DC-DC Converter Module for xEV

KUSAKARI, Nobuharu*　KITAMURA, Shoji*　KATSUKI, Takashi*

ABSTRACT

The market for electric vehicles (xEVs), such as hybrid vehicles, is rapidly expanding worldwide in response to the zero emission vehicle (ZEV) regulations in the United States and the strengthening of CO_2 emission regulations in Japan, Europe and China. Fuji Electric has developed a DC-DC converter module for xEVs by applying the technology developed in small capacity modules for industrial applications. This newly developed product is designed for a full-bridge circuit and uses power MOSFETs with a super-junction structure on the primary side and SBDs on the secondary side. They are used for automotive applications with high reliability while reducing the footprint of a DC-DC converter system by 40%.

1. Introduction

The market for electric vehicles (xEVs), such as hybrid vehicles and plug-in hybrid electric vehicles, is rapidly expanding worldwide with the strengthening of zero emission vehicle (ZEV) regulations in the United States and CO_2 emission regulations in Japan, Europe and China. Fuji Electric has developed a DC-DC converter module for xEVs, which we will introduce in this paper.

2. xEV Power Conversion Equipment

xEVs utilize numerous types of power conversion equipment, such as boost converters that supply power to inverters by boosting high-voltage batteries, inverters that convert DC to AC to drive motors, and DC-DC converters that step down high voltages to supply power needed for devices, including a low-voltage vehicle-mounted electronic control unit (ECU), electric power steering, lamps, wipers, and car navigation systems (see Fig. 1).

Fuji Electric has been mass producing power semiconductors used in boost converters and traction motor drive inverters for xEVs.

In addition, we have also been mass producing products such as discreet metal-oxide-semiconductor field-effect transistors (MOSFETs) and diodes for the conversion circuit of DC-DC converters and electric power steering devices.

In recent years, electrical components have become increasingly used to improve vehicle safety, convenience and comfort. At the same time, it has become necessary to miniaturize power conversion circuits in order to secure the crushable zones*1 and indoor cabin space. Furthermore, since these power conversion circuits are directly connected to high-voltage batteries, high insulation performance is also needed to ensure safety.

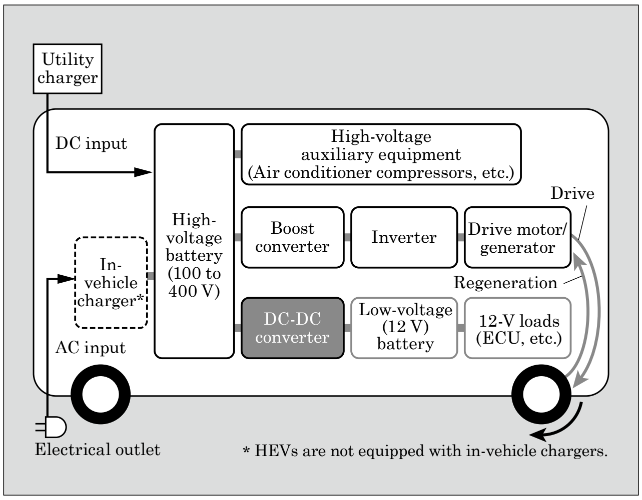


Fig.1 xEV block diagram

Fuji Electric has developed a DC-DC converter module for xEVs by applying the technology it has developed in small-capacity modules for industrial applications (see Fig. 2). For conventional DC-DC converters, multiple discrete products are used, and high voltage part is covered with insulating sheet for insulation from the car body and to ensure safety during inspection. Our newly developed DC-DC converter module densely mounts multiple semiconductor devices in a plastic molded package with ensuring insulation of

*1: Crushable zone: This is a part of a vehicle that has a slightly more flexible structure than the passenger cabin, such as the front hood, which crushes in the event of a collision and absorbs the shock.

* Electronic Devices Business Group, Fuji Electric Co., Ltd.

