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High performance 4th generation Field Stop Trench IGBT with enhanced Latch-Up Immunity

Kevin Lee, IGBT TD

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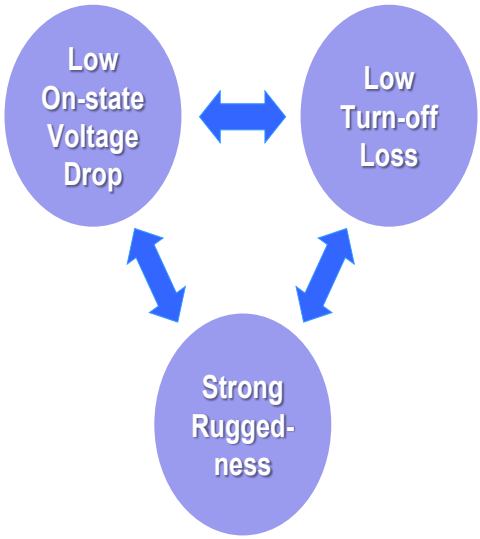
Confidential

Field Stop 4 IGBT Benefits



Power Efficiency

Low Saturation Voltage
High Switching Speed

and… Easy Parallel Operation
Positive Temp coefficient

Reliable Operation

Short-circuit Immunity
Latch Up Immunity

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Target Market

Major Applications

PV Inverter

UPS

Automotive

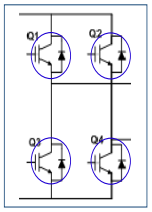
Welder

HVAC/Sys. A/C

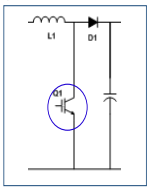
Industrial Inv.

Major Topologies

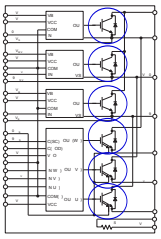
◆ FB Inv. & Conv.



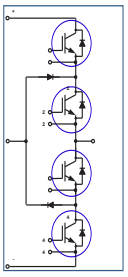
◆ Boost & PFC



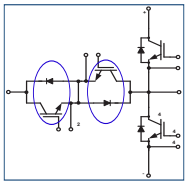
◆ Motor Control by SPM



◆ NPC Inverter



◆ TNPC Inverter



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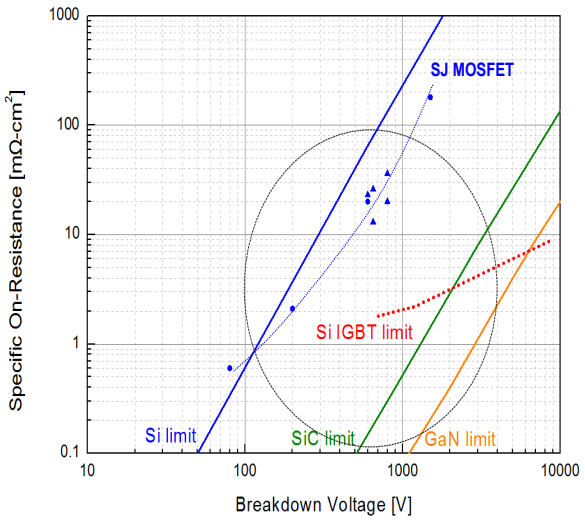
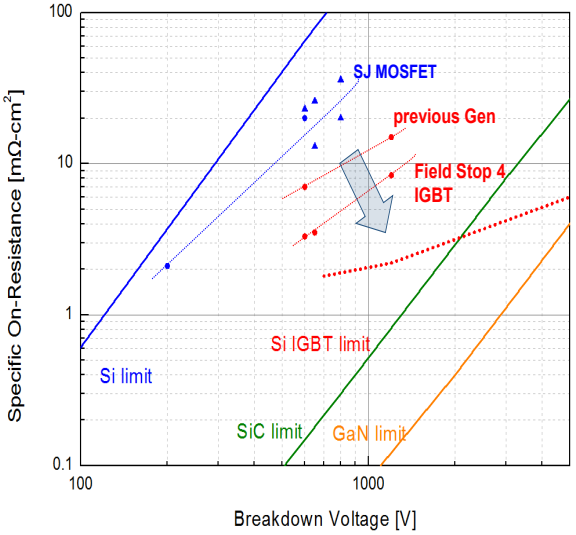
Limit of Silicon IGBTs

