New Trench Power MOSFETs in Isolated Packages

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Abstract

This paper presents a new family of power semiconductor components with low voltage trench MOSFETs in isolated packages: MOSFET and packaging technologies are briefly described. Their knowledge permits to derive tentative ratings and characteristics of several components; some types have already been sampled, others can be developed in the near future. Further, the use of the new components in typical applications is discussed — such as in automotive converters, battery supplied vehicles or power supplies with low input voltage.

1 Component Technology

1.1 Trench MOSFETs

Trench technology reduces the length of the current path in vertical power MOSFETs and thus leads to a low on resistance R_{DSon} [1]. It is mainly used for MOSFETs with a blocking voltage up to 100V to 200V. For control of drives, a moderate MOSFET switching speed would be sufficient. However, attention should be paid to the behaviour of the intrinsic reverse diode, which is used as free wheeling diode — thus a good turn off behaviour is needed. Avalanche capability during unclamped inductive switching is desirable, in particular for use in large high current power sections with their inevitable parasitic inductance.
The basic electrical characteristics of one type of trench MOSFET are given in table 1; it belongs to a series with different chip sizes or on resistances respecitvely and blocking voltages.
If necessary, for example in chopper circuits, the trench MOSFETs can advantageously be complemented by Schottky free wheeling diodes [2] with matched blocking voltage and current capability; their forward voltage drop generally is low, their switching behaviour fast.

1.2 Packages

The package protects the chips against environmental influence, it provides leads for the electrical connections and a thermal interface towards a heat sink. This thermal interface of all components proposed in this paper is isolated from the electrical circuit by a **d**irect **c**opper **b**onded DCB ceramic substrate. Construction and features of a power semiconductor module with DCB base are described in [3], while IXYS' ISOPLUS™technology of discrete components with DCB base is documented in [4] and [5].
Several packages are shown in the following figures together with typical MOSFET circuits which can be incorporated:

- brand new ISOPLUS 220™package for MOSFET single switches with enlarged chip area compared to conventional TO220 in figure 1
- ISOPLUS 247™package for MOSFET single switches with enlarged chip area compared to conventional TO247 in figure 2
- five pin ISOPLUS i4™package for MOSFET phaselegs, choppers or high current single switches in figure 3
- module $40,4 \cdot 93mm^2$ with solder terminals for various topologies, such as three phase MOSFET bridges or dual choppers, in figure 4
- module $62 \cdot 110mm^2$ with screw terminals for phaselegs, choppers or single switches in figure 5

Table 1: typical data of a trench MOSFET chip

blocking voltage	$U_{DSS} = 75V$	
on resistance	$R_{DSon} = 7,6m\Omega$	at $U_{GS} = 10V$, $T_J = 25°C$
current rise time	$t_r = 40ns$	at $U_{DS} = \frac{U_{DSS}}{2}$; $I_D = 50A$ resistive; $T_J = 25°C$
current fall time	$t_f = 55ns$	at $U_{DS} = \frac{U_{DSS}}{2}$; $I_D = 50A$ resistive; $T_J = 25°C$
reverse recovery current	$I_{RM} = 9,2A$	at $U_{DS} = \frac{U_{DSS}}{2}$; $I_D = -50A$; $\frac{di_D}{dt} = 200\frac{A}{\mu s}$; $T_J = 125°C$
reverse recovery time	$t_{rr} = 120ns$	at $U_{DS} = \frac{U_{DSS}}{2}$; $I_D = -50A$; $\frac{di_D}{dt} = 200\frac{A}{\mu s}$; $T_J = 125°C$

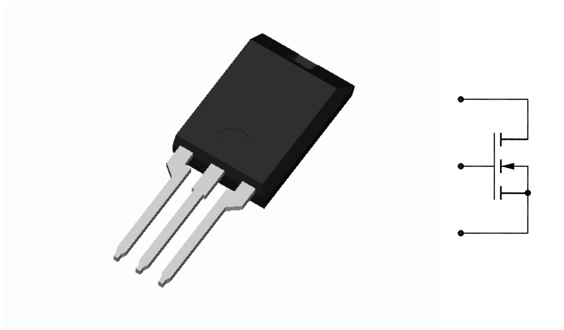

Figure 1: isolated ISOPLUS 220™package $10,5 \cdot 12,5mm^2$; single switch topology

