Development of Intelligent Power Devices for Automotive Applications

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Abstract

More and more electronics are being used in automobiles and the switches in automotive equipment are shifting from mechanical ones to semiconductor ones. NEC Electronics is developing intelligent power devices with high reliability that can withstand the severe operating conditions of automotive applications.

Keywords

intelligent power device, overcurrent protection, overheat detection, TO-252, MCP

1. Introduction

At NEC Electronics, we roughly classify intelligent power devices for automotive applications into two groups, engine control devices and vehicle safety control devices. We are developing products optimized for individual needs. These applications naturally necessitate high performance and reliability but also require device size reduction and energy saving and device cost reduction as vital measures for improving the comfort and economy of driving. With regard to this trend, the need is particularly high for intelligent power devices to replace the multiple mechanical relays used in the electronic control units (ECUs) in order to improve their reliability and service life. We have met this need by implementing a high side switch product in a small package (TO-252) that is equipped with protection functions including overcurrent/overheating detection functions and a self-diagnostic output function as well as large current driving capability, low on resistance and low standby current characteristics (**Fig. 1**).

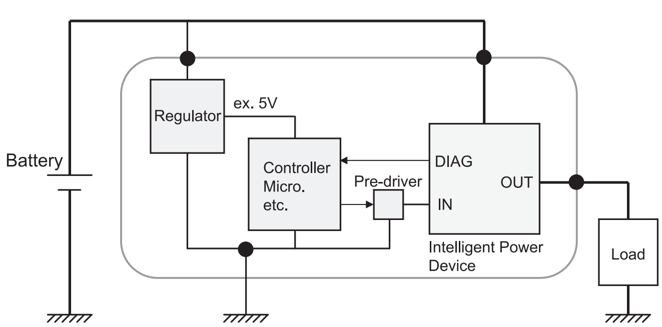

Fig. 1 Example of intelligent power device application.

2. Market Requirements for Intelligent Power Devices

Let's assume that switches used in the control of automotive equipment fail in the overcurrent state, e.g. if one of the wire harnesses distributed in the vehicle contacts the chassis, etc. In this case, it is required by immediately turning the switch output off to prevent the switch as well as the ECU incorporating it and the wire harness from smoking or creating a fire ignition. For this purpose, the intelligent power device needs to have a MOSFET that operates as a switch, a device protection function that detects abnormalities such as overcurrent and overheating and a self-diagnostic information output function for output status monitoring, which are also requested to be implemented in a compact size and at a low cost. More recently, a need for high reliability and for robustness to counter abnormalities has become evident assuming the case in which an abnormality occurs continuously for a long time or repeatedly.

Switches used in vehicle control must minimize standby current from the viewpoint of energy saving. In addition, with a product for lamp application, it is necessary to distinguish the rush current, which flows until the filament is heated after a lamp is switched on, from an abnormal current. Also, since lamp bulb blowing detection is required by law, it is necessary to improve the accuracy of the self-diagnostic output for achieving this function satisfactorily. As is evidenced by the above details, intelligent power devices are required to provide very complicated functions and to feature highly accurate characteristics.

3. Characteristics of the Newly Developed Intelligent Power Devices

3.1 Stacked MCP Structure

A stacked multi-chip package (MCP) has been adopted for compact size and low price. The control chip is stacked on the field effect transistor (FET) chip using UMOS (trench cell structure) technology featuring low resistance and low power consumption. This technology has allowed us to achieve the 10mΩ on resistance optimum for automotive applications including headlamps in a small 5-pin TO-252 package standardized by JEDEC.

Combining FET chip and control chip which are made using the process optimized for each realized a lower cost solution than a monolithic single chip.

3.2 Output Status Monitoring

A function that outputs sense current proportional to the output current during normal operation is provided. In general, the sense current is converted via a resistor into a voltage, which is monitored by the A/D converter of the microcomputer. The ratio between the output current and sense current is specified as a part of the device characteristics and can be used to calculate the output current value from the sense current. The microcomputer can therefore determine whether the automotive equipment connected to the intelligent power device is working normally or abnormally and whether it is the short or open circuit condition based on the calculated output current. In addition, the intelligent power device also incorporates a self-diagnostic output function, which informs the microcomputer of any abnormality, such as overcurrent or overheat that it detects. These functions help the microcomputer identify the output status accurately and contribute to improvements in ECU reliability.

3.3 High Robustness

For the load shorting protection system, we adopted immediate shutdown after overcurrent detection instead of the current limitation system that is used more popularly in the industry. This system is intended to reduce stress on the devices in case of an abnormal state (**Fig. 2**).

The value at which overcurrent due to shorting is detected is set above the current value that may flow when the load is connected normally. Consequently erroneous detection such as mistaking a rush current with lamps on as an overcurrent due to shorting can be avoided. The detection value is dependent on the drain-source voltage of the FET chip so that the stress on the device during an abnormality may be minimized.

