Power Devices an Enabling Technology for Reliable and Efficient Power Converters -Technology Trends and Challenges-

Leo Lorenz
ECPE/Infineon Technologies
München

Role of Power Electronics for Energy Efficiency:

- Precise and High Efficient Control of Flow of el.Energy
- Ultra High Power Density Systems
- Elevated Operating Temperature
- System integration (µE & PE & passive devices & thermal management)
- Highest Reliability and Ruggedness in the whole Energy Supply

Outline

- Introduction
- General Development Trends of Power Devices
- High Power Devices

  => Chip Development

  => Ruggedness & Reliability

  => Development Trend
- Fast Switching Devices

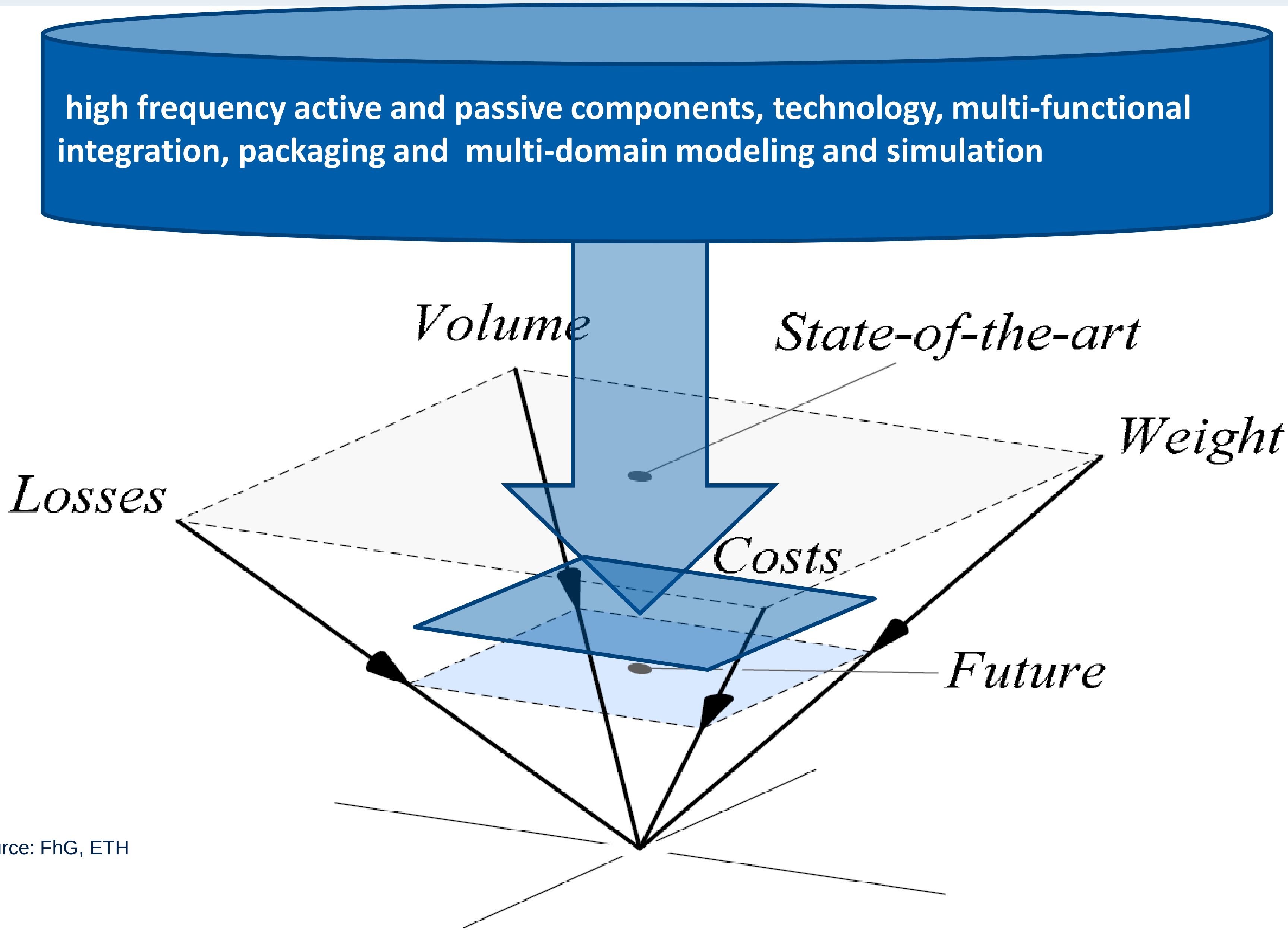
  => SJ-Technologies

  => SiC-Devices

  => GaN-Devices

  => Challenges in Application
- Summary

Multi-Technology-Integration



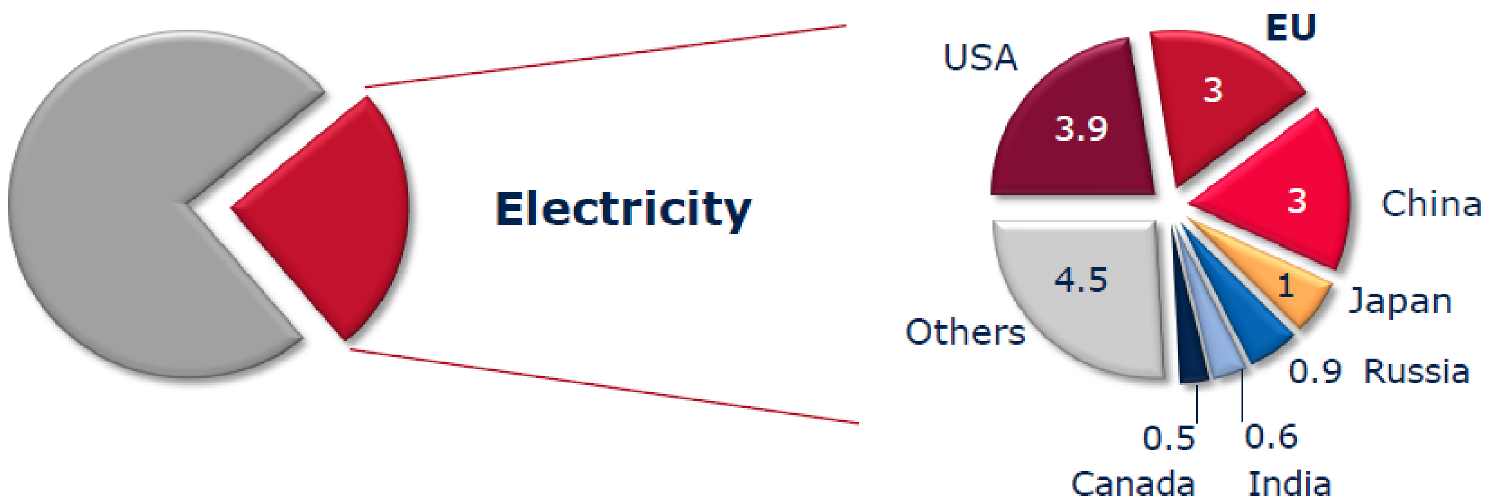
Source: FhG, ETH

Good News is that ~ 1/3 of the Global Energy is Used as Electricity

While debate continues over the environmental impact of different means of electricity production, its final form is relatively clean & it is one of the easiest means of transporting energy over long distances!

