AN-CM2308

POWERMASTER
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1200V ℯSiC M1 MOSFET Series

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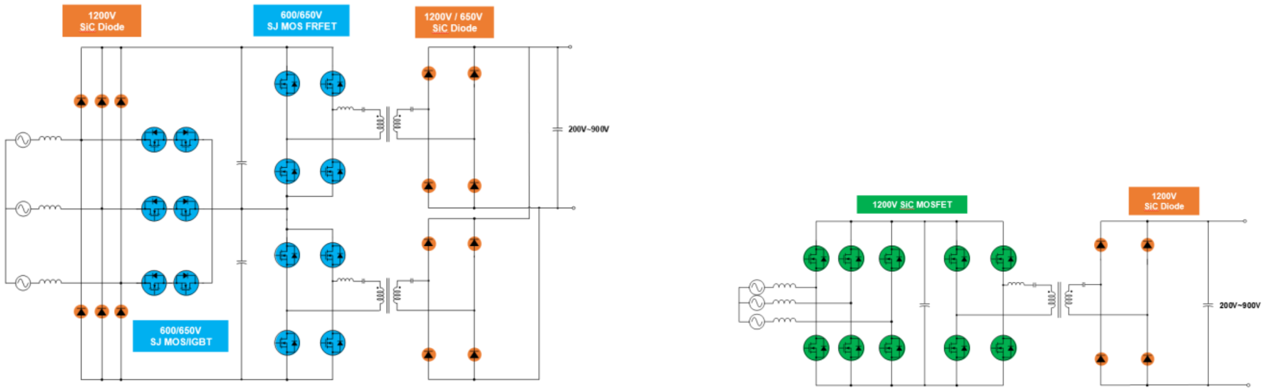
1. Introduction

1200V SiC MOSFETs are quickly penetrating to the DC EV charging station, On board charger(OBC) and solar inverter applications. Power rating per one module of DC EV charger is increasing from 15kW to 30kW, topology is simplified from Vienna PFC and series LLC resonant converter by using 650V super-junction MOSFETs or IGBTs to B6 rectifier PFC) and full bridge LLC by using 1200V SiC MOSFETs. 1200V SiC MOSFETs enable bidirectional charging up to 800V batteries. Increasing PV array voltage of solar inverters up to 1500V (String Inverter) for end to end efficiency improvement and installation cost reduction.1200V SiC MOSFETs are the best solution for stable performance against switching frequency and temperature enables high flexibility in overall system design especially in outdoor applications that is operated under harsh environment. The purpose of this application note is to highlight the key characteristics of Power Master Semiconductor's new 1200V eSiC M1 MOSFET compared to trench and planar competitor's 1200V SiC MOSFETs.

2. Target Applications of 1200V eSiC M1 MOSFET

SiC MOSFETs exhibit higher breakdown voltage, higher operating temperature, higher thermal conductivity and lower conduction and switching losses compared to Silicon IGBTs or MOSFETs. SiC MOSFETs offer significant system advantages such as higher power density, efficiency and less cooling effort due to its much lower power losses. Therefore, SiC MOSFETs are gaining popularity especially for EVs and its charging station applications that required higher power density, efficiency and robustness. As electric vehicle market grows, the demands for fast EV charging system are increasing for various purpose. DC EV charging station is level-3 charger and its power level is increasing by modular configuration as demand of faster charging time and higher battery capacity of EV. DC EV charging provides a mostly constant current output for wide DC output voltage range (200V to 900V) and load profile (single / multiple vehicles).