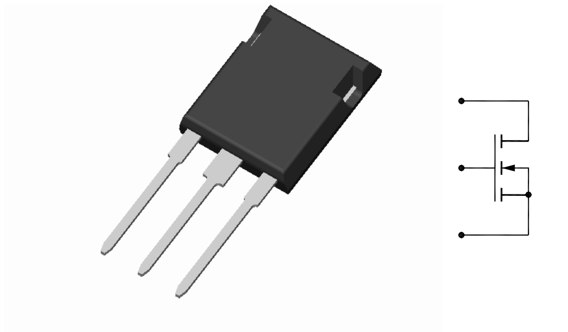

Figure 2: isolated ISOPLUS 247™package $16 \cdot 21mm^2$; single switch topology

Technical details about and the most important features of these packages are listed in table 2:

- Current capability depends on the chip area and the cross section of the metal conductors, such as leads.
- The degree of integration rises with higher current capability or complexity of the topology. The higher the degree integration, the fewer components have to be mounted and thus the lower is the remaining mounting effort.
- Compared to conventional discretes, mounting effort is further reduced because no external insulators are required to assemble the isolated components.
- Reliability of DCB based components generally is high due to the matched thermal expansion coefficients α of DCB substrate and silicon chip:

$\frac{\alpha}{10^{-6}\frac{1}{K}}$	for	at
2,53	Silicon	$T = 25°C$
7,40	DCB	$50°C \leq T \leq 200°C$
16,80	Copper	$0°C \leq T \leq 100°C$

Temperature cycling capability of power semiconductor components with DCB isolation is significantly higher than of conventional discretes, where the silicon chips are directly soldered onto a copper leadframe with high α.

1.3 Results

A variety of isolated power semiconductor components with trench MOSFETs can be obtained, combining the different MOSFET chips and packages as outlined in sections 1.1 and 1.2 respectively. The feasability of several types has been proven, sample production of some of them has begun. Exemplary basic ratings and characteristics of such components are listed in table 3:

- The indications of package and topology refer to figures 1, 2, 3, 4 and 5.
- Please note the extremely low values of the MOSFETs' on resistance R_{DSon}, leading to a high rated current.
- Although the current capability of the leads already has been optimized, the rated current at low case temperature of several components is limited by the package. In applications these

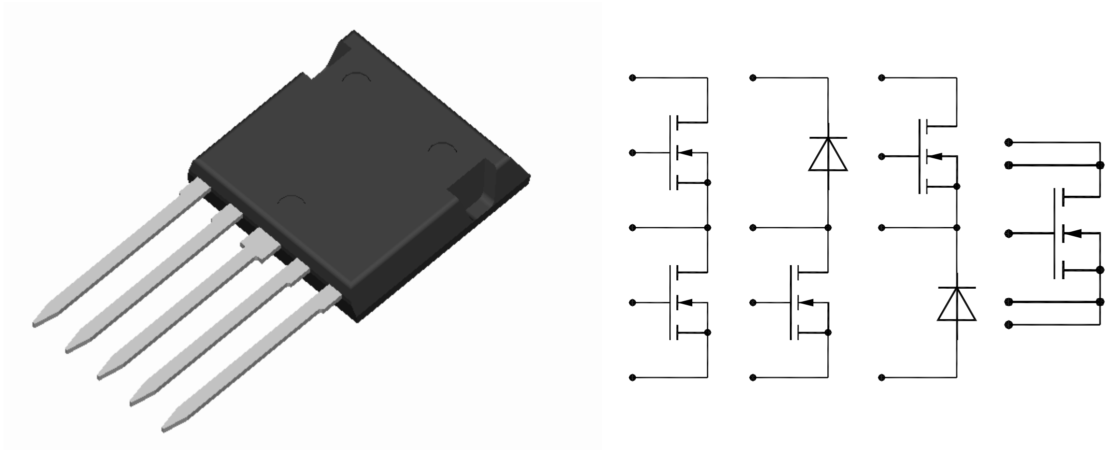

Figure 3: isolated ISOPLUS i4™package $19,9 \cdot 21mm^2$; phaseleg, chopper and single switch topologies