Global energy consumption 2008

Global electricity consumption 2008
17.4 million GWh

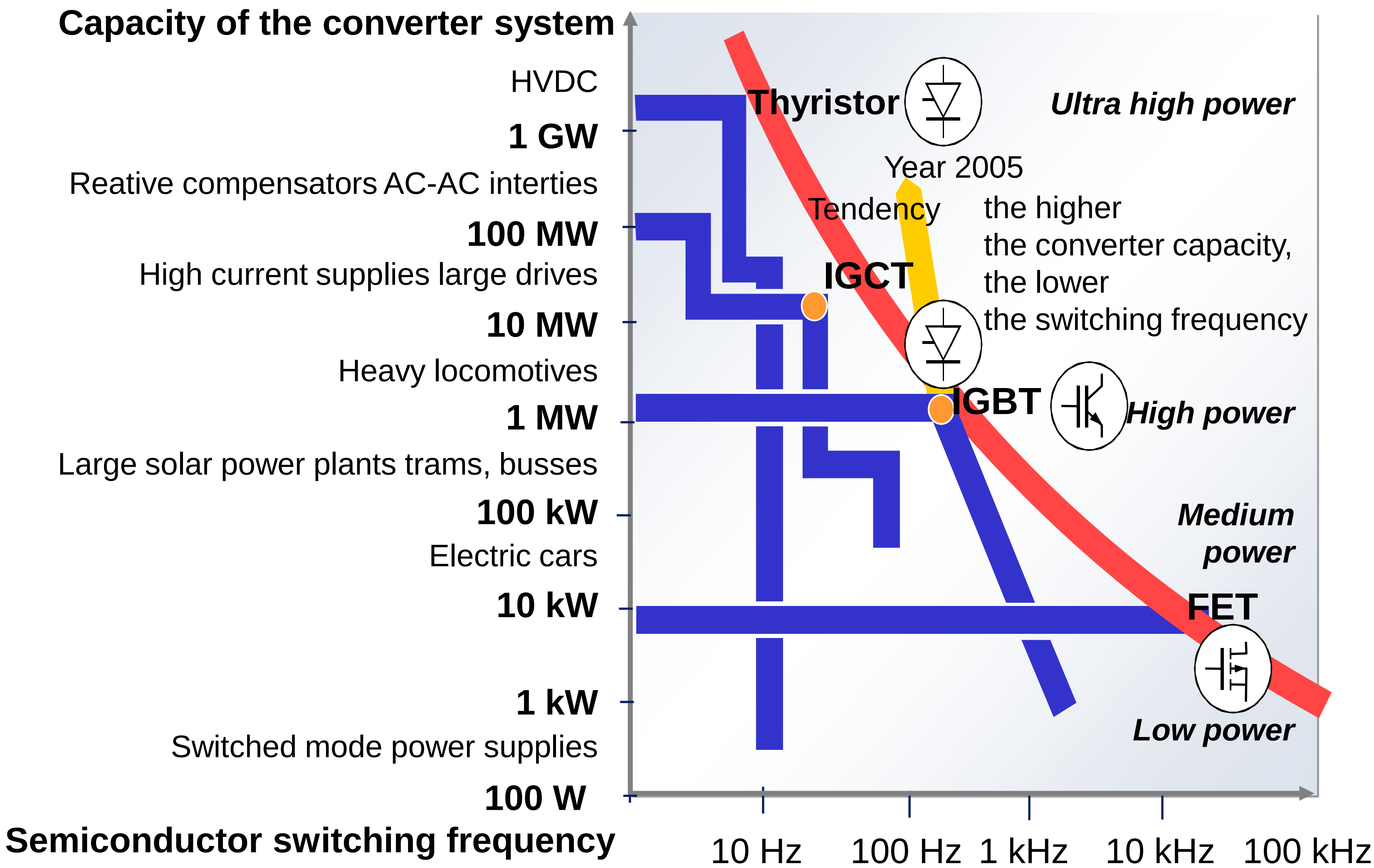


~1/3 of global energy consumption is electricity

USA, the EU and China are the largest consumers of electricity

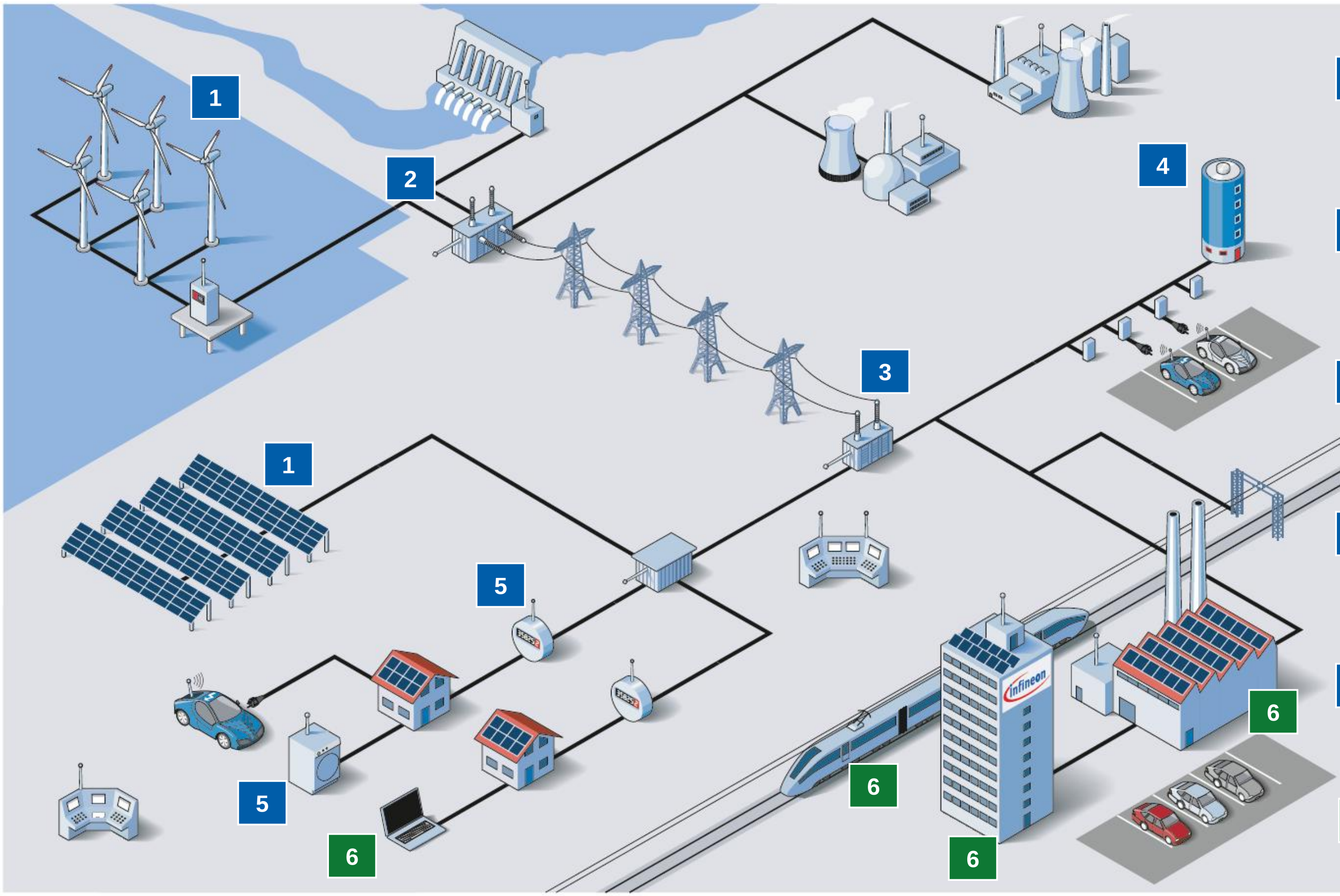
Sources: BP World Energy report; Energy Information Administration (EIA) – International Energy Statistics, 2010
EU includes all 27 member states of the EU (http://europa.eu/abc/european_countries/index_en.htm)

Application for Power Semiconductor Components



Source: IPEC 2000

Smart Grids: advanced power control, intelligence and communications



1 Integration of renewable energy

2 Advanced transmission

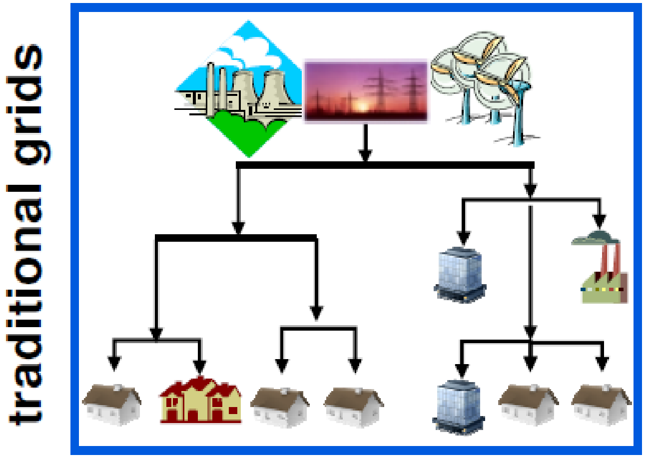
3 Grid monitoring and control

4 Energy storage and EV-charging

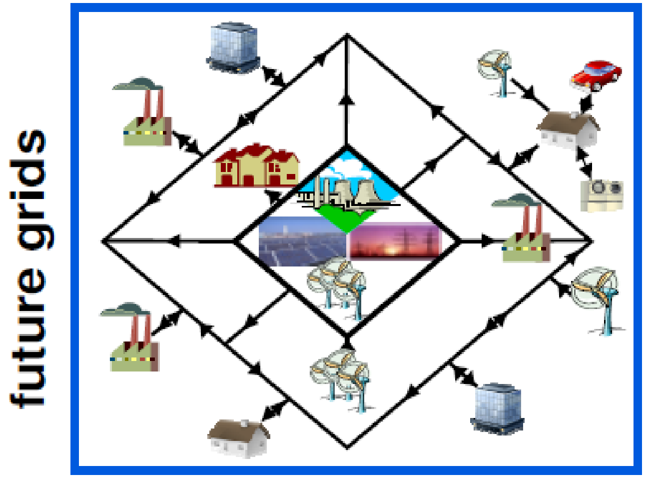
5 Smart metering and appliances

6 Efficient consumption

Evolution of grid design
From traditional to future grids



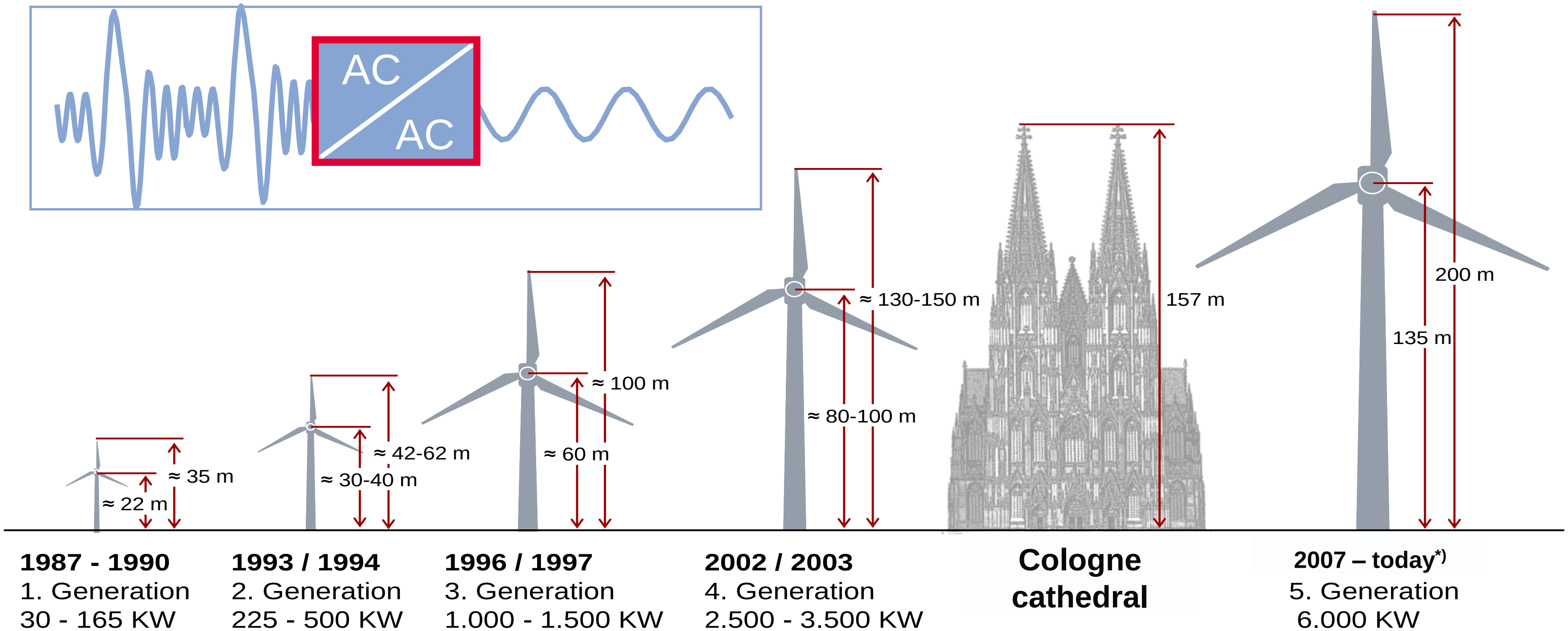
- Centralized power generation
- One-directional power flow
- Generation follows load
- Operation based on historical experience
- Limited grid accessibility for new producers



- Centralized and distributed power generation
- Intermittent renewable power generation
- Consumers become also producers
- Multi-directional power flow
- Load adapted to production
- Operation based more on real-time data

Source: ABB

As consciousness on renewable energy grows, so do the windmills & their output power!

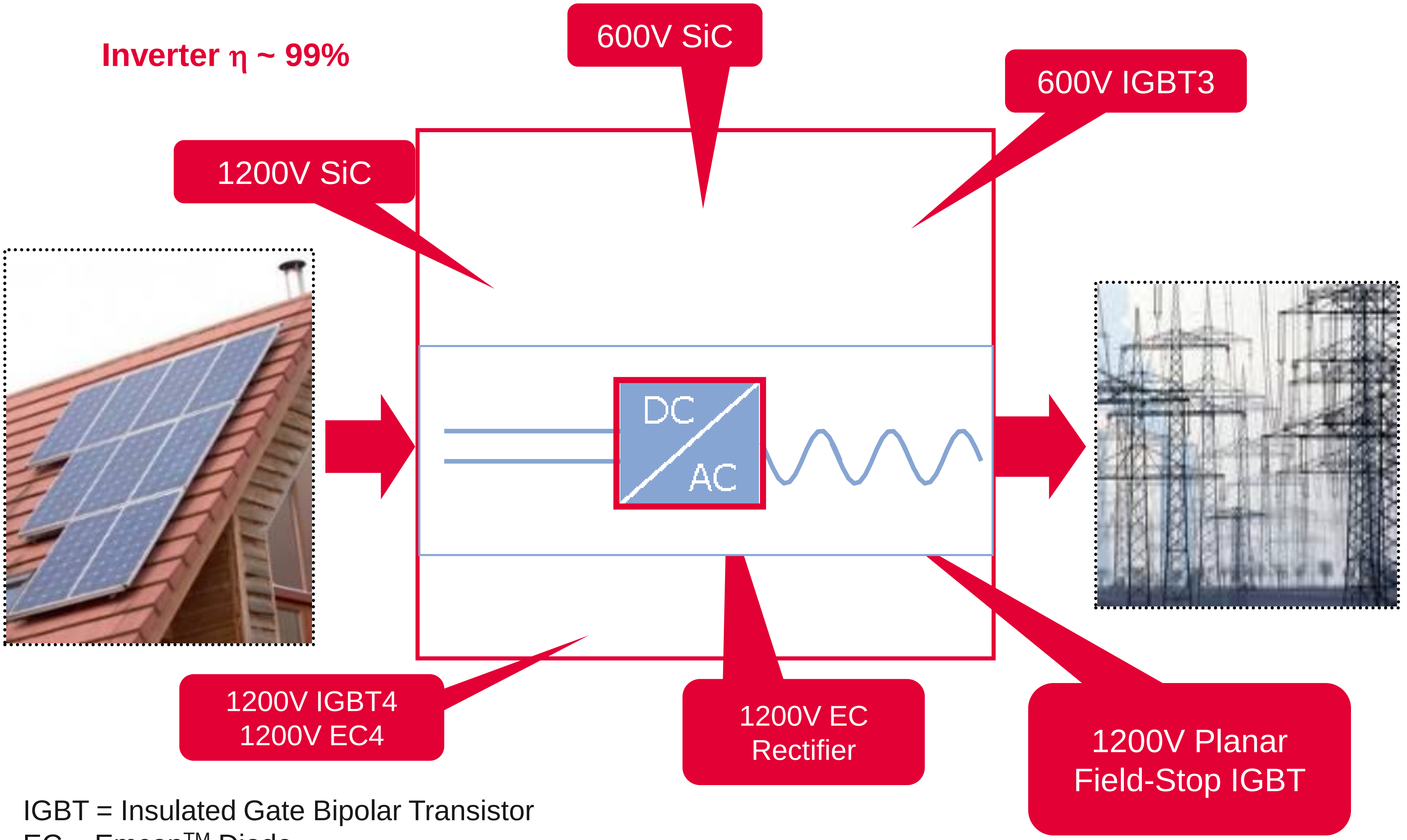


BARD Offshore 1 (Germany's first off-shore wind park)

Location:	90 km northwest of Borkum, North Sea, Germany
Key data:	▪ 80 wind turbines of 5 MW each ▪ 400 MW total power generation ▪ completion expected end of CY 2010
Components:	Power module IHM 1700V

*) Source: Siemens Renewable Energy Division, 2009

Six technologies based on Silicon Carbide and Silicon, enable excellent energy conversion



IGBT = Insulated Gate Bipolar Transistor
EC = Emcon^{TM} Diode
SiC = Silicon Carbide component