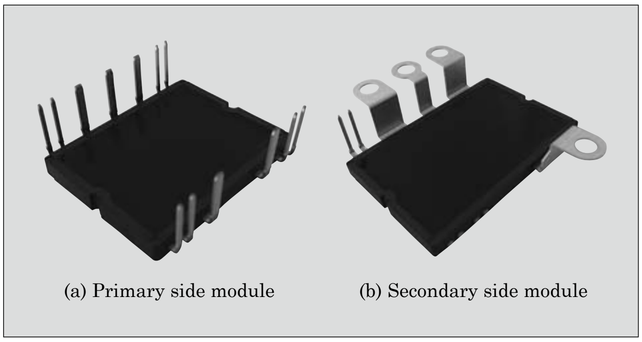


Fig.2 DC-DC converter modules

high-voltage components, thereby achieving significant miniaturization while improving safety.

3. Product Overview

A DC-DC converter is a device that either steps up or steps down or performs both operations for DC with different voltages. Depending on the output power, there are different types of circuit configurations, such as forward and bridge types. Our newly developed DC-DC converter module makes use of a circuit configuration designed for full-bridge types that can accommodate relatively large capacities of several kW (see Fig. 3). Full-bridge types need to use a transformer to electrically insulate the primary side with the high voltage battery from the secondary side. Therefore, the primary and secondary side modules are in separate modules.

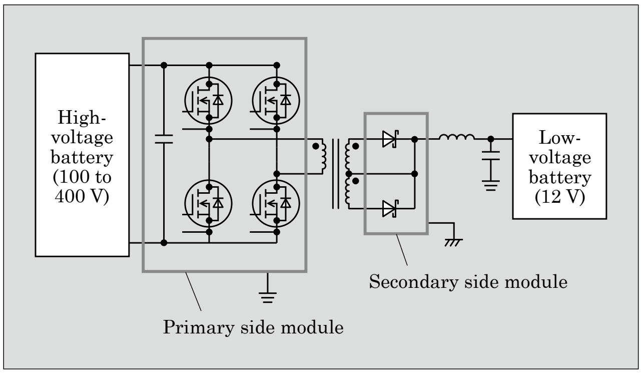


Fig.3 Equivalent circuit diagram of the DC-DC converter module

The primary side module utilizes a full-bridge circuit configuration employing super-junction power MOSFET (SJ-MOSFET) chips, while also integrating snubber capacitors to suppress noise on the input terminal side.

The secondary side module utilizes a cathode common circuit configuration employing Schottky barrier diode (SBD) chips. The product has the following features:

(a) The thickness of these products is as thin as discrete products with lead terminals arranged on the left and right sides of the package.
   ○ Primary side module: W42.0 × D33.0 × H4.7 mm
   ○ Secondary side module: W54.0 × D35.4 × H4.7 mm

(b) Tin plated lead terminal can be soldered directly to a printed circuit board.

(c) Assembly processes is simplified through the use of a metal insulating substrate that eliminates the need for additional components like insulating sheets that were previously required

