address environmental issues have focused on the goal of reducing greenhouse effect gases, while at the same time, in consideration of future energy supply and demand trends associated with the economic growth of developing nations such as the ASEAN and BRICs countries, the trend toward energy savings is accelerating. In particular, energy savings is demanded in various electronic devices that have rapidly come into widespread use, and as a result of the International ENERGY STAR program*[1], power efficiency improvements are regulated, and requests for higher efficiency are intensifying for the switched-mode power supplies that supply electric power to such electronic devices. Requests for lower noise to comply with various noise regulations must also be supported.

Consequently, the power devices installed in switched-mode power supplies that support these requests are required to have low loss and low noise. The power devices are also required to be resistant to damage and easy to use.

Various converter topologies have been proposed for switching-mode power supplies, and soft-switching topologies such as a current resonant type converter, a quasi-resonant converter and the like have been used increasingly in the main converter unit, but many hard-switching topologies are used in the conventional flyback topology, forward topology and power factor improvement circuits (PFC: power factor correction). Figure 1 shows results of the loss analysis of a power MOSFET (metal-oxide-semiconductor field-effect transistor) for both soft-switching and hard-switching topologies. With a soft-switching topology, the drain-source on-resistance loss becomes predominant and therefore devices having low on-resistance characteristics are demanded. On the other hand, with a hard-switching topology, the drain-source on-resistance loss and the turn-off loss account for the majority of loss, and therefore power devices suitable for this circuit are requested to have lower on-resistance, and to improvement of switching performance.

Fig.1 Power MOSFET loss analysis results for soft-switching and hard-switching topologies



Fuji Electric's "SuperFAP-E^3 series" general-purpose product lineup exhibits the characteristics of both low loss as a result of low on-resistance and low noise, and is already an established series of power MOSFETs for realizing higher efficiency and lower noise in switched mode power supplies.

The "SuperFAP-E^{3S} low Q_g series" of 6th generation power MOSFETs retains the low on-resistance, low noise performance and gate resistance controllability of the prior product series while providing improved switching performance, and was developed for PWM (pulse width modulation)-ICs (hard-switching topology). Characteristics and applied results of this new series are described below.

2. Product Overview

The newly developed SuperFAP-E^{3S} low Q_g series for PWM-ICs (hard-switching topology) retains the on-resistance performance, i.e., the industry's lowest on-resistance for a planar type MOSFET, of the existing

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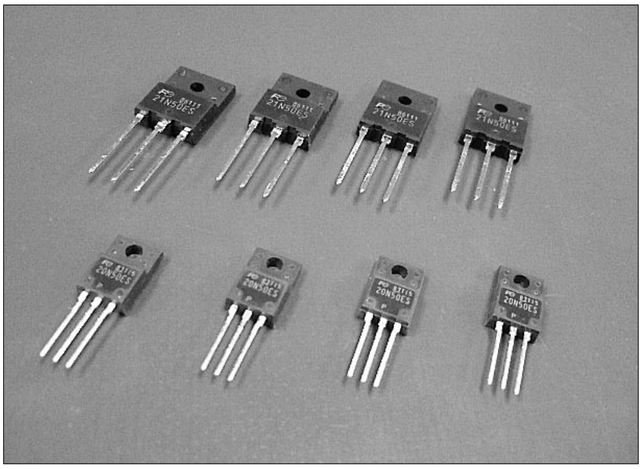
*1: International ENERGY STAR program is an international environmental labeling system for energy savings in OA equipment, and operates under mutual recognition by the Ministry of Economy, Trade and Industry in Japan and the US Environmental Protection Agency (EPA) in the United States.

SuperFAP-E^3 series while realizing an approximate 20% reduction in gate charge Q_g compared to the previous series and lower switching loss. Table 1 compares representative electrical characteristics of the new products with those of the prior product series. Figure 2 shows the appearance of the new products and Table 2 lists the products in the 500 V and 600 V series. Specific design measures are described below.

