AN-CM2308

Masters of Power Solution

1200V *e*SiC M1 MOSFET Series

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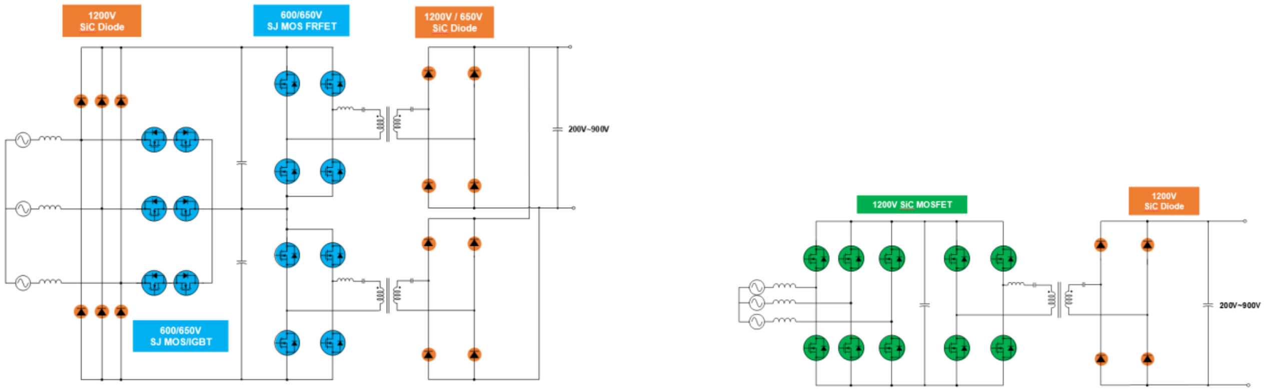
1. Introduction

1200V SiC MOSFETs are quickly penetrating to the DC EV charging stations, On board chargers (OBCs) and solar inverter applications. Power rating per module of DC EV charger is increasing from 20kW to 50kW, and the topology is being simplified from Vienna PFC and series LLC resonant converter (which use 650V super-junction MOSFETs or IGBTs) to B6 rectifier PFC and a full bridge LLC using 1200V SiC MOSFETs. 1200V SiC MOSFETs enable bidirectional charging up to 800V batteries. In solar inverters, the PV array voltage is increasing up to 1500V (String Inverter) for improve end to end efficiency and reduce installation costs.1200V SiC MOSFETs are the best solution for ensuring stable performance against variations in switching frequency and temperature, which enables high flexibility in overall system design especially for outdoor applications operating under harsh environments. The purpose of this application note is to highlight the key characteristics of Power Master Semiconductor's new 1200V *e*SiC M1 MOSFET in comparison to trench and planar competitors' 1200V SiC MOSFETs.

2. Target Applications of 1200V *e*SiC M1 MOSFET

SiC MOSFETs exhibit higher breakdown voltage, higher operating temperature, and higher thermal conductivity while having lower conduction and switching losses compared to Silicon IGBTs or MOSFETs. SiC MOSFETs offer significant system advantages such as higher power density, greater efficiency and reduced cooling effort due to their much lower power losses. Therefore, SiC MOSFETs are gaining popularity especially for EVs and its charging station applications that require higher power density, efficiency and robustness. As the electric vehicle market grows, the demand for fast EV charging systems is increasing for various purposes. The DC EV charging station is level-3 charger and its power level is increasing through modular configuration to meet the demand for faster charging time and higher battery capacity in 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 for a three phase B6 rectifier and a FB LLC resonant converter in the DC EV charging system shown in figure (b). The main advantages of the 1200V SiC MOSFET are its ability to reduce the number of power devices and simplify both the circuit and control scheme. This approach enables bi-directional operation, reduces size and weight of the system by operating at higher frequency while maximizing system efficiency. The on-board charger (OBC) is an essential component in the xEV to recharge high-voltage batteries from the AC grid. OBC power ratings have increased from

6.6kW to 11~22kW for longer driving range and fast charging with higher battery capacity. Bi-directional operation is the key trend for next generation OBC applications, including V2L (Vehicle to Load), V2G (Vehicle to Grid), V2V (Vehicle to Vehicle), and V2H (Vehicle to Home appliance). Therefore, the topology is shifting from Interleaved CCM PFC or Dual boost bridgeless PFC + LLC resonant converters to Totem-pole PFC + CLLC or DAP resonant converters. The typical battery voltage class is 400V_{DC}, but the demand for larger battery capacities and faster charging is driving the adaption of 800V battery systems for BEV application. The 1200V SiC MOSFET is well-suited for 800V battery OBC systems. Power Master Semiconductor's new 1200V *e*SiC M1 MOSFET provide the excellent dynamic C_{OSS} characteristics and switching performance while maintaining ultra-low $R_{DS(ON)}$.