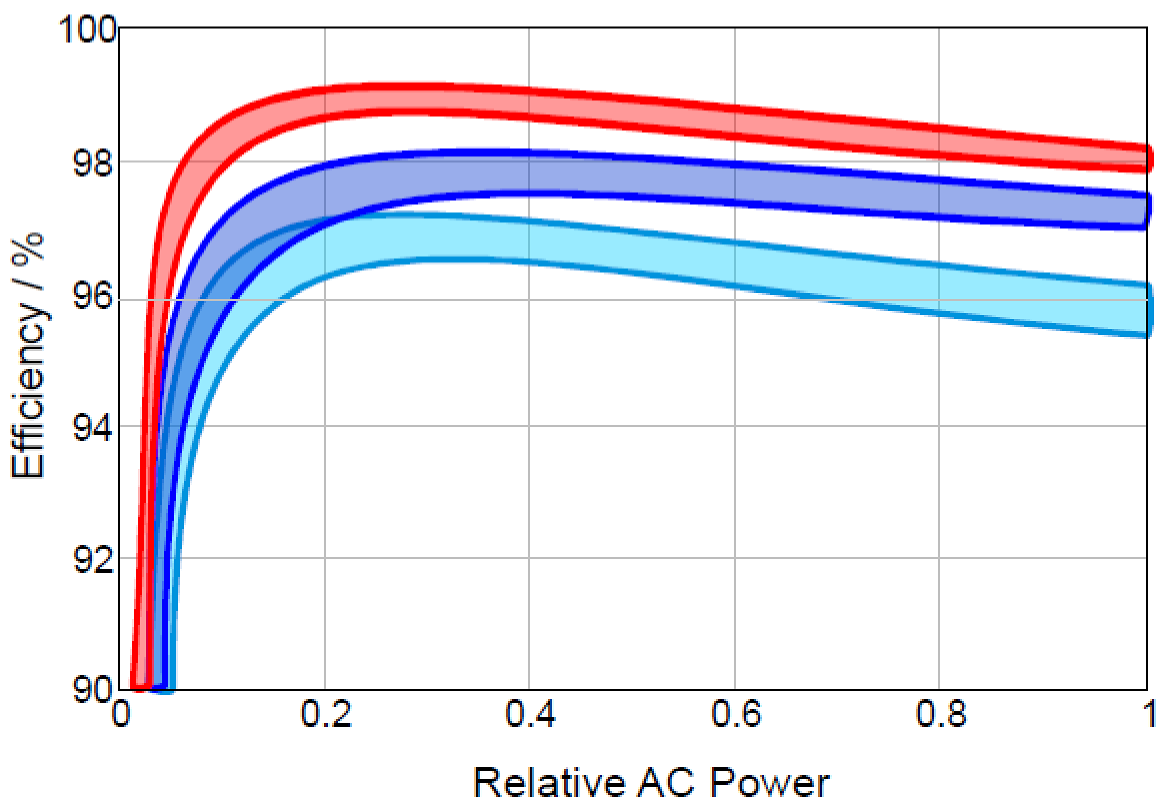
PV-Inverter Efficiency

Efficiency of transformerless PV inverters (5 kW, 16 kHz)

SiC transistors,
three level topologies,
HERIC, H5, 3~NPC

IGBTs,
three level topologies,
HERIC, H5, 3~NPC
or
SiC-transitors,
two level topologies,
H4, B6

IGBTs,
two level topologies,
H4, B6



Source: FhG ISE

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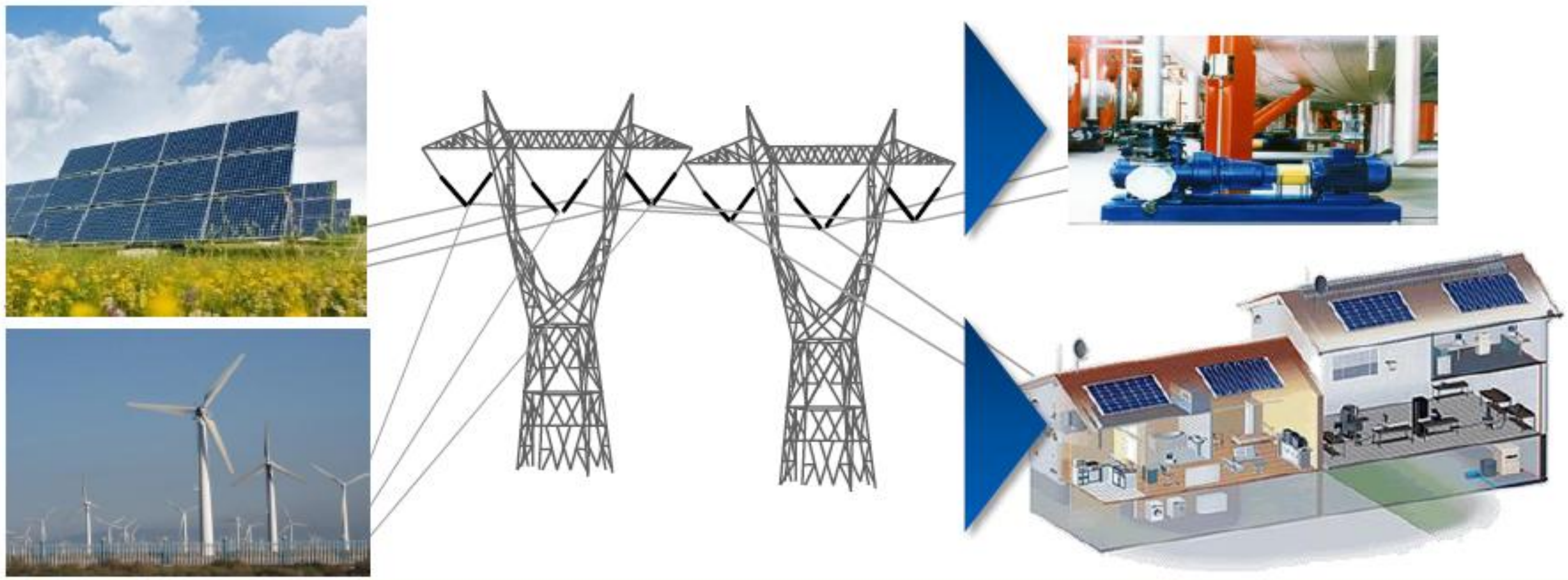
Valve Hall Moyle (2 x 250 MW HVDC Station)
fully equipped with light-triggered, BOD protected thyristors
2 converter stations (1 in Scotland, 1 in Northern Island) connected by sea cable

Semiconductors Play an Important Role in the Whole Electrical Energy Supply Chain

Energy supply chain

Energy generation | **Energy distribution** | **Energy consumption**



Power Semiconductors

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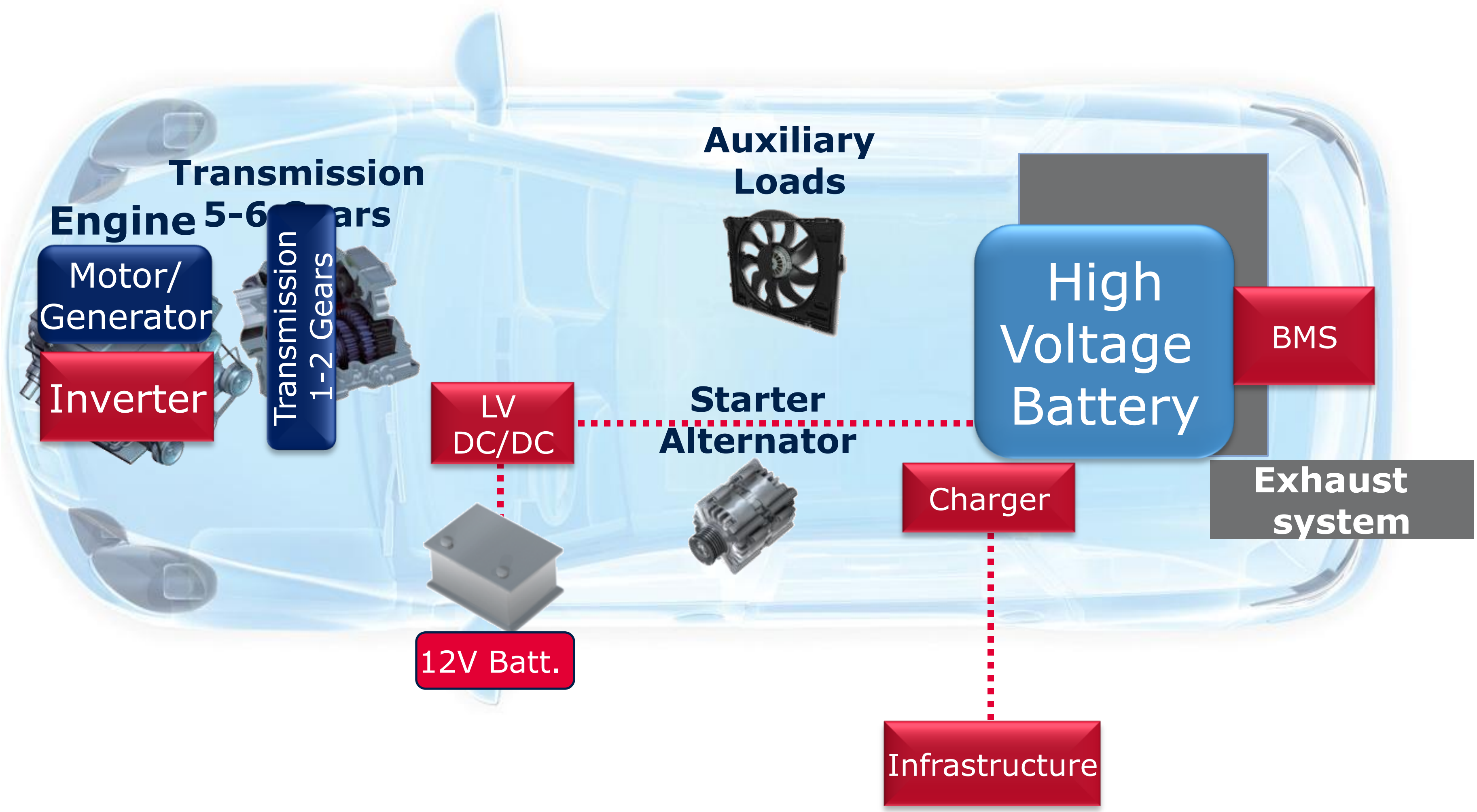
E-Mobility: A Total New Vehicle Architecture



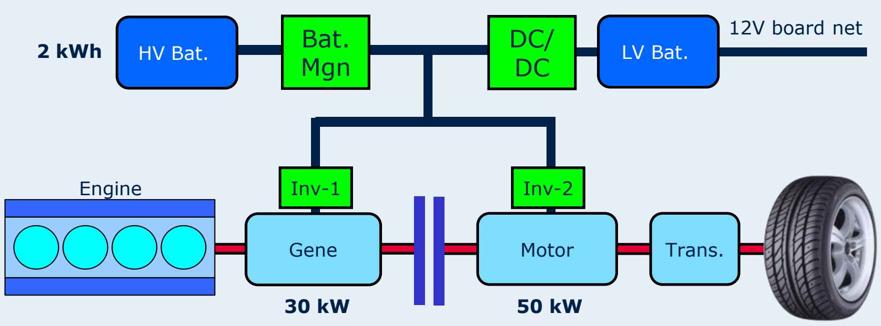
The vehicle electrification: a wide range of architectures

µ Hybrid

Parallel Hybrid

Serial Hybrid

Serial - Parallel Hybrid



Functions

- Start - Stop
- Regenerative braking
- Torque boost
- Low / part speed electric drive

Challenges

- Engine temperature control
- Emissions at Start & Stop
- Control of transient
- Safety critical X-by-wire
- Vehicle stability -> ESP
- High voltage
- Need of cabin heating
- Need of cabin cooling
- …