Table 1 Comparison of characteristics

	SuperFAP-E^{3S} low Q_g series	SuperFAP-E^3 series (prior product)
Model	FMV23N50ES	FMV23N50E
Package	TO-220F	TO-220F
V_{DS}	500 V	500 V
I_D	23 A	23 A
$R_{DS(on)max}$	0.245 Ω	0.245 Ω
V_{GS}	4.2 V (typ.)	3 V (typ.)
g_{fs}	16 S (typ.)	28 S (typ.)
Q_G	76 nC (typ.)	93 nC (typ.)

Fig.2 Appearance of new products



3. Applied Technology

The SuperFAP-E^{3S} low Q_g product is based on the SuperFAP-E^3 concept of "low loss due to low on-resistance characteristics, low noise, and being resistant to damage and easy to use" and additionally aims to improve the switching characteristics.

The Q_g was lowered in order to reduce the turn-off loss and to improve the switching performance. Further, the gain characteristic, g_{fs}, was reduced in order to reduce noise caused by the rush current at turn-on.

As a measure for reducing Q_g and g_{fs}, we increased the thickness of the gate oxide layer. Increasing the thickness of the gate oxide layer causes the gate threshold voltage $V_{GS(th)}$ to rise and the on-resistance to increase, and therefore, improved switching performance and lower on-resistance characteristics are difficult to realize simultaneously. The film thickness must be increased within the range that does not degrade the on-resistance. Considering that the driving voltage of a PWM-IC for a typical switching-mode power supply is at least 10 V, the film thickness was increased by approximately 30% compared to the prior product series. Moreover, if the thickness of the gate oxide film is increased, the diffusion shape will change, maintaining the QPJ (quasi-plane-junction) structure at the same level as with the SuperFAP-E^3 series will become difficult, and the breakdown voltage will decrease. Accordingly, the concentrations of the surface n layer and the channel p diffusion layer are optimized to ensure the same breakdown voltage as with the prior product series.

As shown in Fig. 3, the aforementioned design enables the gate charge Q_g to be reduced by approximately 20% compared to the prior product series. Additionally, by maintaining the QPJ structure, reducing the channel density and optimizing the surface structure, the g_{fs} gain characteristic is reduced by approximately 40% compared to the prior product series, as shown in Fig. 4.

Table 2 SuperFAP-E^{3S} low Q_g series product list

Breakdown voltage BV_{DSS}	Rated current I_D	On-resistance $R_{DS(on)}$	Gate charge Q_g	Package				
				TO-220	TO-220F	T-pack	TO-3P	TO-3PF
500 V	12 A	0.52 Ω	36 nC	FMP12N50ES	FMV12N50ES	FMI12N50ES	–	–
	16 A	0.38 Ω	48 nC	FMP16N50ES	FMV16N50ES	FMI16N50ES	FMH16N50ES	–
	20 A	0.31 Ω	59 nC	FMP20N50ES	FMV20N50ES	FMI20N50ES	–	–
	21 A	0.27 Ω	66 nC	–	FMV21N50ES	–	FMH21N50ES	FMR21N50ES
	23 A	0.245 Ω	72 nC	–	FMV23N50ES	–	FMH23N50ES	FMR23N50ES
	28 A	0.19 Ω	100 nC	–	FMV28N50ES	–	FMH28N50ES	FMR28N50ES
600 V	6 A	1.2 Ω	27 nC	FMP06N60ES	FMV06N60ES	FMI06N60ES	–	–
	12 A	0.75 Ω	37 nC	FMP12N60ES	FMV12N60ES	FMI12N60ES	–	–
	16 A	0.47 Ω	58 nC	FMP16N60ES	FMV16N60ES	FMI16N60ES	–	–
	17 A	0.40 Ω	69 nC	–	FMV17N60ES	–	FMH17N60ES	FMR17N60ES
	19 A	0.365 Ω	81 nC	–	FMV19N60ES	–	FMH19N60ES	FMR19N60ES
	23 A	0.28 Ω	100 nC	–	–	–	FMH23N60ES	FMR23N60ES