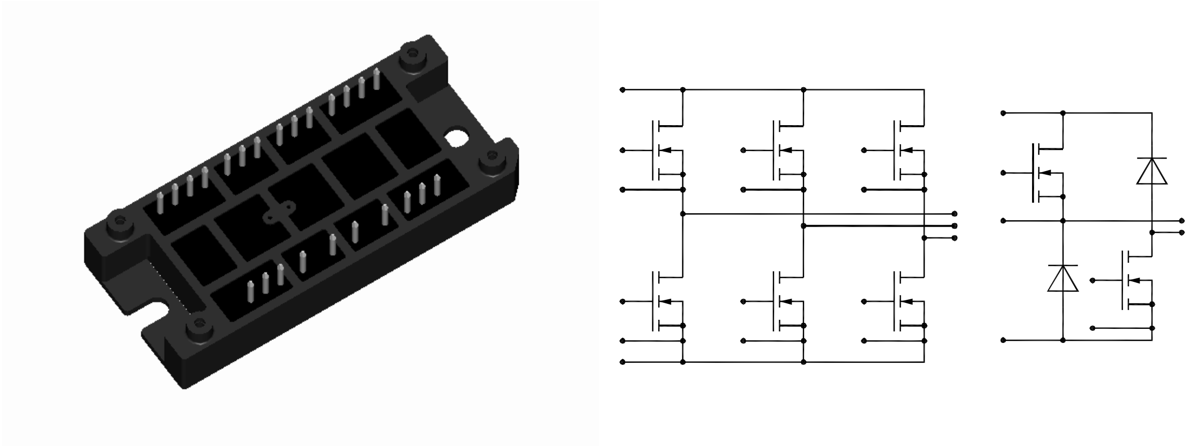

Figure 4: isolated module package $40,4 \cdot 93mm^2$; sixpack and dual chopper topologies

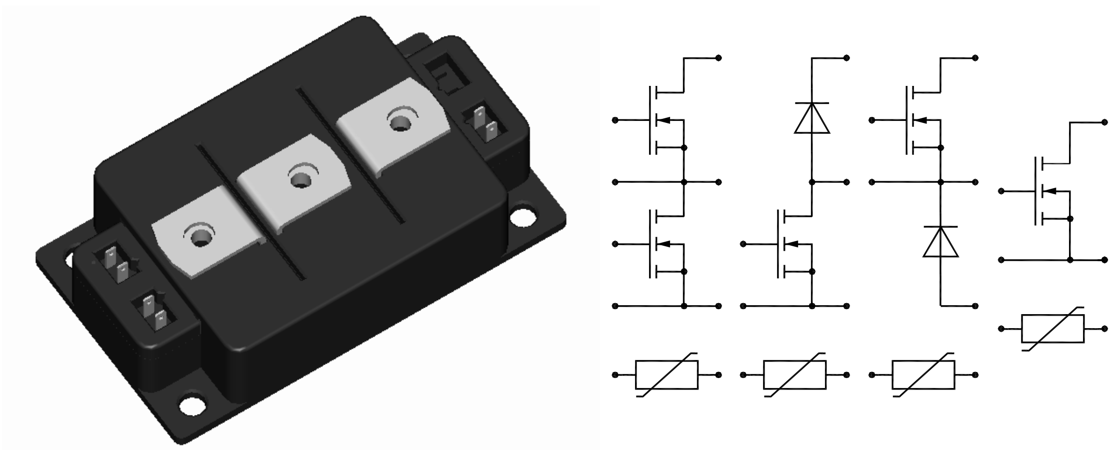

Figure 5: isolated module package $62 \cdot 110mm^2$; phaseleg, chopper and single switch topologies

