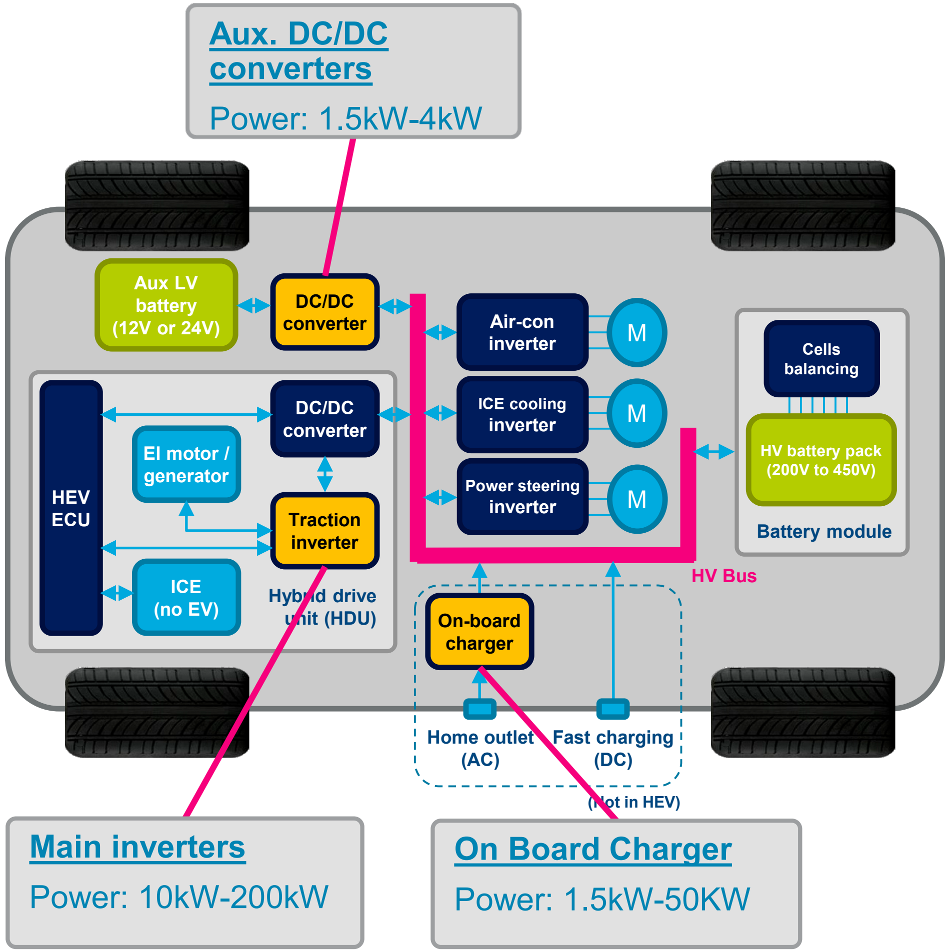
Power Electronics for Electric Vehicles



Aux. DC/DC converters
Power: 1.5kW-4kW

Main inverters
Power: 10kW-200kW

On Board Charger
Power: 1.5kW-50KW

Traction Inverter

On-Board Charger

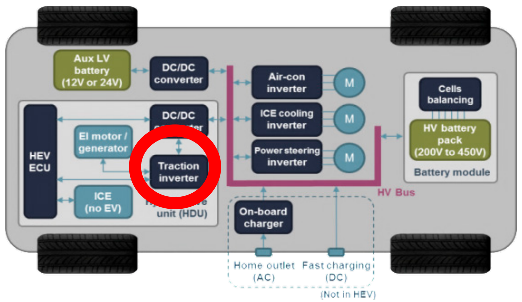
Auxiliary DC/DC Converter

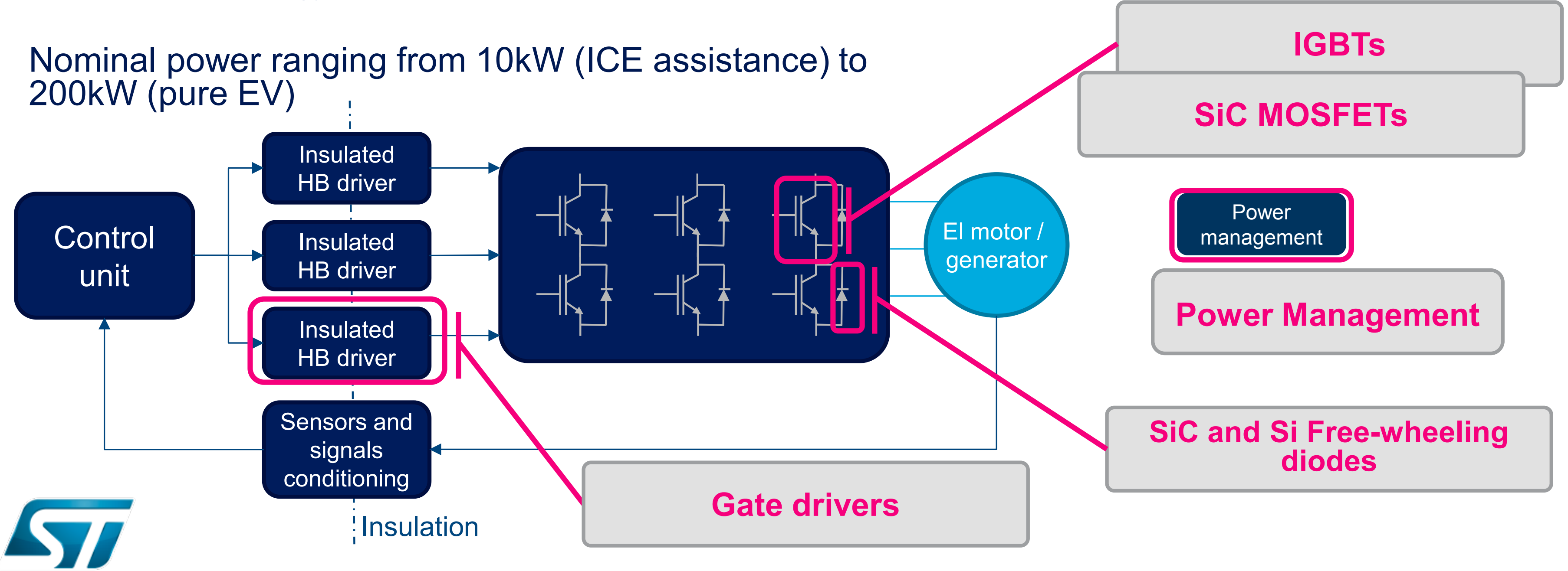
Power Technology

Traction Inverter

SiC MOSFETs can replace IGBTs with a smaller footprint, reduced losses and greater battery autonomy

- Usually 3-phase permanent magnet motors are used for traction
- Operating voltage from 300V to 750V
- Inverter must be bi-directional
  - Feeds the electric motor when driving the wheels
  - Streams energy back on HV Bus when vehicle brakes applied
- Nominal power ranging from 10kW (ICE assistance) to 200kW (pure EV)





SiC MOSFET Based 80kW Traction Inverter

SiC MOSFETs provide

- **More than 50% module/package size reduction**

✓ Much smaller semiconductor area → **ultra compact solution**

- **>1% efficiency improvement (75% lower loss)**

✓ Much lower losses at low-medium load → **longer autonomy**

- **80% cooling system downsize**

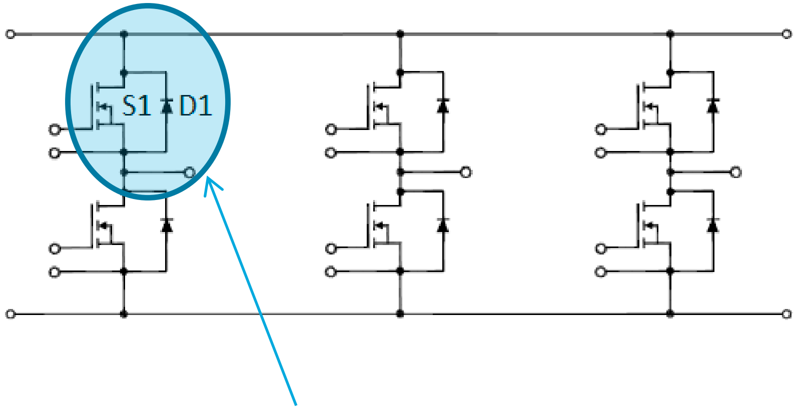
✓ Lower losses at full load → **smaller cooling system**

✓ Lower Delta (T_j-T_{fluid}) in the whole load range → **best reliability**

Power Loss Estimation for 80kW EV Traction Inverter

Switch (S1+D1) implementation

- Topology: Three phase inverter
- Synchronous rectification (SiC version)
- DC-link voltage: 400V_{dc}
- Current 480Arms (peak) 230Arms (nom)
- Switching frequency: 16kHz
- V_{gs}=+20V/-5V for SiC, V_{ge}=±15V for IGBT
- Cos(phi): 0.8
- Modulation index (MI): 1
- Cooling fluid temperature: 85℃
- $R_{thJ\text{-}C(IGBT\text{-}die)}$=0.4℃/W; $R_{thJ\text{-}C(SiC\text{-}die)}$=1.25℃/W
- $T_j \leq 80\% * T_{jmax}$℃ at any condition



Si IGBT requires antiparallel Si diode,
SiC MOSFETs do not

4 x 650V,200A IGBTs + 4 x 650V,200A Si diodes
vs.
7 x 650V, 100A SiC MOSFETs SCTx100N65G2

Power Loss at Peak Condition (480Arms,10sec)

SiC MOSFETs run at higher junction temperatures in spite of lower losses
This is due to the exceptional SiC R_{DSON} x Area FOM

Loss Energy	**Si-IGBTs + Si-diodes Solution**	**Full-SiC Solution**
Total chip-area	400 mm^2 (IGBT) + 200mm^2 (diode)	140 mm^2
Conduction losses* (W)	244.1	377.9
Turn-on losses* (W)	105.1	24.1
Turn-off losses* (W)	228.4	32.7
Diode's conduction losses* (W)	45.9	Negligible
Diode's Q_{rr} losses* (W)	99.5	Negligible
(S1+D1) Total losses* (W)	**723**	**435**
Junction Temperature (℃)	**142.8**	**162.6**