Fig.3 Q_g comparison

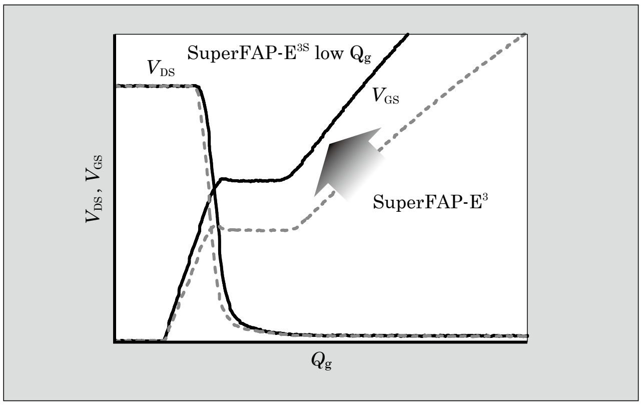


Fig.4 g_{fs} comparison

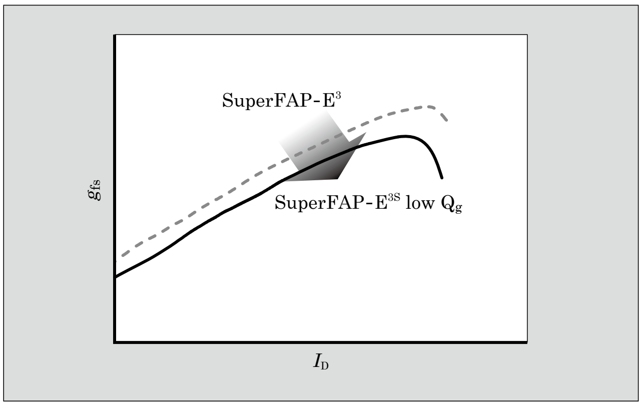
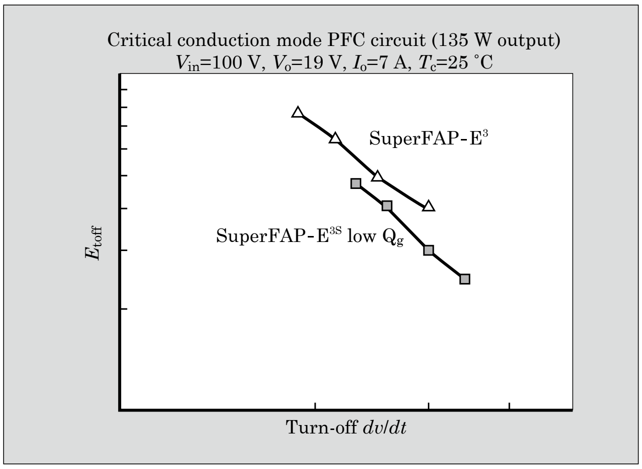


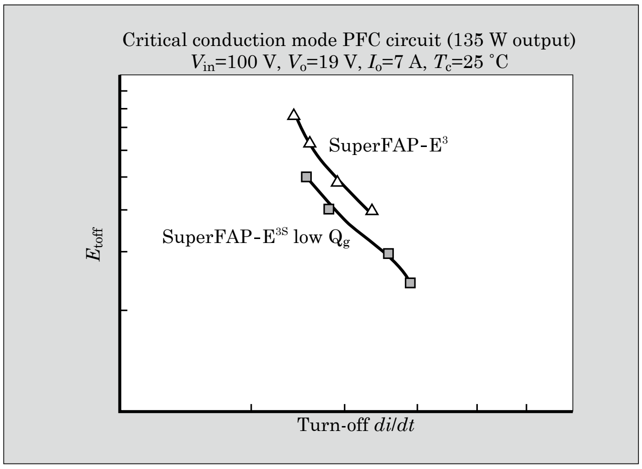
Fig.5 Turn-off loss E_{toff} vs. turn-off dv/dt



The switching performance improves as a result of reduction of Q_g and g_{fs}, and Fig. 5 shows the tradeoff relation between turn-off loss E_{toff} and turn-off dv/dt, a cause of noise at switching.

While keeping the same gate resistance controllability as in the prior product series, the tradeoff between turn-off loss E_{toff} and the drain-source voltage change rate dv/dt at turn-off is improved by approximately 25% for the same dv/dt conditions. Also, as shown in Fig. 6, the tradeoff relation between the current change rate di/dt at turn-off and the turn-off loss

Fig.6 Turn-off loss E_{toff} vs. turn-off di/dt



improves and better switching performance is realized.

