Low I_R Schottky Barrier Diode Series

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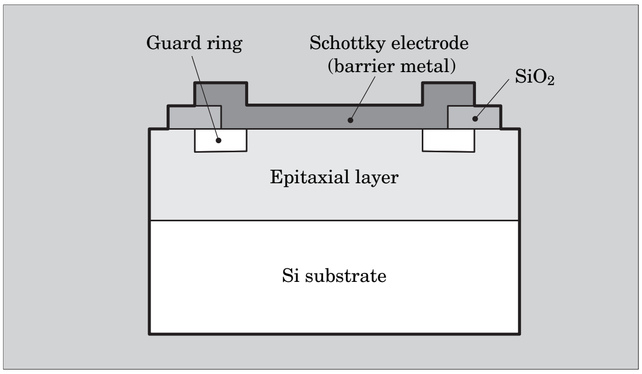
1. Introduction

Representative of the recent trends towards smaller size and higher functionality of portable devices and towards higher speed CPUs for computers, electronic devices are rapidly becoming smaller in size, lighter in weight and are achieving higher performance, and it is essential that their circuit boards and switching power supplies be made to consume less power, are more efficient, generate less noise and support higher density packaging. Moreover, in order to suppress the surge voltage that is applied across a diode during switching and the noise generated by a steep *dv/dt* characteristic, snubber circuits, beads and the like are used, but as a result the number of components increases, leading to greater cost. In order to achieve better portability, AC adapters for notebook computers are being miniaturized; however, the trend toward higher power consumption results in higher internal temperatures, increasing the severity of the environment in which these semiconductor devices are used. Consequently, semiconductor devices are strongly required to provide the characteristics of lower loss, improved suppression of thermal runaway, higher maximum operating temperature and lower noise. In particular, an improvement in the characteristics of the secondary source output rectifying diode, which accounts for nearly 50 % of the loss in a switching power supply, is strongly desired.

2. Overview

Schottky barrier diodes (SBDs) exhibit the properties of low forward voltage (V_F), soft recovery and low noise, and are widely used in the secondary source rectifying circuits of switching power supplies. Fuji Electric has previously developed a product line of conventional 20 to 100 V SBDs (low V_F type) and 120 to 250 V SBDs [low reverse current (I_R) type] as a diode series available in a variety of packages and supporting various output voltages and current capacities in order to be applicable to a wide range of power supply applications. However, when the conventional low V_F type SBD operates at high temperatures, its I_R becomes large, and as a result reverse loss increases, efficiency decreases and thermal runaway may occur, making it difficult to use this low V_F SBD in a small power supply packages such as an AC adapter.