Table 2: features of different types of DCB isolated power semiconductor packages

	isolated discrete	**module**
see figures	1, 2, 3	4, 5
construction	chip soldered on DCB wire bond connections transfer molded package	chip soldered on DCB wire bond connections potted package
current capability	low	medium to high
degree of integration	medium	high
mounting effort	low to medium	low
component cost	medium	high
reliability	high	high

Table 3: tentative ratings and characteristics of power semiconductor components with trench MOSFETs in isolated packages

type	topology	rated voltage U_{DSS}	on resistance R_{DSon25}	rated current MOSFET I_{D25}	rated current leads I_{RMS}	package
IXUC100N055	single switch	55V	7,7$m\Omega$	100A	45A	ISOPLUS 220™
IXUC200N055	single switch	55V	5,1$m\Omega$	200A	45A	ISOPLUS 220™
FMM150-0075P	phaseleg	75V	6,2$m\Omega$	150A	75A	ISOPLUS i4™
FMD/FDM150-0075P	choppers	75V	6,2$m\Omega$	150A	75A	ISOPLUS i4™
VRM700-0075P	dual chopper	75V	2,1$m\Omega$	700A	$\geq$200A	40mm module
VWM350-0075P	sixpack	75V	3,1$m\Omega$	350A	200A	40mm module
VMM1500-0075P	phaseleg	75V	0,8$m\Omega$	1500A	$\geq$500A	62mm module

devices are targeted to, this however is not a real constraint because the devices can either be operated at high case temperature with a reasonable remaining chip current capability — or power losses are minimized due to low on resistance at low case temperature. Some applications, these operational modes occur in, are described in the following section 2.

2 Applications

2.1 Automobiles with Combustion Engine

In automotive applications, power semiconductor components are cooled either by the cooling system of the combustion engine, reaching temperatures above $100°C$, or only by air flow in warm environment; thus an optimum match is achieved if current capability of the chips and of the leads correspond to each other at high case temperature. Further, particularly regarding temperature cycles, the requirements on reliability are high. In addition, the components should be light weight. These criteria are fulfilled by DCB based isolated components as described in section 1.2.

The increasing demand of electrical power in cars shall be handeled by a new electrical system with a voltage level of 42V [6]. Some new aggregates with power electronic control in the 42V architecture are discussed in the following:

- In motor operation, a starter generator starts the combustion engine, while it charges the battery in generator operation, when the latter is running. Its function is shown in figure 6.

  The MOSFET power section has to switch currents of up to several 100A; so modules of VMM type or a parallel connection of isolated discretes of FMM type — see table 3 — are most suitable.

- The valves of the combustion engine conventionally are driven by the crankshaft via the camshaft; contrary to this fixed mechanical connection, an electro magnetic or piezo electric valve actuation offers many possibilities to economically optimize the operational behaviour of the combustion engine, variing the open and close times of the valves. Figure 7

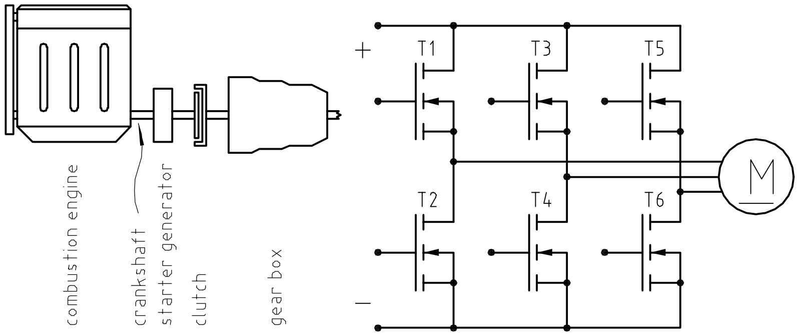

Figure 6: arrangement of and power section for starter generator

shows the principle: One actuator for opening and closing each is controlled by one dual chopper.