(a) Three phase Vienna PFC + Series LLC resonant converter

(b) Three phase rectifier (B6) + FB LLC resonant converter

Figure 1. DC EV Charging module

The three-phase Vienna PFC and series LLC resonant converters in figure. 1 (a), using SJ MOSFETs or IGBTs and SiC diodes, are widely used for unidirectional DC EV charger applications. 1200V SiC MOSFETs are suitable in three phase B6 rectifier and FB LLC resonant converter for the DC EV charging system in figure (b). Main advantages of 1200V SiC MOSFET are to reduce the number of power devices and simplify circuit and control scheme. This approach enables to make di-directional operation, reduce size and weight of system by higher frequency while maximize system efficiency. The on-board charger (OBC) is an essential block into the xEV to recharge high voltage battery from the AC grid. OBC power rating is increased from 6.6kW to 11~22kW for longer drive regulation and fast charging with higher battery capacity. Bi-directional is the key trend for the next on-board charger (OBC) application for V2L (Vehicle to Load), V2G (Vehicle to Grid), V2V (Vehicle to Vehicle), V2H (Vehicle to Home appliance). Therefore, topology is moving to Totem-pole PFC + CLLC or DAP resonant converter from Interleaved CCM PFC or Dual boost bridgeless PFC + LLC resonant converters. Typical battery voltage class is $400V_{DC}$, but larger battery capacity and faster charging demands are driving 800V battery system for BEV application. 1200V SiC MOSFET is suitable for 800V battery OBC systems. Power Master Semiconductor's new 1200V *e*SiC M1 MOSFET provide the excellent dynamic C_{OSS} loss and switching performance while providing ultra-low $R_{DS(ON)}$.

3. 1200V *e*SiC M1 MOSFET Technology

Two typical structures (planar and trench) of SiC MOSFET are available today, SiC MOSFET structures depend on the performance of the device, strategy, the target applications [1]~[3]. The planar structure is easier to fabricate but has the disadvantage of having a higher R_{SP} (Resistance per unit area) compared to the same rating trench one. This is due to the channel current flowing perpendicularly to the vertical direction and the existence of the inner JFET region. Trench structure is good to reduce both $R_{DS(ON)}$ and switching performance because, the main reason is that the electron mobility of the channel formed in the trench sidewall is greater than that of the surface part. but disadvantage of trench is that need complex SiC trench etching process and lower ruggedness compared to planar structure. 1200V *e*SiC M1 technology is Power Master Semiconductor's first generation of SiC MOSFET.

3.1. Performance benchmark of 1200V SiC MOSFETs

Table 1 shows the key parameter comparison of 1200V SiC MOSFETs. Advantage of 1200V M1 *e* SiC MOSFET(PCZ120N80M1) in TO-247-4L package is the reduced switching losses and dynamic C_{OSS} losses (E_{Dyn}).

Table 1. Key Parameter Comparison of Power Master Semiconductor's 1200V/80mΩ *e*SiC MOSFET M1 (PCZ120N80M1) and Competitors

Specification	PCZ120N80M1	Comp. A (Trench)	Comp. B (Planar)	Comp. C (Trench)
BV_{DSS} [V]	1200	1200	1200	1200
I_D [A]	30	26	29	31
V_{GS_op} [V]	-5 / +18	0 / +18	-5 / +20	0 / +18
V_{GS_max} [V]	-10 / +22	-7 / +23	-15 / +25	-4 / +22
$R_{DS(on)}$ [mΩ] (typ) / (max)	80 / 104	90 / 125	80 / 110	80 / 104
V_{TH} [V]	2.0 / 3.0 / 4.5	3.5 / 4.5 / 5.7	1.8 / 2.75 / 4.3	2.7 / - / 5.6
E_{DYN} [uJ]	4.1	3.3	7.8	4.3
Q_G [nC]	52	21	56	60
E_{ON} [µJ] @ I_D=20A, R_G=2Ω	95	88	129	168
E_{OFF} [µJ] @ I_D=20A, R_G=2Ω	53	40	60	117

Recently, power loss by hysteresis C_{OSS} (E_{Dyn}) is analyzed in many papers [4]~[5]. Unexpected power losses associated especially for SJ MOSFETs in ZVS topologies generated due to the hysteretic phenomenon of the output capacitance, C_{OSS}. This power losses related to C_{OSS} hysteresis is more critical when operating under high frequency soft switching conditions, especially in medium and light loads.

