New Power MOSFET

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1. Introduction

Due to the finer patterns and higher integration of LSIs, functions that were used a few years ago in mini-computers have now been realized in personal computers. The popularity of the internet has also spread the use personal computers. In particular, because of their compact size, notebook type hand-held computers are widely used in the office. In addition, portable electronic devices such as LCD TVs or personal handy phones are also widely used.

These portable devices require batteries and a battery charger (AC adapter). Because portable devices are most beneficial when they can be operated for a long time, batteries must be small and have a high-energy density. Instead of the conventional Ni-Cd battery, Li-ion batteries have begun to be utilized as a new second battery for these devices. Because the charging the discharging of Li-ion batteries must be precisely controlled to prevent the degradation, ICs (integrated circuits) and power MOSFETs (metal-oxide-semiconductor field-effect-transistors) have been used to control them. The necessary characteristics of the power MOSFET are low pn resistance and a small surface mounting package. To lengthen the discharge time for each charge of the battery, it is important to increase the DC-DC converter efficiency which stabilizes the output voltage. To increase the efficiency, a synchronous rectifier circuit that uses a power MOS FET is being used in the rectifying circuit of DC-DC converters.

Fuji Electric has developed a SOP (small outline package) -8 series power MOSFET suited for the power control of portable devices. In this paper, an outline of the power MOSFET will be presented.

2. Application of Power MOSFETs

2.1 Li-ion battery

Figure 1 shows the charge-discharge control circuit of a Li-ion battery used in portable devices. As shown in Fig. 1, individual power MOSFETs are used to control the charging and discharging of the battery. An SOP-8 package, effective as a small sized battery pack, is used as the IC package and contains 2 power MOSFETs.

2.2 DC-DC converter

Although the output voltage of the battery is high when fully charged, the voltage is reduced as it is discharged. In certain situations, semiconducting parts such as ICs that control devices will not operate correctly when the supply voltage is unstable. To stabilize the supply voltage, a DC-DC converter is used.

Fig.1 Internal circuit of Li-ion battery

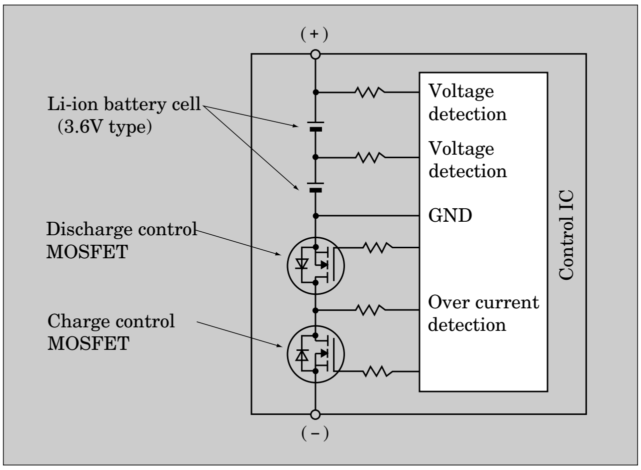
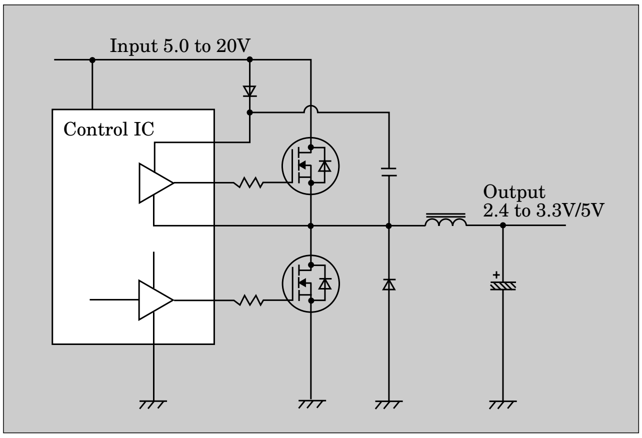


Fig.2 Synchronous rectifier circuit



The output voltage of DC-DC converters has decreased from 5V to 3.3V and 2.9V to 2.4V due to lower operating voltages of ICs and LSIs in portable devices. Because the forward voltage drop of the rectifying diode has a large effect on efficiency, lowering the output voltage of DC-DC converter reduces the efficiency. It is important to lessen the amount of this decrease in efficiency. For this reason, the use of power MOSFETs in a synchronous rectifying system has been increasing. The synchronous rectifier circuit is shown in Fig. 2. Compared to typical rectifying system with Schottky diodes, the synchronous rectifier circuit can reduce the threshold voltage loss of the diode. Figure 3 compares forward voltage characteristics for the Schottkey diode and power MOSFET. Since loss in the synchronous rectifier circuit can increase in certain situations when the timing of the input excites the switching and rectifying power MOSFET, dead time for the signal must be set reasonably. Figure 4 shows gate control time versus reverse recovery time for the switching power MOSFET when the input is in the ON-state and the rectifying power MOSFET when the input is in the OFF-state.