Outline

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- **General Development Trends of Power Devices**
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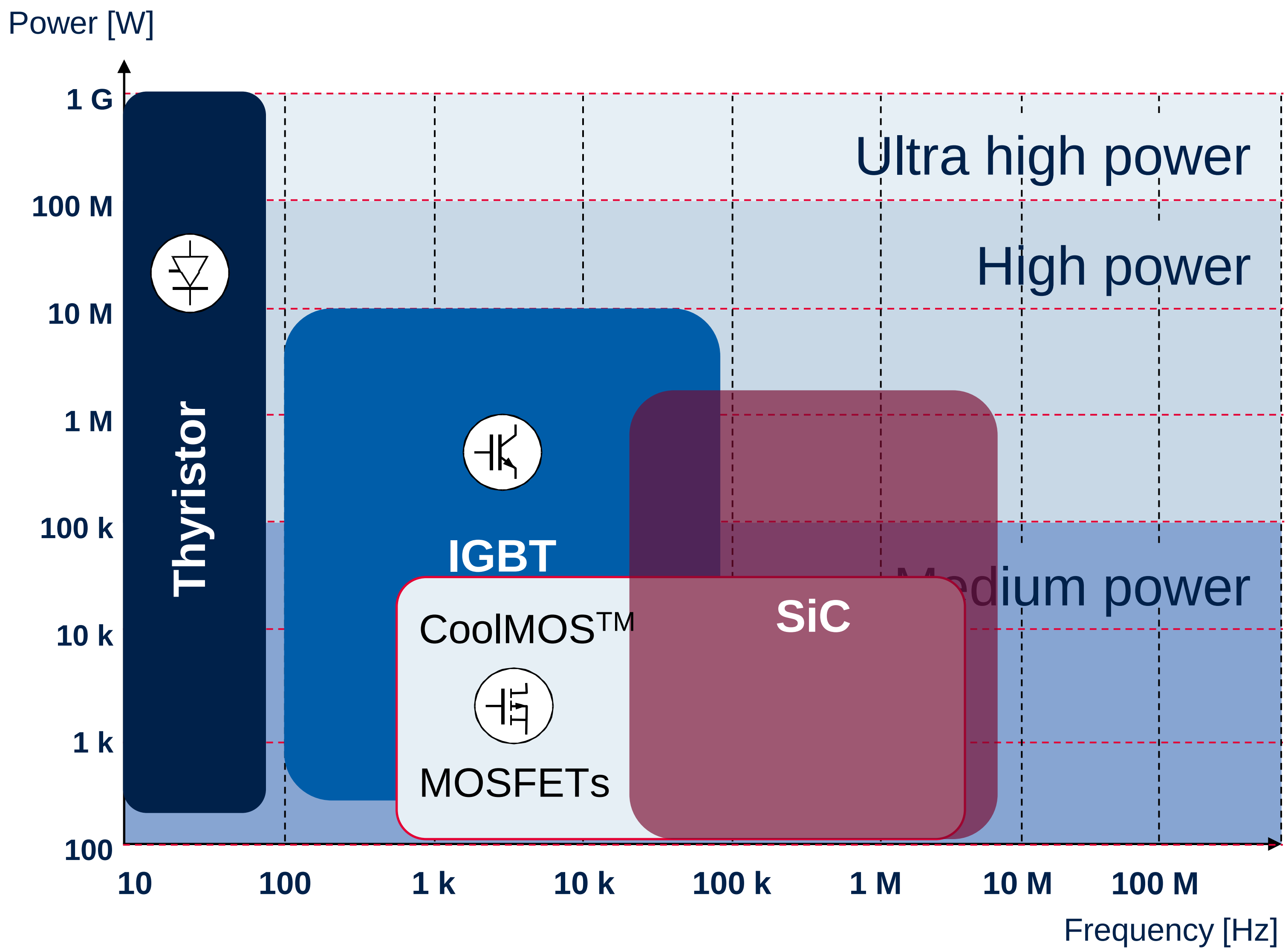
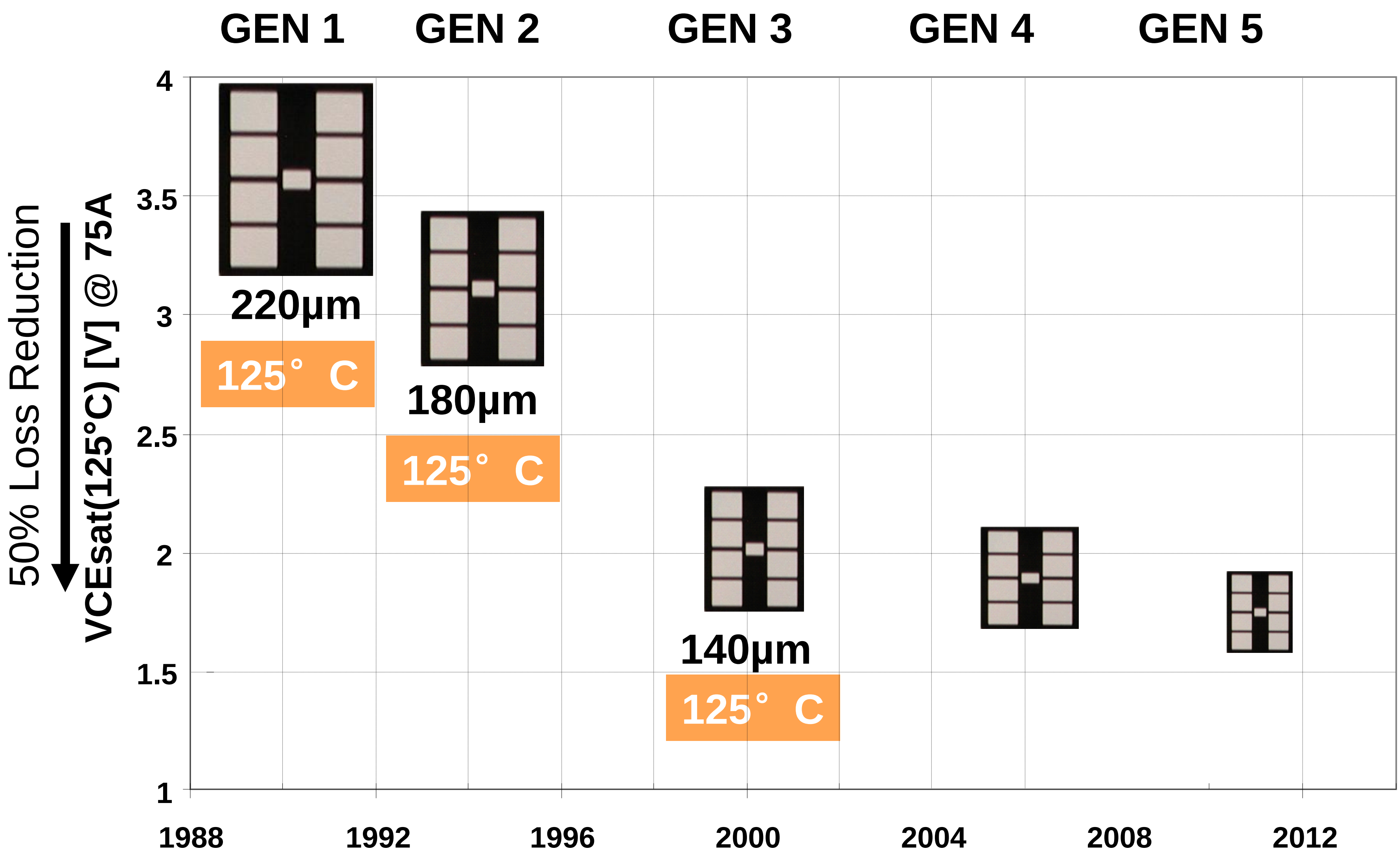
  - => Chip Development
  - => Ruggedness & Reliability
  - => Development Trend
- Fast Switching Devices
  - => SJ-Technologies
  - => SiC-Devices
  - => GaN-Devices
  - => Challenges in Application
- Summary

Power Semiconductors - Overview
Main characteristics: Power vs Frequency



Efficiency and Increased Power Density !
Leads to Reduction in Losses, Increased Temperature



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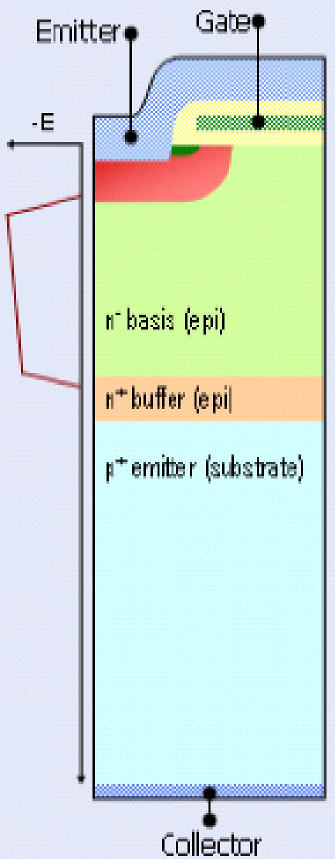
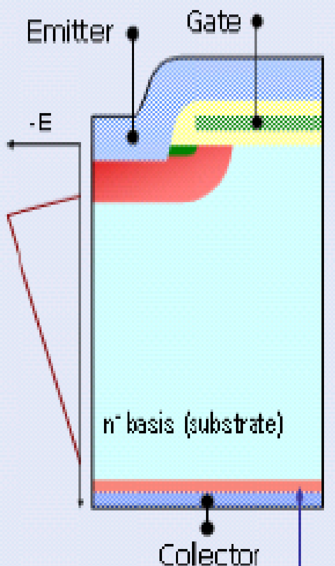
Source:Infineon Technology

Features > IGBT Chip Technologies

Punch Through



IGBT1/2 Non Punch Through



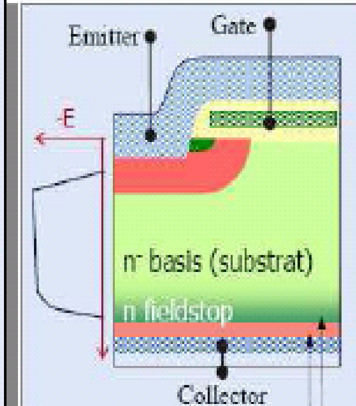
Advantage

- Implanted back-emitter better adjustable

Performance

- Lower switching losses
- Higher switching robustness

IGBT2 Field-Stop



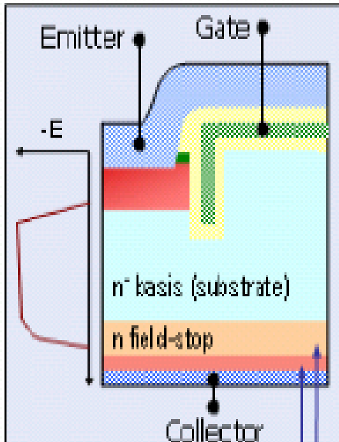
Advantage

- Implanted Back-Emitter
- Implanted Fieldstop enables thinner base region

Performance

- Lower VCEsat
- Lower Switching Losses
- Robustness like NPT

IGBT3 Trench + Field-Stop



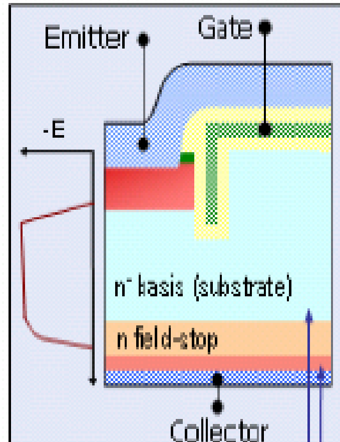
Advantage

- Implanted back-emitter
- Implanted field-stop enables thinner base region

Performance

- Lower V_{CEsat}
- Lower switching losses
- Robustness like IGBT2

IGBT4 Trench + Field-Stop



Advantage

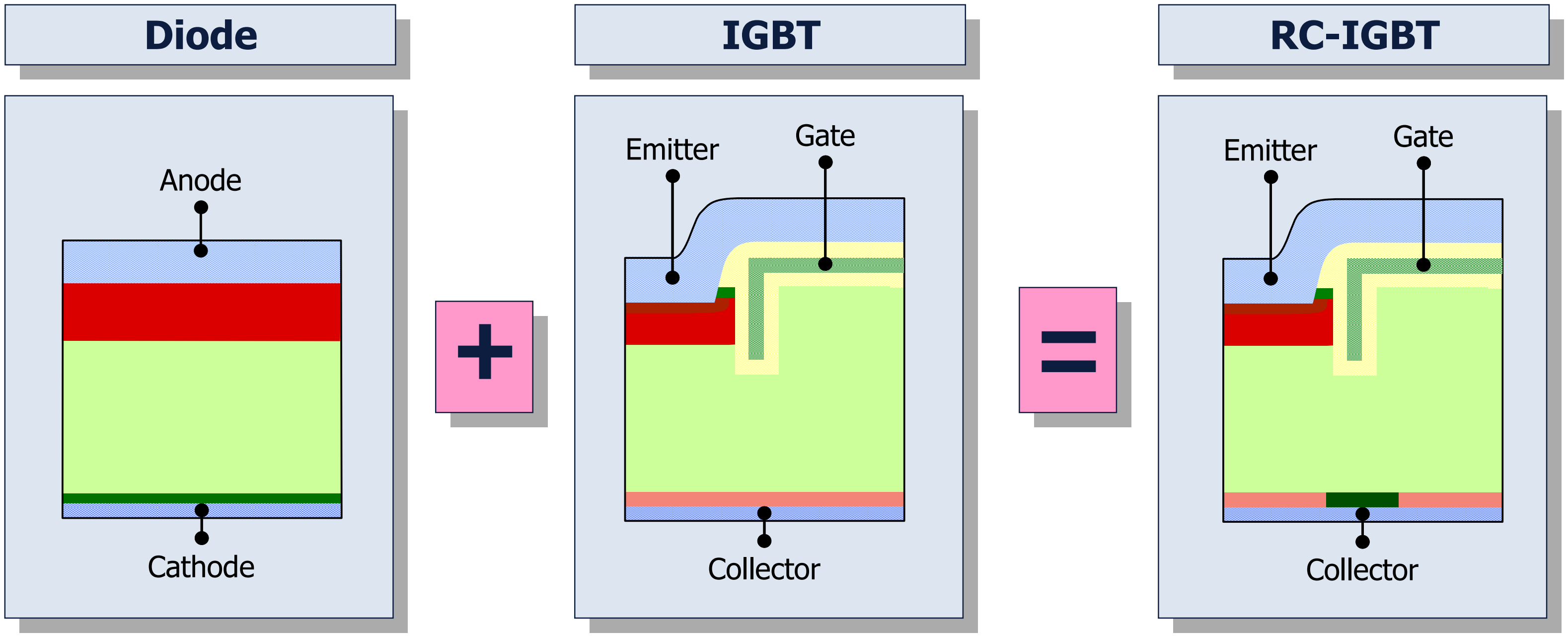
- Optimized $R_{Modulation}$
- Adjusted Backside

