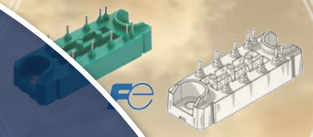
Next-Generation Power Module Patent Landscape

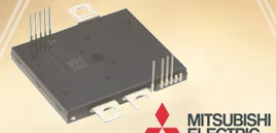
WBG technologies | EV/HEV applications

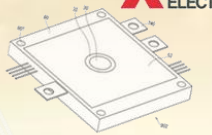
Rémi Comyn

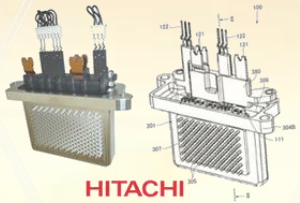
Power America Annual Meeting

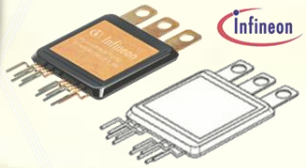
February 25th, 2021 | ONLINE

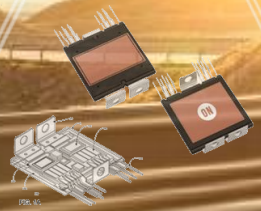


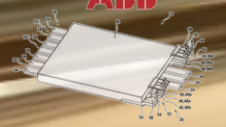


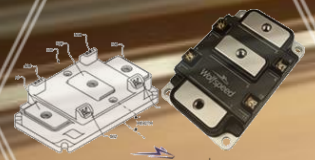












KnowMade
Patent & Technology Intelligence

Introduction

Why to investigate the power module patent landscape?

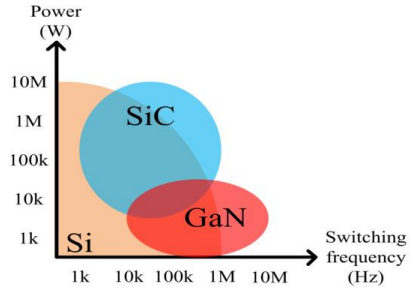
Society

CO_2 emission reduction

New Applications

EV/HEV applications boom

Energy savings



New Technologies

Power SiC & GaN adoption

Impact

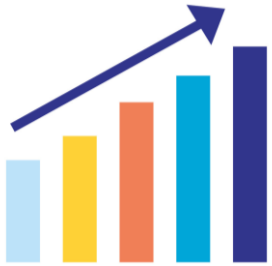
Power Module Patent Landscape

IP players

New IP players

Latest patents

Addressing the new technical challenges



Evolving dynamics

Market vs. Technology vs. IP

New interactions

IP collaborations & IP transfers across the EV/HEV supply chain

Next-Generation Power Module

Patent Landscape Overview

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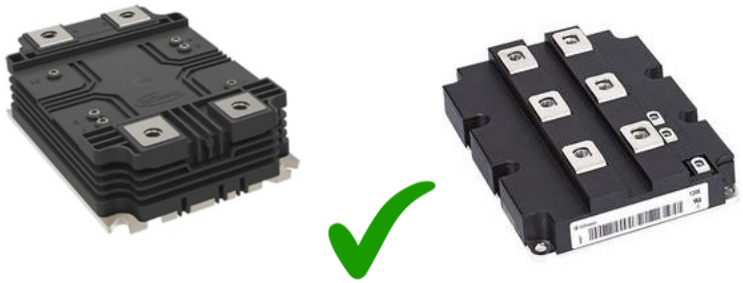
Next-Generation Power Module Patent Landscape

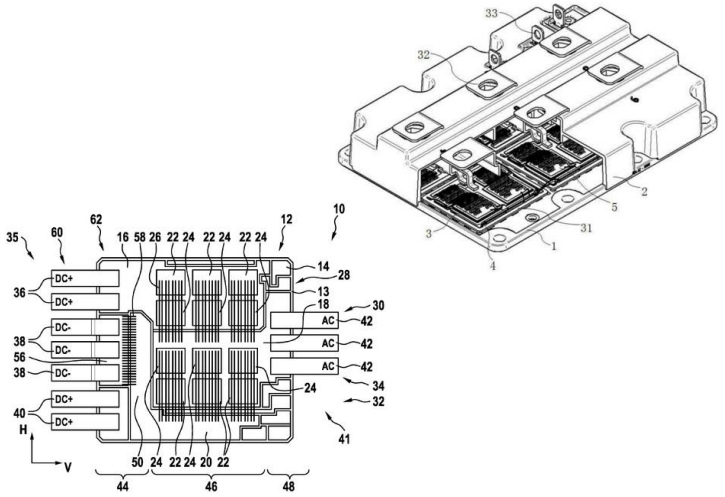
What is a power module patent?

A **power module** consists of an assembly of several power electronics components such as transistors and diodes in **a single package**:

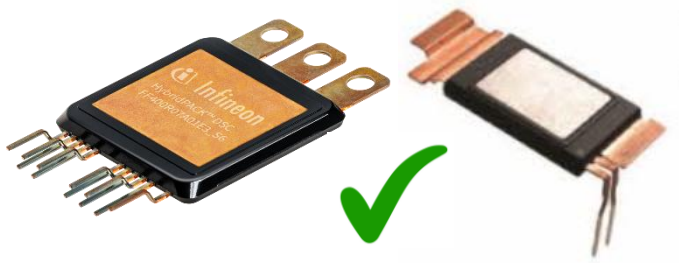
Power Modules



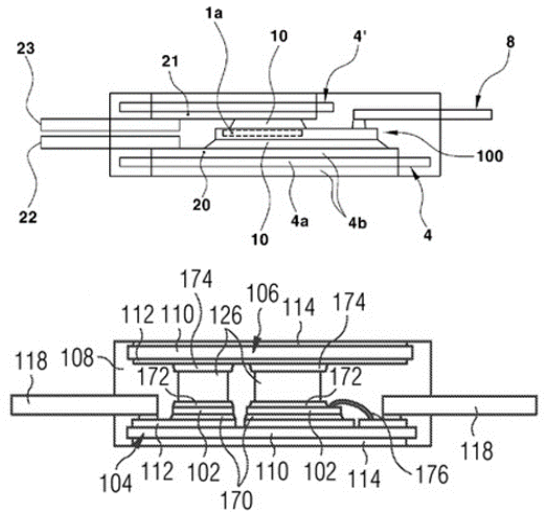
e.g. 6-in-1 power modules



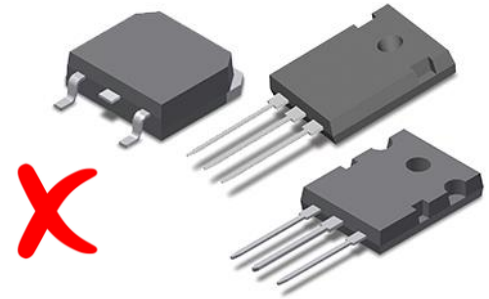
"Discrete-like" power modules



1-in-1 or 2-in-1 power modules



Discrete Power Devices



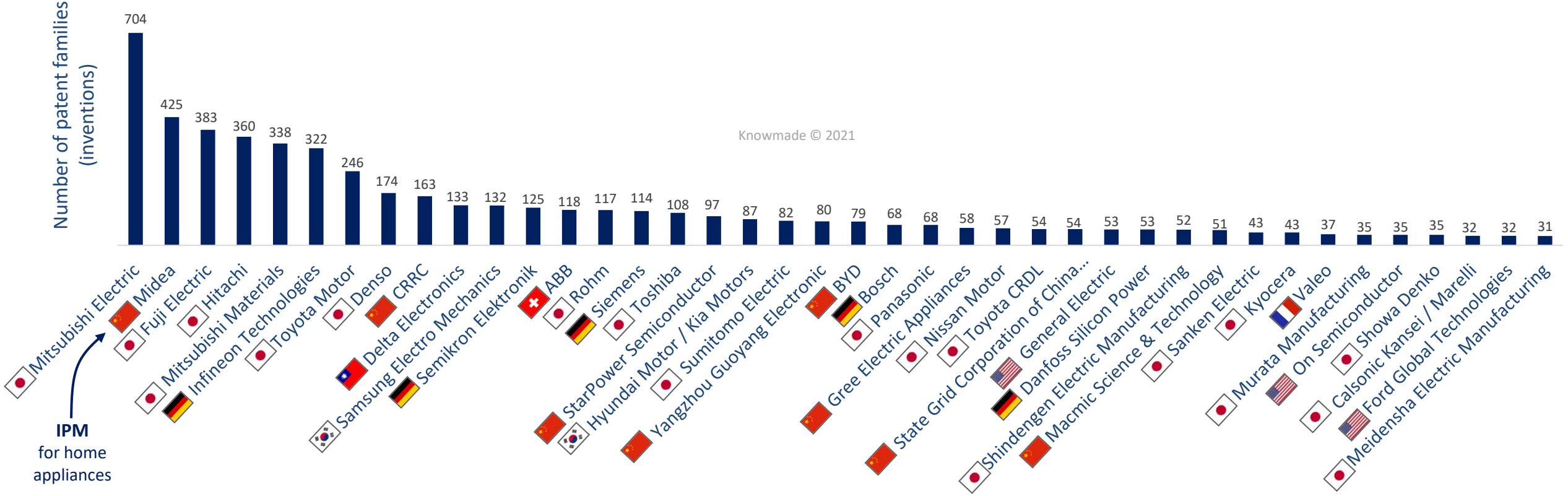
Small-size modules (usually looking like slim "card-like modules") have been identified as a trend in **EV/HEV applications** in the last couple of years.

Next-Generation Power Module Patent Landscape

Main patent applicants

Next-Generation Power Modules

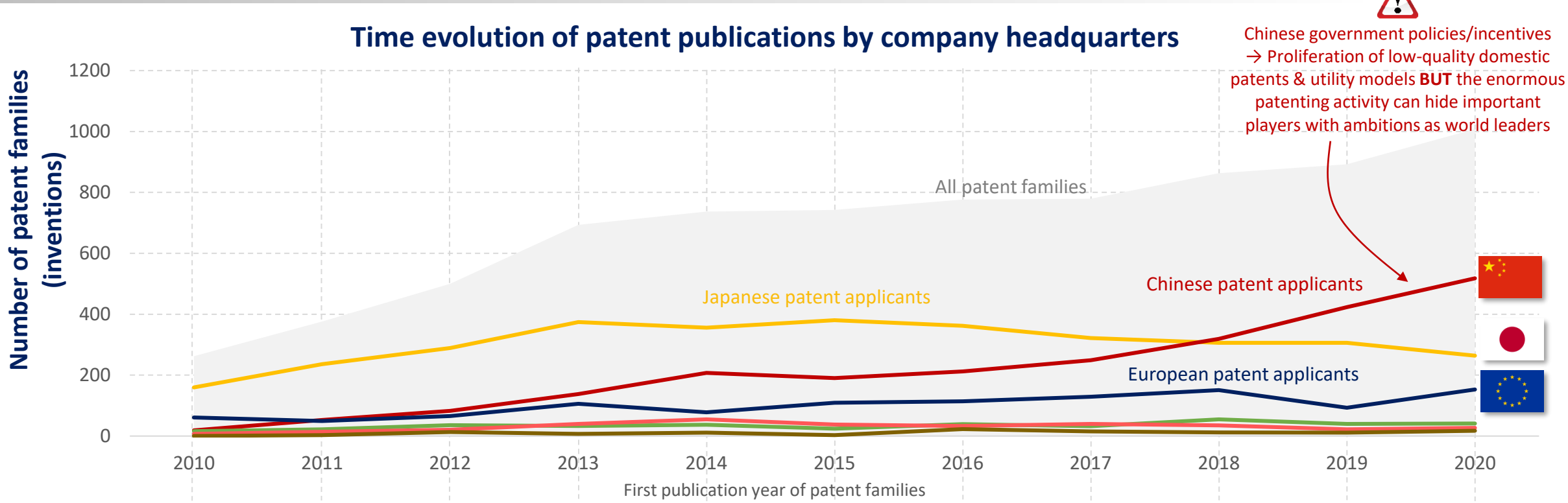
Ranking of patent applicants according to the number of patent families (inventions) published in 2010-2020



- The main players of the **IGBT module market** are well-positioned in terms of patenting activity.
- Japanese IP players domination over the last decade, competing mainly with European and Chinese IP players.