Fig.3 Comparison of forward voltage characteristics

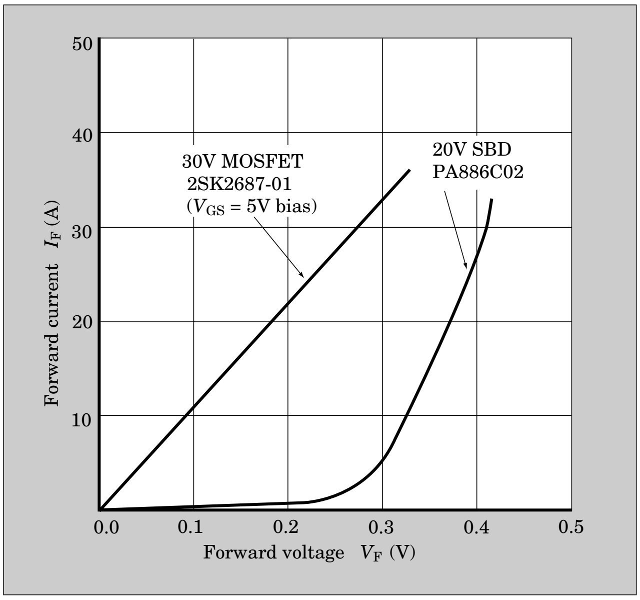
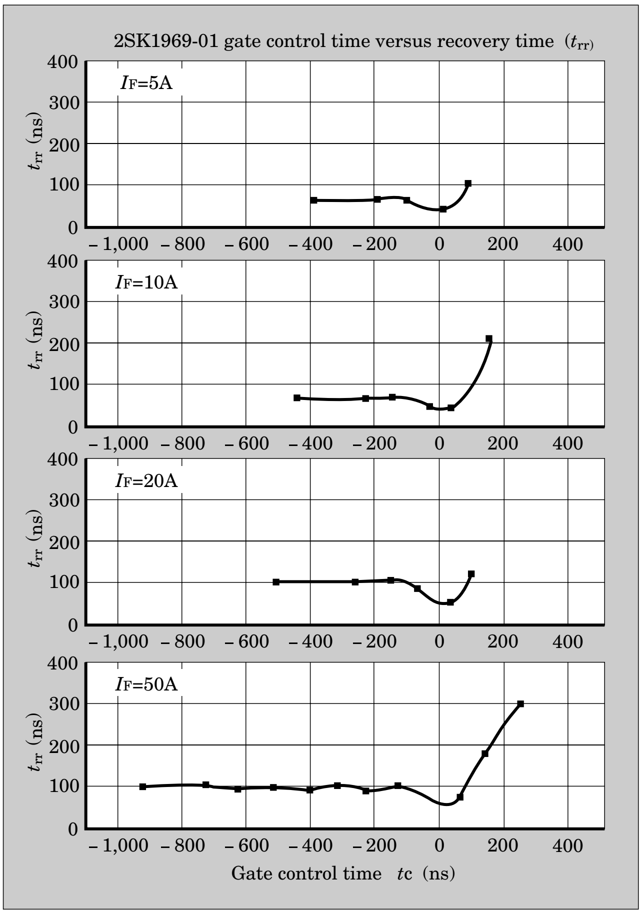


Fig.4 Control time versus recovery time



3. SOP-8 Power MOSFET

The ratings and characteristics and an overview of the SOP-8 Power MOSFET, developed in consideration of the requirements for Li-ion batteries and DC-DC converters as described above, are shown in Table 1 and Fig. 5, respectively.

Table 1 Ratings and characteristics of SOP-8 power MOSFET

Item \ Model	F8006N	F7007N
V_{DS}	20V	30V
I_D	±5A	±7A
I_{Dpulse}	±60A	±84A
P_D	2W	2W
$V_{GS(th)}$	0.5 to 1.5V	1.0 to 2.0V
$R_{DS(on)}$	48mΩ at V_{GS}=4V	25mΩ at V_{GS}=10V
Package	2 devices SOP-8	1 device SOP-8

Note 1) I_D and I_{Dpulse} are the rated values for 1 device.
Note 2) P_D is the rated value when mounted on a 1,000mm^2 FR-4 type glass epoxy substrate.
Note 3) The P_D of F8006N is for 2 devices operating in parallel. When 1 device is operating, the P_D is guaranteed to be 1.7W.