Performance

- Lower switching losses
- Increased softness
- Robustness like IGBT3

Discontinued | In use | In use | In use | Latest

NEW INNOVATION – Reverse Conducting Technology for Drives

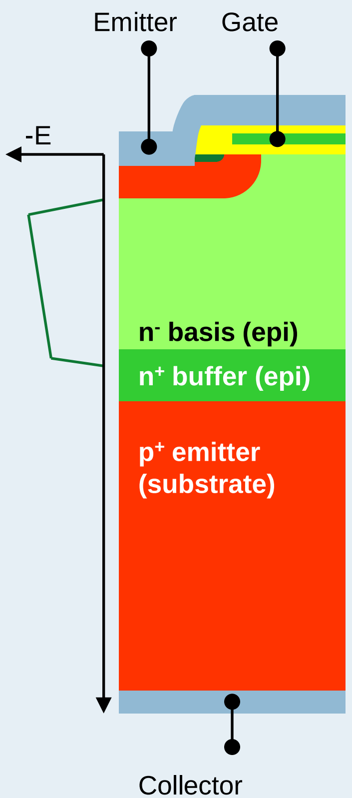


- **RC-D**: Infineon now offers the free wheeling diode monolithically integrated into the TRENCHSTOP IGBT-die for hard switching applications (**R**everse **C**onducting for **D**rives)
- Same DC current rating of diode and IGBT
- This leads to current classes [<15A] being available in new package classes.

IGBT Technology selection

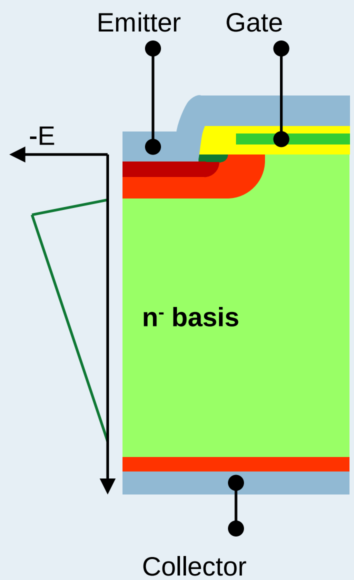
Punch Through

(ROW: 1988)



Non Punch Through

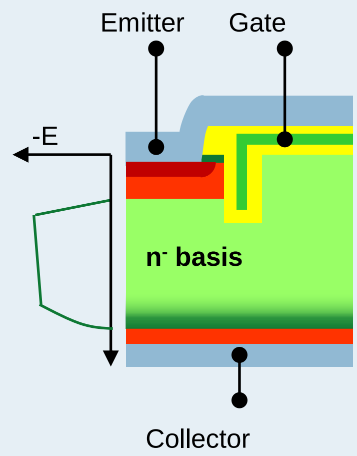
(IFX: 1990 ROW:1997)



Advantages
Implanted Back-Emitter
better adjustable
Performance
Lower Switching losses
Higher Switching
Robustness

TRENCHSTOP™

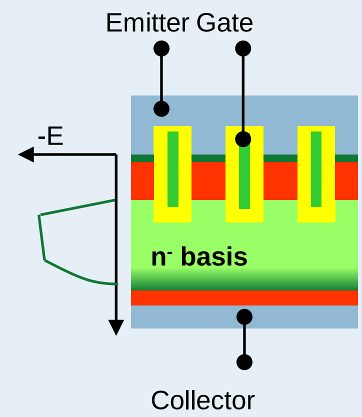
(IFX: 2000 ROW:2006)



Advantages
Implanted Back-Emitter
Thinner Base Region
Performance
Lower VCEsat
Lower Switching losses
Robustness like NPT

TRENCHSTOP™ 5

(IFX: 2012



Advantages
Highly adjustable Emitter
Carrier Profile Optimization
Performance
Very low VCEsat
Very low switching losses

High Speed 5

The TRENCHSTOP™5 Family Structure

TRENCHSTOP™5

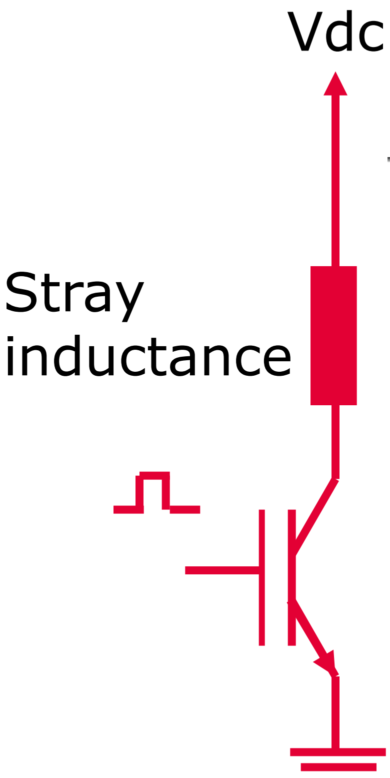
High speed 5 – "**H**"
High speed variant

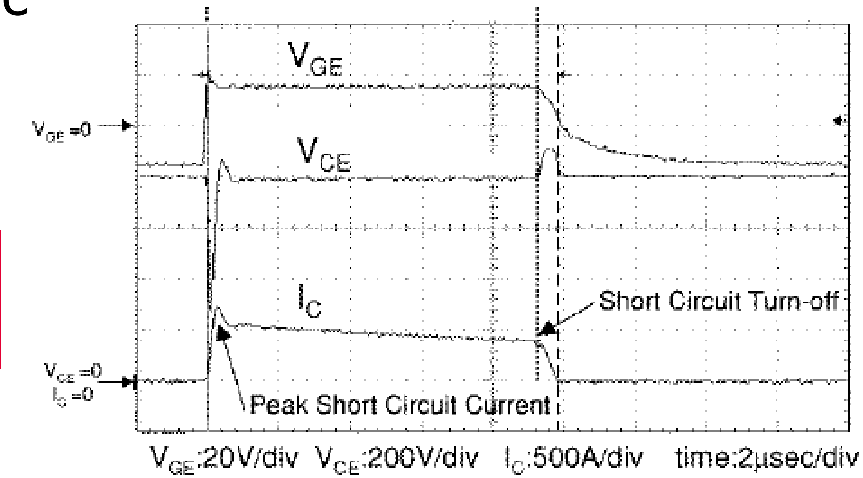
High speed 5 FAST –"**F**"
Highest efficiency

*Resonant variant "**R**"*
Induction Heating

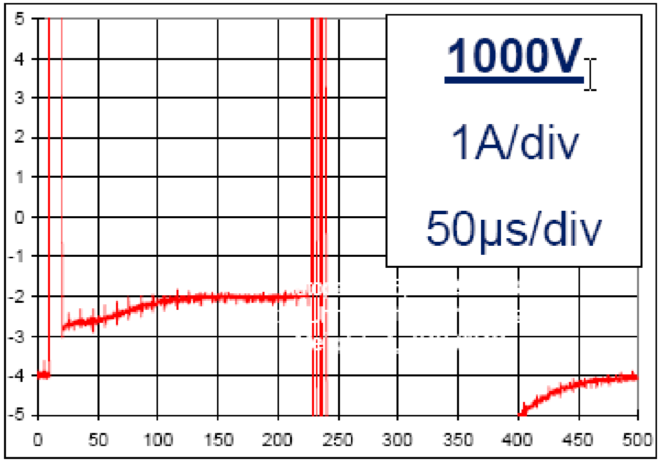
*Low Vce(sat) variant "**L**"*
Solar

Short circuit operation





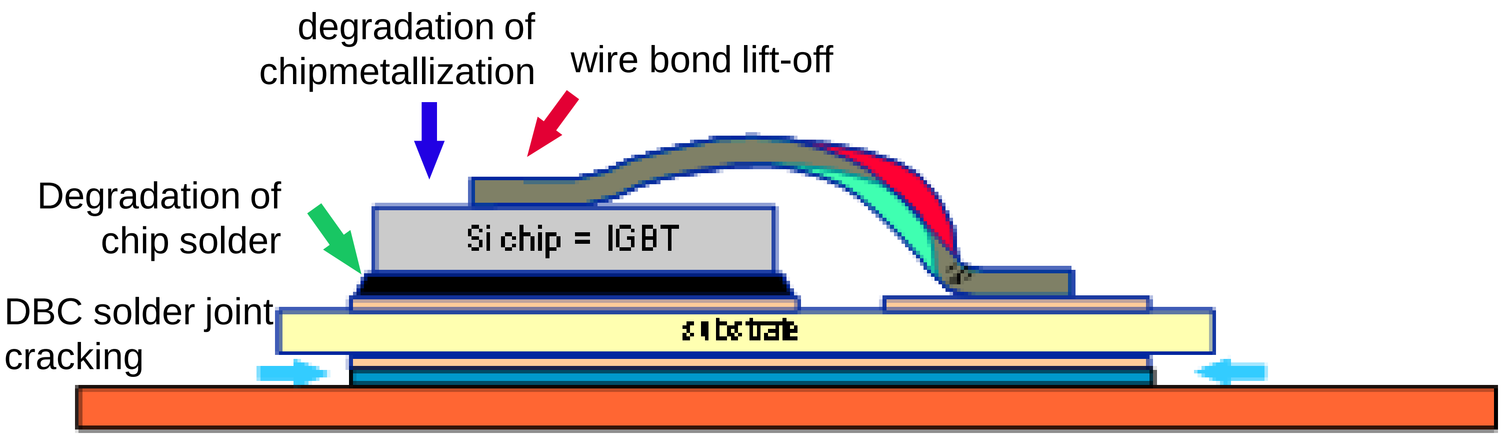
Destruction after the sc pulse

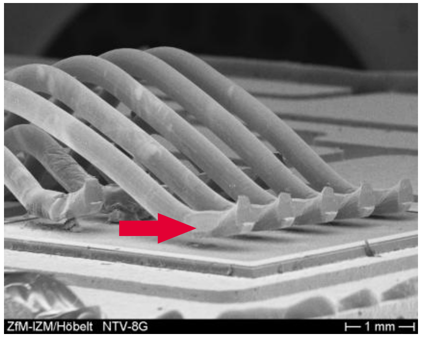


- Especially thin (600V .. 1200V) IGBTs are failing in this mode if the allowed short circuit time is exceed
- Thinner silicon / high channel width
  - Reduced power losses
  - Reduced short circuit capability