" Theoretical Investigation of Silicon Limit Characteristics of IGBT "
- Akio Nakagawa, ISPSD 2006



ZOOM IN



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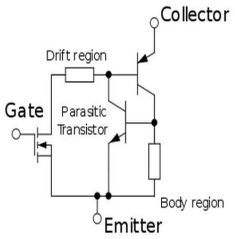
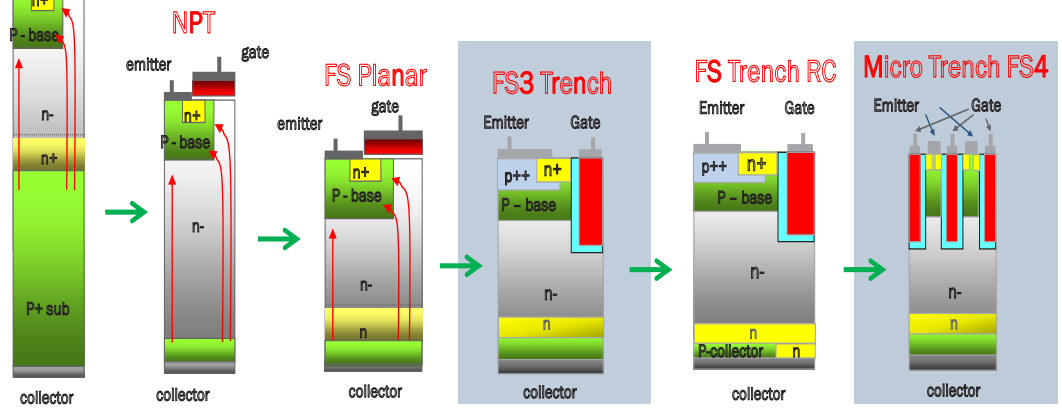
IGBT Evolution

- Increasing cell density
- Reduction of the device thickness

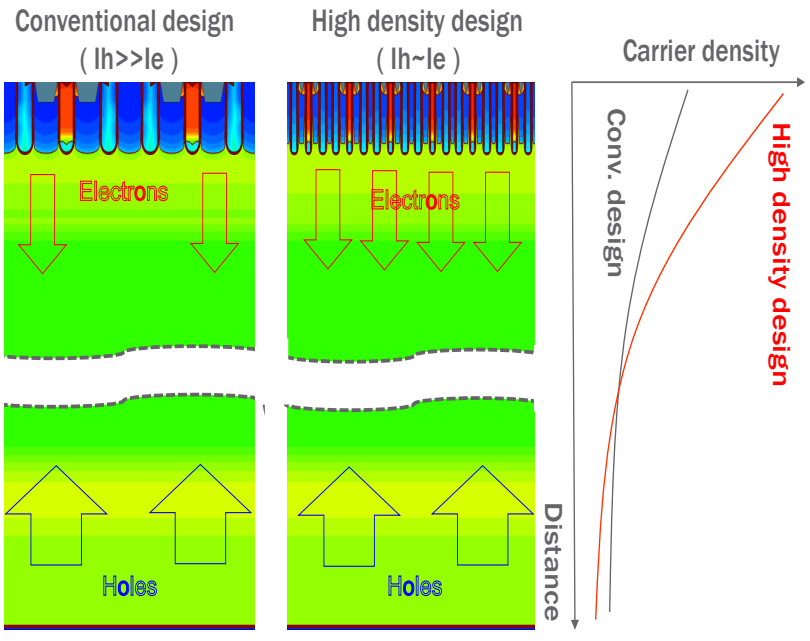




FS4: High Performance Design Concept

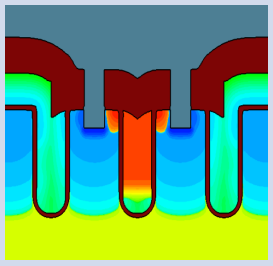
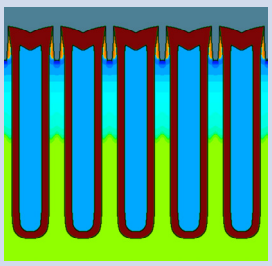
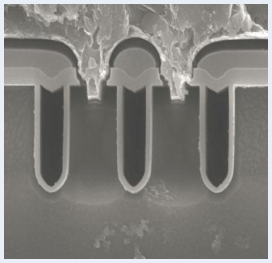
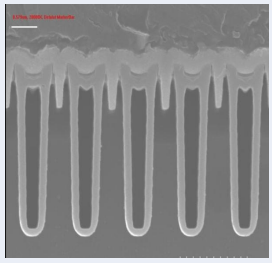
Design concept for highly enhanced device performance:

- It = Ie + Ih
- Increase electron carrier injection (High density cell) resulting in low conduction loss
- Decrease hole carrier injection resulting in high speed switching



Field Stop 4 IGBT

Cathode design (Active cell)

previous generation	Field Stop 4
	
	

Comparing prev. gen. IGBT

- Drastically reduced cell pitch
- Submicron mesa width design
- Self balancing design
- 30 % increased current density

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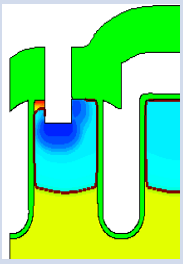
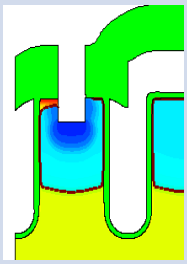
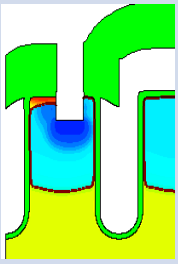
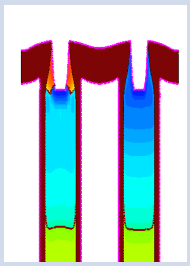
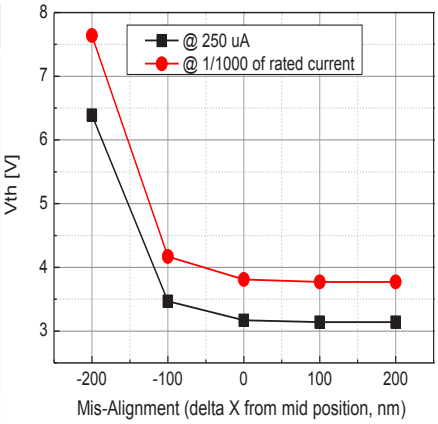
Field Stop 4 IGBT

Cathode design (Active cell)

Novel Self-balancing cell design

Previous generation			Field Stop 4
			
<Mis-Align -200nm>	<Aligned>	<Mis-Align 200nm>	<Aligned>
Photo alignment variation → Non-uniform doping → Non-uniform current flow			Process variation immunity → Stronger ruggedness

Threshold Voltage Mismatch



~ Current crowding to lower threshold voltage region

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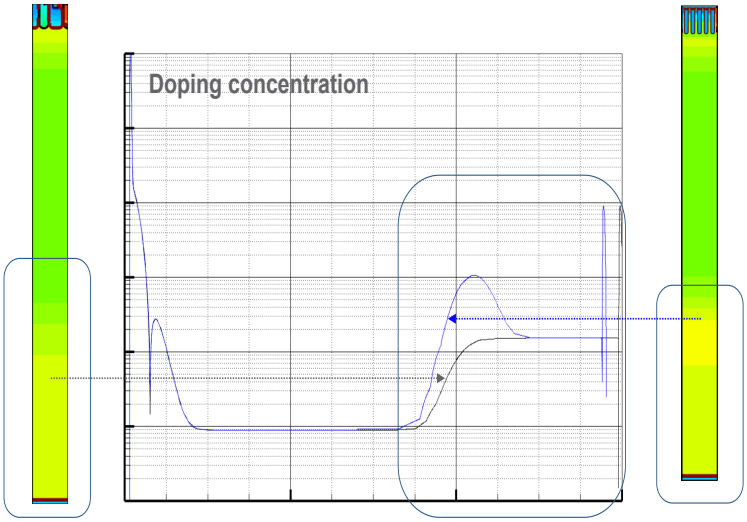
Field Stop 4 IGBT

Anode design (Back side engineering)



Comparing prev. gen. IGBT

- Thinner multiple buffer structure
- Optimized collector doping according to the electron injection