Fig.5 External view of SOP-8 power MOSFETs

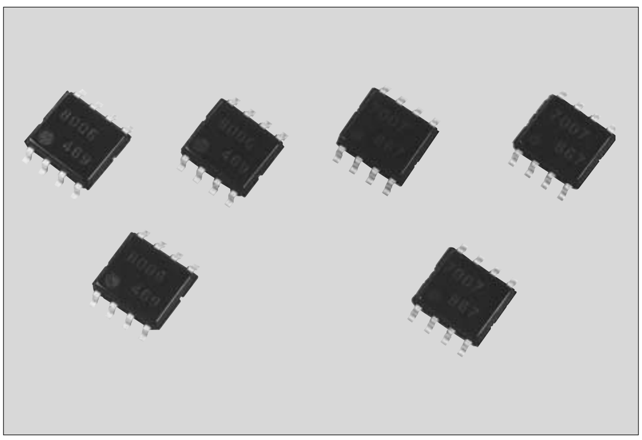
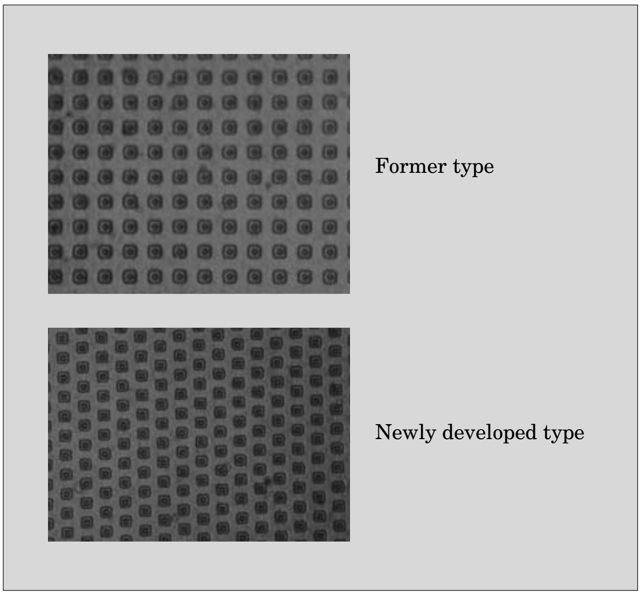


Fig.6 Cell photographs



3.1 Chip development

(1) Lower RDS (on)

There are many requests for low voltage power MOSFET with lower RDS (on). Manufacturing technologies for lower RDS (on) in the newly developed power MOSFET are listed below.

(a) Arsnide doped Si substrate, which has approximately 30% lower resistivity than Antimon doping

(b) 60% reduction in cell size compared to conventional devices (cell photos of conventional and newly developed power MOSFETs are shown in Fig. 6)

(c) Lower resistivity and optimized depth of epitaxial layer

(d) Lower metal layer resistively

By using above the technologies, RDS (on) was reduced by approximately 50% compared to conventional devices.

(2) Zener diode inserted between gate and source (G-S)

Since the DC-DC converter for Li-ion batteries and portable devices generates a low voltage, the power MOSFET must be able to operate at a low voltage. However, driving a lower gate voltage causes a problem of reduced gate blocking capability. For this reason, a twin type zener diode is inserted between the gate and source of an SOP-8 power MOSFET to increase gate block capability.

3.2 Package development

(1) Improved heat radiation

Because of the importance of heat radiation, the design criteria of a power device such as the power MOSFET is different than that of ICs. To improve the heat radiation, an SOP-8 package has been designed

Table 2 Items for improved thermal characteristics

Item	IC	Power MOSFET
Lead frame	Isolated frame	Die-pad integrated frame
Die bonding	Silver paste	Solder
Mold resin	Low stress	Low stress Higher heat conduction

Fig.7 Comparison of frame structure

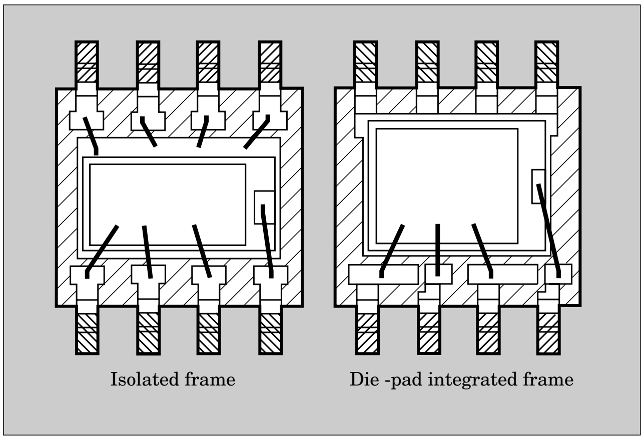
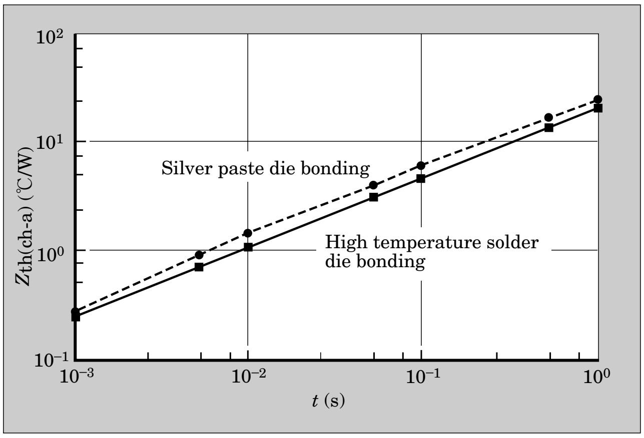