3. 1200V *e*SiC M1 MOSFET Technology

Two typical structures (planar and trench) of SiC MOSFET are available today, The choice of SiC MOSFET structures depends on the performance of the device, strategy, and the target applications [1]~[3]. The planar structure is easier to fabricate but has the disadvantage of a higher R_{SP} (Resistance per unit area) compared to a trench MOSFET of the same rating. This is due to the channel current flowing perpendicularly in the vertical direction and the existence of the inner JFET region. The trench structure is advantageous for reducing both $R_{DS(ON)}$ and switching losses because the electron channel mobility in the trench sidewall is greater than that of the surface region. However, a major disadvantage of the trench structure is that it requires a complex SiC trench etching process and has lower ruggedness compared to the 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 a comparison of key parameters for 1200V SiC MOSFETs. A key advantage of the 1200V M1 *e*SiC MOSFET(PCZ120N80M1) in a TO-247-4L package is its lower switching losses and reduced 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 due to hysteresis in C_{OSS} (E_{Dyn}) has been analyzed in many papers [4]~[5]. Unexpected power losses in ZVS topologies, especially in SJ MOFETs, occur due to the hysteretic behavior of the output capacitance, (C_{OSS}). These power losses related to C_{OSS} hysteresis become more critical when operating at high frequency soft switching conditions, especially under medium and light loads.

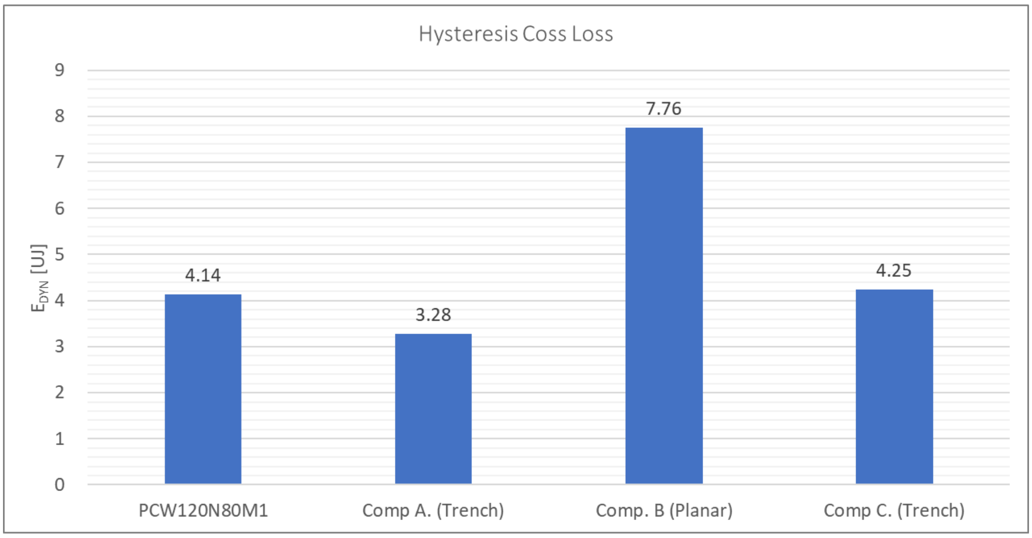
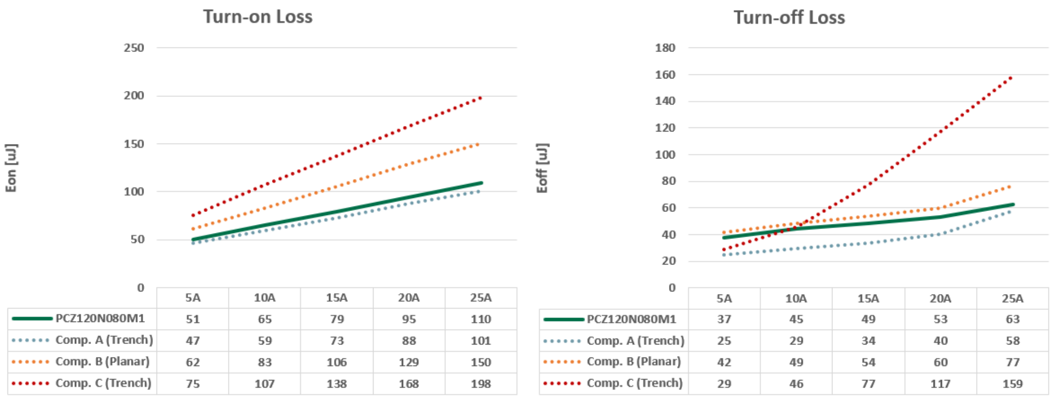