Single buffer

Multiple buffer

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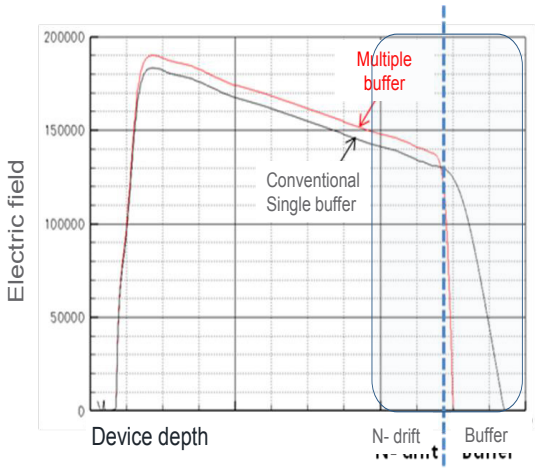
Field Stop 4 IGBT

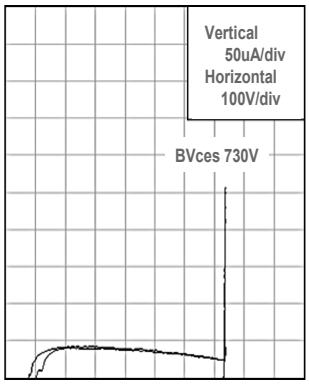
Anode design (Back side engineering)

Electric field distribution



➔ Efficient electric field blocking

Breakdown Voltage Characteristics



➔ Very hard breakdown voltage waveforms

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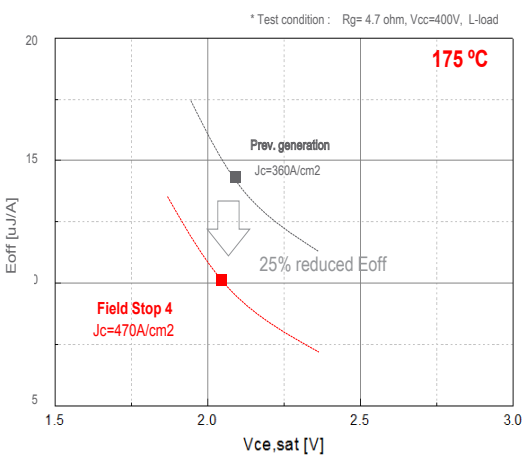
Trade off Performance

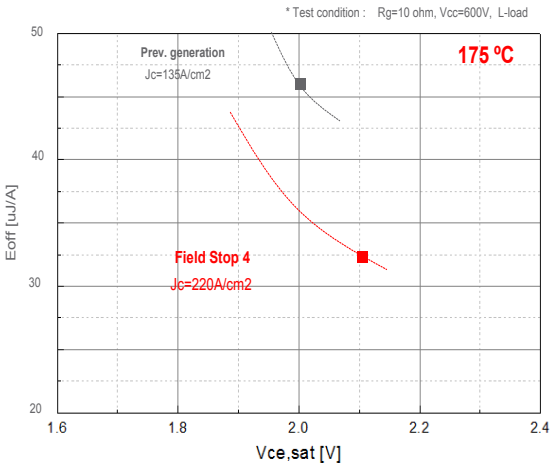
650V IGBT

Trade off performance at Max Temp.



1200V IGBT

Trade off performance at Max Temp.



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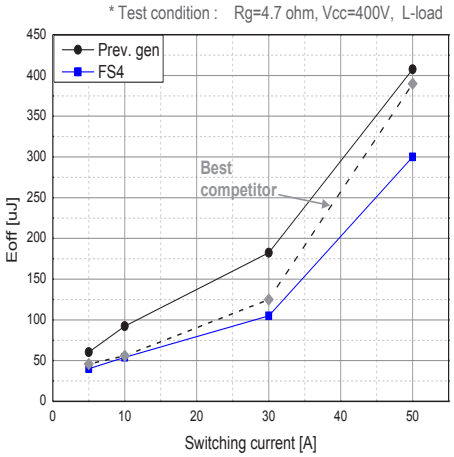
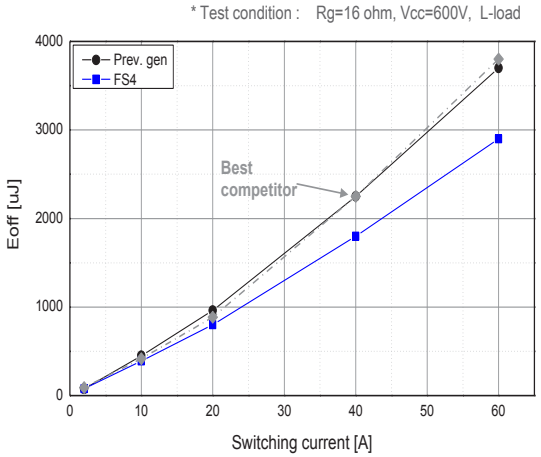
Switching Energy Loss vs Load Current