4. Application Results

4.1 Application to continuous and critical mode PFC circuits

Figure 7 shows waveforms at turn-off in a critical mode PFC circuit. The SuperFAP-E^{3S} low Q_g product has a shorter turn-off interval t_{off} due to its low gate charge characteristics and realizes approximately 20% less switching loss than the prior SuperFAP-E^3 product.

Figure 8 shows the results of analysis of the generated loss of a continuous mode PFC circuit and of a critical conduction mode PFC circuit in actual applications. In the figure, P_{on} indicates the on-resistance loss, P_{toff} indicates the turn-off loss, and P_{ton} indicates the turn-on loss. In the continuous mode PFC circuit, as in the critical mode PFC circuit, the turn-off loss is reduced by approximately 20% compared to the SuperFAP-E^3 product. Moreover, each circuit results in an approximately 17% reduction in total loss by the effect of the reduction in turn-off loss, and as shown in Table 3, a decrease in the device temperature rise by approximately 4 to 6 °C and an improvement in power conversion efficiency η by approximately + 0.4%, as compared to the SuperFAP-E^3 product, enable improved performance of a power supply system.

4.2 Application to flyback circuit

Figure 9 shows the effect of reducing rush current at turn-on, which is one cause of noise in a flyback circuit. With the prior SuperFAP-E^3 product, in order to suppress rush current, the gate resistance had to be set to a value approximately 20% larger than that of the SuperFAP-E^{3S} low Q_g product and the turn-on loss increased as a result. The SuperFAP-E^{3S} low Q_g product, however, realizes low turn-on loss and the same or lower rush current as the prior SuperFAP-E^3 product which has a large gate resistance. By applying this SuperFAP-E^{3S} low Q_g product to a flyback circuit, the

Fig.7 Comparison of turn-off waveforms in critical conduction mode PFC circuit

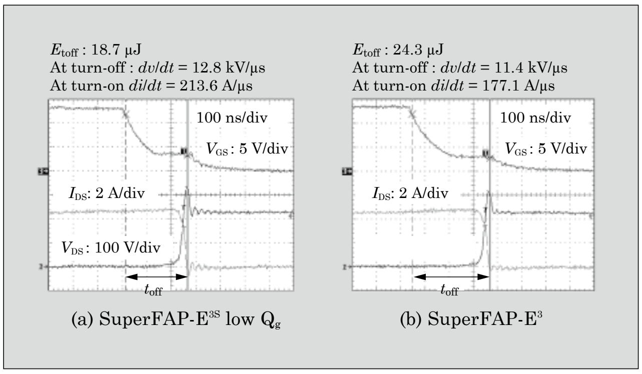
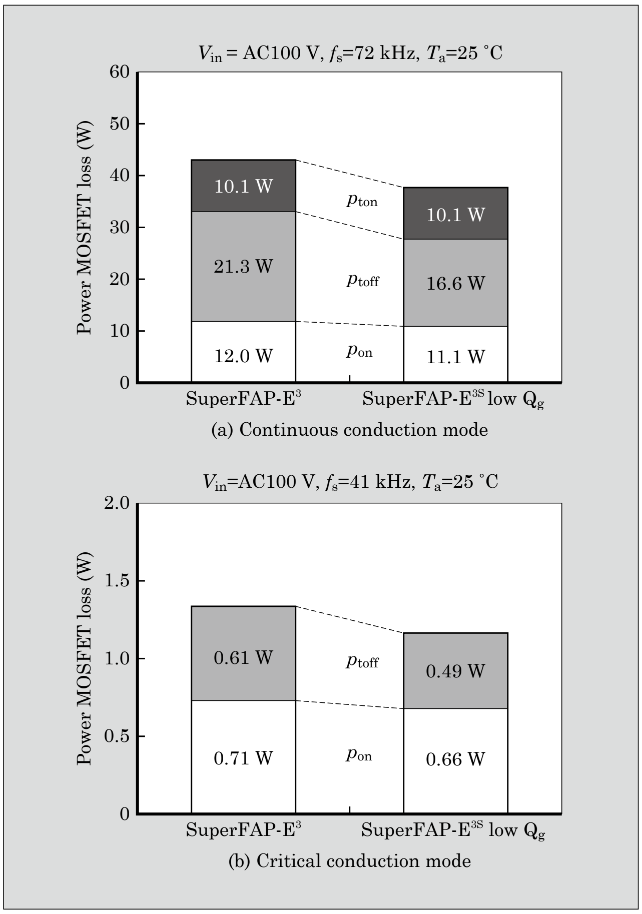


Fig.8 Result of analysis of loss in PFC circuit



noise caused by rush current is reduced and the lower loss is realized.