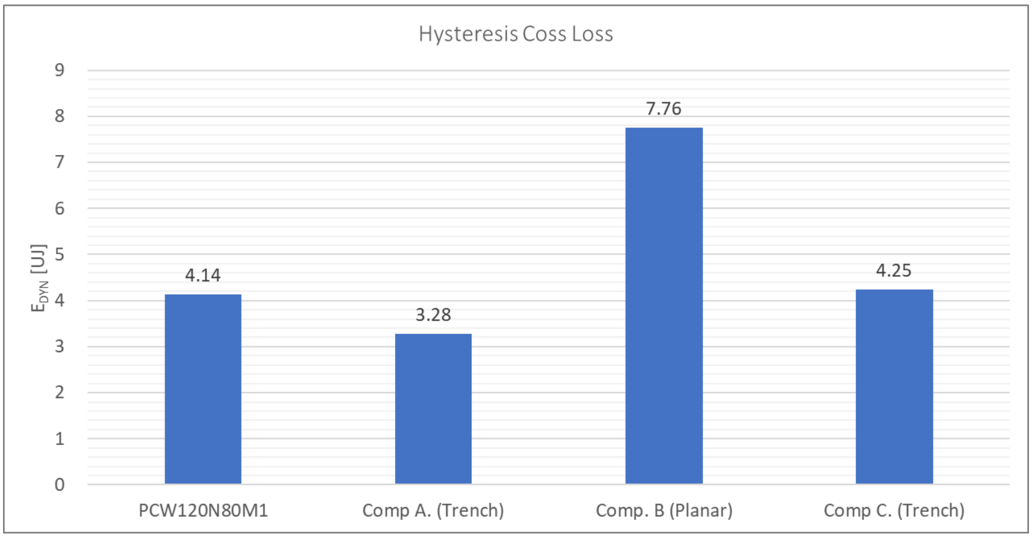
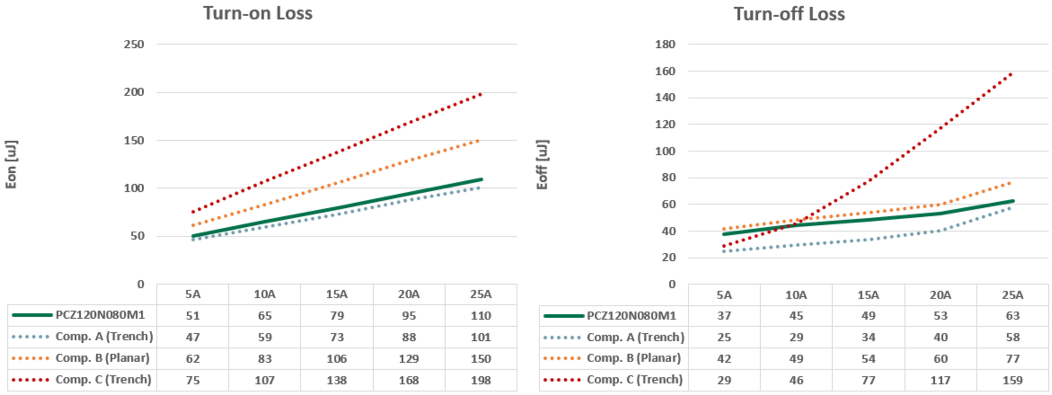


Figure 2. Comparison dynamic C_{OSS} loss of 1200V eSiC MOSFETs (PCW120N80M1) vs. Competitors

Consequently, a certain amount of energies are generated. Dynamic C_{OSS} loss (E_{Dyn}) can be defined as the difference between charging energy and discharge energy except some lost energy during discharging process. The dynamic C_{OSS} losses (E_{Dyn}) exist in SiC MOSETs and this loss is affected by device structure, die size, switching dV_{DS}/dt. Figure 2 shows a dynamic C_{OSS} loss measurement of the 1200V eSiC MOSFETs, and competitor under same condition, V_{DS}=0~800 V. The dynamic C_{OSS} loss of 1200V eSiC MOSFETs is less than Comp B.(planar) and Comp. C (trench). Figure 3 shows the measurement of switching losses (E_{ON} and E_{OFF}) comparisons for 1200V/80mΩ eSiC MOSFET M1 and competitors (trench and planar) under V_{DD}=800V, V_{GS}=-3V/+18V, FWD=PCH120S10D1, R_G=2Ω in various I_D conditions. E_{ON} is 26% and 44% less and E_{OFF} is 11% and 55% less for 1200V/80mΩ eSiC MOSFET M1 compared to that of 1200V/80mΩ competitor B(planar) and competitor C(trench) under same condition.