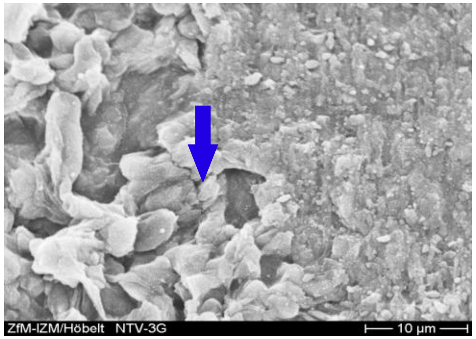
Source: ISPSD 2010

Reliability: modules failure mechanisms

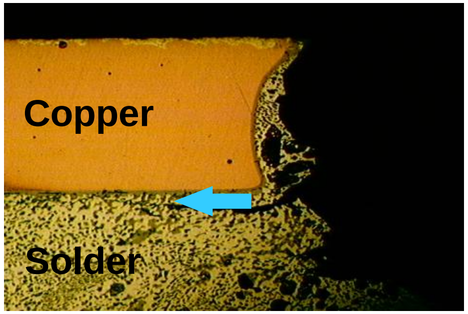




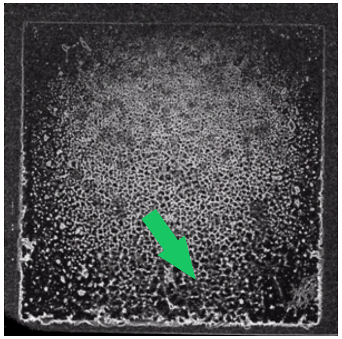
wire bond lift-off



degradation of chipmetallization



solder joint cracking



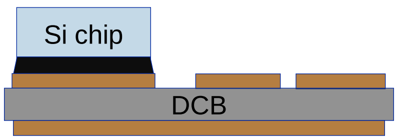
Degradation of chip solder

Future power module with .XT technology

Standard Technology

.XT technology

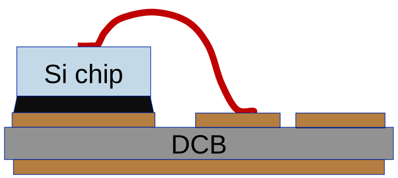
Chip-to-substrate joint



Soft soldering with SnAg paste

Diffusion soldering

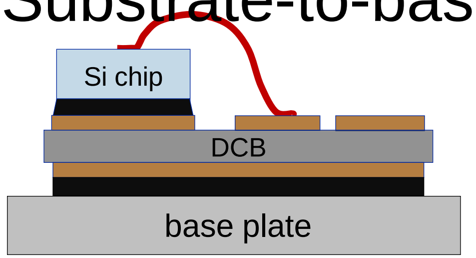
Front side interconnect



Al wedge bonding

Cu wedge bonding

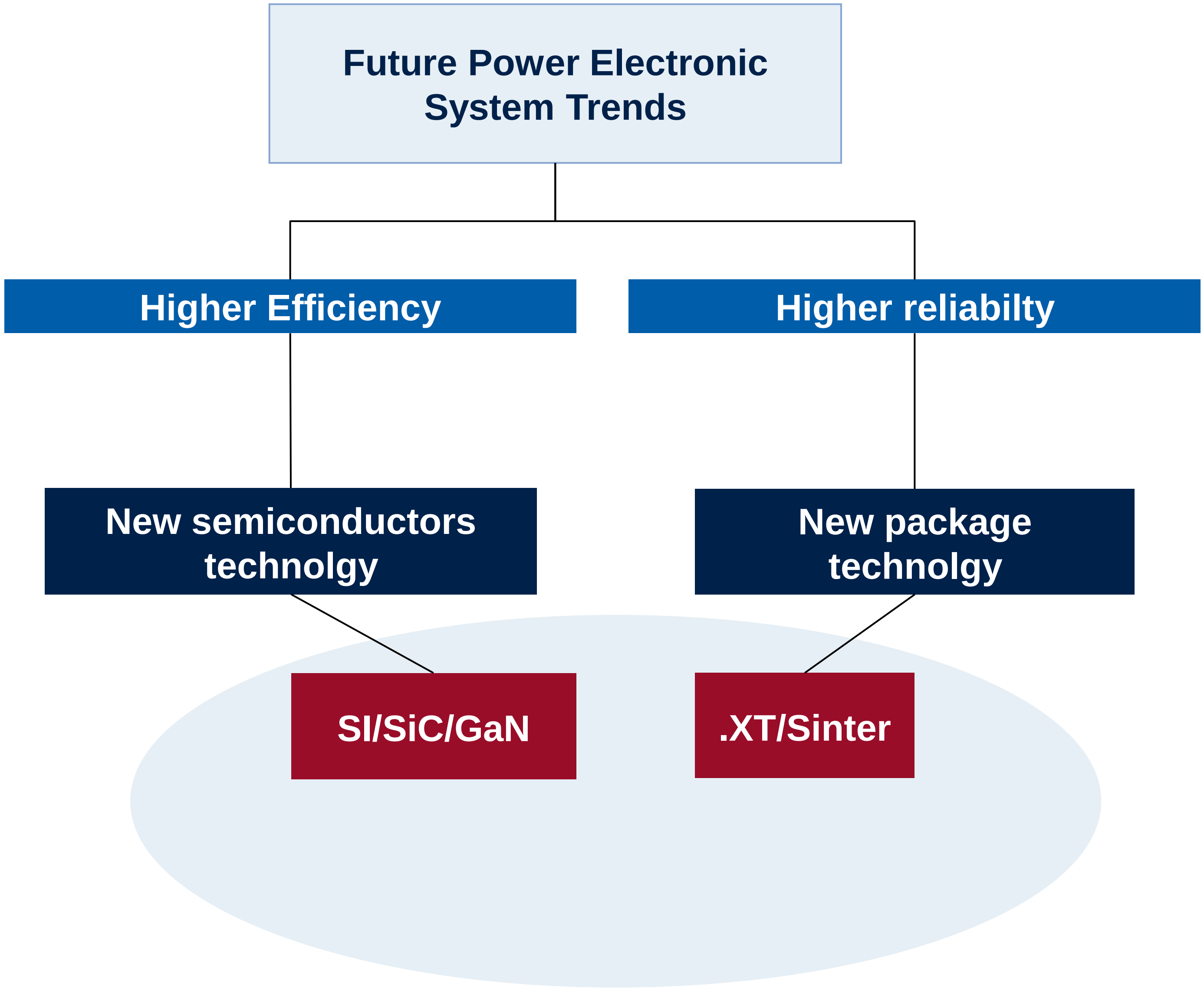
Substrate-to-base plate joint



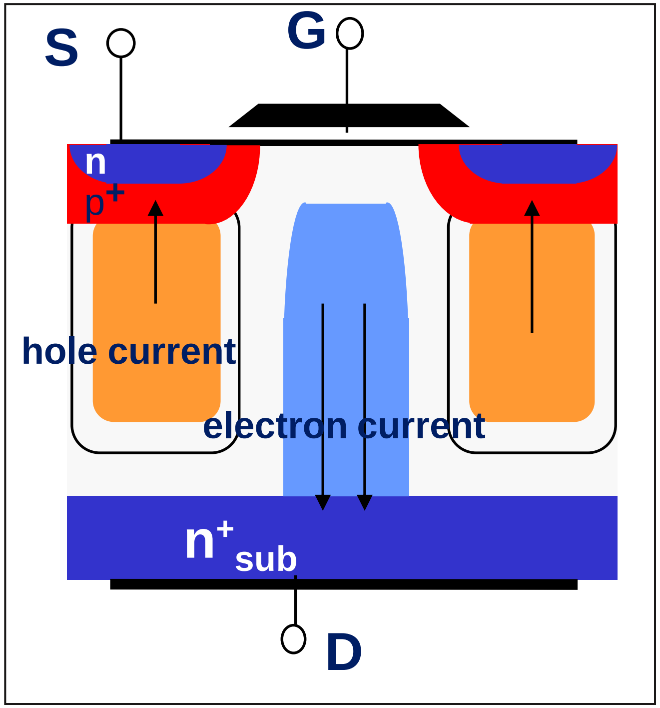
Soft soldering with SnAg pre form

High reliability system soldering

Development Trends for High Reliable Systems



Where does the non-linearity in Cds and Cgd come from?



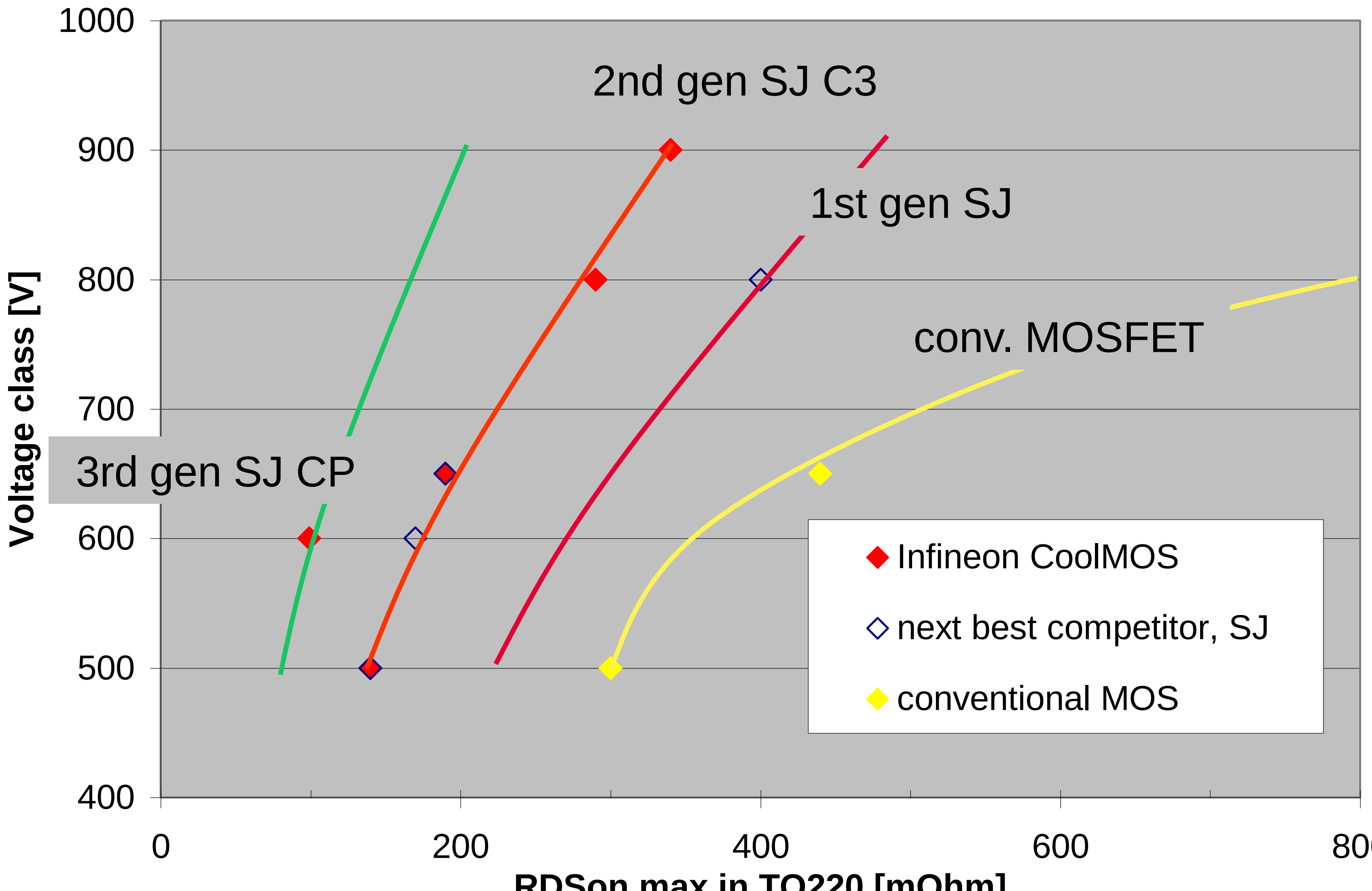
- Fast expansion of space charge region (SCR) from large area lateral pn-junction: high drain-source area at low voltage, strong decrease in area and increase in SCR width as a function of voltage

- Full depletion of active area at around 1/10th of nominal breakdown voltage

- High voltage limit of output capacitance given by width of SCR and active area of chip

- High voltage limit of reverse capacitance given by width of SCR and area overlap gate-to-drain

Infineon is contributing to efficiency targets from the power semiconductor side with CoolMOS™…