4.3x lower

> 4x lower

> 7x lower

40% lower

T_J ~ 80% Tjmax

* Typical power loss values

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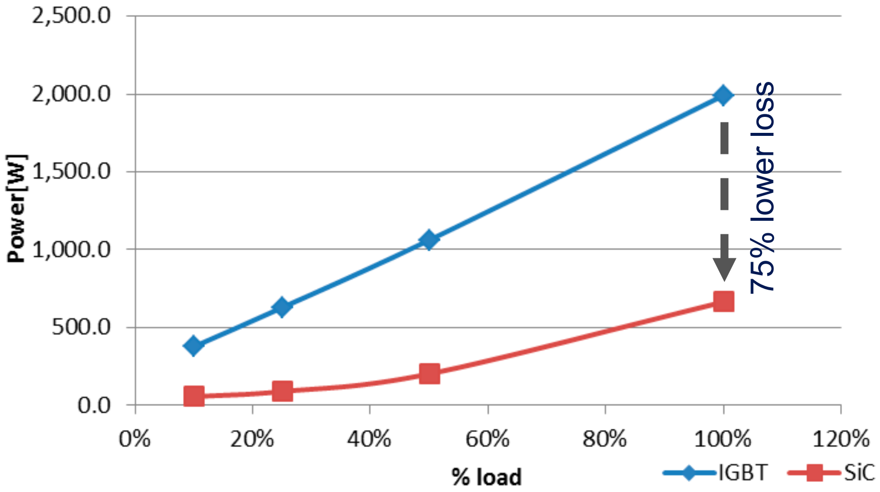
SiC MOSFET Enables Lower Power Dissipation and Higher Efficiency

f_{sw}=16kHz, Operating phase current up to 230A_{rms}

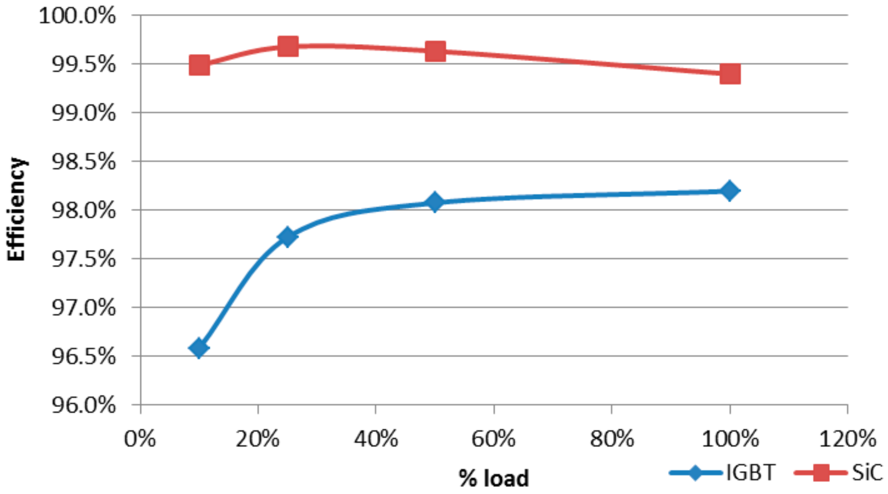
Lower losses mean smaller cooling system and longer battery autonomy

Inverter losses vs %load



SiC shows much lower losses in the whole load range

Inverter efficiency vs %load



* Simulated efficiency takes into account only the losses due to the switches and diodes forming the bridge inverter

SiC offers 1% higher efficiency or more over the whole load range!

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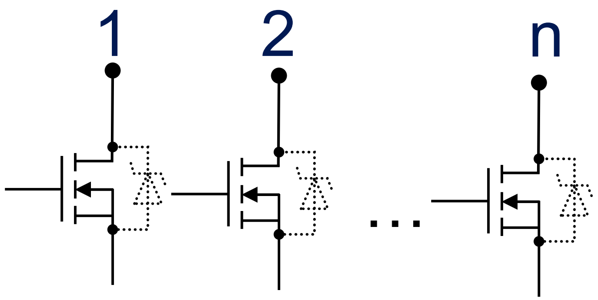
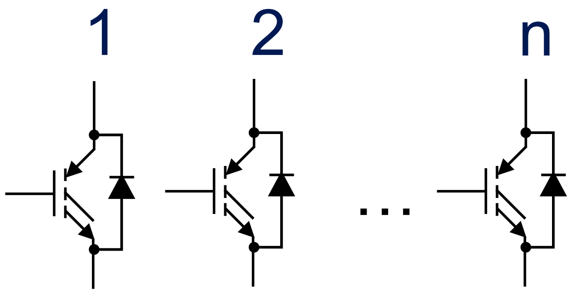
SiC MOSFETs have the Lowest Conduction Losses

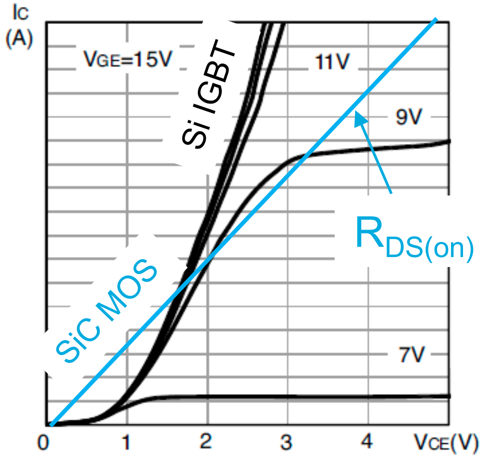
The lowest possible conduction losses can only be achieved with SiC MOSFETs



When “n” MOSFETs are paralleled the total $R_{DS(on)}$ must be divided by “n” allowing ideally zero conduction losses



When “n” IGBTs are paralleled the $V_{ce(sat)}$ doesn’t decrease linearly, the minimum achievable on-state voltage drop is about 0.8 – 1V



Hard-Switched Power Losses

SiC MOSFET vs. Si IGBT

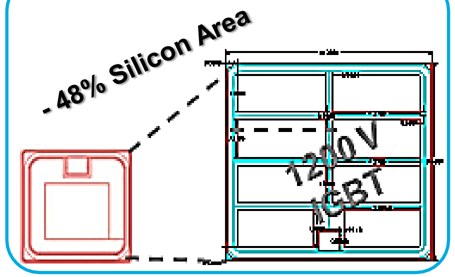
SiC MOSFET vs. trench gate field-stop IGBT

Parameters & Conditions	Die size (Normalized)	V_{on} typ. (V) @ 25°C, 20A	V_{on} typ. (V) @ 150°C, 20A	E_{on} (µJ) @ 20A, 800V 25°C / 150°C	E_{off} (µJ) @ 20A, 800V 25°C / 150°C	E_{off} 25°C / 150°C difference (%)
SiC MOSFET	0.52	1.6	1.8	500 / 450*	**350 / 400**	+15% from 25°C to 150°C
IGBT	1.00	1.95	2.2	800 / 1300**	**800/ 1900**	+140% from 25°C to 150°C

* Including SiC intrinsic body diode Q_{rr} ** Including the Si IGBT copack diode Q_{rr}

SiC MOSFET

- Data measured on SiC MOSFET engineering samples;
- SiC MOSFET device : SCT30N120, 1200V, 34A (@100°C), 80mΩ, N-channel
- Si IGBT device: 25A(@100°C) 1200V ST trench gate field-stop IGBT ($T_{j\text{-}max}$=175°C)
- SiC switching power losses are considerably lower than the IGBT ones
- At high temperature, the gap between SiC and IGBT is insurmountable

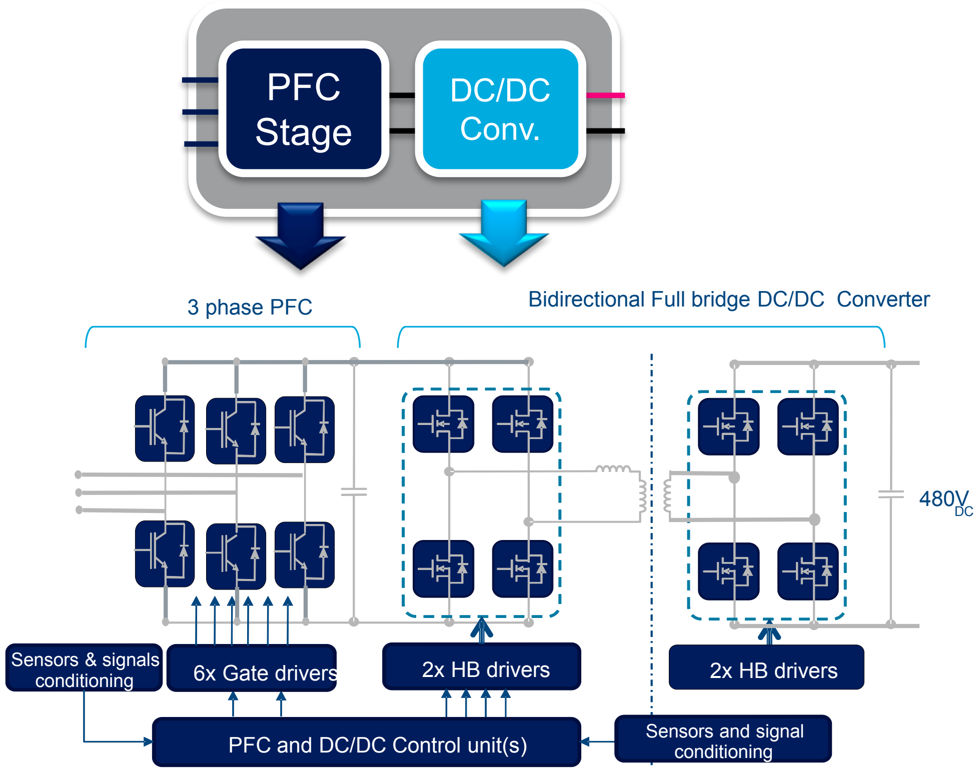


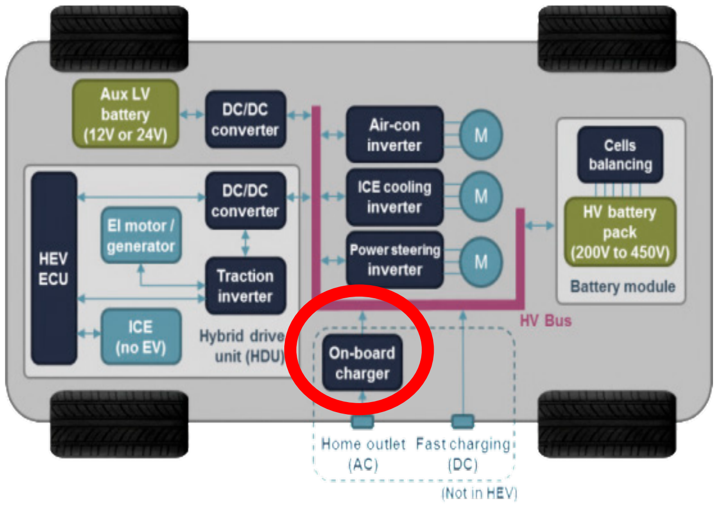
SiC die size compared to IGBT

➤ SiC MOSFET is the optimal fit for High Power, High Frequency and High Temperature applications

On-Board Charger

SiC MOSFETs offer more efficient solutions at higher switching frequency and smaller size



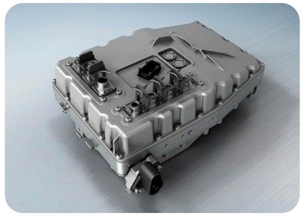


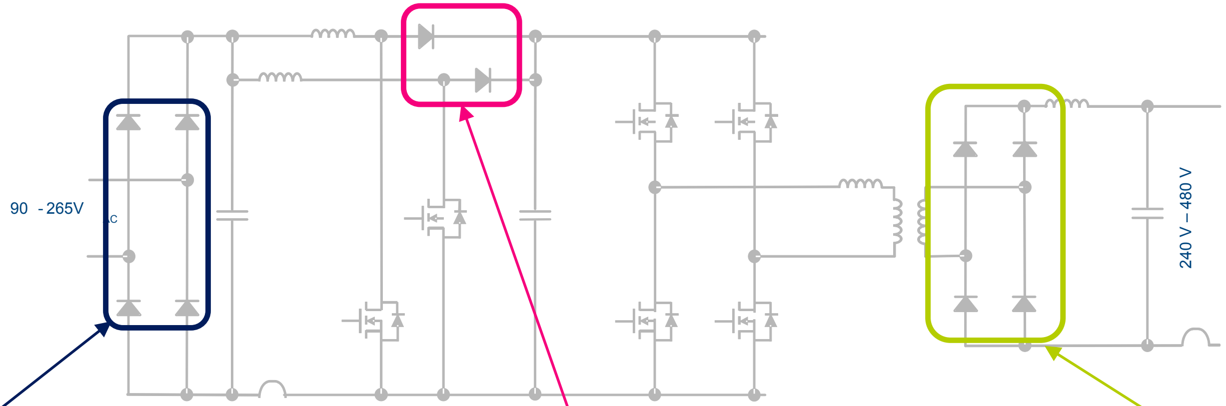
Single-phase architecture→ SiC MOS 650V

Three-phase architecture→ mainly SiC MOS 1200V

Power Rectifiers for OBC

All AEC-Q101 qualified PPAP capable





Input bridge
1000V / 1200V rectifiers and thyristors

Auto-grade rectifiers:

1000V diodes	1000V low-V_F diode	1200V diodes
STTH6010WY STTH3010WY STTH1210WY	STTH60L10WY High efficiency	STTH1512WY

Auto-grade thyristor:

Hi temperature1200V SCR
TN5050H-12WY

High efficiency

Function: inrush protection in mixed-bridge topology + disconnection of the bridge in idle mode

PFC
600V / 650V rectifiers

Auto-grade SiC Schottky rectifiers:

6A to 20A, 650V SiC
STPSC6C065DY STPSC10H065DY STPSC12C065DY STPSC20H065CTY STPSC20H065CWY High efficiency

Auto-grade ultrafast rectifiers:

5A & 8A, 600V	30A, 600V	60A, 600V
STTH5R06-Y STTH8R06-Y	Low Q_{RR} STTH30ST06-Y Low V_F STTH30L06-Y	Low Q_{RR} Soft recovery STTH60T06-Y

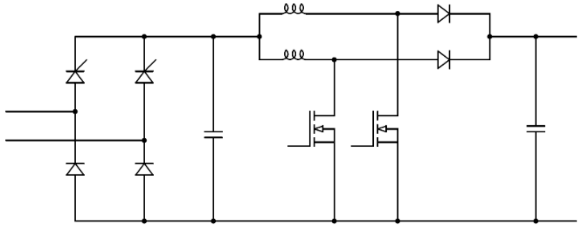
Secondary Rectification
600V rectifiers

Auto-grade ultrafast rectifiers:

5A & 8A, 600V	30A, 600V	60A, 600V
STTH5R06-Y STTH8R06-Y	Low Q_{RR} STTH30ST06-Y Low V_F STTH30L06-Y	Low Q_{RR} Soft recovery STTH60T06-Y High efficiency

SiC MOSFET improves PFC Boost Topologies

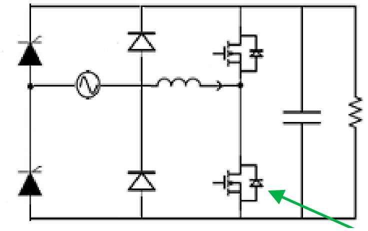
PFC Boost Topologies



Cases	$P_{cond\text{-}switch}$ [W] (Each Switch)	$P_{turn\text{-}off}$[W] (Each Switch)	$P_{turn\text{-}on}$[W] (Each Switch)	$P_{cond,diode}$[W] (Each Diode)	$P_{turn\text{-}off,diode}$ [W] (Each Diode)	Each $P_{TN5050H\text{-}12W}$ [W]	$P_{TOT(BOOST)}$[W]	$P_{TOT(SiC)}$[W]	Efficiency
120VAC, 16Arms	1.13	3.67	11.29	3.59	TBD	7.20	68.13	19.67	96.452%
240VAC, 27Arms	1.40	4.51	12.42	16.11	TBD	13.15	121.50	34.44	98.125%
220VAC, 32Arms	2.39	5.03	12.97	19.48	TBD	16.13	144.27	39.87	97.951%

Interleaved PFC boost, single phase

VDC(OUT)=400V, Switch: SiC MOSFET, 650V, 25mOhm(25C,typ), Diode: 600V SiC Schottky, 20A (STPSC20H065C-Y), T_J=125C



Cases	$P_{cond\text{-}switch}$[W] (Each Switch)	$P_{turn\text{-}off}$[W] (Each Switch)	$P_{turn\text{-}on}$[W] (Each Switch)	$P_{cond,sync\text{-}rec}$[W] (Each Switch)	$P_{Qrr,body\_diode}$ [W] (Each Switch)	Each $P_{TN5050H\text{-}12W}$ [W]	$P_{TOT(BOOST)}$[W]	$P_{TOT(SiC)}$[W]	Efficiency
120VAC, 16Arms	2.25	2.51	6.48	1.34	TBD	7.20	39.56	12.59	97.939%
240VAC, 27Arms	2.80	4.17	7.82	7.26	TBD	13.15	70.40	22.05	98.914%
220VAC, 32Arms	4.78	5.21	8.49	9.30	TBD	16.13	87.80	27.77	98.753%

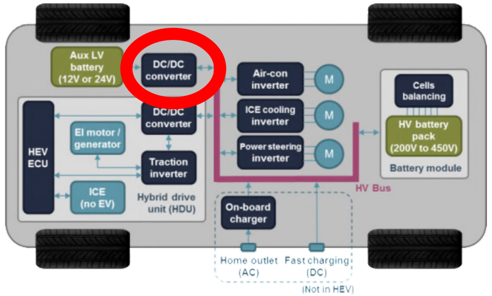
Totem-pole semi-bridgeless PFC boost, single phase

VDC(OUT)=400V, Switch: SiC MOSFET, 650V, 25mOhm(25C,typ), T_J=125C

More compact, Lower Power Loss

Auxiliary DC/DC converter

ST can cover the whole system with state-of-the-art technologies including SiC and Isolated GAP drivers

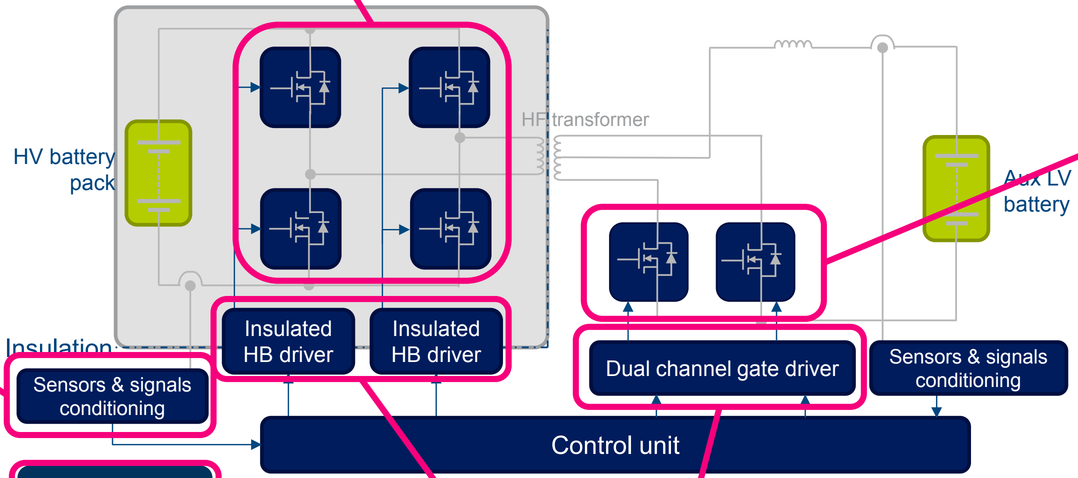


High voltage MOSFETs

MDmesh^{TM} M2 series
(not automotive grade yet)
proves to be the best choice in resonant converters while representing the best option for low/medium power PFC

MDmesh^{TM} M5 series
For higher power density designs & very low Rdson

FDmesh^{TM} II
For Full Bridge Phase Shifted ZVS



Low voltage MOSFETs, power Schottky diodes

Diodes

- **STPS family of power Schottky (from 30V up to 150V)**

MOSFETs

- **STripFET VI DeepGATE (40V, 60V)**
- **STripFET VII DeepGATE (40V, 75V, 100V)**

Sensors and signal conditioning

- **TSX Series op-amp**
- **TSC10 current sensor**

Power Mng

LDO, DC/DC converter

Gate drivers

- **A8834, A6491, GapDRIVE^{TM}**

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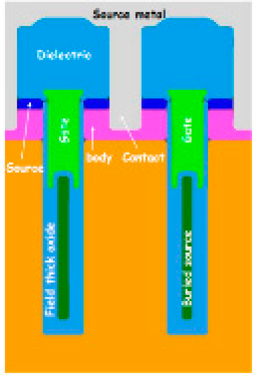
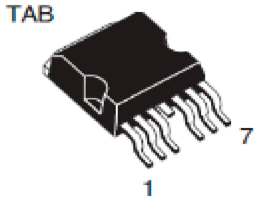
New 80/100V MOSFET Series: STripFET F7

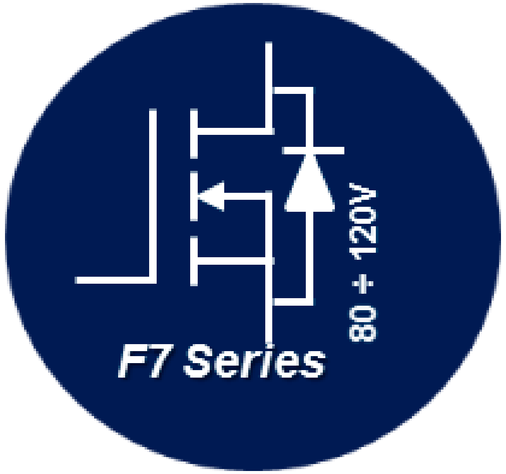
ST cover the complete system with state-of-the-art technologies including SiC and Isolated GAP drivers



- **STH315N10F7-2/ STH315N10F7-6**
- **Rdson 1.9 mΩ typ**
- **VDS = 100 V**
- **ID = 180 A**
- **100% avalanche tested**
- **Tjmax 175° C**
- **Available in H²PAK-2/6**
- **AEC Q101 qualified in KGD die form**