Next-Generation Power Module Patent Landscape

Time evolution of company headquarters



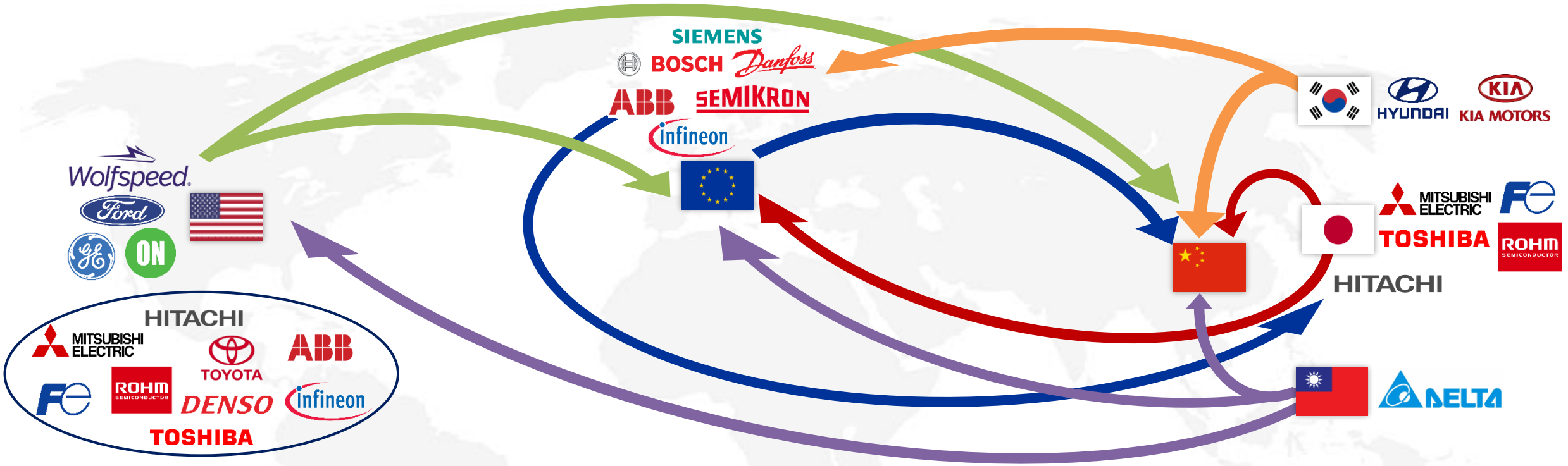
Starting IP activity during the last decade

MITSUBISHI ELECTRIC, HITACHI, MITSUBISHI MATERIALS, TOSHIBA, Infineon, SEMIKRON, Fe, SUMITOMO ELECTRIC, TOYOTA, DENSO, NISSAN, MACMIC, ROHM SEMICONDUCTOR, ABB, SAMSUNG, MEIDEN, Midea, Danfoss, CETC, CRRC, BOSCH, DELTA, SIEMENS, BYD, starpower, Wolfspeed, CalsonicKansei, Ford, GE, HYUNDAI, ShinDengen, muRata, GREE

And more than 30 Chinese IP newcomers in 2019/2020

Next-Generation Power Module Patent Landscape

IP strategies of main patent applicants



Well established patent owners in US

Current IP strategy of main players (pending patent applications)

Next-Generation Power Module

Wide bandgap (SiC, GaN) & EV/HEV applications

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Introduction

How to identify WBG power module patents or patents for EV/HEV applications?

- **Wide bandgap (WBG) power module patents** are based on SiC or GaN power devices. However, this feature is not always explicitly or unambiguously given in patents:

WBG-focused patents

The invention is explicitly directed to WBG power devices (**specific claims** and/or **specific embodiments** for SiC and/or GaN)

✓

WBG-related patents

The invention is explicitly **applicable to WBG power devices but not only**. In most cases, SiC and/or GaN technologies are mentioned in examples alongside other technologies such as Si, diamond, etc.

✓

IGBT module & Generic module patents

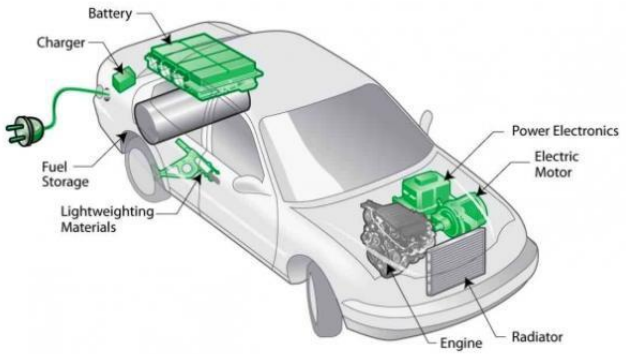
The invention does not mention any preferred semiconductor technology (generic) or refers to non WBG technologies (mainly Silicon IGBT) in claims and/or embodiments.

✗

- **EV/HEV application patents** mention in the description a power module for an **electric drive** (e.g. traction/main inverter, drive motor), and/or a power module for use in **EV charging** of electric vehicles (e.g. charging stations).