Figure 2. Comparison dynamic C_{OSS} loss of 1200V ℮SiC MOSFETs (PCW120N80M1) vs. Competitors

Consequently, a certain amount of energy is lost. Dynamic C_{OSS} loss (E_{Dyn}) is defined as the difference between charging energy and discharge energy, excluding the energy lost during the discharging process. Dynamic C_{OSS} losses (E_{Dyn}) exist in SiC MOSETs and this loss is influenced by the device structure, die size, and switching dV_{DS}/dt. Figure 2 shows a dynamic C_{OSS} loss measurement of the 1200V ℮SiC MOSFETs and competitors under the same conditions, (V_{DS}=0~800 V.). The dynamic C_{OSS} loss of the 1200V ℮SiC MOSFETs is lower than that of Comp B.(planar) and Comp. C (trench). Figure 3 shows a comparison of switching losses (E_{ON} and E_{OFF}) for the 1200V/80mΩ ℮SiC MOSFET M1 and the 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% lower and E_{OFF} is 11% and 55% lower for the 1200V/80mΩ ℮SiC MOSFET M1 compared to that of 1200V/80mΩ competitor B(planar) and 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 ℮SiC 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 enables higher power density and greater system efficiency. However, the performance of SiC MOSFET cannot always be fully optimized due to the limitation of traditional packages, such as TO-247-3L, which suffer from parasitic inductors. Kelvin source packages of SiC MOSFET can enhance overall system efficiency by reducing switching losses thanks to reduce the parasitic inductance effect, which negatively impacts switching performance. As shown in figure 4, TO-247-4L package features an additional “drive source” lead that is directly connected to gate loop and separated from power source loop. This additional drive source lead in the kelvin source TO-247-4L package eliminates the negative of induced voltage drop, significantly reducing switching losses-particularly at the turn-on transient- and minimizing gate oscillation at turn-off transient.