H²PAK-6



Already used for 48V DC/DC converters by key customer

Power Technology

ST offers both silicon and silicon carbide discrete power components

SiC Schottky Rectifiers

IGBTs

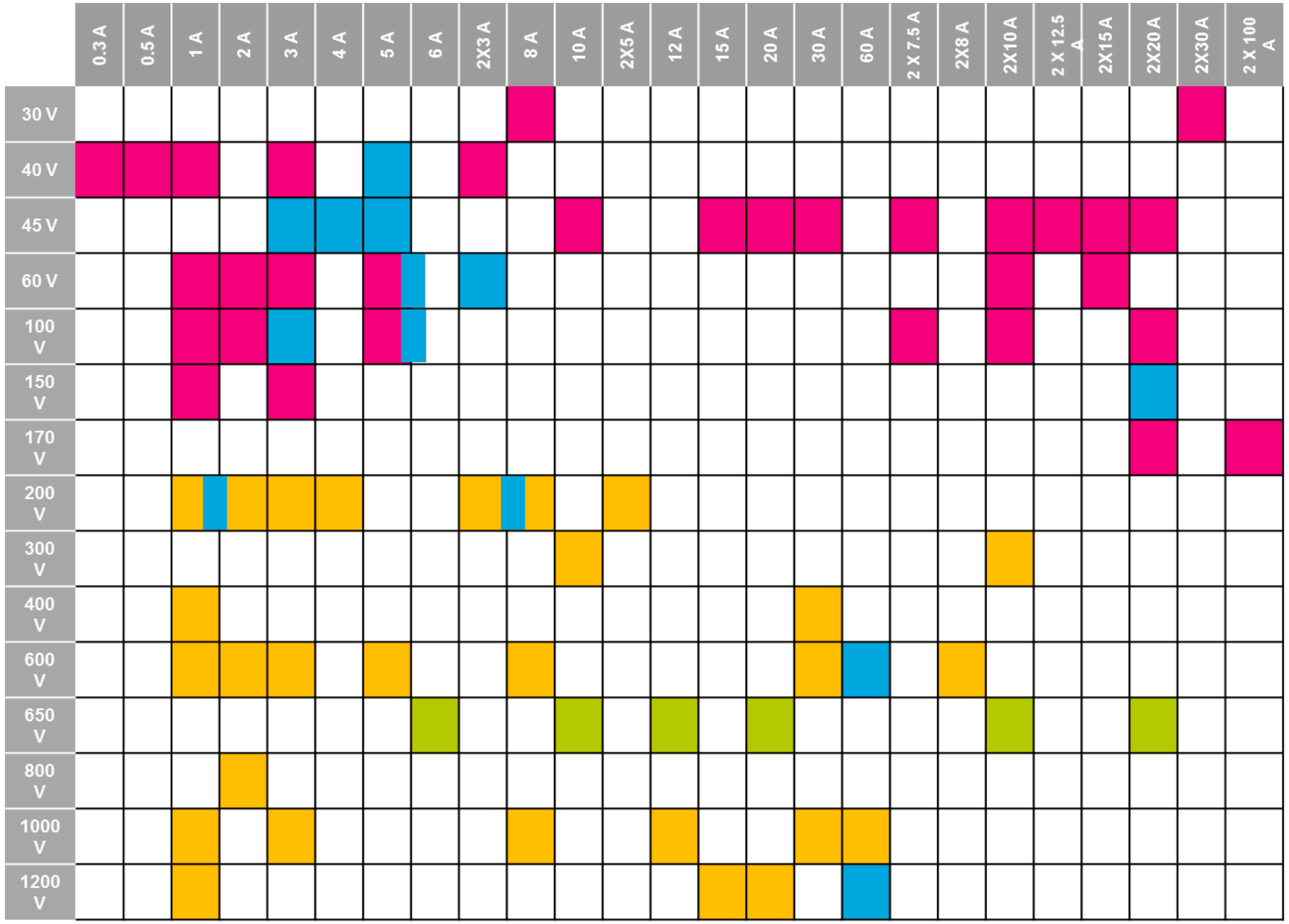
gapDRIVE™

SiC MOSFETs

Silicon MOSFETs

Automotive Grade Rectifier Portfolio

Ultrafast, SiC and Schottky



	0.3 A	0.5 A	1 A	2 A	3 A	4 A	5 A	6 A	2X3 A	8 A	10 A	2X5 A	12 A	15 A	20 A	30 A	60 A	2 X 7.5 A	2X8 A	2X10 A	2 X 12.5 A	2X15 A	2X20 A	2X30 A	2 X 100 A
30 V										🟥														🟥	
40 V	🟥	🟥	🟥		🟥		🟦		🟥																
45 V					🟦	🟦	🟦				🟥			🟥	🟥	🟥		🟥		🟥	🟥	🟥	🟥		
60 V			🟥	🟥	🟥		🟥🟦		🟦											🟥		🟥			
100 V			🟥	🟥	🟦		🟥🟦											🟥		🟥			🟥		
150 V			🟥		🟥																		🟦		
170 V																							🟥		🟥
200 V			🟨🟦	🟨	🟨	🟨			🟨	🟦🟨		🟨													
300 V											🟨									🟨					
400 V			🟨													🟨									
600 V			🟨	🟨	🟨		🟨			🟨						🟨	🟦		🟨						
650 V								🟩			🟩		🟩		🟩					🟩			🟩		
800 V				🟨																					
1000 V			🟨		🟨					🟨			🟨			🟨	🟨								
1200 V			🟨											🟨	🟨		🟦								

Qualified

🟨 (Ultrafast)

🟩 (SiC)

🟥 (Schottky)

In Development 🟦

Sept 2016

Automotive Grade SiC Rectifier

SiC Schottky

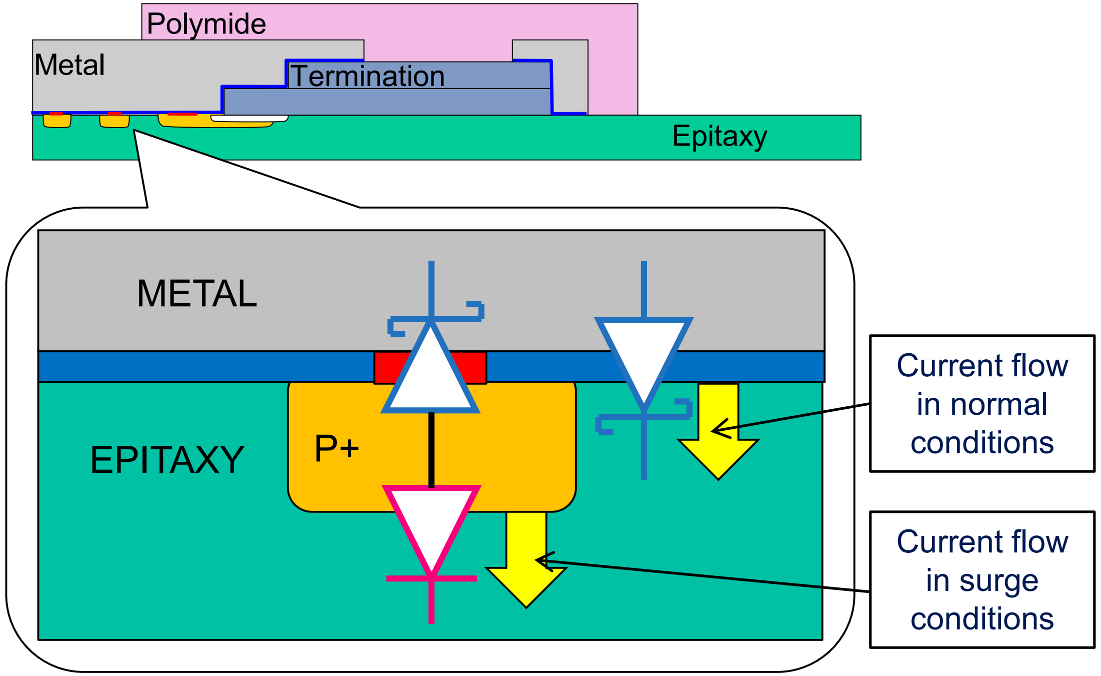
Part number	$I_{F(AV)}$	V_F [V] max (per diode) @I_0		I_{FSM} [A] (per diode)		I_R [µA] (per diode)	Q_{cj} [nC] (per diode)	Packages					
		25°C	150°C	10µs 25°C	10ms 125°C	Vr=650V 150°C	V_R=400V	TO-220AC	TO-220AB	DO-220I	DO-247	TO-247	D²PAK
SiC New blank series 650V													
STPSC6C065-Y	6 A	1.75	2.5	375	43	250	15.2	🟩					
STPSC10H065-Y	10 A			470	80	425	28.5	🟩					🟩
STPSC12H065-Y	12 A			400	90	500	36	🟩					
STPSC12065-Y	12 A	1.45	1.65	220	40	1000	12	🟩					
STPSC20H065C-Y	2 x 10A	1.75	2.5	470	80	425	28.5		🟩			🟩	
STPSC20065-Y	20 A	1.45	1.65	300	60	2000	30	🟩		🟩			
STPSC40065CWY	2x20A			300	60	2000	30				🟩		

Part number	$I_{F(AV)}$	V_F [V] max		I_{FSM} [A]		I_R [µA] max	Q_{cj} [nC] typ	Package	
		$I_F = I_0$							
		25°C	150°C	10µs 25°C	10ms 25°C	Vr=1200V 150°C	V_R=800V	TO-220	D²PAK
SiC 1200V									
STPSC10H12-Y	10 A	1.5	2.25	220	55	400	60	🟩	🟩
STPSC15H12-Y	15 A			330	80	600	70	🟩	
STPSC20H12-Y	20 A			440	110	800	95	🟩	🟩

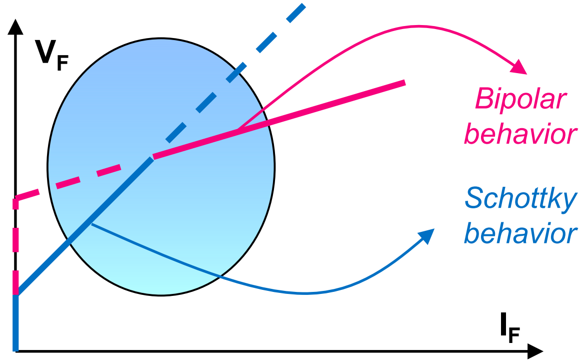
ST SiC Schottky Rectifiers

Silicon Carbide Schottky Rectifiers

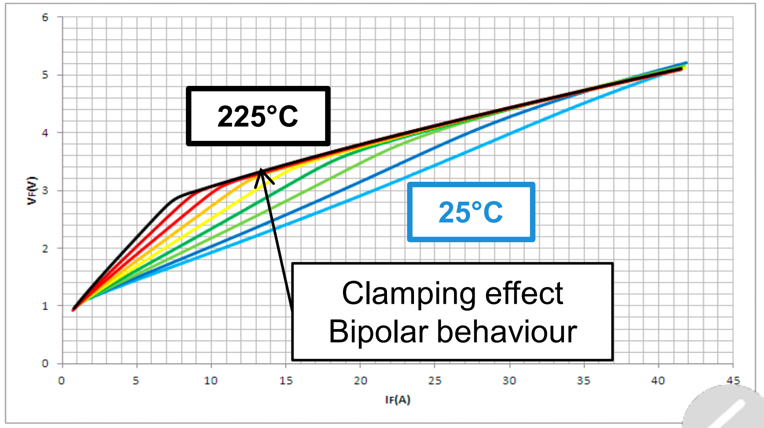
- SiC 650 V G2 and 1200 V technology: using JBS (Junction-Barrier Schottky)