Power module for electric drive

✓



Power module for EV charging

✓

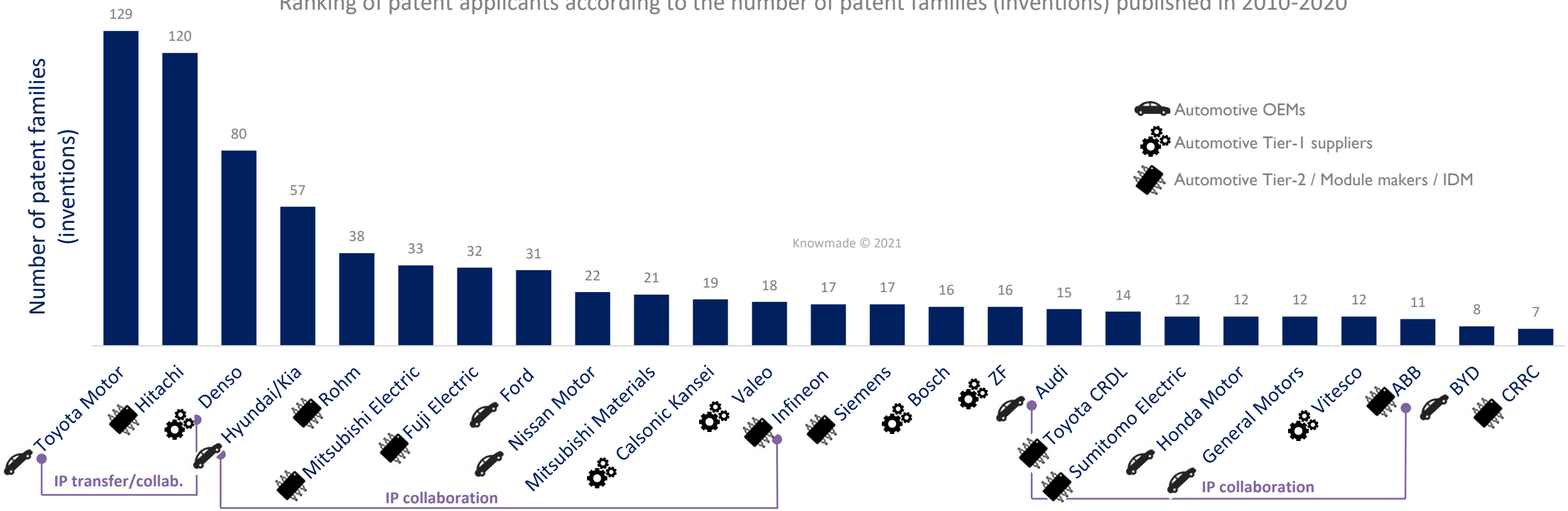
Power Module for EV/HEV Applications

Power Modules for EV/HEV Applications

Main patent applicants

Power Modules for EV/HEV Applications

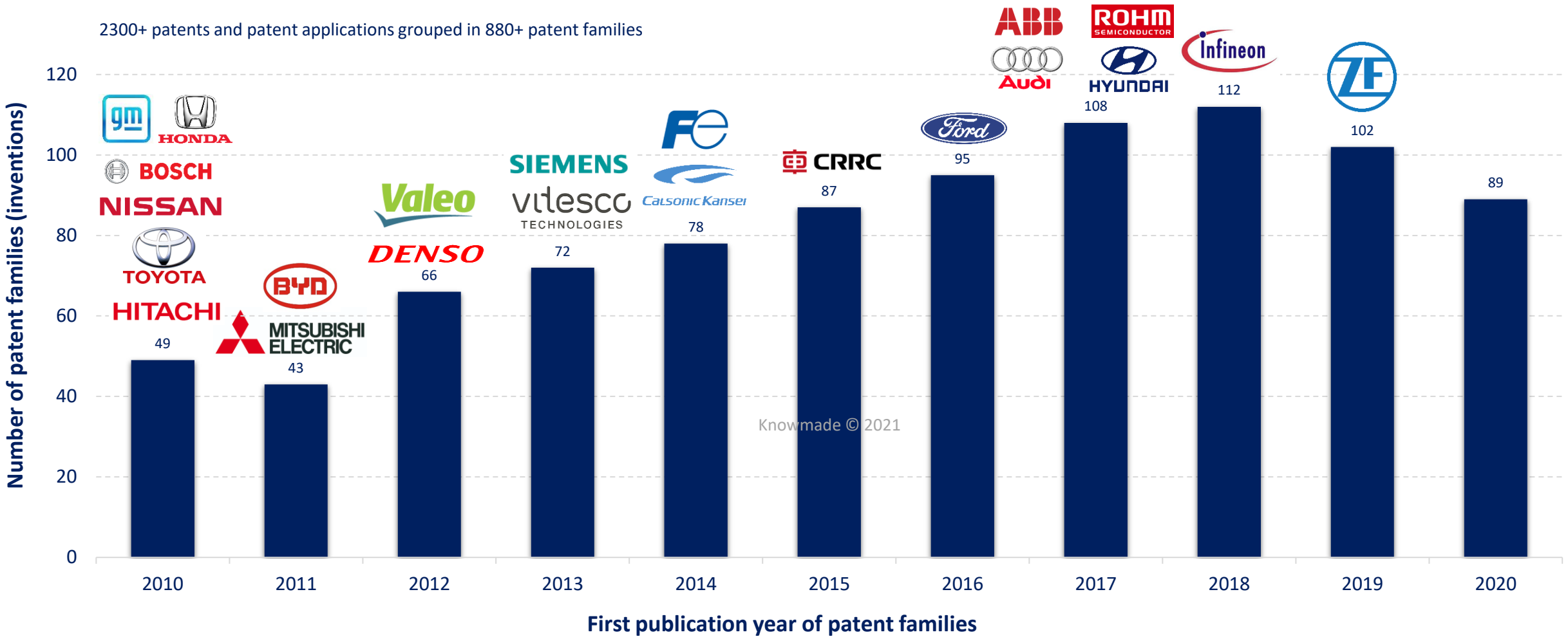
Ranking of patent applicants according to the number of patent families (inventions) published in 2010-2020



Power Modules for EV/HEV Applications

Timeline of patent publications

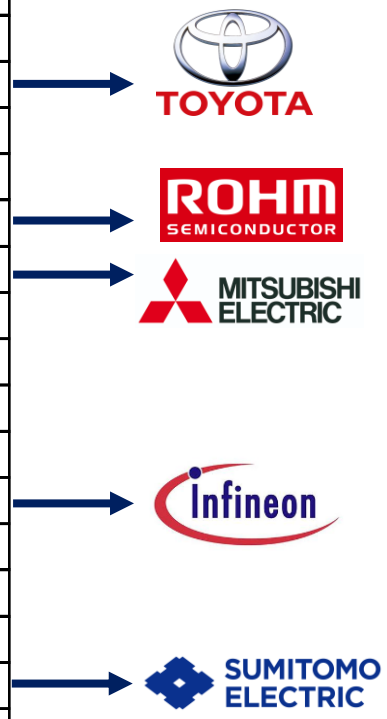
Time evolution of patent publications related to power modules for EV/HEV applications