Fig.1 Cross-sectional structure of SBD chip

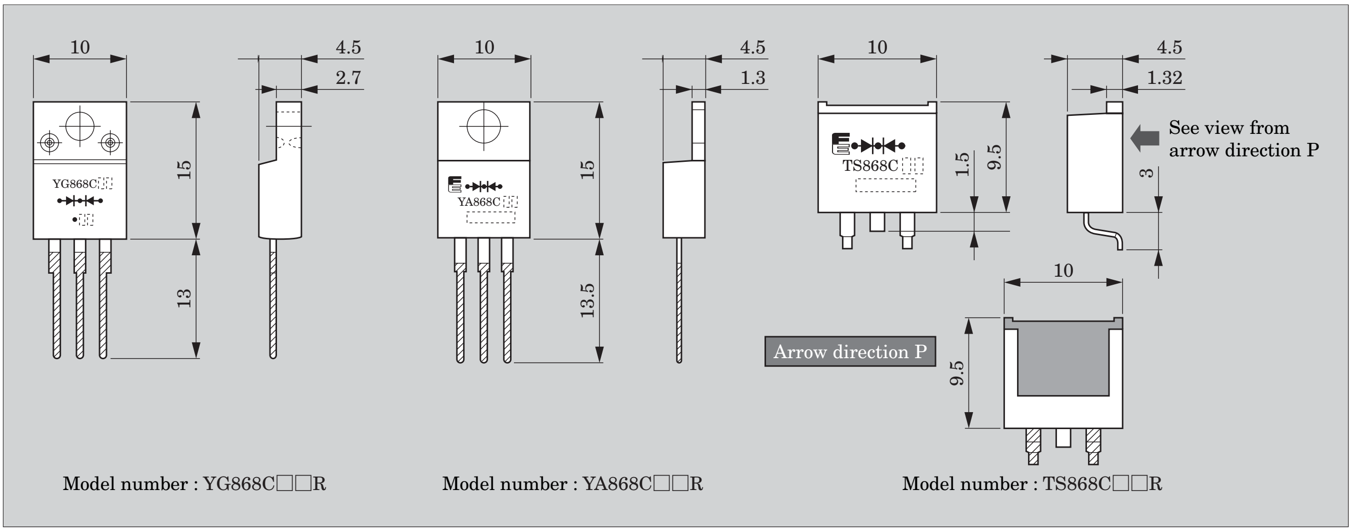


The newly developed low I_R-SBD is considered to be the ideal diode for secondary source rectification in a switching power supply, and is especially well suited for rectification in a high temperature environment. Figure 1 shows the cross-sectional structure of the SBD chip. The chip design incorporates a guard ring to prevent premature breakdown, and the doping density, specific resistance and thickness of the epitaxial layer (n^- layer), diffusion depth, and barrier metal that have been optimized to develop a low I_R-SBD series that provides not only low I_R, but also breakdown voltages of 40, 60 and 100 V, comparable to the conventional V_F. Compared to a conventional SBD having the same breakdown voltage, this product achieves an approximate single-digit decrease in I_R, a large decrease in reverse loss, a higher temperature at which thermal runaway occurs, and a higher maximum operating temperature. Moreover, this new series has a high avalanche breakdown voltage and is expected to be capable of withstanding the large surge voltage that occurs when a power supply is turned on. The new series is also expected to enable the design of switching power supply circuits that realize increased efficiency, smaller size and greater flexibility. Table 1 lists the absolute maximum ratings and electrical characteristics of this low I_R-SBD series and Fig. 2 shows external

Table 1 Absolute maximum ratings and electrical characteristics of low I_R SBD