JBS blocking the positive thermal coefficient effect

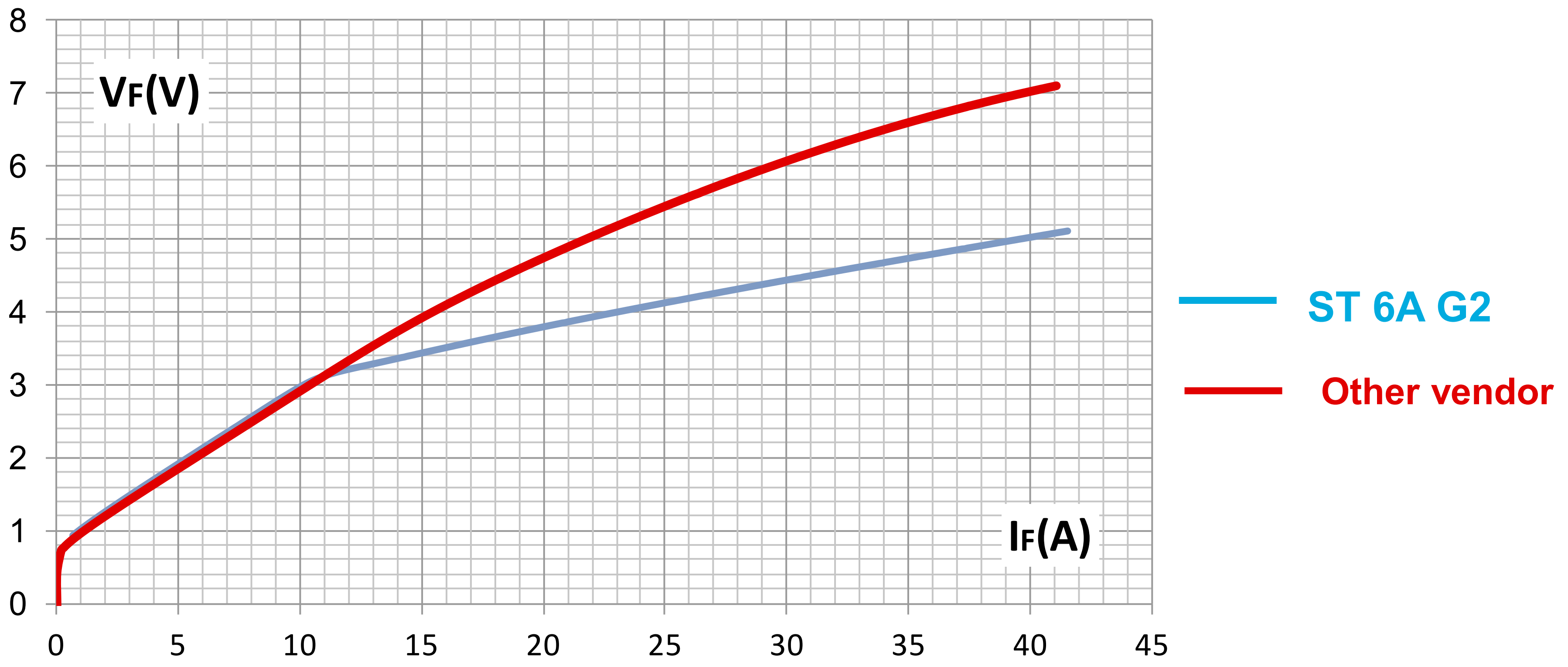


The addition of P+ implantation in the schottky structure creates P/N junctions.The surge forward current capability can be increased while



ST SiC Schottky Rectifiers have Superior Forward Surge Capabilities

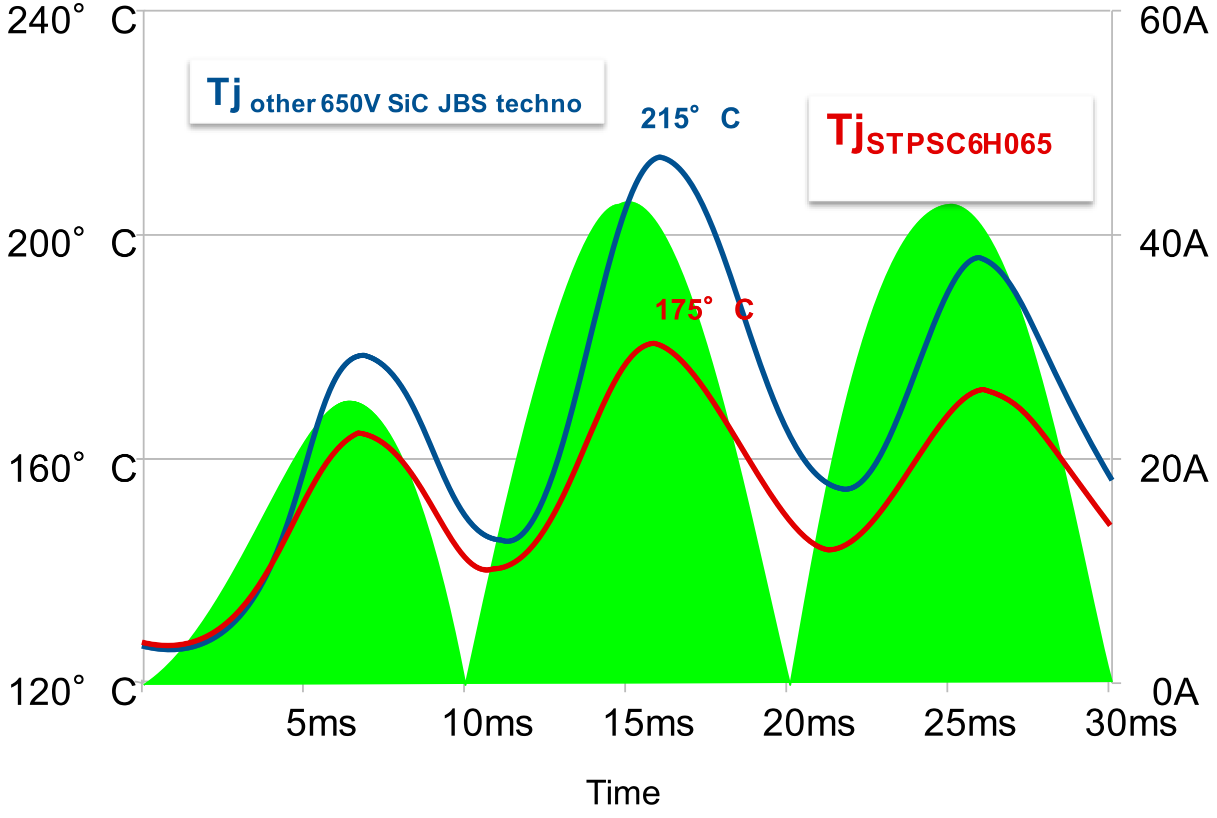
The ST advantage



…Clamping effect more efficient for ST device

ST SiC Schottky Rectifiers exhibit Smaller Temperature Swing

Comparing to other vendor (using electro-thermal model)



1000W PFC start-up Pspice simulation
90V, 70kHz, Cout = 600µF, L = 270µH, Tc = 125°C

Better clamping effect and lower V_F permits to significantly reduce the junction temperature during transient phases in the application.
➔ Impact on thermal fatigue

ST SiC Rectifier Benefits

The ST SiC advantage

Low forward conduction losses and low switching losses

High efficiency → high added value of the power converter

Possibility to reduce size and cost of the power converter

Soft switching behaviour

Low EMC impact → easy design/certification → Good time to market

High power integration (dual-diodes)

BOM cost reduction

High added value of the power converter

Gain on PCB and mounting cost

High forward surge capability (G2)

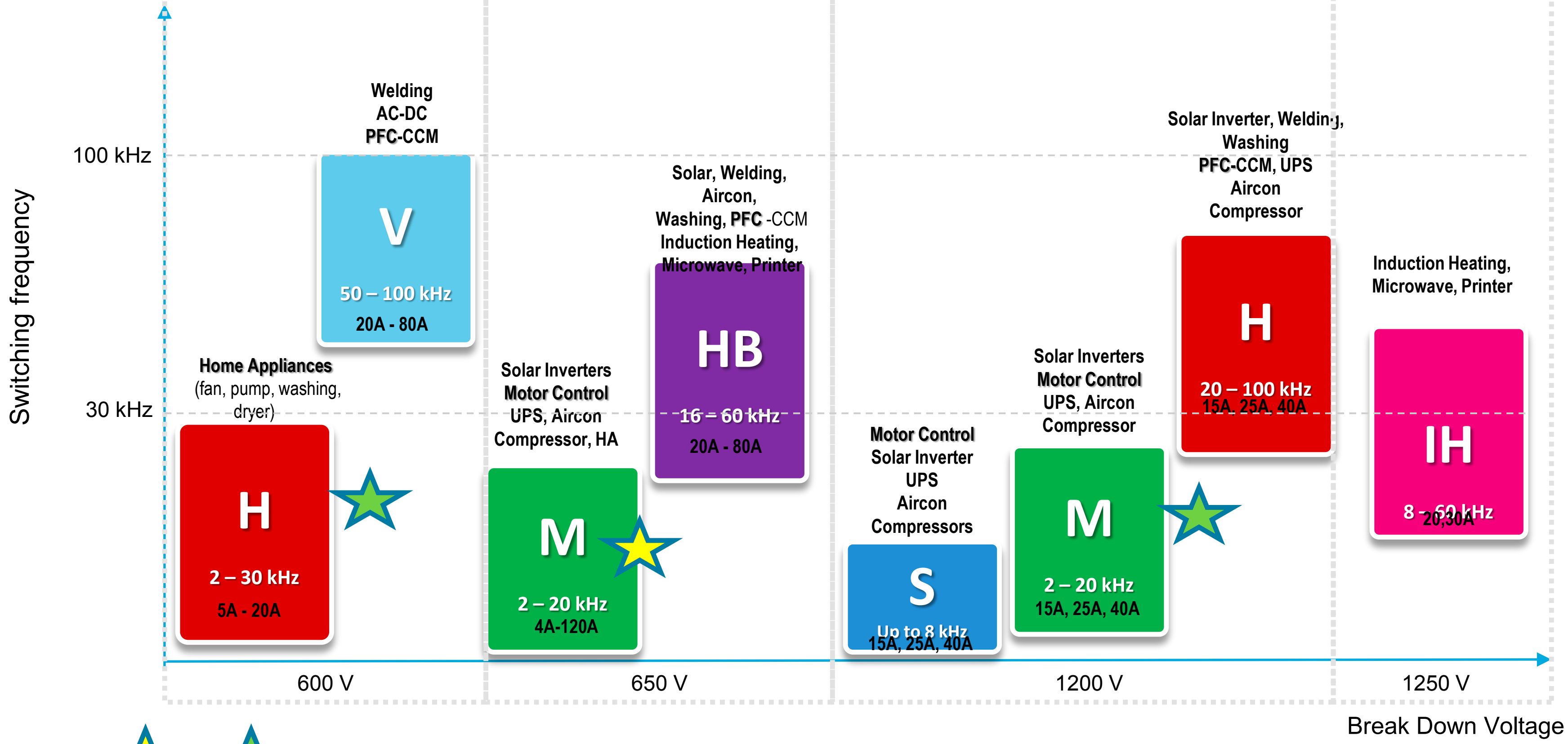
High robustness → Good reliability of the power converter

Easy design → Good time to market

Possibility to reduce diode caliber → BOM cost reduction

Silicon IGBT Technologies

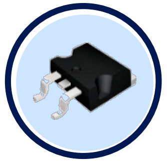
Switching Frequency vs. Break Down Voltage



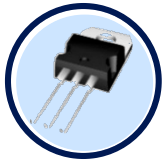
☆ AG

☆ AG development

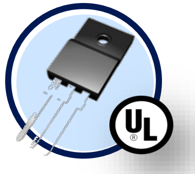
DPAK/D2PAK



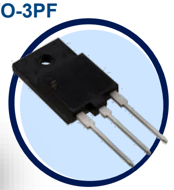
TO-220



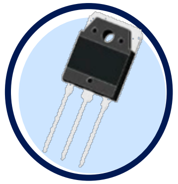
TO-220FP



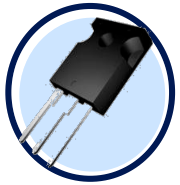
TO-3PF



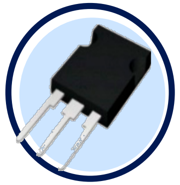
TO-3P



TO-247/TO-247 (LL)