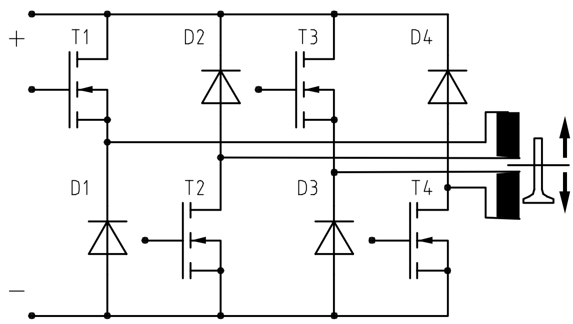

Figure 7: operational principle of a valve actuator

Power semiconductors with suitable topology and rating are either modules of VRM type or isolated discretes of FMD and FDM type according to table 3.

- It is not trivial to extinguish the arc when turning off a large current at 42V DC by a relay. Electronic switches according to figure 8 overcome this problem. They further permit to introduce an intelligent control: This may provide additional functionality — such as control of the air flow generated by a fan which is fed by a chopper, or reduce hardware effort — for example replacing the huge amount of cables and fuses to separately supply all loads by a simple DC line and a logic bus for transfer of information; the loads would then be controlled and overcurrent protected by decentral power electronic switches located nearby.

Depending on the current ratings required, power semiconductor components of IXUC or FDM type — the former complemented by discrete Schottky diodes — would be suitable according to table 3.

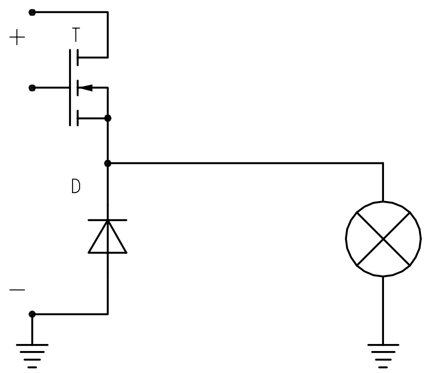

Figure 8: schematic of a load controller

2.2 Battery Powered Vehicles

Besides the automobiles driven by a combustion engine, there are electric cars [7] and other electric vehicles, such as fork lift trucks, whose propulsion power is supplied by a battery. Typically AC drives fed by a converter are used. Reliability requirements and operational conditions differ from the starter generator as described in section 2.1, figure 6; topology of and components for use in the power section however are similar.

2.3 Power Supplies with Low Input Voltage

Power supplies may be fed by energy sources with low output voltage, such as batteries or fuel cells [8] and solar cells, whose application currently gains importance. A converter with low voltage primary switches can adapt the voltage to a higher level and possibly a different shape, as frequently required for example to supply loads with AC mains

input. Efficiency of conversion, which is an important feature in particular of converters for regenerative energy sources, can be optimized by using components with low on state resistance R_{DSon}; this leads to low conduction losses in the converter.
Converters are required for a large power range, and they can be realized with a variety of topologies. Which particular component of the list in table 3 is suitable thus depends on nominal power and circuit: For low power converters, the current capability of isolated discrete components is sufficient, while higher power can be handeled by a parallel connection of discrete components or modules. Typical topologies on the primary side of boost converters would be choppers or phaselegs, possibly combined to H bridges etc. Taking into account the switching speed of the MOSFETs — see table 1 — and the aim to minimize the size of the transformers or chokes will result in switching frequencies up to several 10kHz.

3 Conclusion

This paper has given an insight into the current development of a new series of power semiconductor components: Low voltage trench MOSFET chips are used in combination with DCB isolated packages. Examples show, that characteristics and ratings of the new components in general and of particular types meet the requirements of different emerging applications — such as 42V automotive, battery powered industrial or other vehicles and various power supplies with a low voltage energy source.

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