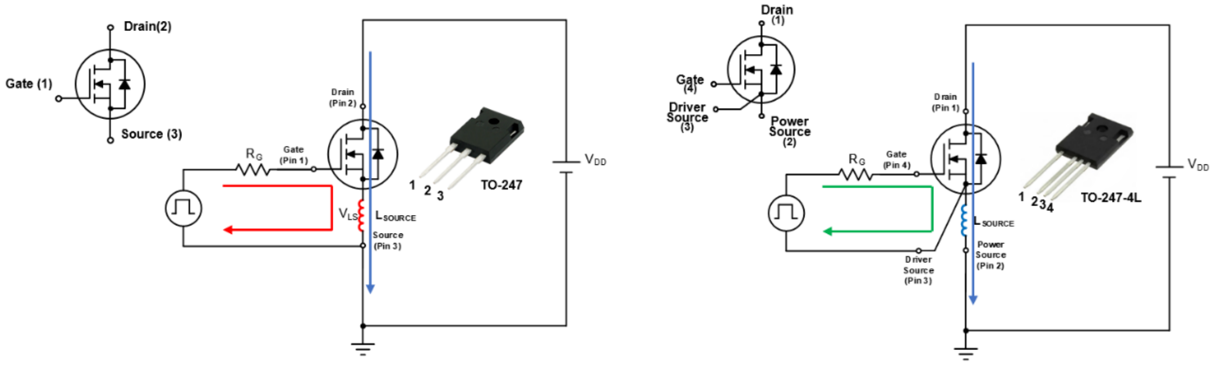


Figure 4. Gate driving circuit for TO-247-3L and TO-247-4L

As shown in figure. 5, TO-247-3L package exhibits a turn-on delay due to reduced internal gate-source voltage caused by the positive induced voltage across source inductance during the turn-on transient. In contrast, TO-247-4L package enables shorter transient time and lower E_{ON} by preventing the induced voltage across power source in gate driving loop, thanks to its additional driver source. E_{ON} of the PCZ120N80M1 in TO-247-4L is 71% lower (110μJ) compared to the PCW120N80M1 in TO-247-3L package (E_{ON}:384μJ). During turn-off transient, TO-247-3L package exhibits higher gate ringing. leading to a turn-off delay and increased turn-off loss. In contrast, the TO-247-4L package significantly reduces gate ringing due to its kelvin source configuration. As a result, the TO-247-4L package minimizes turn-off delay and lowers turn-off switching losses. E_{OFF} of the PCZ120N80M1 in the TO-247-4L is 28% lower (63μJ) than compared to the PCW120N80M1 in TO-247-3L package (E_{OFF}:88μJ).

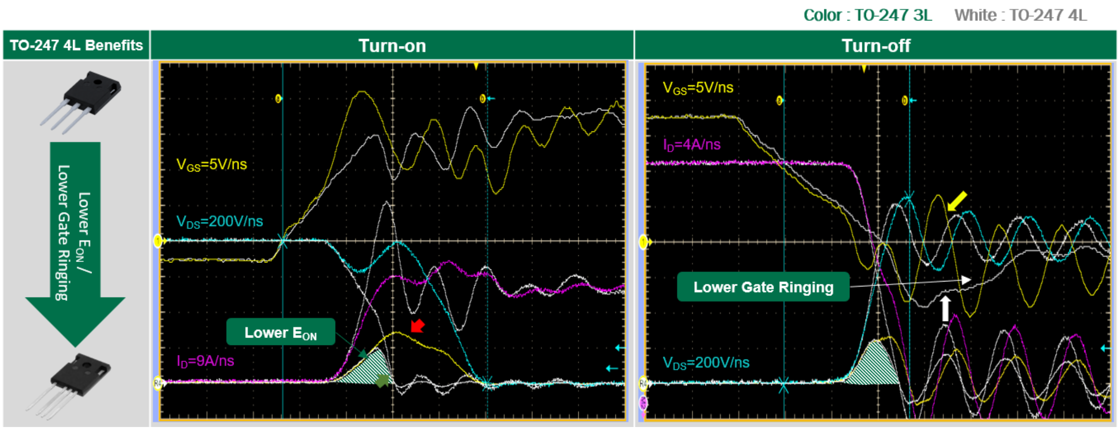


Figure 5. Switching behavior comparison between TO-247-3L and TO-247-4L under V_{DD}=800V, I_D=25A, V_{GS}=-3V/+18V, FWD=PCH120S10D1, R_G=2Ω

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 the 1200V / 80mΩ *e*SiC MOSFET M1 were analyzed with the 1200V / 80~90mΩ SiC competitors in FB LLC resonant converter of a 25kW DC EV charging module. The input voltage of DC EV charging module is three-phase 380V_{AC} with an output voltage and output current of 750V and 33A, respectively. The switching frequency is 140kHz. The output voltage range of the EV charging module is 200~750V, depending on the battery voltage of the electric vehicles. As shown in figure 6, power distribution in the MOSFETs is highly dependent on $R_{DS(ON)}$, while 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 must be minimized, especially in resonant topologies. In addition, the power losses of SiC MOSFETs, as presented in table 1, were analyzed in 5kW boost converter for solar inverter. The input voltage is 400V_{DC} with an output voltage of 630V_{DC} and switching frequency of 40kHz. Figure 7 summarize the power loss distribution of the 1200V / 80mΩ *e*SiC MOSFET M1 and its competitors in boost converter of 5kW solar inverter under full load condition.