650V FS4 turn off energy loss



1200V FS4 turn off energy loss



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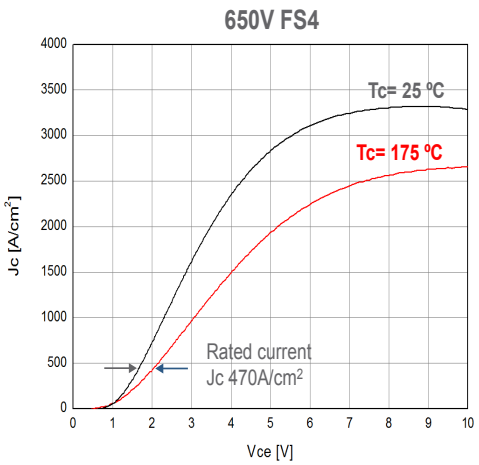
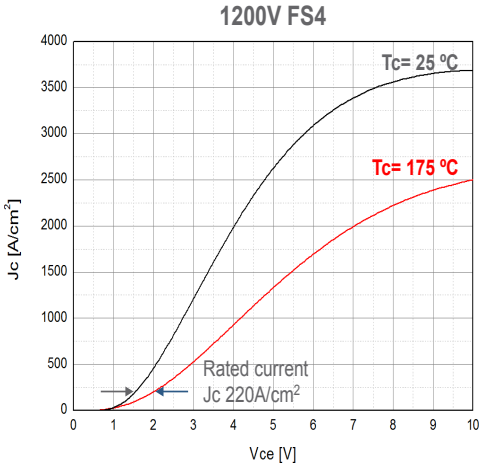
Static Latch up immunity

Static latch up immunity & Positive temperature coefficient





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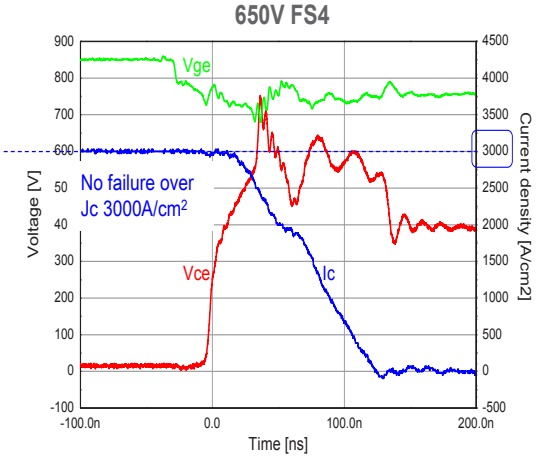
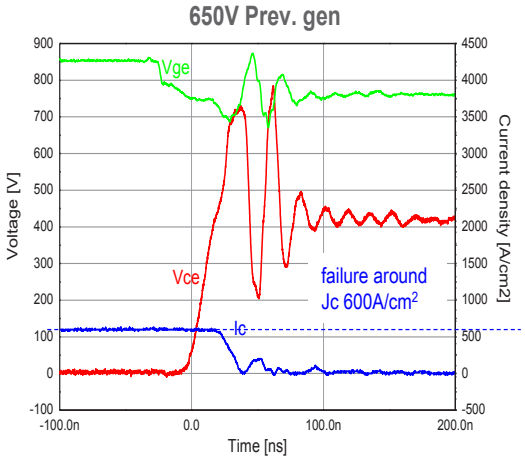
Dynamic Latch up immunity