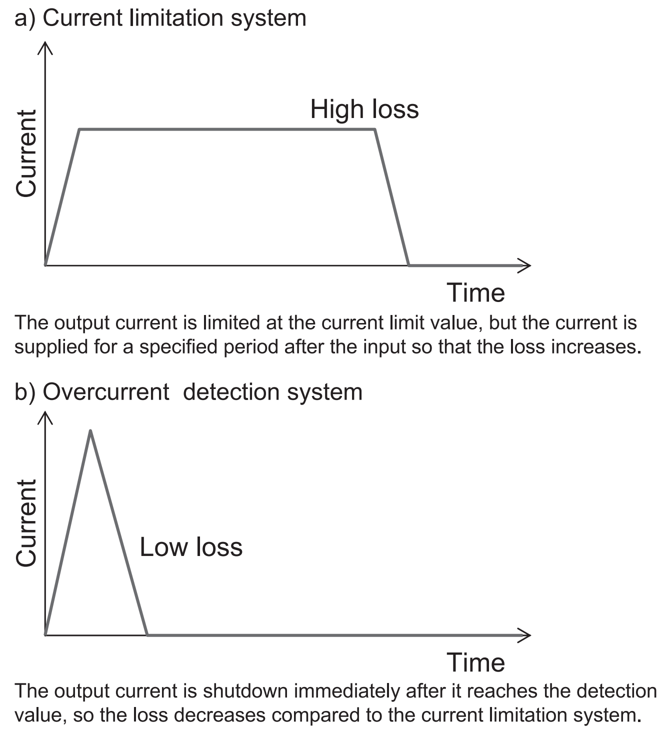

Fig. 2 Comparison of load shorting protection systems (Device activated at load short condition).

In order to examine the risk of smoking or fire ignition of the device after repeated or long-lasting shorting, the short circuit reliability test standard (AEC Q100-012) has been made by the AEC (Automotive Electronics Council). This newly developed intelligent power device passed the AEC's short circuit reliability test at the highest grade due to use of the protection systems described above.

3.4 Slew Rate Control for Noise Reduction

The intelligent power device incorporates a function for limiting sudden current changes by adjusting the ON and OFF slew rate. This has made it possible to reduce noise that might be produced due to a sudden change in current and which might harm the accurate operation of the automotive application.

4. Product Characteristics and Future Product Roadmap

Photo 1 shows an external view of 5-pin TO-252 package,

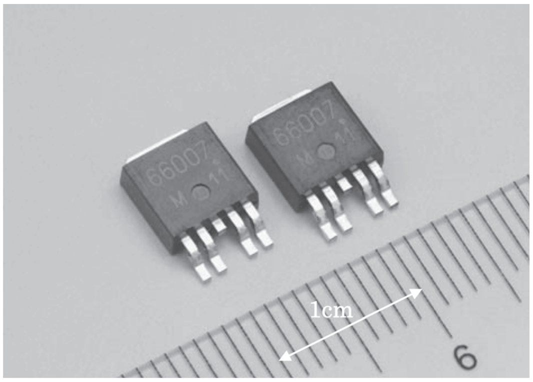

Photo 1 External view of 5-pin TO-252 package.

Fig. 3 shows the cross-sectional structure of the newly developed product, and **Photo 2** shows its SEM micrograph. The stack structure mounting the control chip on the FET chip is employed as shown in Fig. 3 and in Photo 2.

Fig. 4 shows the internal block diagram and **Table** shows the main characteristics.

Fig. 5 shows the anticipated future roadmap of products. For the purpose of engine control, we are developing products guaranteed for high-temperature operations, while maintaining high quality and high reliability in order to contribute to the

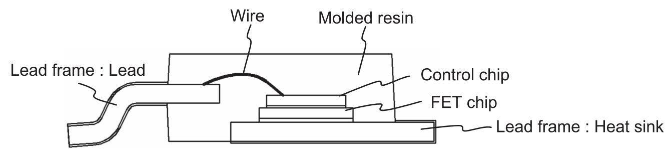

Fig. 3 Cross-sectional structure.

Table Main characteristics.