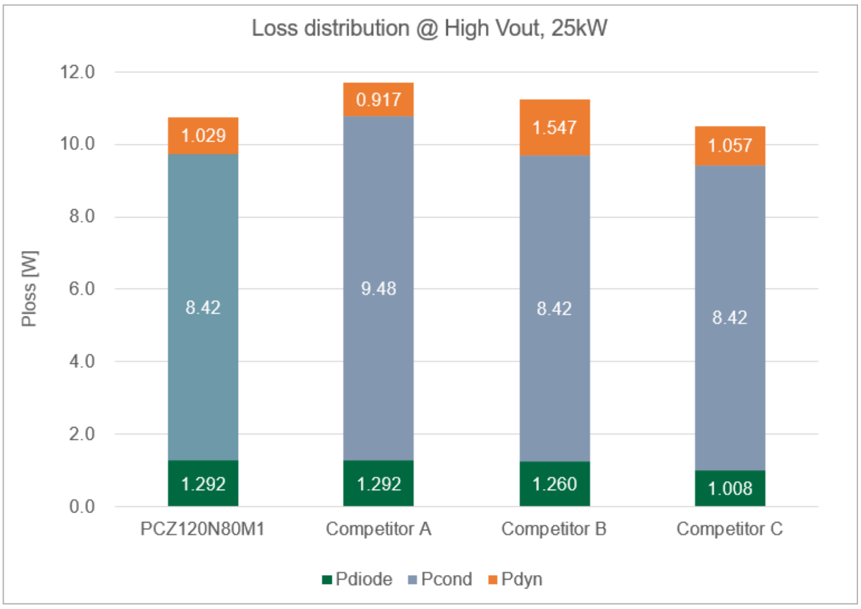


Figure 6. Power Loss Analysis under Full Load in FB LLC of 25kW EV Charging Module

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

As shown in figure.7, the total power loss of the 1200V *e*SiC MOSFET M1 is approximately 11% lower than that of competitor B and 30% lower than that of competitor C, despite having the same $R_{DS(ON)}$. This is due to the superior switching performance of Power Master Semiconductor's 1200V / 80mΩ *e*SiC MOSFET M1 in full load condition. The turn-on loss of the PCZ120N80M1 (TO-247-4L) is 42% lower than that of the PCW120N80M1(TO-247-3L). Furthermore, the total power loss of the PCZ120N80M1 is about 18% lower than that of the PCW120N80M1, thanks to kelvin-source configuration of TO-247-4L package. The kelvin source package significantly reduces turn-on switching losses, especially in hard switching topologies.

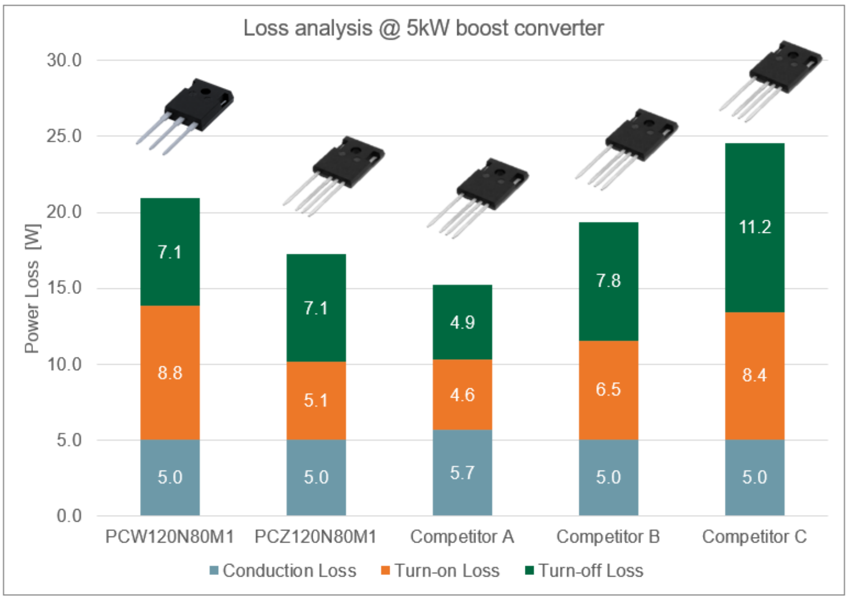


Figure 7. Power Loss Analysis under Full Load in Boost Converter of 5kW Solar Inverter