	5A	10A	15A	20A	25A
PCZ120N080M1	51	65	79	95	110
Comp. A (Trench)	47	59	73	88	101
Comp. B (Planar)	62	83	106	129	150
Comp. C (Trench)	75	107	138	168	198

	5A	10A	15A	20A	25A
PCZ120N080M1	37	45	49	53	63
Comp. A (Trench)	25	29	34	40	58
Comp. B (Planar)	42	49	54	60	77
Comp. C (Trench)	29	46	77	117	159

Figure 3. Comparison of Switching Losses - 1200V/80mΩ eSiC MOSFET M1 vs. competitors under V_{DD}=800V, V_{GS}=-3V/+18V, FWD=PCH120S10D1, R_G=2Ω

3.2. Package influence at Switching behavior of 1200V SiC MOSFETs

The faster switching of SiC MOSFETs enable higher power density and higher system efficiency. However, performance of SiC MOSFET cannot be always maximized due to limitation of the traditional packages such as TO-247-3L by parasitic inductors. Kelvin source packages of SiC MOSFET can maximize overall system efficiency by lower switching losses thanks to reducing the parasitic inductance effect that impact on switching performance. As shown in figure 4, TO-247-4L package has additional “drive source” lead that is directly connected to gate loop and separated from power source loop. Thanks to additional drive source lead of the kelvin source TO-247-4L package, negative effect by induced voltage drop can be eliminated and switching losses can dramatically reduce especially at turn-on transient and reduce gate oscillation at turn-off transient.

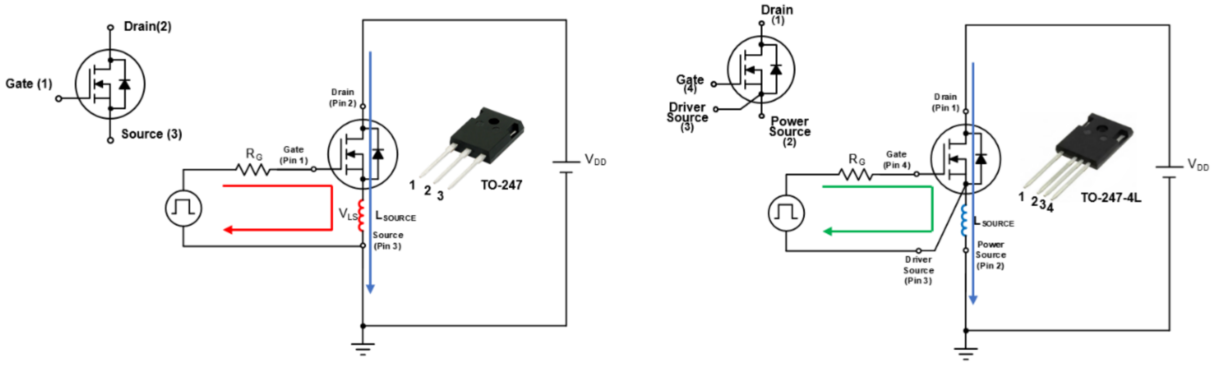


Figure 4. Gate driving circuit for TO-247-3L and TO-247-4L

As shown in Fig. 5, TO-247-3L package shows turn-on delay by reduced internal gate-source voltage from the positive induced voltage across source inductance at turn-on transient. However, TO-247-4L package enable shorter transient time and lower E_{ON} by avoiding induced voltage across power source in gate driving loop thanks to additional driver source of TO-247-4L. E_{ON} of PCZ120N80M1 in TO-247-4L is 71% (110μJ) less than one (E_{ON}:384μJ) of PCW120N80M1 in TO-247-3L. At turn-off transient, TO-247-3L package shows higher gate ringing and it leads to turn-off delay and higher turn-off loss. Gate ringing is highly reduced thanks to its separated power and drive source of TO-247-4L package. Consequently, TO-247-4L package enable to reduce turn-off delay and lower turn-off switching loss. E_{OFF} of PCZ120N80M1 in TO-247-4L is 28% (63μJ) less than one (E_{OFF}:88μJ) of PCW120N80M1 in TO-247-3L.