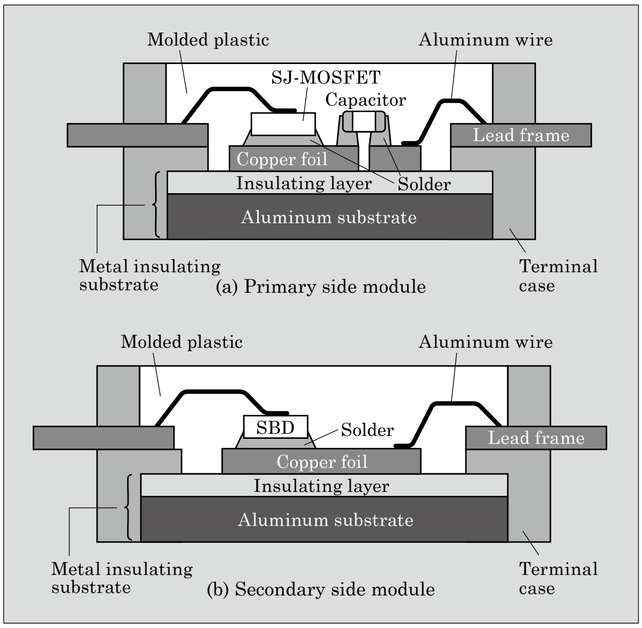


Fig.4 Cross-sectional structure of the DC-DC converter module

Table 1 Line-up and main features of the DC-DC converter modules

Item	Primary side module		Secondary side module	
Dimensions (mm)	W42.0 × D33.0 × H4.7		W54.0 × D35.4 × H4.7	
Mounted chip	SJ-MOSFET		SBD	
BV_{DSS} (V)	600		—	
V_{RM} (V)	—		120	
I_D (A)	15	23	—	
I_F (A)	—		120	150
$R_{DS(on)}$ (mΩ)	125 max.	70 max.	—	
I_R (at µA, V_R = 14 V)	—		15	30
V_F (at V, I_F = rating)	—		0.96 max.	0.91 max.
V_{iso} (V)	3.0 k		1.7 k	

when mounting discrete products.

Table 1 shows the line-up and main characteristics. Two types of primary and secondary side modules are available to accommodate differences in rated current corresponding to the output capacity of DC-DC converters.

Figure 4 shows the cross-sectional structure of the DC-DC converter module. The primary side module is equipped with SJ-MOSFET chips on the metal insulating substrate and noise-reducing snubber capacitors. The secondary side module utilizes SBDs.

4. Supporting Technologies

4.1 Metal insulating substrate technology

In the DC-DC converter module, thermal resistance reduced by about 10% compared with previous products by optimizing the filler in the insulation layer of the substrate so as to ensure the high heat dissipation and insulation reliability needed for achieving the miniaturization required in automotive applications.

Furthermore, high insulation reliability is secured by using polymer-based resin insulation materials as the base material for the insulation layer since they have better insulation properties than general epoxy-based organic insulation materials (see Fig. 5).

Moreover, we use aluminum for the heat sink by using metal insulating substrate technology utilized in industrial modules. The optimization of the thickness of the aluminum plate suppresses heat sink warpage and achieves target heat dissipation performance.

4.2 Primary side module technology

The SJ-MOSFET mounted on the full-bridge circuit of the primary side module has improved breakdown voltage characteristics by optimizing the impurity concentration of the super-junction structure. By reducing the on-resistance $R_{on} \cdot A$ per unit area, the module achieved 600 V/70 mΩ with a chip size that can be mounted in the limited space of the primary side module.

Furthermore, by integrating a snubber capacitor, which is normally mounted on a printed circuit board, the module greatly reduces the radiation loop area between the switching device and the snubber capacitor, while also facilitating snubber capacitor cooling. This has had the effect of reducing emission noise and improving reliability.

4.3 Secondary side module technology

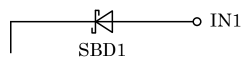
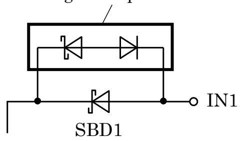
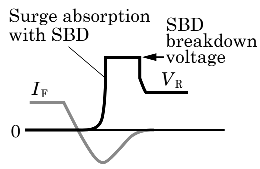
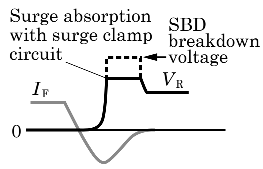
The secondary side module is equipped with SBDs that realize low reverse current I_R and low forward voltage V_F by optimizing barrier metal materials. This improves the loss during operation and suppresses the natural discharge of the low-voltage battery while not working.

In the secondary module using conventional SBDs, local electric field concentration in the breakdown voltage structure occurred and could be destroyed due to surge voltage during switching. Therefore, it has been necessary to lay out a surge clamp circuit that absorbs surge voltage in parallel with a SBD (see Table 2).

Our recently developed module optimizes the breakdown voltage structure in order to mitigate electric field concentrations due to surge voltage applied during switching (see Fig. 6).