5. Conclusion

The latest 1200V *e*SiC MOSFET M1 technology demonstrates exceptional switching performance and low dynamic C_{OSS} (E_{dyn})loss, even compared with trench SiC MOSFETs. The *e*SiC MOSFET M1 technology is designed to achieve higher efficiency across all load conditions by minimizing dynamic C_{OSS} and switching losses in both 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

Package / RDS(ON)_typ	Grade	Bare Die	D2PAK-7L	TO-247-3L	TO-247-4L
					
21mΩ	**Industrial**	**PCO120N21M1**		**PCW120N21M1**	**PCZ120N21M1**
40mΩ	**Industrial**	**PCO120N40M1**		**PCW120N40M1**	**PCZ120N40M1**
80mΩ	**Industrial**	**PCO120N80M1**	**PCBF120N80M1**	**PCW120N80M1**	**PCZ120N80M1**
	Automotive		**PCBF120N80M1A**		**PCZ120N80M1A**

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

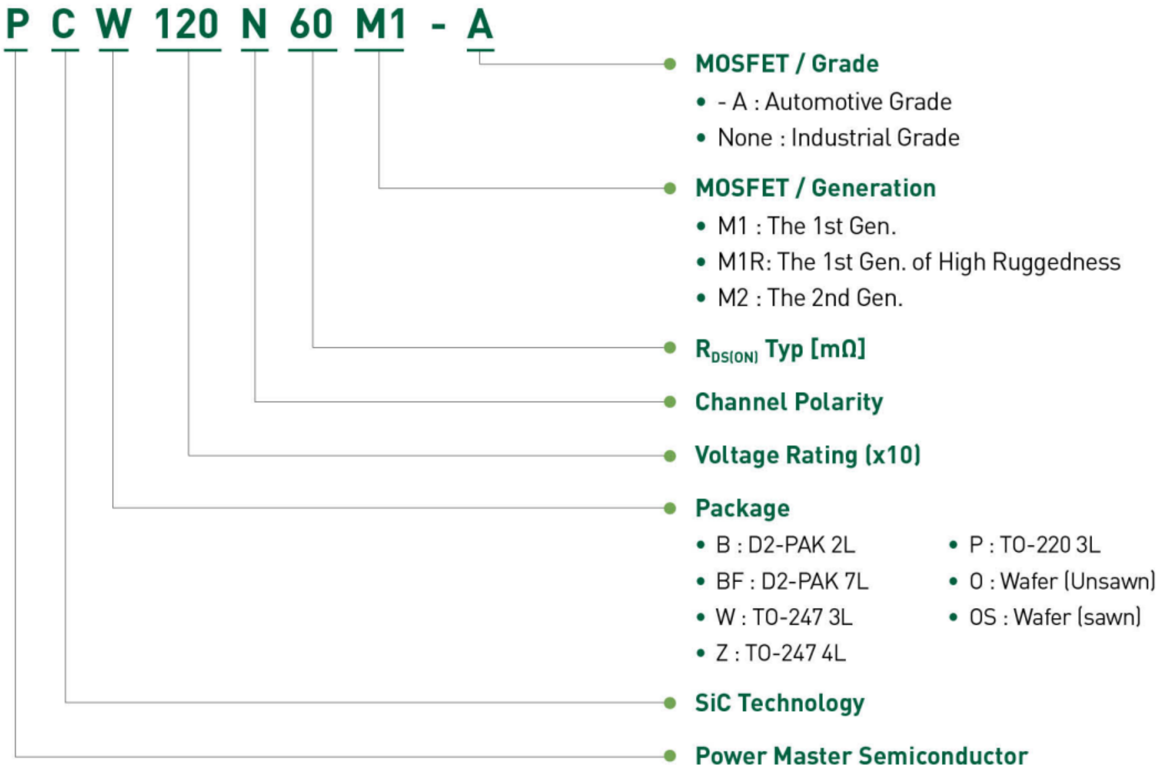

Figure 8. eSiC MOSFET nomenclature scheme

8. Document Revision History

Major changes since the last version

Date	Description of change
25-July-2023	First Release
27-March-2025	Revised Table 1. 1200V *e*SiC MOSFET Product Portfolio

Important Notice