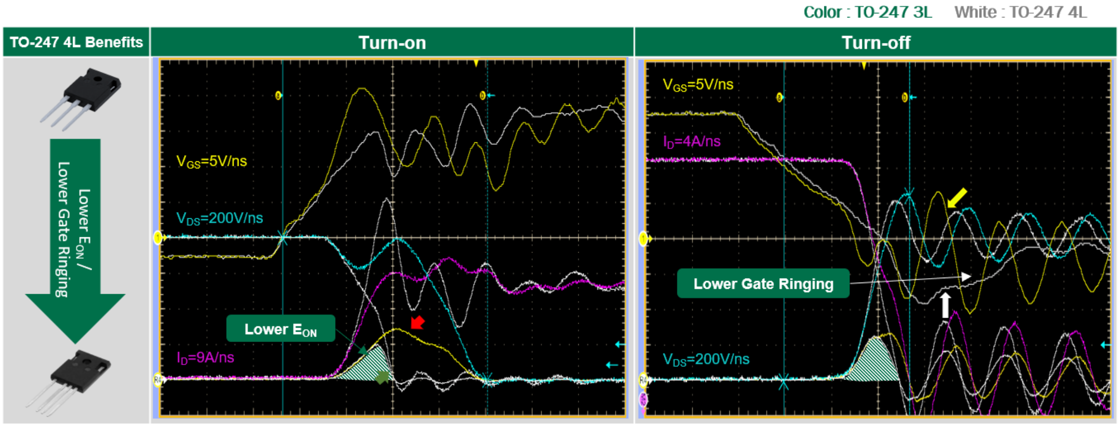


Figure 5. Switching behavior comparison between TO-247-3L and TO-247-4L under V_{DD}=800V, I_D=25A, V_{GS}=-3V/+18V, FWD=PCH120S10D1, R_G=2Ω

4. Simulation of Losses Analysis in DC EV Charging System and Solar Inverter System

4.1. Simulation of Power Loss in FB LLC of 25kW DC EV Charging system

Power losses of 1200V / 80mΩ *e*SiC MOSFET M1 are analyzed with the 1200V / 80~90mΩ SiC competitors in FB LLC resonant converter of 25kW DC EV charging module. The input voltage of DC EV charging module is three-phase 380V_{AC} and output voltage and output current set to 750V and 33A, respectively. Switching frequency is 140kHz. The output voltage range of the EV charging module is 200~750V and depends on the battery voltage of electric vehicles. Fig 6 shows the power loss distribution of the SiC MOSFETs in FB LLC resonant converter of DC EV charging module under full load condition. As shown in Fig. 8, Power dissipation in the MOSFETs is highly dependent on $R_{DS(ON)}$ and the E_{Dyn} loss is also critical in soft switching applications. These parasitic-related losses are a function of dV_{DS}/dt and the E_{Dyn} of output capacitance of the MOSFET. The losses are proportional to the switching frequency. In order to improve system efficiency, E_{Dyn} loss has to be reduced especially in resonant topologies.

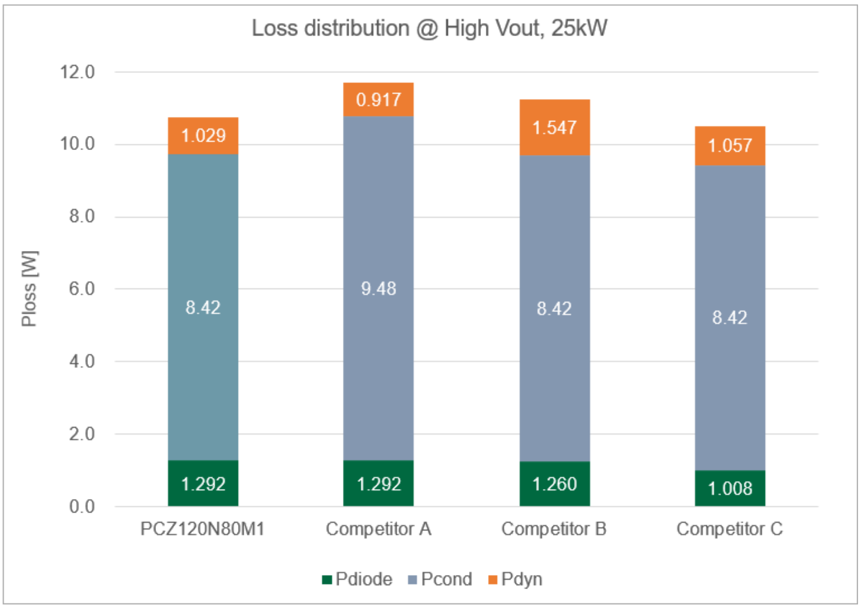


Figure 6. Power Loss Analysis under Full Load in FB LLC of 25kW EV Charging Module