Model number	Package	Absolute maximum ratings					Electrical characteristics		
		V_{RRM} (V)	V_{RSM} (V)	I_O (A)	I_{FSM} (A)	P_{RM} (W)	V_{FM} (V) $I_F = 0.5 \times I_O$ (T_j = 25°C)	I_{RRM} (μA) $V_R = V_{RRM}$	$R_{th(j\text{-}c)}$ (°C/W)
YG862C04R	TO-220F	45	45	10	125	330	0.61	150	3.50
YA862C04R	TO-220	45	45	10	125	330	0.61	150	2.00
TS862C04R	T-Pack	45	45	10	125	330	0.61	150	2.00
YG862C06R	TO-220F	60	60	10	125	330	0.68	150	3.50
YA862C06R	TO-220	60	60	10	125	330	0.68	150	2.00
TS862C06R	T-Pack	60	60	10	125	330	0.68	150	2.00
YG862C10R	TO-220F	100	100	10	125	330	0.86	150	3.50
YA862C10R	TO-220	100	100	10	125	330	0.86	150	2.00
TS862C10R	T-Pack	100	100	10	125	330	0.86	150	2.00
YG865C04R	TO-220F	45	45	20	145	330	0.63	175	2.50
YA865C04R	TO-220	45	45	20	145	330	0.63	175	1.75
TS865C04R	T-Pack	45	45	20	145	330	0.63	175	1.75
YG865C06R	TO-220F	60	60	20	145	660	0.74	175	2.50
YA865C06R	TO-220	60	60	20	145	660	0.74	175	1.75
TS865C06R	T-Pack	60	60	20	145	660	0.74	175	1.75
YG865C10R	TO-220F	100	100	20	145	660	0.86	175	2.50
YA865C10R	TO-220	100	100	20	145	660	0.86	175	1.75
TS865C10R	T-Pack	100	100	20	145	660	0.86	175	1.75
YG868C04R	TO-220F	45	45	30	160	1,000	0.63	200	2.00
YA868C04R	TO-220	45	45	30	160	1,000	0.63	200	1.25
TS868C04R	T-Pack	45	45	30	160	1,000	0.63	200	1.25
YG868C06R	TO-220F	60	60	30	160	750	0.74	200	2.00
YA868C06R	TO-220	60	60	30	160	750	0.74	200	1.25
TS868C06R	T-Pack	60	60	30	160	750	0.74	200	1.25
YG868C10R	TO-220F	100	100	30	160	750	0.86	200	2.00
YA868C10R	TO-220	100	100	30	160	750	0.86	200	1.25
TS868C10R	T-Pack	100	100	30	160	750	0.86	200	1.25