ABSOLUTE MAXIMUM RATING (Tch=25℃)

Parameter	Symbol	Test Condition	Product Name: μPD166007 (Under mass-production) Rating	Unit
Vcc voltage	Vcc1		28	V
Vcc voltage for full short circuit	Vcc2		18	V
Vcc voltage (Load Dump)	Vcc3	td=250ms	36	V
Channel temperature	Tch		150	℃

ELECTRICAL CHARACTERISTICS (Vcc=12V,Tch=25℃)

Parameter	Symbol	Test Condition	Product Name: μPD166007 (Under mass-production) MIN	TYP	MAX	Unit
On State Resistance	Ron	I_L=7.5A		8	10	mΩ
Standby Current	Icc(off)	I_{IN}=0A		4	6	μA
Output voltage drop at reverse battery condition	Vds(rev)	Vcc=-12V,I_L=-7.5A,R_{IS}=1kΩ		0.8	0.84	V
Turn on Time	ton	R_L=2.2Ω,Ta=-40℃～150℃		200	400	μs
Turn off Time	toff	R_L=2.2Ω,Ta=-40℃～150℃		250	700	μs
Short circuit detection current	$IL_{12.3(SC)}$	Von=3V	76	105		A
Output clamp voltage (Inductive load switch off)	Von(CL)	IL=40mA	30	34	40	V
Thermal shutdown temperature	Tth		150	175		℃
Current sense ratio	K_{ILIS} *1	V_{IS}<Vout-6V,I_{IS}<$I_{IS.lim}$ I_L=30A	8300	9400	10600	
		V_{IS}<Vout-6V,I_{IS}<$I_{IS.lim}$ I_L=7.5A	8000	9500	10800	
		V_{IS}<Vout-6V,I_{IS}<$I_{IS.lim}$ I_L=2.5A	6500	9600	12800	
Sense current offset current	$I_{IS.offset}$	V_{IN}=0V,I_L=0A	0		60	μA

*1 $K_{ILIS}=I_L/I_{IS}$

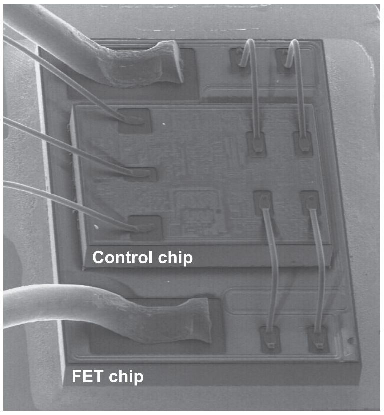

Photo 2 SEM micrograph.

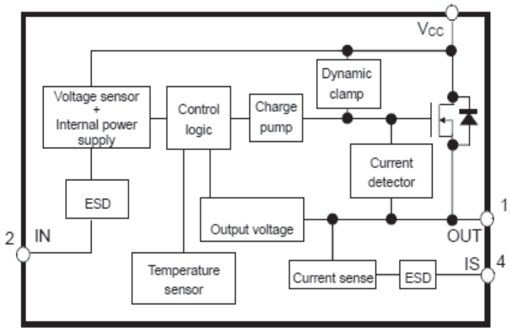

Fig. 4 Internal block diagram.

operation of ECUs under high-temperature conditions. For the purpose of chassis control and safety control, new devices will be based on the intelligent power device explained in this article and will feature enhanced functions such as improved protection in case of a reverse battery connection. More accurate current sense output, higher current driving capability and lower on resistance as well as multi-channel capability using a power SOP package will also be featured.

5. Conclusion

The newly developed intelligent power device is intended to replace the relay. It achieves output characteristics with low on resistance, various protection functions and a self-diagnostic output function in a small, stacked multi-chip package (MCP). It is also expected to contribute to size reduction and reliability improvements in the ECU.

In the future, we will continue to develop highly robust, intelligent power devices featuring high performances by developing new wafer processes and power packages and by implementing optimum protection functions.

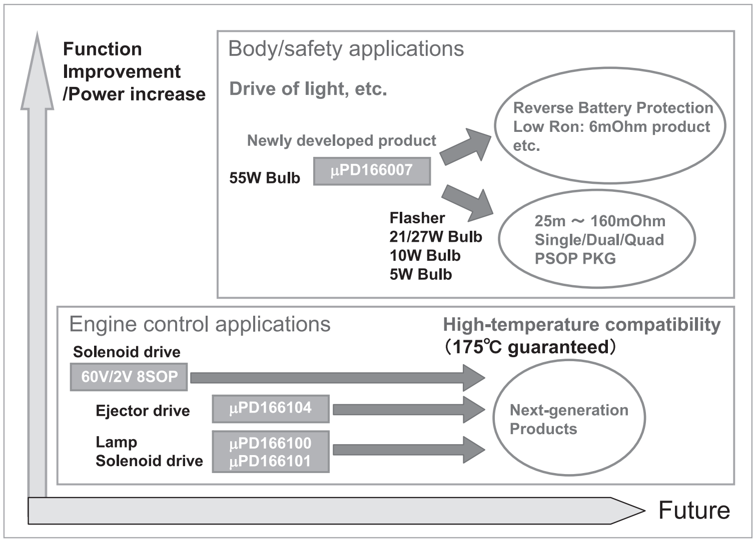

Fig. 5 Future product deployment.

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