4.2. Simulation of Power Loss in Boost Converter of 5kW Solar inverter

Power losses of SiC MOSFETs, in table 1, are analyzed in 5kW boost converter for solar inverter. Input voltage is 400V_{DC} and output voltage set to 630V_{DC}. Switching frequency is 40kHz. Fig 7 is summary of the power loss distribution of 1200V / 80mΩ *e*SiC MOSFET M1 and competitors in boost converter of 5kW solar inverter under full load condition. As show in Fig.7, total power loss of 1200V *e*SiC MOSFET M1 is reduced about 11% and 30% respectively compared to competitor B and competitor C that has same $R_{DS(ON)}$, thanks to excellent switching performance of Power Master Semiconductor's 1200V / 80mΩ *e*SiC MOSFET M1 in full load condition. Turn-on loss of PCZ120N80M1 (TO-247-4L) is 42% less than that of PCW120N80M1(TO-247-3L). Total power loss of PCZ120N80M1 is about 18% lower than that of PCW120N80M1 thanks to kelvin source configuration of TO-247-4L package. Kelvin source package can greatly reduce turn-on switching loss especially in hard switching topologies.

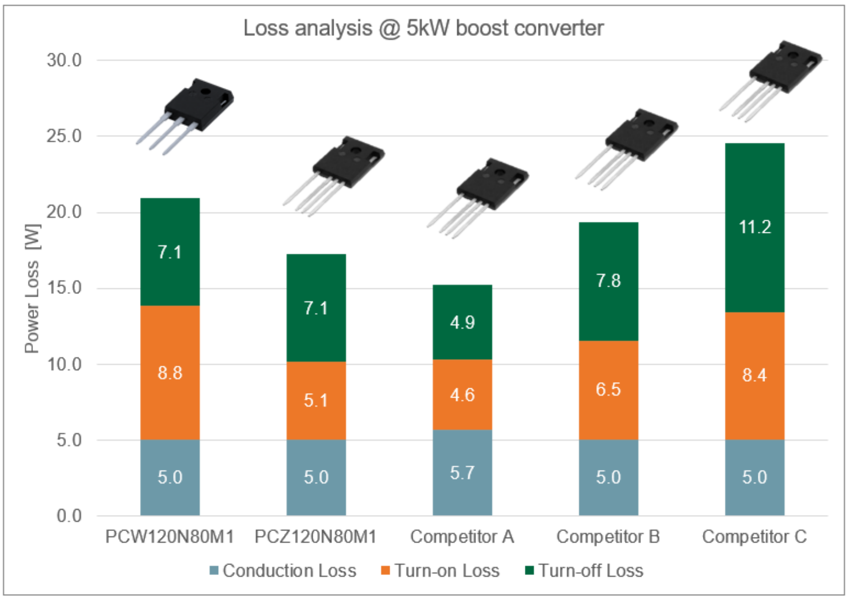


Figure 7. Power Loss Analysis under Full Load in Boost Converter of 5kW Solar Inverter

5. Conclusion

The latest 1200V eSiC MOSFET M1 technology shows the excellent switching performance and low dynamic C_{OSS} (E_{dyn})loss even compared with trench SiC MOSFETs. The eSiC MOSFET M1 technology is designed to achieve higher efficiency at entire of the load conditions by minimize dynamic C_{OSS} and switching losses in hard and soft switching topologies.

6. Reference

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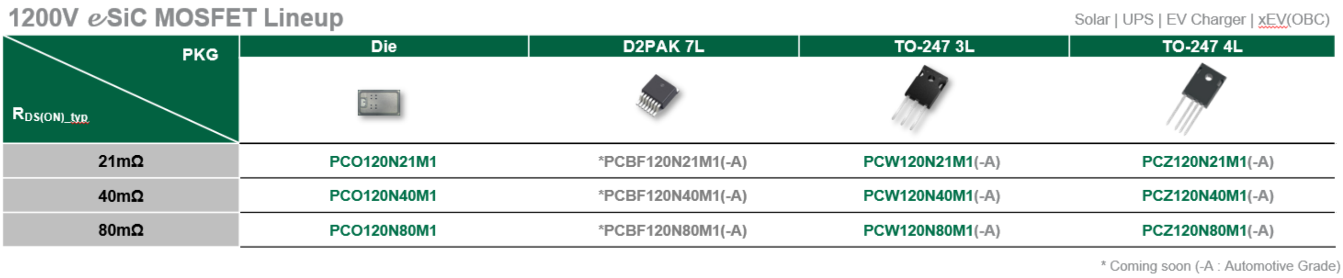
7. 1200V eSiC MOSFET Product Portfolio & Nomenclature