Power Modules for EV/HEV Applications

EV/HEV applications vs. WBG power modules

Power modules for EV/HEV applications vs. WBG power modules		
Patent applicants	**Number of inventions related to power modules for EV/HEV applications**	**Number of inventions related to WBG power modules**
Hitachi	131	18
Toyota Motor	128	34
Denso	85	17
Hyundai/Kia	57	3
Rohm	38	37
Mitsubishi Electric	33	23
Fuji Electric	32	4
Ford Motor	31	3
Nissan	23	3
Calsonic Kansai	19	1
Infineon Technologies	17	13
ZF	16	1
Audi	15	7
Toyota CRDL	14	8
Sumitomo Electric	12	12
ABB	11	6



IP players focusing on
WBG power modules
for **EV/HEV applications**

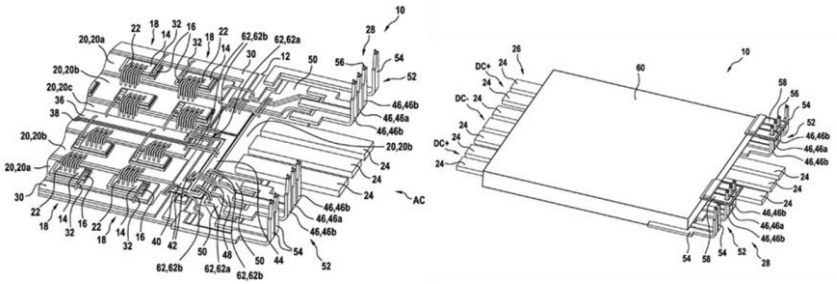
Power Modules for EV/HEV Applications

Focus on ABB/Audi collaboration

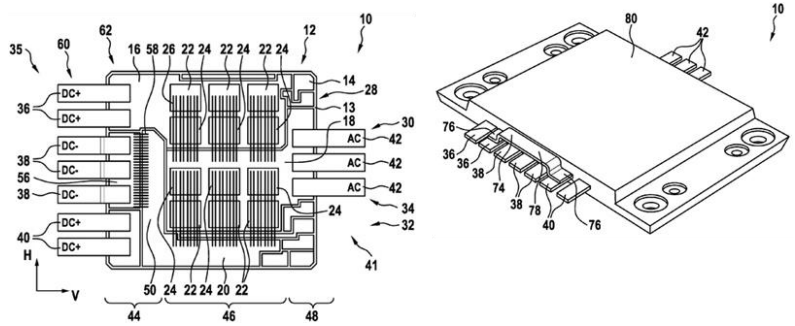
ABB & **Audi** has co-filed at least 70 patent applications between 2015 and 2019, grouped in 17 patent families (inventions), most of them for **EV/HEV applications**:

PATENTS

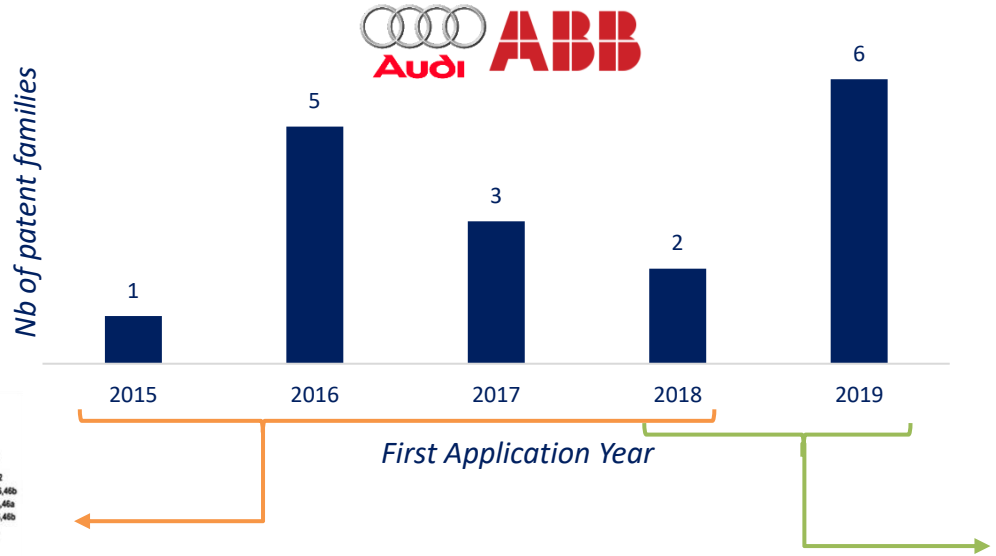
WBG power modules



Reduction of stray inductance



IP collaboration on power module

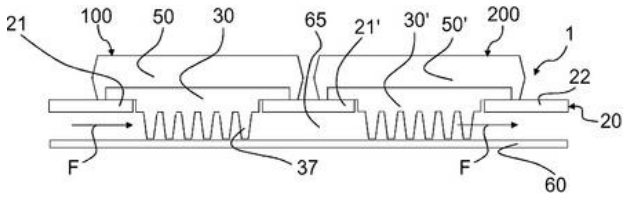


Context of the collaboration

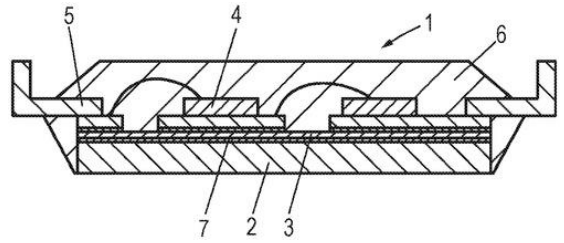
- **Hitachi** announced in 2019 **Audi** will use its EV inverter based on **Hitachi**'s compact DSC IGBT modules in **Audi**'s first mass-produced EV model (e-tron)
- **Audi** made announcements in 2019-2020 of multiple partnerships with **ABB** for the development of the EV charging infrastructure
- In 2019, **ABB** disclosed a new SiC / Si module platform to address EV/HEV performance requirements
- In July 2020, **Hitachi** completed the acquisition of **ABB Power Grids**