Fig.2 External view of the packages



views of the packages. The current ratings are 10 A, 20 A and 30 A and the product packages are available as the TO-220, the TO-220F full-mold type, and the T-Pack (S) surface mount type.

The newly developed low I_R-SBD is described below.

Fig.3 Comparison of forward characteristics

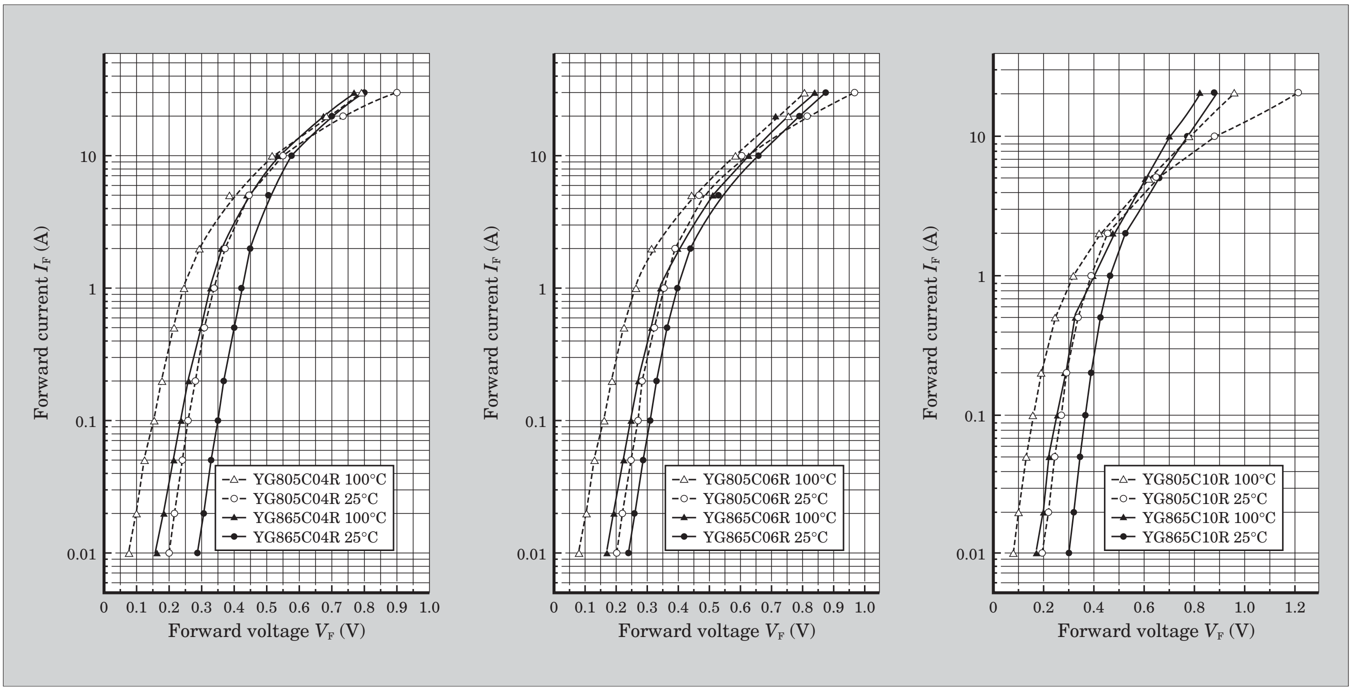
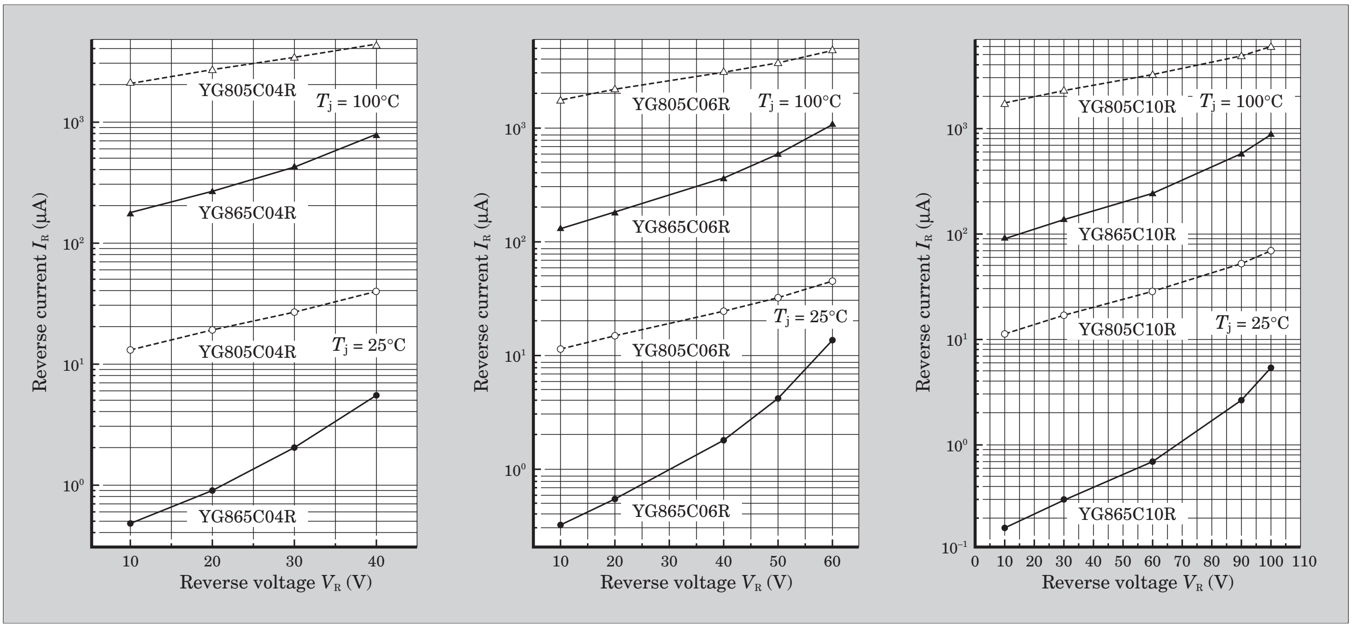