7.1. 1200V eSiC MOSFET Product Portfolio

Table 1. 1200V eSiC MOSFET Product Portfolio



1200V eSiC MOSFET Lineup

Solar | UPS | EV Charger | xEV(OBC)

PKG / $R_{DS(ON)\_typ}$	Die	D2PAK 7L	TO-247 3L	TO-247 4L
21mΩ	PCO120N21M1	*PCBF120N21M1(-A)	PCW120N21M1(-A)	PCZ120N21M1(-A)
40mΩ	PCO120N40M1	*PCBF120N40M1(-A)	PCW120N40M1(-A)	PCZ120N40M1(-A)
80mΩ	PCO120N80M1	*PCBF120N80M1(-A)	PCW120N80M1(-A)	PCZ120N80M1(-A)

* Coming soon (-A : Automotive Grade)

For more product information, please visit https://www.powermastersemi.com

7.2. Nomenclature

Device part number contains a lot of information such as technology, package, voltage rating and generation, etc. Figure 8 shows Power Master Semiconductor's eSiC MOSFET nomenclature

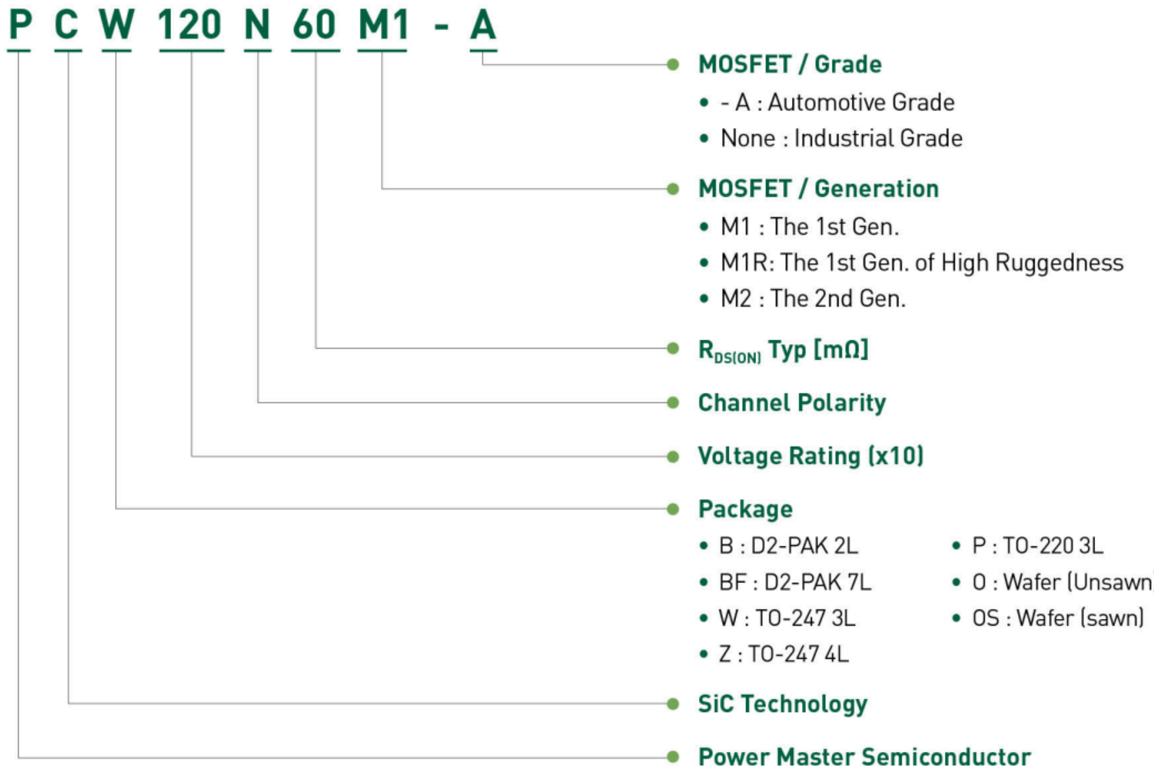


Figure 8. eSiC MOSFET nomenclature scheme

8. Document Revision History

Major changes since the last version

Date	Description of change
25-July-2023	First Release

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