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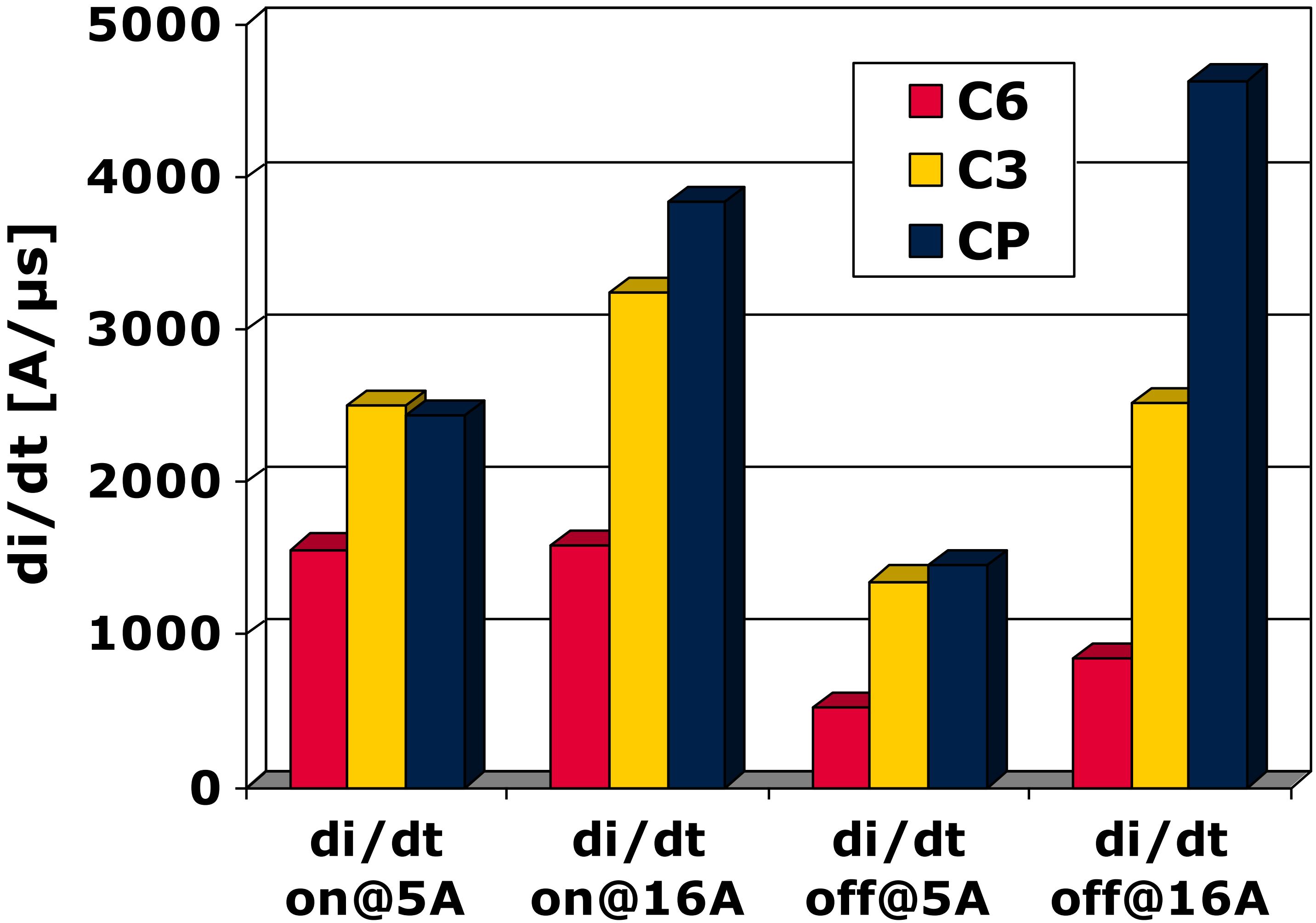
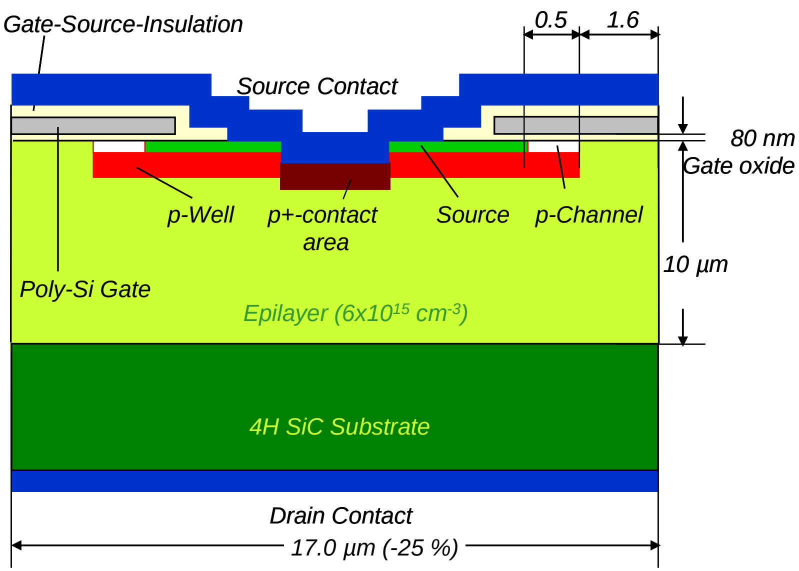
Comparison di/dt of CoolMOS C6 vs C3 and CP

190 / 199 mOhm types, Rg 3.3 Ohm, Tj=125° C



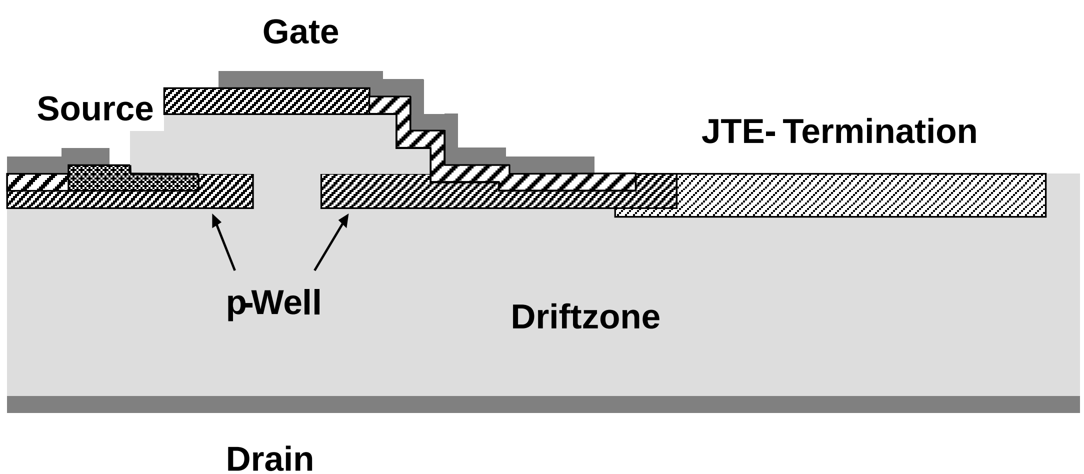
Choice of Device Concept:
SiC MOSFET vs SiC JFET



Pro: normally-off

Con: channel mobility

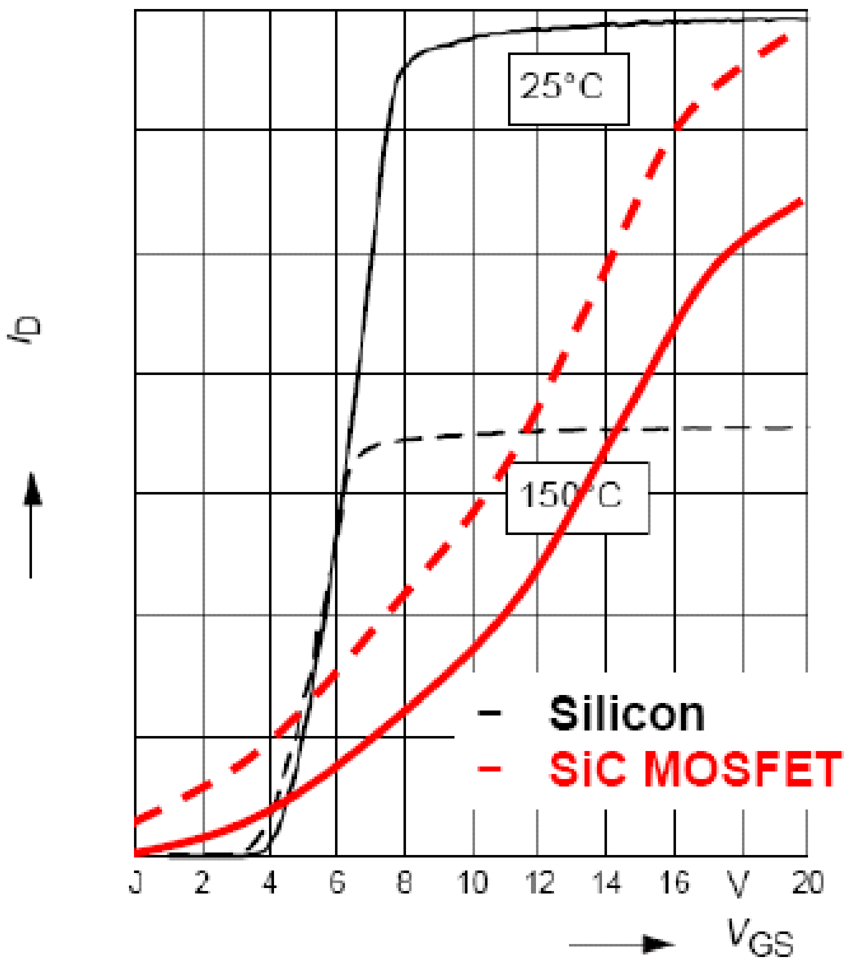
Oxide interface stability



Pro: Reliability
Performance

Con: normally-on

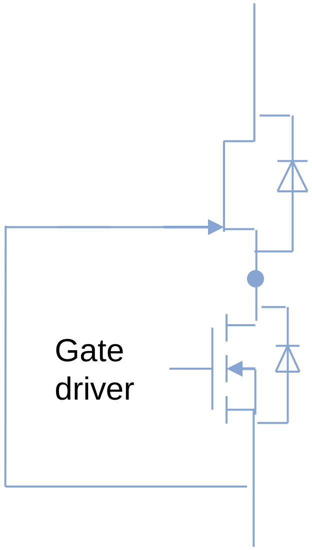
Channel mobility and treshold issue

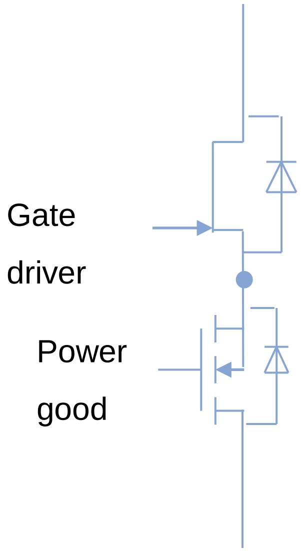


SiC MOSFET:
- Weak subtreshold characterisitic
- High Millerplateau level, low gfs
- Strong gate drivers required

Challenge normally-on: Cascode concepts

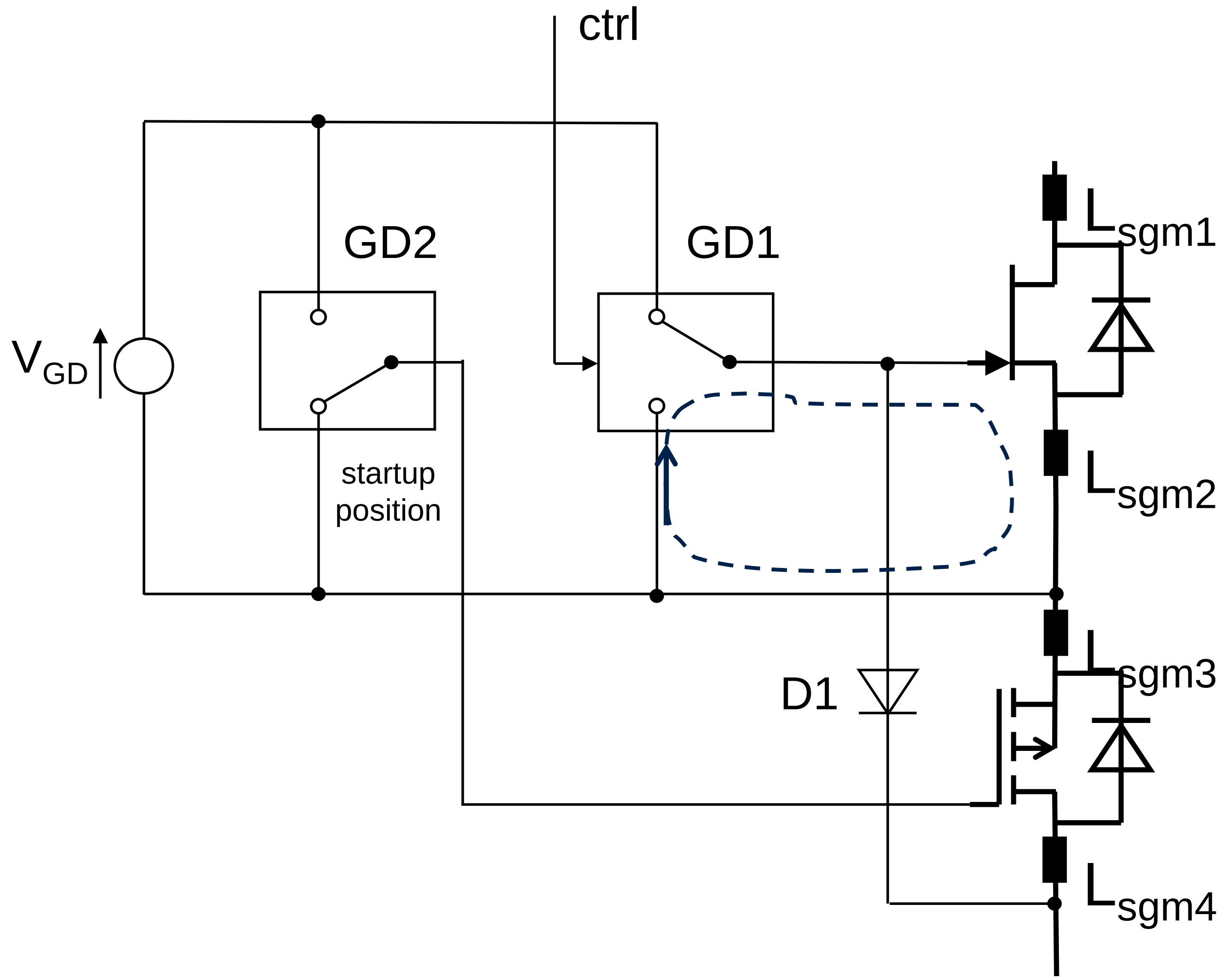
	Cascode	Cascode light
Advantage	Normally off	best efficiency
	3 terminal device	direct control of JFET
Disadvantage	no feedback from JFET to Gate of LV MOS	normally on
	High capacitive charge from LV MOS	negative drive voltage required
	Injection of body diode Qrr in reverse operation	LV MOS still needed as safety valve