Turn off Switching waveforms

* Test condition : Rg=0 ohm, Vg = ± 15V, Vcc=400V, L = 20uH, Tc=175C





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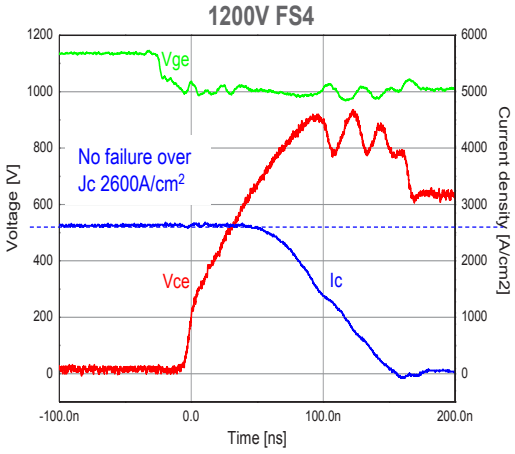
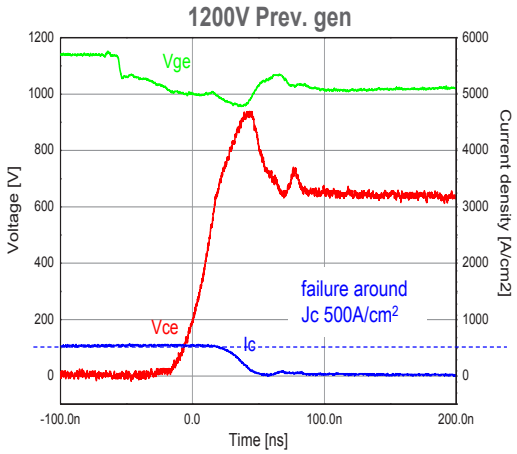
Dynamic Latch up immunity