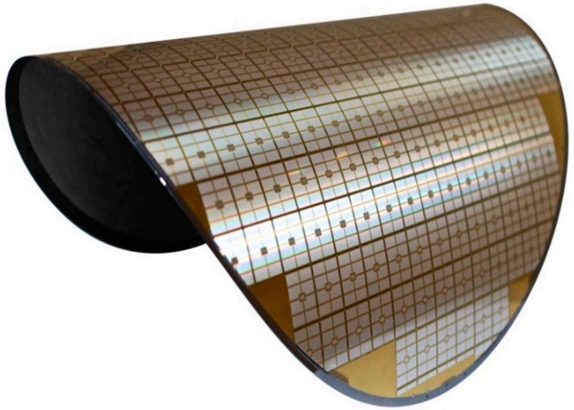
MAX-247 LL



650V “M” Series IGBTs

Trench field stop technology

Thin IGBT wafer technology at 650 V for a more rugged, efficient and reliable power drive system. For EV/HEV motor control



Automotive

Key Features

- A wide Product Range up to 120A
- 175ºC max junction temperature
- Very Low VCE(sat) (1.55V typ) at ICN 100ºC
- Self ruggedness against short circuits events
- Low switching-off losses
- Safe paralleling
- Optimized co-packed free wheeling diode option
- AEC-Q101 qualified for die form in T&R KGD

Auto Grade Thyristors

In-rush current limiting SCR for OBC

Design Value

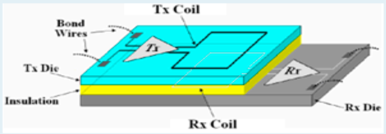
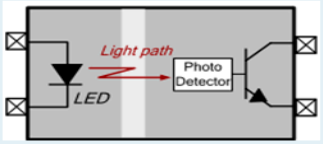
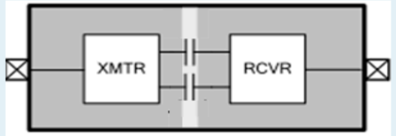
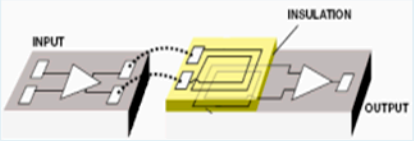
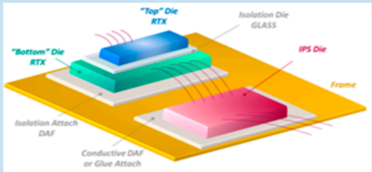
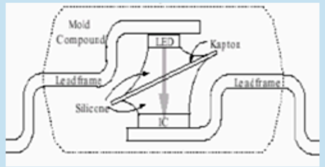
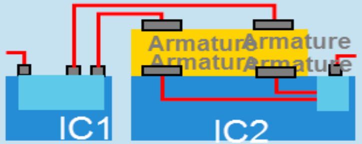
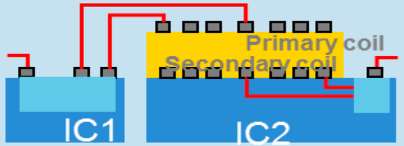
- AEC-Q101 PPAP Available on request
- High switching life expectancy
- Enable system to resist 6kV surge
- High speed power up / line drop recovery

Features	TN5050H	TN3050H
V_{DRM} / V_{RRM}	1,200 V over T_J range	
Max T_J	-40°C to +150°C	
V_{DSM} / V_{RSM}	1300 V	1400 V
I_{TRMS} (T_C=125°C)	80 A	30 A
I_{TSM} (10ms,25°C)	580 A	300 A
V_{TO} (150°C)	0.88V	0.88V
R_D (150°C)	6 mΩ	14 mΩ
I_{GT} (25°C)	10 to 50 mA	10 to 50 mA
dV/dt (800V-150°C)	1 kV/µs	

A better way to turn on your system

Existing Isolation Technologies

Isolation technologies

Polymeric/Ceramic Isolation		Thick Oxide Isolation	
Isolation: film of **polymer** (or other dielectric such as DAF, glass). Custom assembly process required.		Isolation: **Silicon Oxide** grown on top of active silicon area (standard silicon IC technologies)	
RF Couplers  	**Optocouplers**  	**capacitive coupling**  	**magnetic coupling** 
 	 	 	
• Good **parametric stability** over time • **Good CMTI immunity** • **Limited** communication **speed** • **Assembly complexity**	• Dielectric **ageing**: **parametric instability** over time • **Limited CMTI immunity**	• Good **parametric stability** over time • **Limited CMTI immunity** • **Sensitive** to electric fields	• Good **parametric stability** over time • **Very good CMTI immunity** • Good **immunity to magnetic and electric fields**

gapDRIVE™ :Galvanically Isolated Gate Driver

Galvanically Isolated Gate Driver technology

- Automotive (Hybrid\Electric Vehicles)
  - Motor Control
  - DC/DC Converters
  - Battery Chargers

- Industrial
  - 600/1200 V Inverters
  - Automation, Motion Control
  - Welding

- Power Conversion
  - Solar Inverters
  - UPS Systems
  - AC/DC, DC/DC Converters
  - Windmills

- Home/Consumer
  - Induction Cooking
  - White goods

The STGAP1S ***galvanically isolated*** gate driver, features advanced **controls**, **protections** and **diagnostic.**

- **CONTROL:** A SPI interface to enable, disable and configure several features → Optimize your driving conditions.
- **PROTECTION:** Several features to mange anomalous conditions (OCP, DESAT, 2LTO, VCE_Clamp) and to prevent them (UVLO, OVLO, ASC, MillerCLAMP)
- **DIAGNOSTIC:** The SPI interface allows access to registers containing information about the status of the device.

Main Applications

Industrial Drive

EV / HEV

STGAP1S – Main Features

Galvanically Isolated Gate Driver technology

AEC-Q100 grade 1
Wide operating range (-40°C -125°C)

SPI Interface
Parameters programming and diagnostics
Daisy chaining possibility

Advanced features
5A Active Miller clamp, Desaturation, 2-level turn-off, VCEClamp, ASC

Short propagation delay
(100 ns typ.; 130 ns max over temperature)
5 A sink/source current

Fully protected – System safety
UVLO, OVLO, Over-Current, INFilter, Thermal Warning and Shut-Down

High Voltage Rail up to 1.5 kV
Positive drive voltage up to 36 V
Negative Gate drive ability (-10 V)

STGAP1S Isolation Characteristics

Conforms with IEC60664-1, IEC60747-5-2 and UL1577 standards

Parameter	Symbol	Test Conditions	Characteristic	Unit
Maximum Working isolation Voltage	V_{IORM}		1500	V_{PEAK}
Input to Output test voltage	V_{PR}	Method a, Type and sample test $V_{PR} = V_{IORM} \times 1.6$, t_m= 10 s Partial discharge < 5 pC	2400	V_{PEAK}
		Method b, 100% Production test $V_{PR} = V_{IORM} \times 1.875$, t_m = 1 s Partial discharge < 5 pC	2815	V_{PEAK}
Transient Overvoltage	V_{IOTM}	Type test; t_{ini} = 60 s	4000	V_{PEAK}
Maximum Surge isolation Voltage	V_{IOSM}	Type test;	4000	V_{PEAK}
Isolation Resistance	R_{IO}	V_{IO} = 500 V at T_S	> 10^9	Ω
Isolation Withstand Voltage	V_{ISO}	1 min. (type test)	2500\3536	$V_{rms\backslash PEAK}$
Isolation Test Voltage	$V_{ISO,test}$	1 sec. (100% production)	3000\4242	$V_{rms\backslash PEAK}$

Parameter	Symbol	Value	Unit	Conditions
Creepage (Minimum External Tracking)	CPG	8	mm	Measured from input terminals to output terminals, shortest distance path along body
Comparative Tracking Index (Tracking Resistance)	CTI	≥ 400		DIN IEC 112/VDE 0303 Part 1
Isolation group		II		Material Group (DIN VDE 0110, 1/89, Table1)

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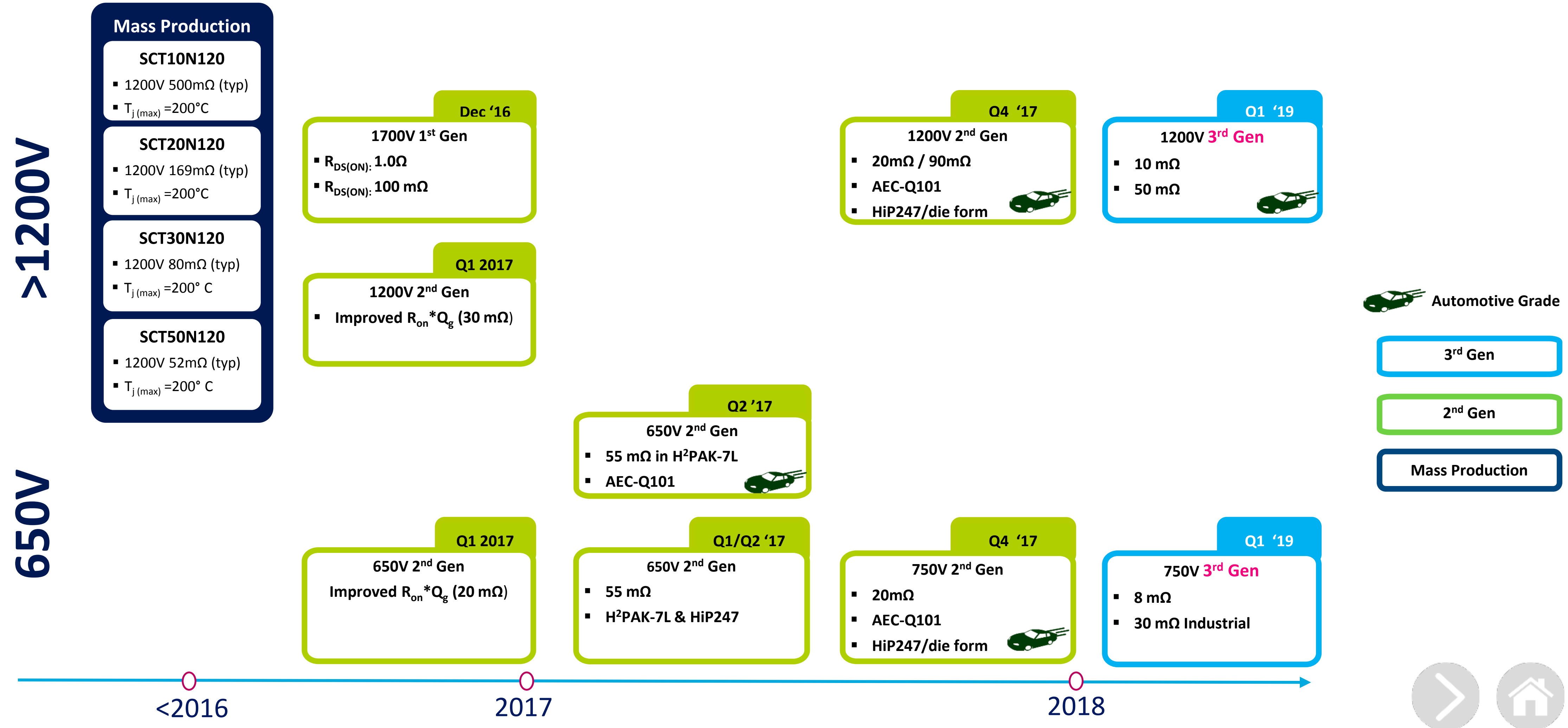
SiC MOSFET Technology Roadmap