Direct driven schematic for SiC JFET

p-channel based solution



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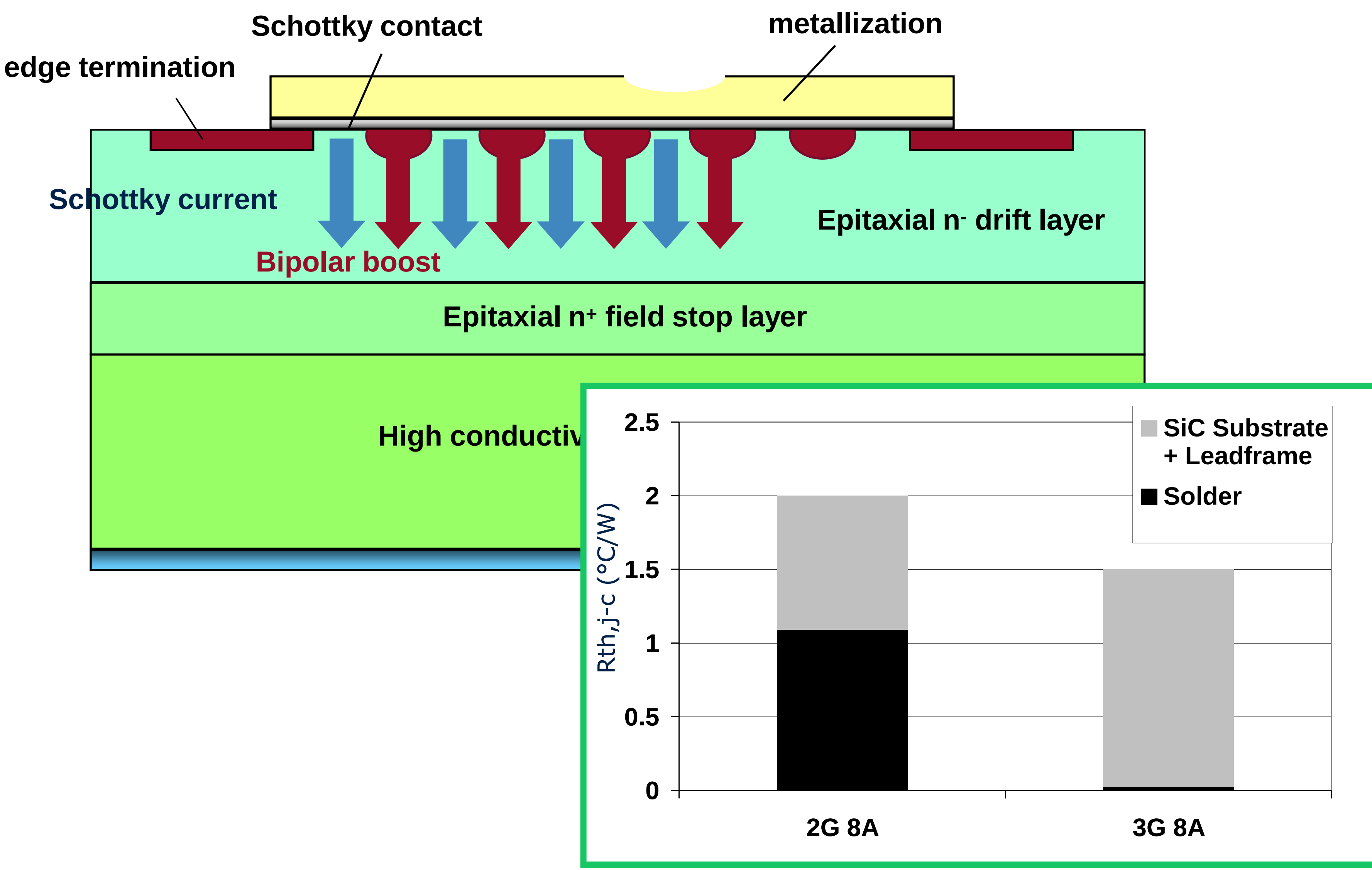
The p-islands make the difference for the 2nd generation, substantiallly reduced solder resistivity for the 3rd gen!

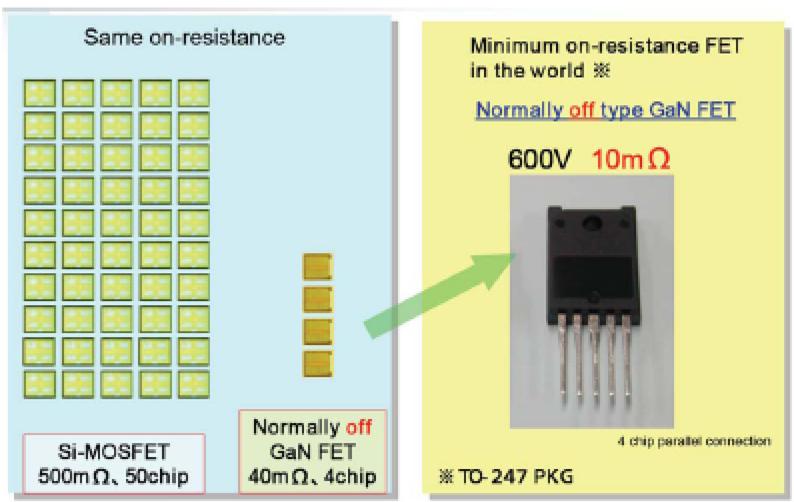


Comparison of Si & GaN devices

GaN vs. Si Switching Transistor Benchmarking

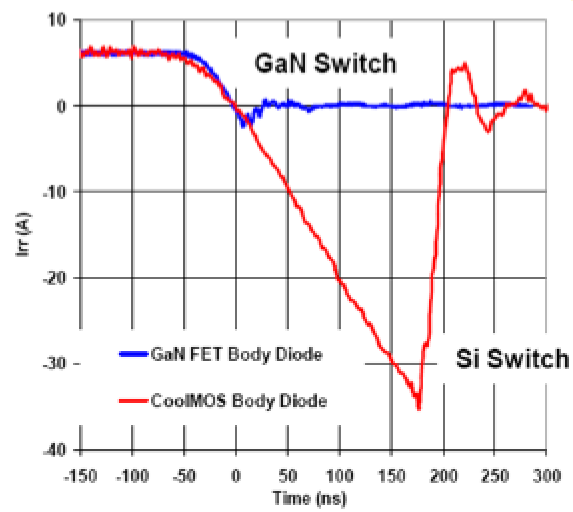
		GaN transistor	Si MOSFET
conduction losses (600 V)	$R_{DSon} \times A$	0.001 Ωcm^2	0.01 Ωcm^2
switching losses (200 V)	$R_{DSon} \times Q_G$	200 pVs	2000 pVs
temperature dependence	$R_{DSon}(125°C)/R_{DSon}(25°C)$	1.5	2.2
maximum junction temperature	T_{Jmax}	~ 300 °C	175 °C

→ reduced chip size



Sanken, ISPSD `09

→ reduced reverse recovery current



IR, APEC `10

Source: Leibniz Insti.

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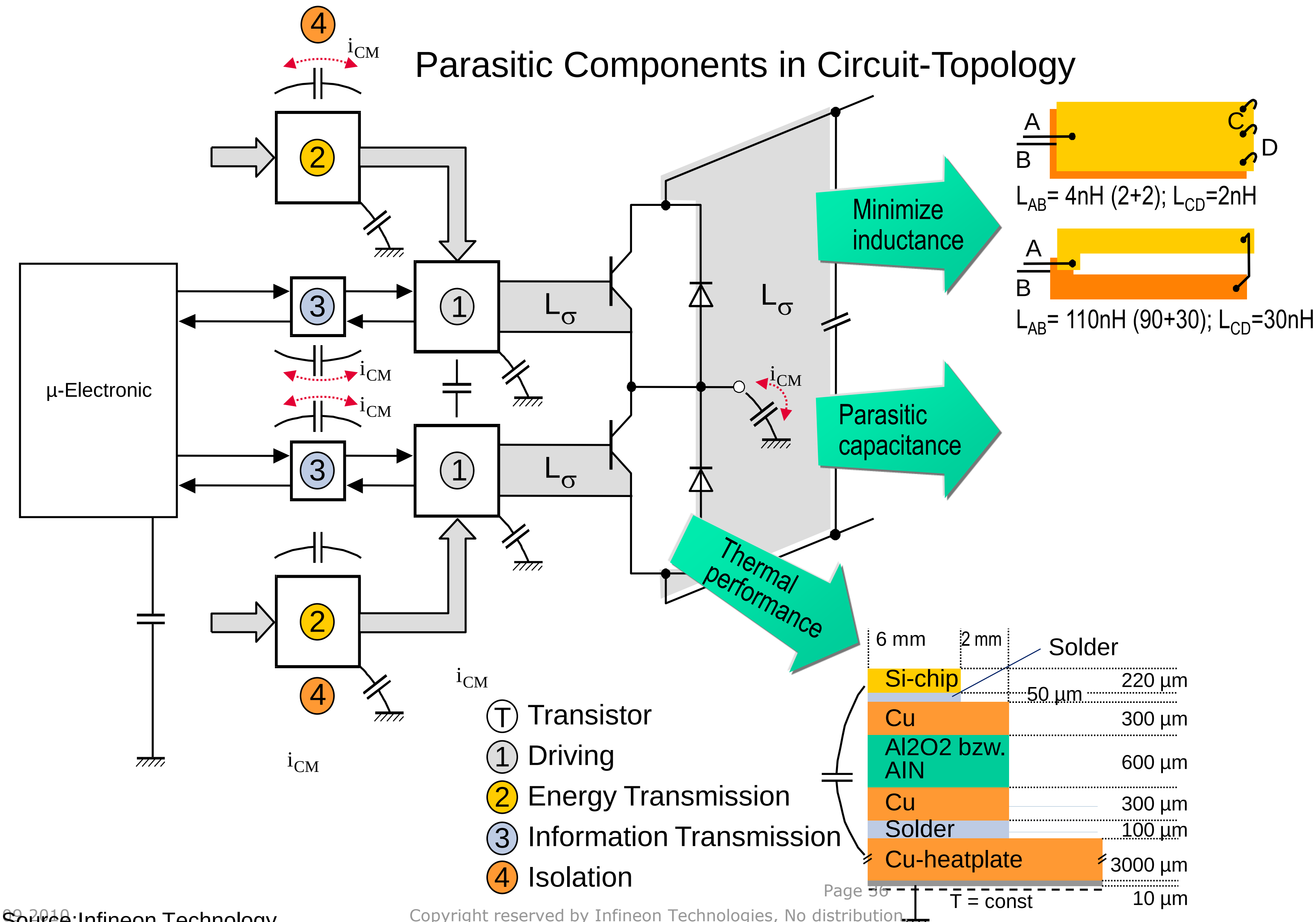
Fast Switching Power Transistor in Application



Source:Infineon Technology