PATENTS

Heat dissipation



Molding encapsulation



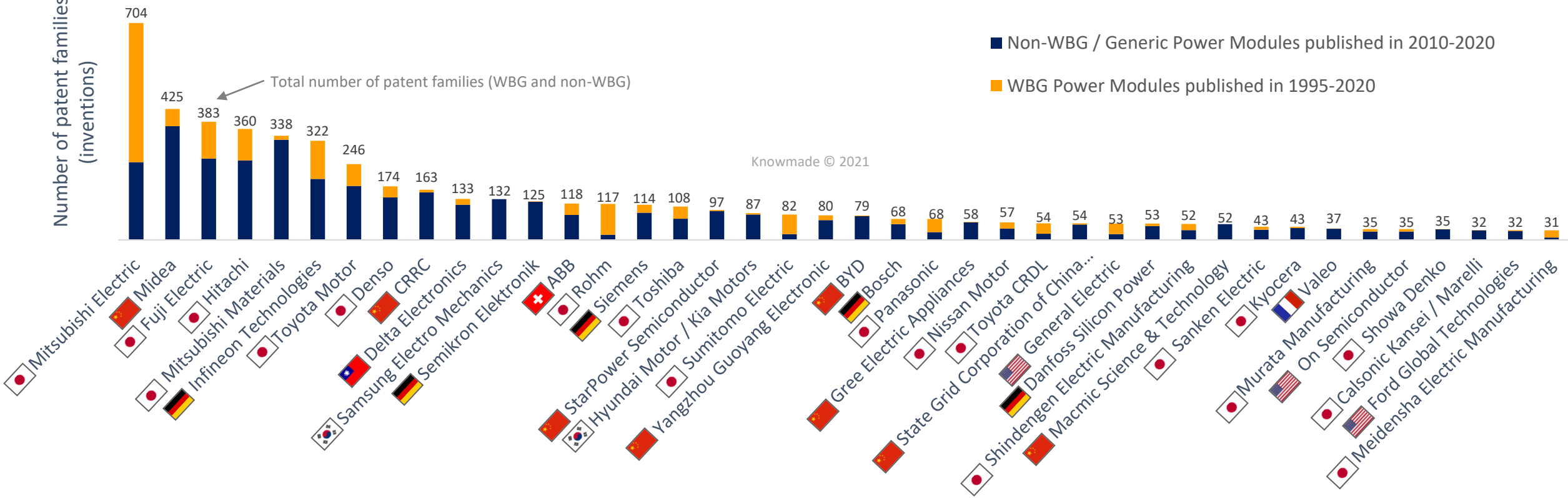
Wide Bandgap Power Modules

WBG Power Modules

Main patent applicants

Next-Generation Power Modules

Ranking of patent applicants according to the number of patent families (inventions)

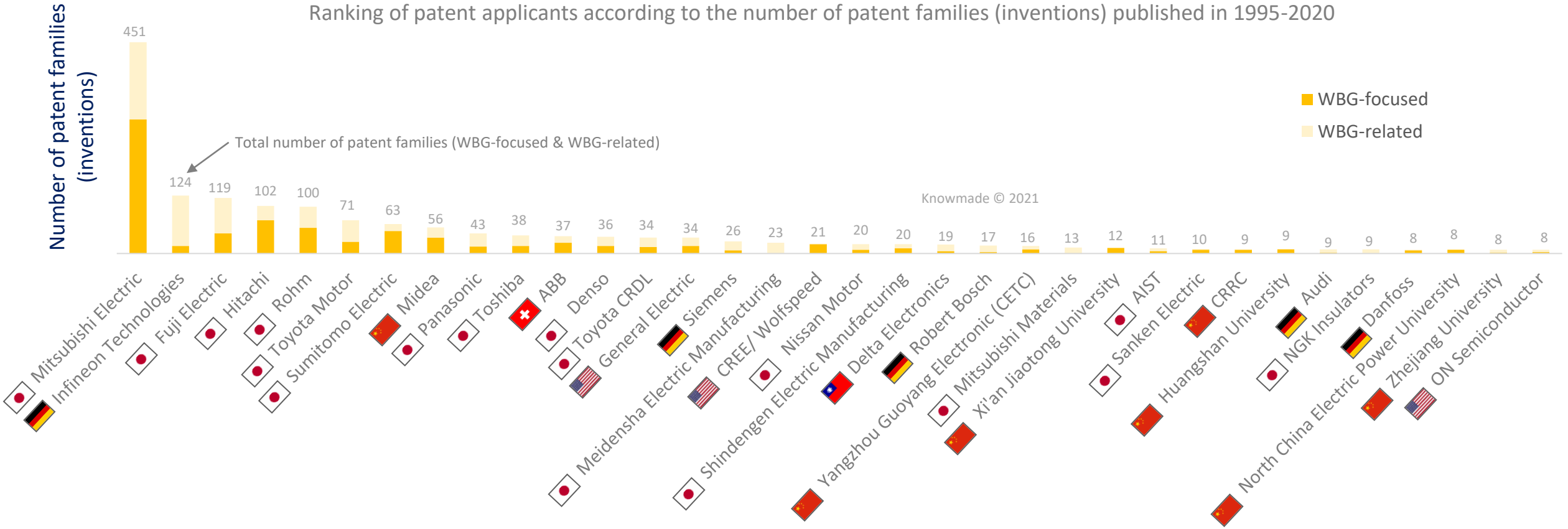


WBG Power Modules

Main patent applicants

Wide Bandgap Power Module Patent Landscape

Ranking of patent applicants according to the number of patent families (inventions) published in 1995-2020



WBG-focused patents: The invention is explicitly directed to WBG power devices (**specific claims** and/or **specific embodiments** for SiC and/or GaN).

WBG-related patents: The invention is explicitly **applicable to WBG power devices but not only**. In most cases, SiC and/or GaN technologies are mentioned in examples alongside other technologies such as Si, diamond, etc.