Figure 10 shows the results of analysis of the loss when using the SuperFAP-E3S low Q_g product. The lower turn-on and turn-off loss of the SuperFAP-E3S low Q_g product enable an approximate 12% reduction in total loss compared to the prior product series. An approximate 6 °C reduction in the device temperature rise and an approximate + 0.4% improvement in power conversion efficiency η enable the realization of improved performance of the power supply system.

Table 3 Effects of applied new circuit and method

Application	Applied circuit and method	Item	Present product	New product	Improvement effect
AC adapter 135 W	PFC circuit (critical conduction mode)	Power efficiency η	86.7 %	87.1 %	+0.4 %
		Case temperature rise ΔT_c	34 °C	30 °C	−4 °C
PC power supply 400 W	PFC circuit (continuous conduction mode)	Power efficiency η	72.9 %	73.3 %	+0.4 %
		Case temperature rise ΔT_c	98 °C	92 °C	−6 °C
AC adapter 65 W	Main converter (flyback)	Power efficiency η	87.3 %	87.7 %	+0.4 %
		Case temperature rise ΔT_c	90 °C	84 °C	−6 °C

Fig.9 Comparison of turn-on characteristics in flyback circuit

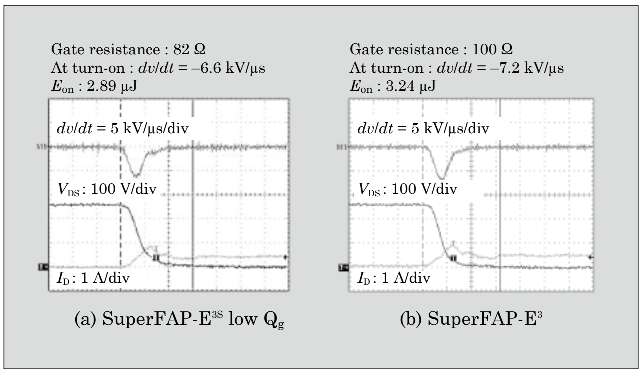
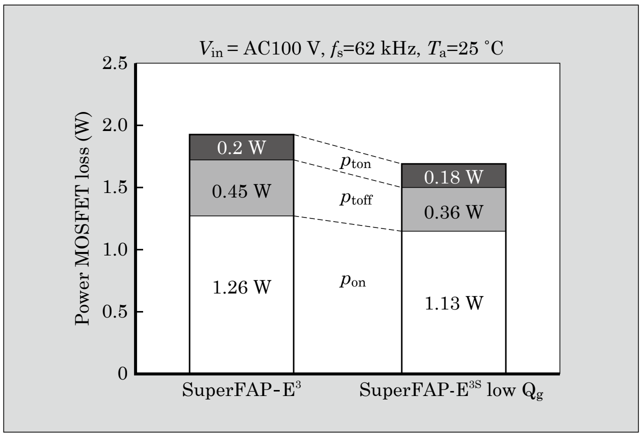


Fig.10 Result of analysis of loss in flyback circuit



5. Postscript

This paper has described the product characteristics and application results of Fuji Electric's newly developed SuperFAP-E3S low Q_g series of power MOSFETs that realize improved switching performance due to lower gate charge characteristics. The SuperFAP-E3S low Q_g product series achieves a balanced tradeoff between low on-resistance, low switching loss and low noise, which are requested of power devices installed in switching-mode power supplies, and when used in applications, realizes improved power efficiency and lower temperature rise of electronic device systems, and can contribute to energy savings.

Reference

(1) Kobayashi, T. et al. High-voltage Power MOSFETs Reached Almost to the Silicon Limit. Proceedings of ISPSD '01.2001. p. 435-438.