Turn off Switching waveforms

* Test condition : Rg=0 ohm, Vg = ± 15V, Vcc=600V, L = 20uH, Tc=175℃

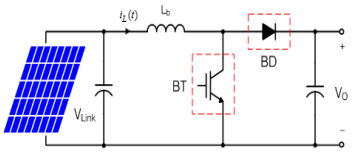


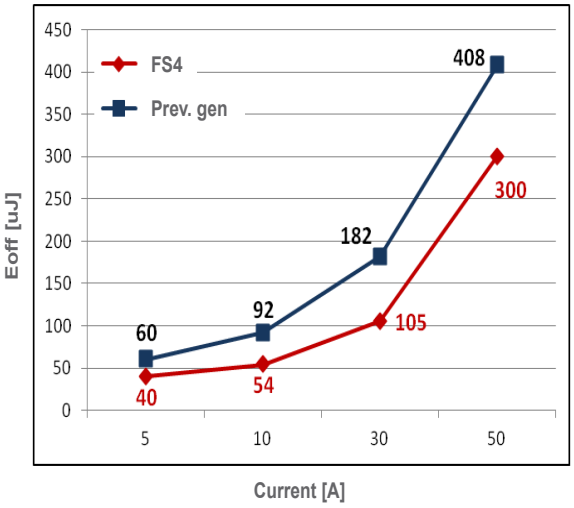


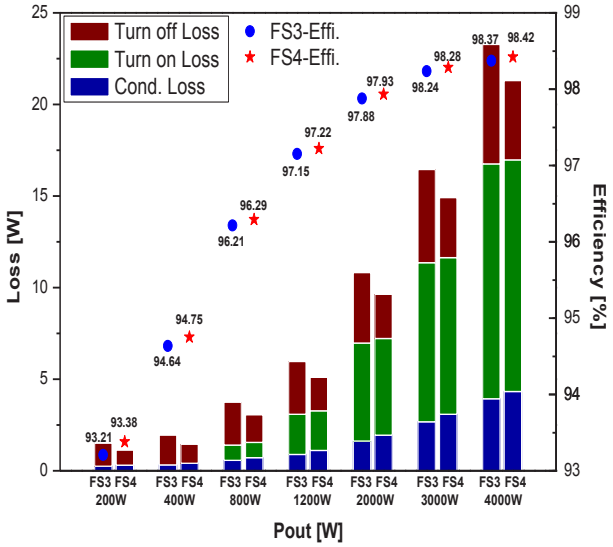
Application engineering evaluation

◆ 650V 50A evaluation for Boost Converter

•Test condition : Vin=300V, fs=40kHz, Rg=4.7ohm



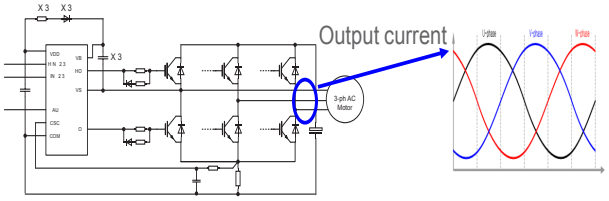




Application engineering evaluation

◆ 1200V FS4 evaluation for inverter application

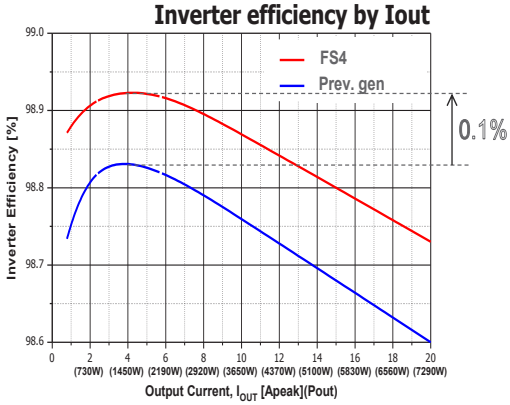
•Test condition : DC bus=600V, Vge=15V, Tc=100℃, Rgon=75Ω, Rgoff=16Ω, M.I=0.9, P.F=0.9, SVPWM



Chip size
FS Prev. gen: 5000 * 5000
FS4 : 4300 * 4300

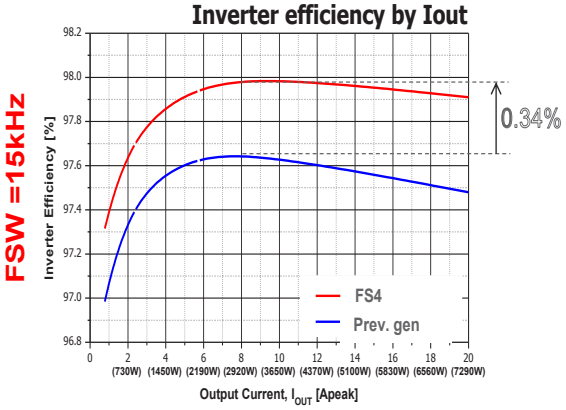
Inverter efficiency by Iout

FSW = 5kHz



Inverter efficiency by Iout

FSW =15kHz



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Qualified Technology Proliferation

Tech Name	Pkg, Product	Required Attributes	Release Date	Technology Qualification
650V FS4	Discrete, PIM, IPM	▪ Auto rated SCR >5uS, 20-100A ▪ RC & SCR >5uS ▪ LS & HS 50-100A	▪ Q2'18 ▪ Q1'18 ▪ Q4'17	YES Being qualified PD, PIM Gen-III 1100V Q2PACK
750V FS4	Discrete, AHPM	▪ Auto rated STM bare die SCR IS/TS ▪ SCR, IS/TS, ENIG STM AHPM DSC	▪ Q2'18 ▪ Q2'18	Under Development and Qual for large die; Auto, AHPM DSC, Discrete
950V FS4	Discrete, PIM	▪ Balanced & slow speed, Epi FRD wafer sales and PIM Gen-III 1500V	▪ Q3'17	YES Under proliferation , discrete, wafer sales
1200V FSII	Discrete, AHPM, PIM, IPM	▪ Auto rated SCR, IS/TS	▪ Q4'17	YES Under proliferation for AHPM, PIM, IPM
1200V UFS	Discrete, IPM, PIM	▪ Auto rated SCR IS/TS ▪ PIM Gen-III	▪ Q4'18 ▪ Q4'17	▪ YES – Being qualified PIM, IPM, PD
1400V UFS (FSIII)	Discrete	▪ Industrial RC	▪ Q4'16	NO – Being qualified in TO247 Industrial
1700V FS4	Discrete	▪ Auto	▪ Q4' 2018	Under Development
FS 7 Next Gen 650V - 1200V	Discrete, AHPM, PIM, IPM	▪ Auto, Industrial, Consumer	▪ Q4' 2019	Under R&D

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Summary – FS4 IGBT technology

Enabling Greater Efficiency and reliability

- ✓ The 4th generation FS IGBT technology successfully developed.
- ✓ Excellent trade off performance by enhanced carrier control
  - Improved efficiency
  - Smaller system design & BOM reductions
  - Increased switching frequency
- ✓ Strong latch up immunity
  - Better reliability
  - Withstand severe hard switching conditions
- ✓ ON semiconductor takes over leadership in high-performance and robust IGBTs

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