WBG Power Modules

Timeline of patent publications (main IP players)

Patent applicant	Patent families	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
PANASONIC	43							1	1	1		2	2	2	2		2	6	4	10	5	2		1	1		1
SUMITOMO ELECTRIC	63										1	6	5	5	5	2	1		2	6	4	9	3	3	6	2	3
NISSAN MOTOR	20										2		2							2	2	5	4	1	1		1
INFINEON TECHNOLOGIES	124								1		1	1	1	10	2	4		3	6	12	20	12	10	13	17	5	6
TOYOTA CRDL	34												1	3	5	2	2		1		1	2	1	1	2	12	1
SIEMENS	26											2		1	1	2	1	1				4	2	3	5	2	2
MEIDENSHA ELECTRIC MANUFACTURING	23																	1	4	8	3	5	1	1			
MITSUBISHI MATERIALS	13										1	1		1						1	3			2	2	1	1
AIST	11														1	1		1	1	1	3			1		2	
SANKEN ELECTRIC	10																		2	2	3	1	1			1	
NGK INSULATORS	9																		2	4	1	1		1			
NGK SPARK PLUG	8											1								2	1	1	3				
SAMSUNG ELECTRONICS	8																	2		1	1	4					
MITSUBISHI ELECTRIC	451							1	1	3	2	1		2	1	1	9	29	35	48	32	67	54	52	46	47	20
HITACHI	102						1					1		3	2	1	1	2	4	4	4	17	23	20	7	7	5
TOSHIBA	38											3		1			1			3	5	7	4	4	3	6	1
DENSO	36												1		3				4	7	1	1	4	5	2	2	6
CREE / WOLFSPEED	21	1																1		2		3	3	4	4	1	2
CRRC	9																	3		1			1	1		2	1
FUJI ELECTRIC	119												1		1				9	11	19	11	17	20	5	10	15
ROHM	100															2	1	3	4	13	10	12	9	11	14	10	11
TOYOTA MOTOR	71											2	2	1	2	4	2		2	6	4	4	3	4	4	20	11
ABB	37	1				1												1			1	2	9	8	12	1	1
GENERAL ELECTRIC	34												1	1	1		1	1	1	2	2	1	5	4	10	2	2
ROBERT BOSCH	17																2			1	1	1	2	8	1		1
ZHEJIANG UNIVERSITY	8																				4				2	1	1
MURATA MANUFACTURING	8														1				1		1			2	1	2	
DELTA ELECTRONICS	19																			1	2	1	3	6	2		4
YANGZHOU GUOYANG ELECTRONIC	16																						2	7	6	1	
MIDEA	56																					1	1	10	15	27	2
XI'AN JIAOTONG UNIVERSITY	12																				3	1				4	4
AUDI	9																							4	4	1	
DANFOSS	8																			1					4		3
NORTH CHINA ELECTRIC POWER UNIVERSITY	8																							2	2	2	2
ON SEMICONDUCTOR	8																	1						1	1	3	2
DENKA	8																			1				1	1	5	
SHINDENGEN ELECTRIC MANUFACTURING	20																								9	10	1
HUANGSHAN UNIVERSITY	9																									9	

First publication year of the family

Earliest patent applicants

IP transfer

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SUMITOMO ELECTRIC

Infineon (acquired 20+ inventions from IQE in 2015)

SIEMENS

Now less active: SanKen, Panasonic, NISSAN, MITSUBISHI, MITSUBISHI MATERIALS, AIST, MEIDEN