Conforms with IEC60664-1, IEC60747-5-2 and UL1577 standards



>1200V

Mass Production

SCT10N120
- 1200V 500mΩ (typ)
- $T_{j\,(max)}$ =200°C

SCT20N120
- 1200V 169mΩ (typ)
- $T_{j\,(max)}$ =200°C

SCT30N120
- 1200V 80mΩ (typ)
- $T_{j\,(max)}$ =200° C

SCT50N120
- 1200V 52mΩ (typ)
- $T_{j\,(max)}$ =200° C

Dec '16

1700V 1st Gen
- $R_{DS(ON)}$: 1.0Ω
- $R_{DS(ON)}$: 100 mΩ

Q1 2017

1200V 2nd Gen
- Improved R_{on}*Q_g (30 mΩ)

Q4 '17

1200V 2nd Gen
- 20mΩ / 90mΩ
- AEC-Q101
- HiP247/die form

🚗

Q1 '19

1200V 3rd Gen
- 10 mΩ
- 50 mΩ

🚗

650V

Q2 '17

650V 2nd Gen
- 55 mΩ in H^2PAK-7L
- AEC-Q101

🚗

Q1 2017

650V 2nd Gen

Improved R_{on}*Q_g (20 mΩ)

Q1/Q2 '17

650V 2nd Gen
- 55 mΩ
- H^2PAK-7L & HiP247

Q4 '17

750V 2nd Gen
- 20mΩ
- AEC-Q101
- HiP247/die form

🚗

Q1 '19

750V 3rd Gen
- 8 mΩ
- 30 mΩ Industrial

<2016 2017 2018

🚗 Automotive Grade

3rd Gen

2nd Gen

Mass Production

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Silicon-Carbide MOSFETs

Key Benefits

Extremely low Energy Losses and Ultra-Low $R_{DS(on)}$ especially at very high T_j

Higher operating frequency for smaller and lighter systems

Good Thermal Performance

High operating temperature (T_{jmax} = 200°C)
Reduced cooling requirements & heat-sink, Increased lifetime

Easy to Drive

Fully compatible with standard Gate Drivers

Very fast and robust intrinsic body diode

More compact Inverter

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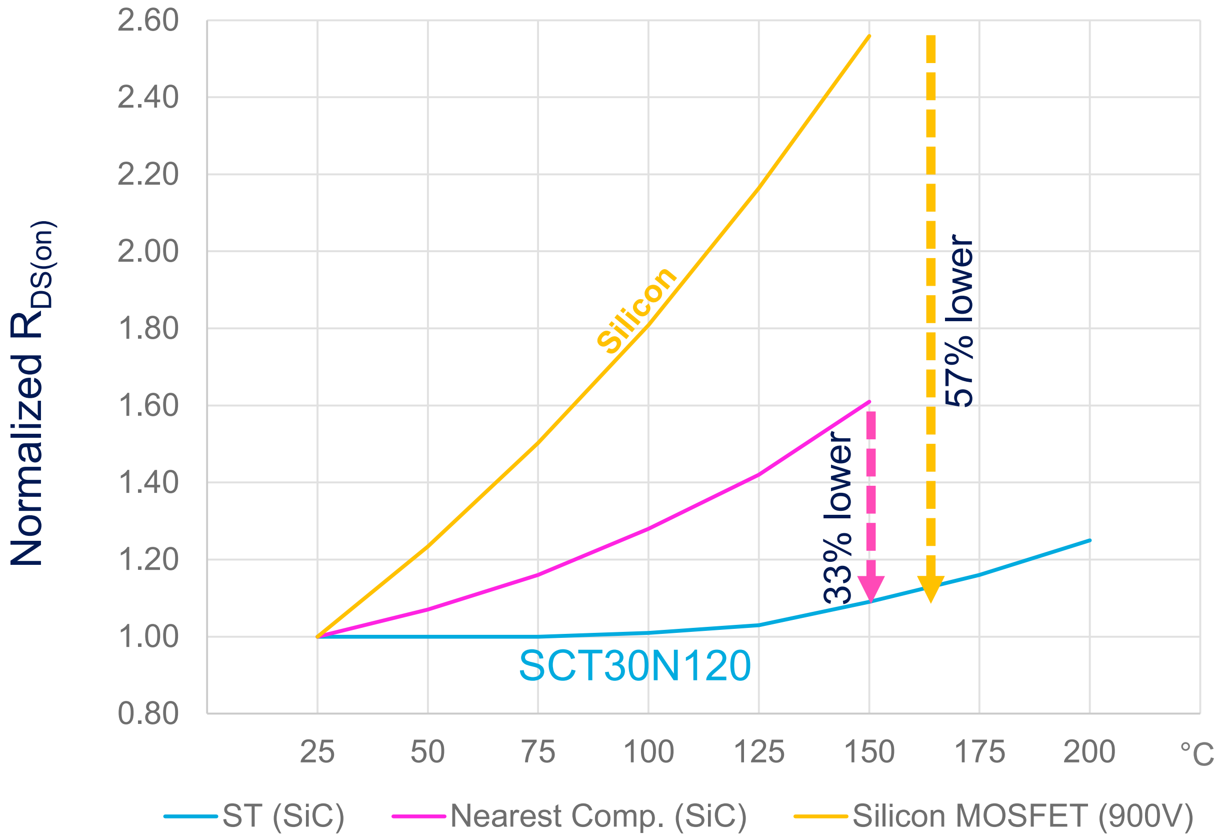
On-Resistance Versus Temperature

ST is the only supplier to guarantee max Tj as high as 200°C in plastic package



ST SiC MOSFET shows lowest Ron at high temperatures

Wide Bandgap Materials

SiC represents a radical innovation for power electronics

	Si	GaN	4H-SiC
E_g (eV) – Band gap	1.1	3.4	3.3
V_s (cm/s) – Electron saturation velocity	$1\text{x}10^7$	$2.2\text{x}10^7$	$2\text{x}10^7$
ε_r – dielectric constant	11.8	10	9.7
E_c (V/cm) – Critical electric field	$3\text{x}10^5$	$2.2\text{x}10^6$	$2.5\text{x}10^6$
k (W/cm K) thermal conductivity	1.5	1.7	5

E_c → **low on resistance**

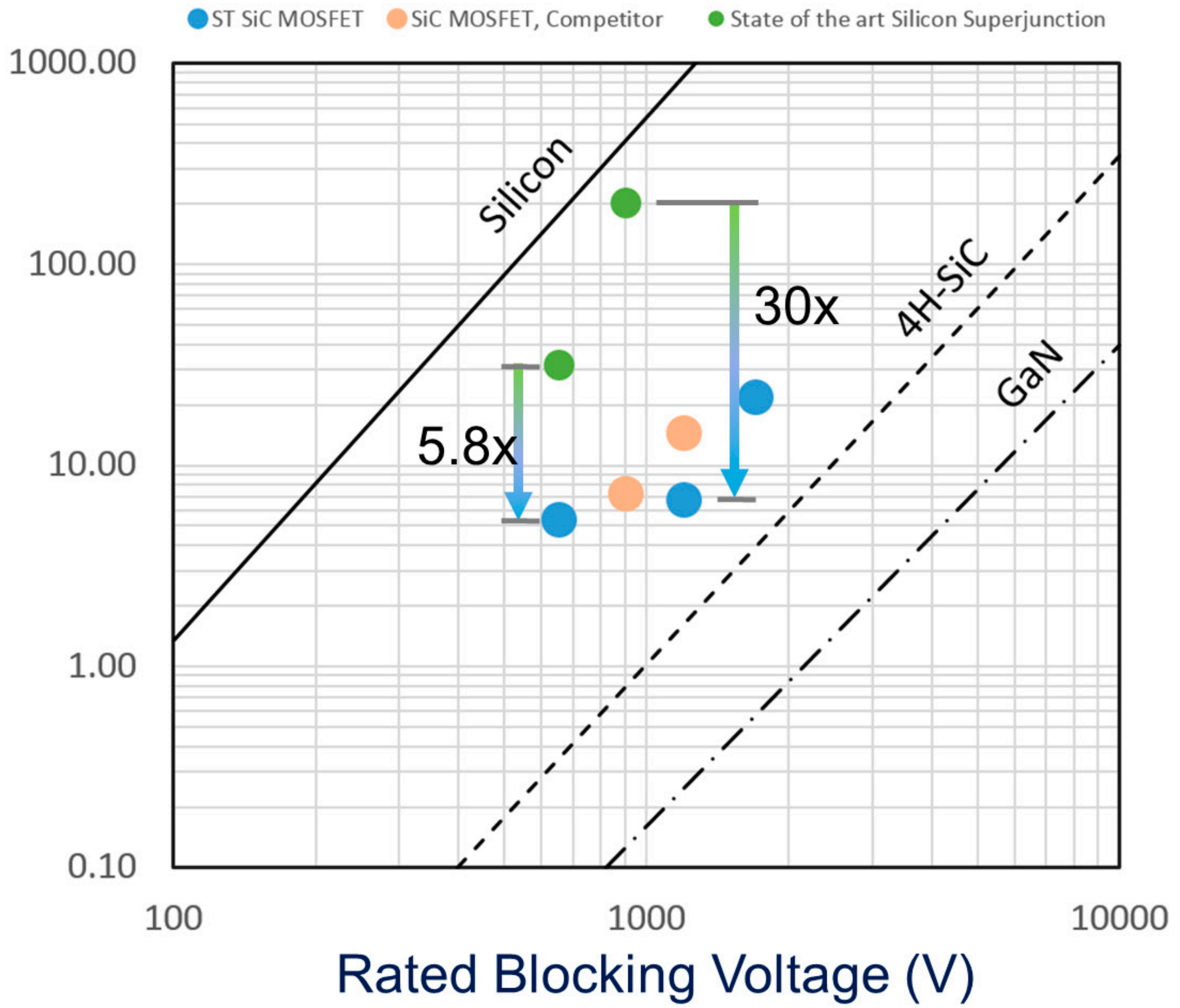
E_g → **low leakage, high Tj**

k → **Operation > 200 ˚C**
Reduced Cooling Requirements

V_s **Higher switching frequency**
Lower switching losses

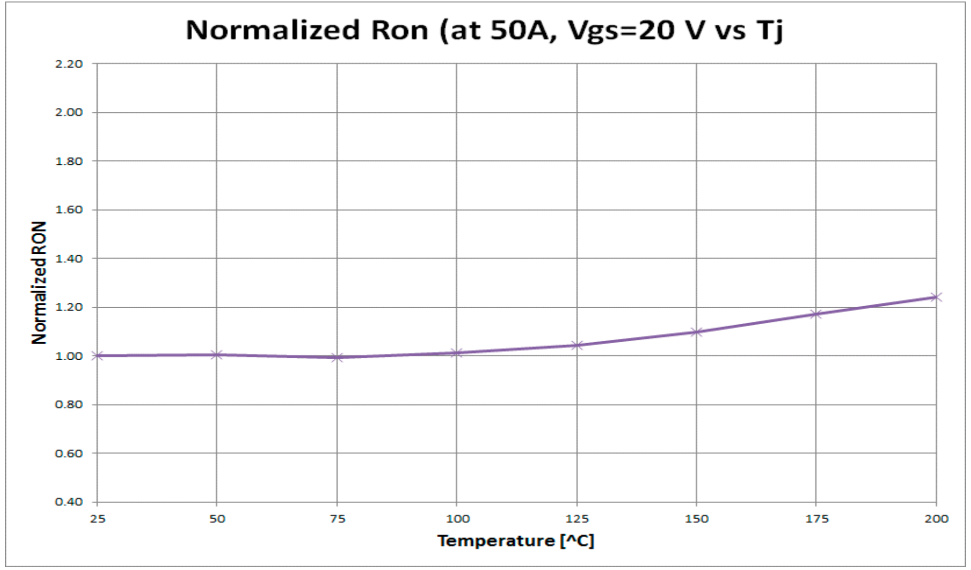
MOSFET RDS(on) Figure of Merit at TJ=150C