Fig.4 Comparison of reverse characteristics



3. Device Characteristics

Figure 3 compares the forward characteristics of the low I_R-SBD with those of conventional products, and Fig. 4 compares their reverse characteristics. The SBD loss is the sum of the forward and reverse losses, and it is desirable that this loss be reduced within the actual operating temperature range. In particular, the reverse loss caused by increased I_R at higher temperatures must be considered. A tradeoff relation exists between V_F and I_R, however, and V_F typically increases when I_R is reduced. The newly developed 40 to 100 V SBD achieves a dramatic decrease in loss at high temperatures through the use of a new barrier metal as described in chapter 2 and optimized crystal specifications in order to achieve an approximate 10 % increase in V_F at rated current compared to a conventional product, and an I_R that is reduced to approximately 1/10th that of the conventional product.

4. Consideration of the Generated Loss

A simulation was performed to calculate the loss

Fig.5 Junction temperature vs. estimated loss (60 V/20 A)

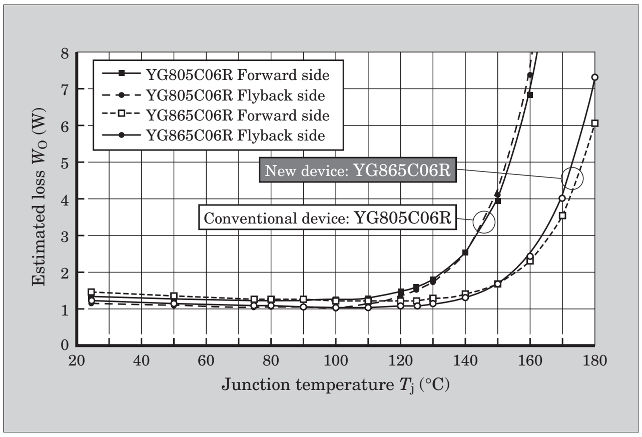
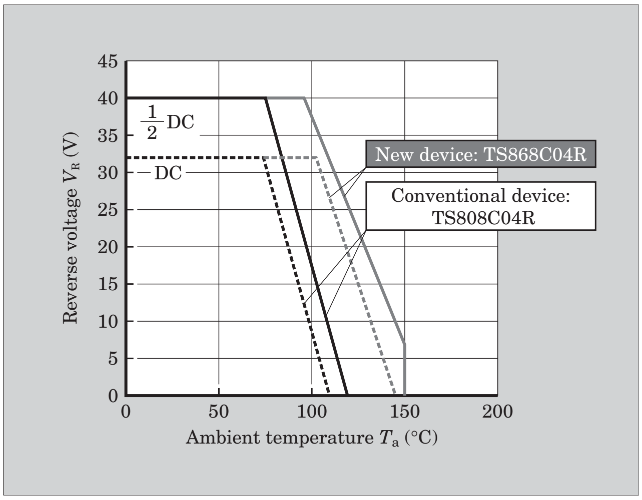


Fig.6 Thermal runaway data (TS868C04R, TS808C04R)



generated in the case of a 24 V power supply (V_{dc} = 380 V, I = 5 A) for a liquid crystal display (LCD) TV. Figure 5 shows the relationship between junction temperature (T_j) and estimated loss (W_o) for a 60 V/20 A product. For the sake of comparison, a conventional SBD is also shown. In the region of low T_j, the conventional product has less loss, but because IR has a large effect on loss at high temperatures, the low I_R device achieves less loss than the conventional device at high temperatures, and at T_j = 150°C, the low I_R product achieves approximately 76 % less loss than the conventional product, and its application to higher efficiency power supplies is anticipated.

5. Consideration of the Thermal Runaway Temperature

The temperature of an element rises as its loss increases, and I_R becomes more noticeable as it increases at higher temperatures. As a result, a vicious cycle ensues in which the increase in I_R leads to an increase in loss, which generates heat in the element, leading to an increase in I_R, etc. In some cases, this phenomenon ultimately leads to thermal damage (thermal runaway) of the element. Figure 6 shows thermal runaway data of the ambient temperature vs. reverse voltage for a 40 V/30 A product. For the sake of comparison, a conventional SBD is also shown. Compared to the conventional product, it can be seen that the allowable operating temperature range has been expanded due to the lower I_R. Table 2 shows the estimate thermal runaway temperatures for a 60 V/20 A product in 24 V output power supplies (V_{dc} = 380 V, I = 3.5 A or 5 A) for 23-inch and 30-inch LCD TVs, which approximate actually installation conditions. Compared to the conventional product, the thermal runaway ambient temperature is estimated to be 32 % higher (98°C) at the forward side and 28 % higher at the flyback side (108°C) in the case of the 23-inch LCD, and 34 % higher (97°C) at the forward side and 29 % higher at the flyback side (100°C) in the case of the 30-inch LCD. With a high maximum allowable operating temperature, these new devices are well suited for high temperature applications.

Table 2 Ambient temperature when beginning thermal runaway at LCD-TV 24 V output power supply

Condition : installation cooling fin (30°C/W)

Model number	23-inch LCD-TV power supply (+24 Vout/3.5 A)		30-inch LCD-TV power supply (+24 Vout/5.0 A)	
	Forward	Flyback	Forward	Flyback
Conventional device : YG805C06R	Approx. 74°C	Approx. 84°C	Approx. 72°C	Approx. 77°C
New device : YG865C06R	Approx. 98°C	Approx. 108°C	Approx. 97°C	Approx. 100°C

6. Conclusion

An overview of the low I_R-SBD and its application to secondary source rectification applications in switching power supplies have been presented.

In response to the anticipated future requests for power supplies that are smaller in size, generate less loss and have higher efficiency, Fuji Electric intends to further improve SBD characteristics and to develop a product line of small package products. Fuji will continue to make additional improvements in order to develop high quality products and enrich this product series.