Fig.8 Thermal resistance of SOP-8 power MOSFET



and applied in a way as shown in Table 2. (Figure 7 shows the frame structure)

Measured thermal resistance of the SOP-8 power MOSFET is shown in Fig. 8.

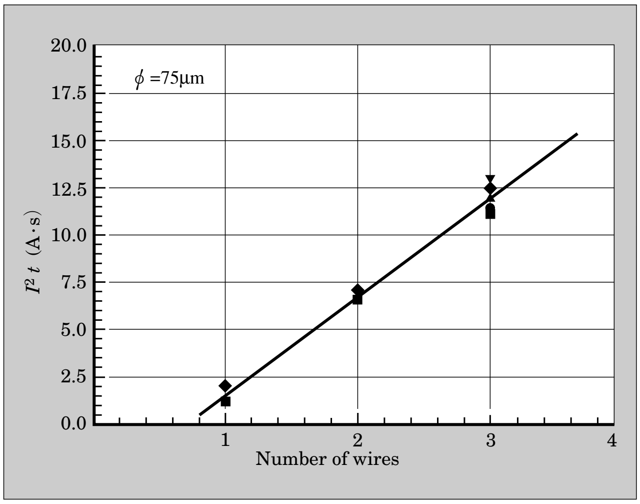
(2) Improved blocking capability

When using Li-ion batteries, the inrush current causes an over-current to flow through the power MOSFET. Bonding wire for the power MOSFET must be designed to withstand the over-current and not melt down. Blocking capability of the wire has been strengthened by using larger diameter (greater than 75μm in diameter) and multi-lined wire (3 lines). Measured wire melt down in shown in Fig. 9.

(3) Decreased wire touch

The wire loop height is limited by the frame, chip and wire widths in a SOP-8 package covered by 1.6mm thick resin. When the die pad and thermal electrode are connected on the same step, it is difficult to avoid

Fig.9 Wire meltdown characteristics



contact between the wire and chip edge without increasing the wire loop height. In order to solve the contact problem, the frame has been constructed by using different steps with a lower plane for the die pad and an upper plane for the terminal electrode.

3.3 Reliability

Surface mount packages such as the SOP-8 are soldered onto a printed substrate with flow or reflow solder. When designing for reliability, the effect of package cracks caused by thermal stress generated during the soldering process must be examined. The following pretreatments are being implemented to ensure reliability of the SOP-8 power MOSFET.

(1) Humidity 85°C, 65%, subject to 168h

(2) Thermal (solder dipping) 250°C, 5s

Reliability test items and results are listed in Table 3.

Table 3 Reliability test items and results

Item	Standard value and condition	Result
High temperature storage	T_a=150°C 1,000h	No faults detected in 22 samples of each item
Low temperature storage	T_a=– 55°C 1,000h	
Moisture resistance (steady state)	T_a=85°C, 85%RH 1,000h	
Thermal humidity bias	T_a=85°C, 85%RH V_{DS}=0.8×V_{DSmax} 1,000h	
Pressure cooker	T_a=130°C, 85%RH 48h	
Temperature cycle	– 55 to RT to +150°C 30min. 5min. 30min. 100 cycles	
Temperature moisture resistance cycle	T_a=– 10 to 65°C 80 to 95%RH 10 cycles	
Intermittent operation	ΔT_c=90°C 5,000 cycles	
High temperature reverse bias	T_a=150°C, V_{DS}=V_{DSmax} 1,000h	
High temperature gate bias	T_a=150°C, V_{GS}=V_{GSmax} 1,000h	

4. Conclusion

This paper has presented an outline of the SOP-8 power MOSFET developed for Li-ion batteries and DC-DC converters in portable devices.

Fuji Electric intends to meet the challenge of developing a p-channel SOP-8 power MOSFET and a TSSOP (Thin Shrink SOP) with lower height and narrower terminal pitch, as well as new devices to satisfy the diversifying market's need for portable devices.