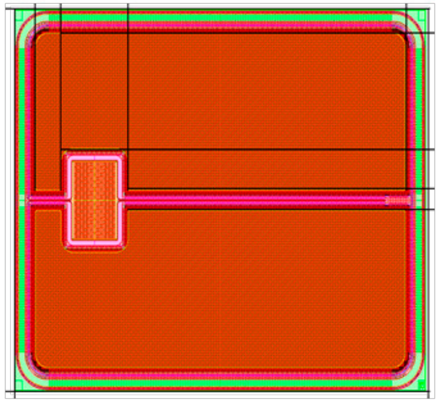
SiC MOSFETs are not all the same



ST 650V 2nd Gen SiC MOSFETs

SCTW100N65G2AG – 2nd Generation





SCTW100N65G2AG

- $R_{DS(on)}$ (typ @25°C) : 20 mOhm
- $R_{DS(on)}$ (typ @200°C) : 23 mOhm
- Q_g (typ) : 215 nC
- Package : HiP247™

- **ST SiC MOSFET shows lowest Ron increase at high temperatures**
- **ST is the only supplier to guarantee max Tj as high as 200°C**
- **Gate driving voltage = 20V**

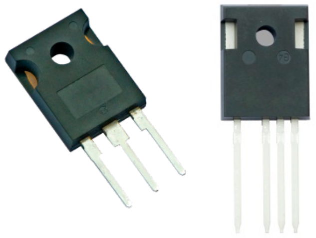
- Full Maturity: July 2016 (Industrial Grade)
- Full Maturity: H1 2017 (Automotive Grade)

Silicon Carbide MOSFET Packages

Through hole proposal

Able to guarantee 200 ˚C as max Junction temperature

The 4L option (with kelvin source) coming soon



HiP-247™

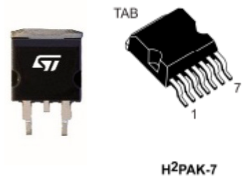
Basically the same of the well known industry standard TO-247 with some improvements on the process.

HiP247 standard lead and with long leads version already in production

SMD

Compatible with H2PAK package used for Silicon MOSFET

Rated @ 175 ˚C



H^{2}PAK
2 and 7 leads

H^{2}PAK 7L option with kelvin source to improve the switching performance

Qualification on going

NEXT STEP: PowerFLAT™ 8x8 qualification

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HV Silicon Power MOSFET Technologies

MDmesh ™ M5-Series

The leading technology for hard- switching topologies

Key Features

- Industry's lowest R_{DS}(on) in the Market
- High switching speed
- 550 / 650V classes

Benefits

- highest efficiency in the application
- Smaller form factor of final system
- Especially targeted for hard switching (PFC, Boost, TTF, Flyback)

MDmesh ™ M2-Series

The best fit for resonant / LLC topologies

Key Features

- Up to 30% lower Qg (equivalent die size)
- Optimized Coss profile
- 400 / 500/ 600 / 650V classes

Benefits

- Reduced switching losses through optimized (Qg) (Ciss, Coss)
- Enhanced immunity vs ESD & Vgs spikes in the application
- Especially targeted for HB LLC, TTF, Flyback..)

SuperMESH ™ K5-Series

State-of-the-arte in the VHV (Very-High-Voltage) Class

Key Features

- Extremely good RDS(on) at very high BVDSS
- High switching speed
- 800 / 850 / 950V classes available now
- 1050 / 1.2k / 1.5kV classes in development

Benefits

- High efficiency with lower design complexity
- Especially targeted for flyback LED topologies and high voltage range in the application

MDmesh ™ DM2-Series

The best fit for F/B ZVS topologies

Key Features

- Integrated fast body diode
- Softer commutation behavior
- Back-to-Back G-S zener protected
- 500 / 600 / 650V classes

Benefits

- Reduced switching losses through optimized (Qg) (Ciss, Coss)
- High peak diode dV/dt capabilities
- Best use in Full Bridge ZVS

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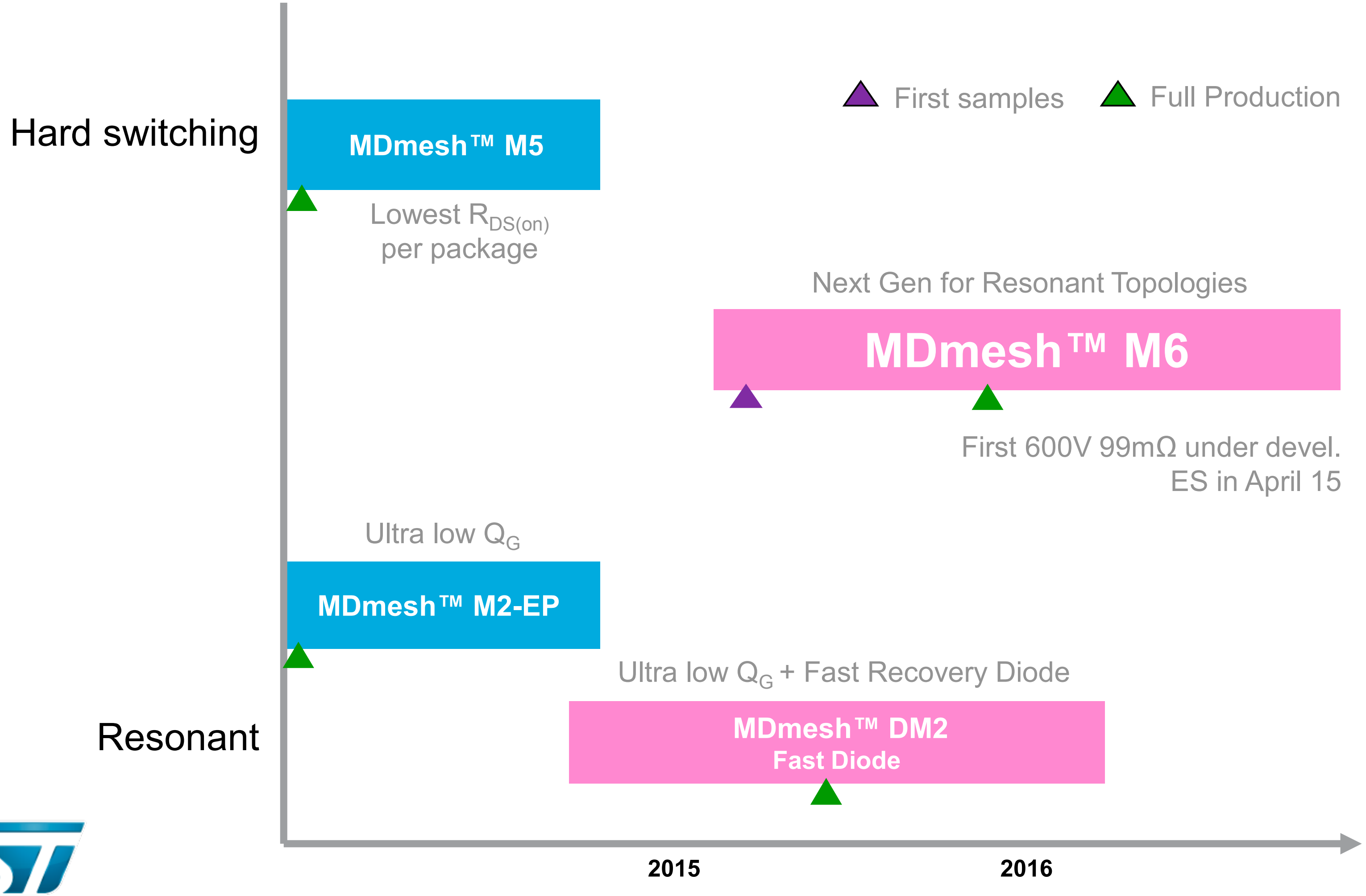
Silicon: MDmesh™ 600-650V SJ Technologies

Short Term Roadmap



▲ First samples ▲ Full Production

Hard switching

MDmesh™ M5

Lowest $R_{DS(on)}$ per package

Next Gen for Resonant Topologies

MDmesh™ M6

First 600V 99mΩ under devel.
ES in April 15

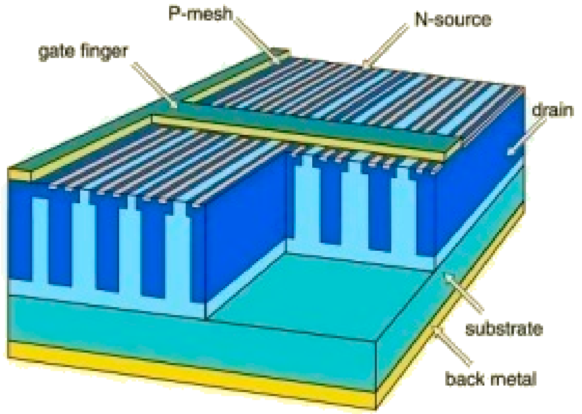
Ultra low Q_G

MDmesh™ M2-EP

Ultra low Q_G + Fast Recovery Diode

MDmesh™ DM2
Fast Diode

Resonant



LV Silicon Power MOSFET Technologies

Mass Production

STripFET F7 [100V]
- Low on-state resistance
- High current capability
- Extremely low thermal resistance
- Reduced EMI for motor control 🚗

STripFET F6/F7 [80V]
- Low on-state resistance
- High current capability
- Extremely low thermal resistance
- Reduced EMI for motor control 🚗

STripFET F7 [40V]
Low on-state resistance
- SOA/Rdson balance
- ESD and EMI best in class 🚗

STripFET H6 [30V]
- Low on-state resistance
- High quality & reliability 🚗

STripFET H7 [30V]
- Schottky diode embedded
- Low on-state resistance
- High quality & reliability

Q3

STripFET F7 LL [40-45V]
- Low on-state resistance
- Extremely low thermal resistance
- High quality & reliability

Q3

STripFET F7 [150V]
- Low on-state resistance
- High current capability
- Extremely low Rth
- High quality & reliability

Q3

STripFET F7 [120V]
- Low on-state resistance
- High current capability
- Extremely lowt Rth
- High quality & reliability

Q4

STripFET F8 [40-45V]
- Very low on-state resistance
- Extremely low FoM
- High quality & reliability

Jan’17

STripFET F8 [150V]
- Very low on-state resistance
- Extremely low FoM
- High quality & reliability

Jan’17

STripFET F8 [100V]
- Very low on-state resistance
- Extremely low FoM
- High quality & reliability

Q2’17

STripFET F8 [80V]
- Very low on-state resistance
- Extremely low FoM
- High quality & reliability

Q2’17

STripFET H8 [30V]
- Very low on-state resistance
- Extremely low FoM
- High quality & reliability

Q2’17

STripFET H8 [25V]
- Very low on-state resistance
- Extremely low FoM
- High quality & reliability

2015 2016 2017

🚗 **Automotive Grade**

🟦 Mass Production

🟩 Development

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