As a result, allowable peak current value for the recovery avalanche capability (as an alternative characteristic of surge voltage capability during switching) is increased to approximately 3 times its previous

Table 2 Circuit configuration and waveform image of secondary side module

Item	Developed product	Conventional product
Circuit configuration		
Waveform image		

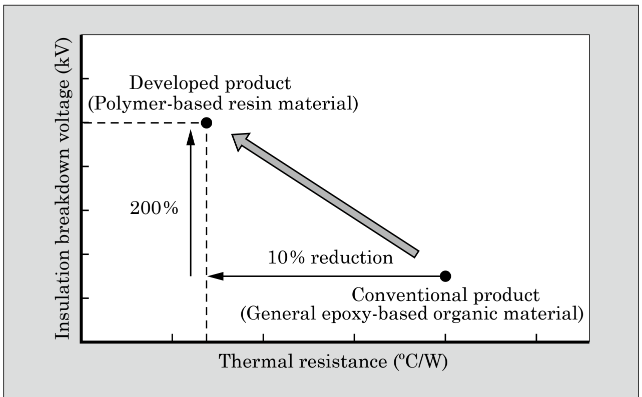


Fig.5 Comparison of insulating layers

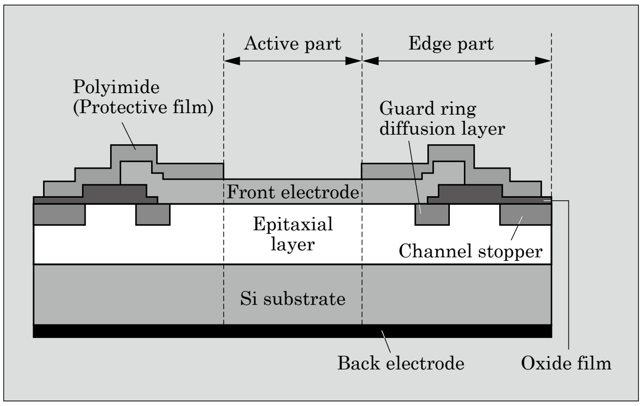


Fig.6 SBD cross-sectional image

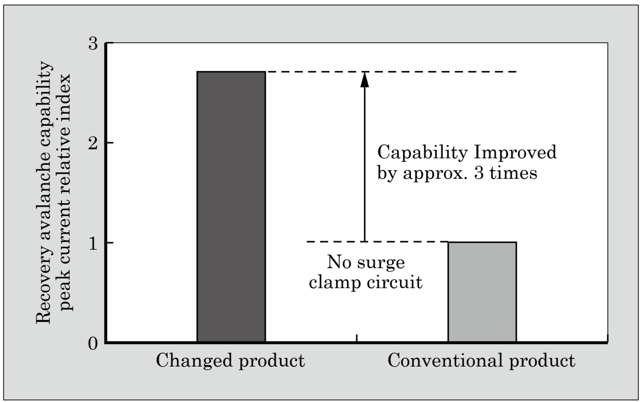


Fig.7 Comparison of surge voltage tolerance

value (see Fig. 7), thereby eliminating the need for the surge clamp circuit.

5. Application Effects

The use of the above mentioned technologies ensures the reliability of the DC-DC converter module when used for automotive applications and reduces the footprint of the DC-DC converter system by 40% (see Fig. 8).

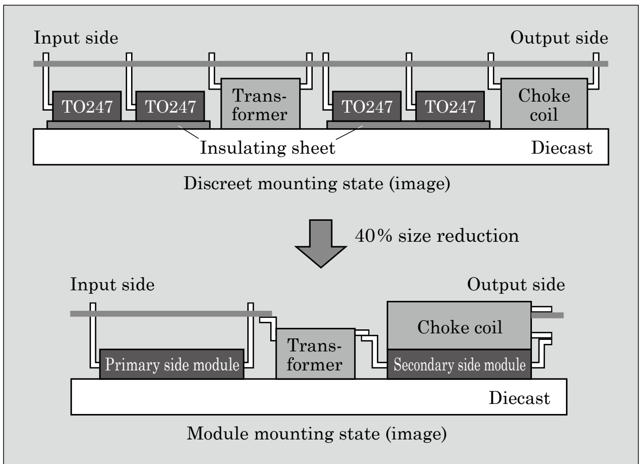


Fig.8 Footprint ratio of a DC-DC converter system

6. Postscript

In this paper, we introduced our DC-DC converter module for xEVs.

In the future, we will continue to pursue technological innovation and contribute to energy conservation and size reductions for the entire system.

References

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