MITSUBISHI ELECTRIC

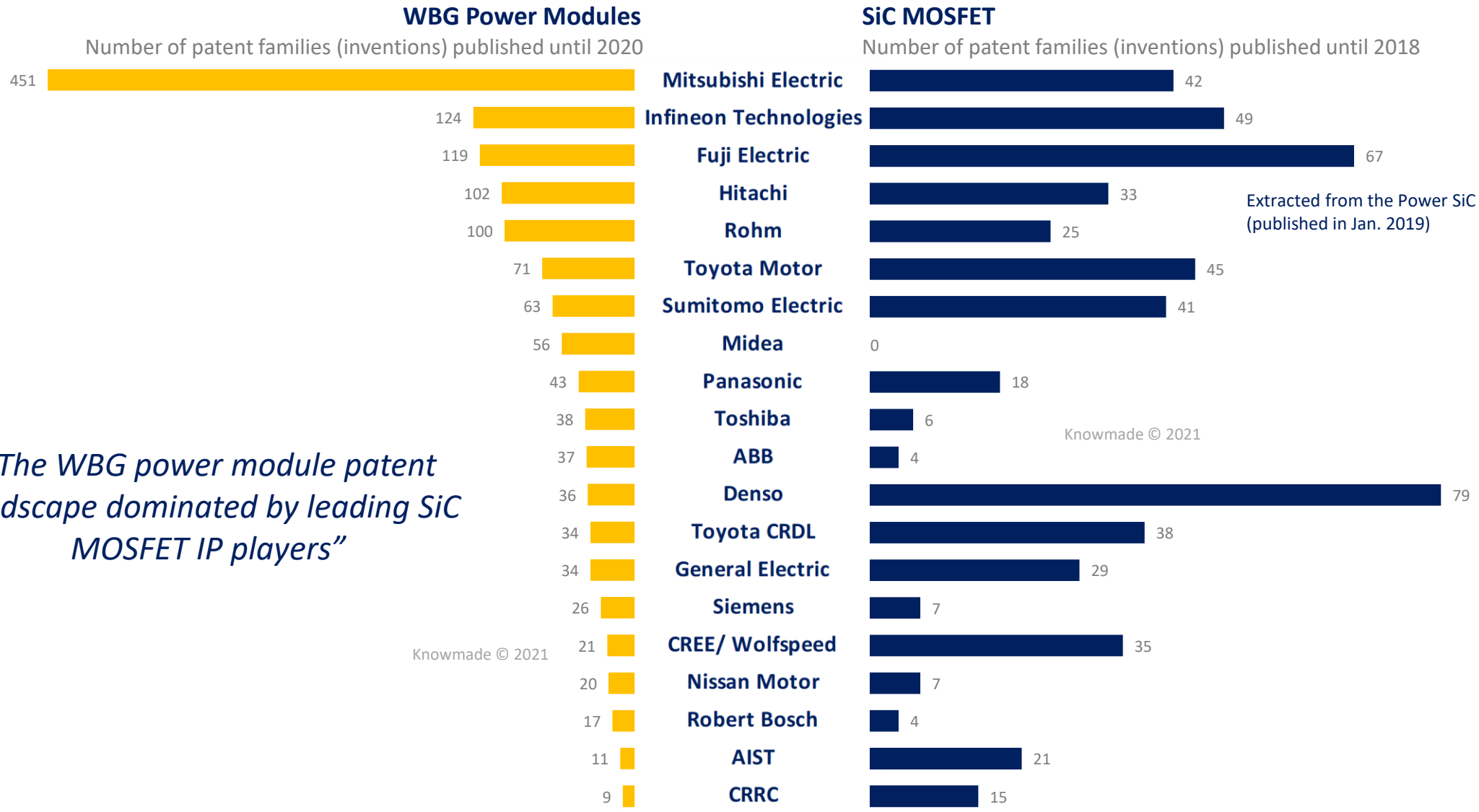
HITACHI

Fe, ROHM SEMICONDUCTOR, TOYOTA, ABB, GE

Newcomers in the WBG Power Module Patent Landscape: Audi, ON, DELTA, Danfoss, Midea, ShinDengen, CETC

WBG Power Modules

WBG power modules vs. SiC MOSFET

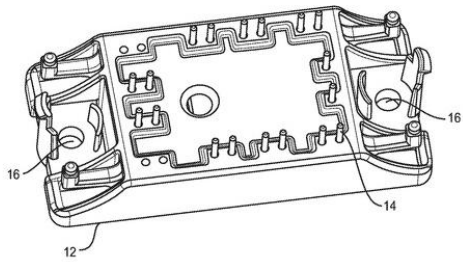


"The WBG power module patent landscape dominated by leading SiC MOSFET IP players"

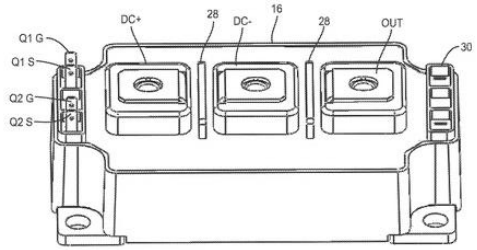
WBG Power Modules

Pure WBG player: Cree/Wolfspeed's patents

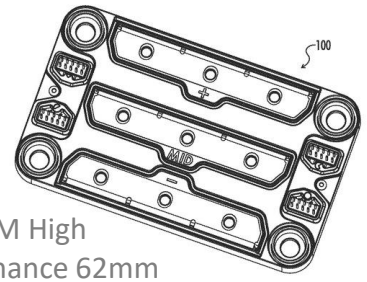
Cree/Wolfspeed is a fairly new IP player in the Power Module Patent Landscape, which started actively filing patents after the acquisition of **Arkansas Power Electronics International** (**APEI**).



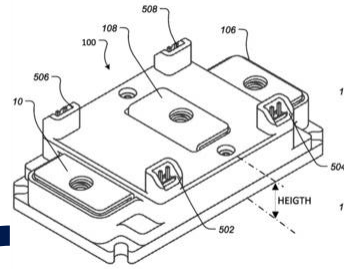
45mm



62mm



HM High Performance 62mm

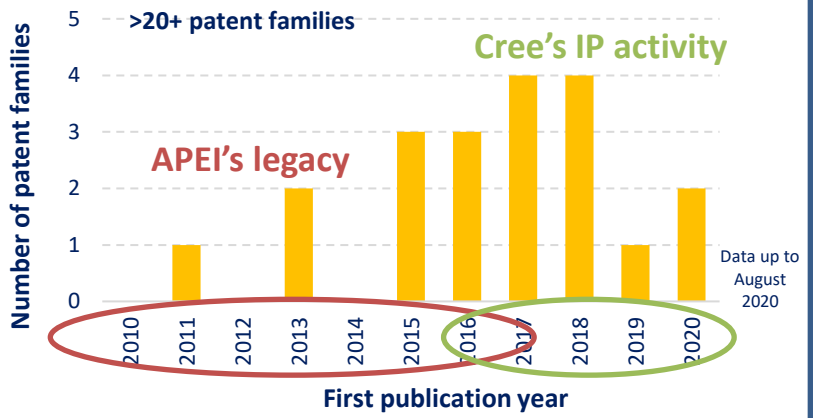


XM3

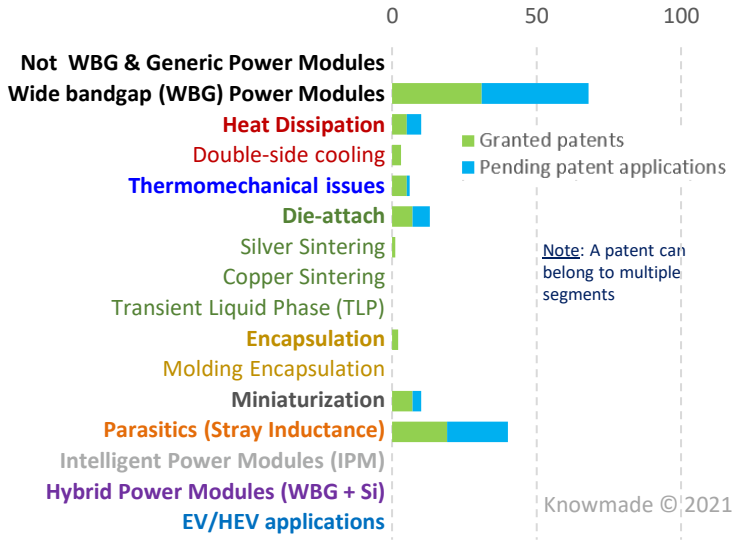
> 10 related documents (design, patent applications, etc.)

- Highly optimized to achieve the maximum performance out of all sizes of commercially available 650-1700V **SiC MOSFETs**
- Capability to carry high currents (300 to > 600 A) in **a small footprint** (53 mm x 80 mm)

Time evolution of the patenting activity



Segmentation of the patenting activity

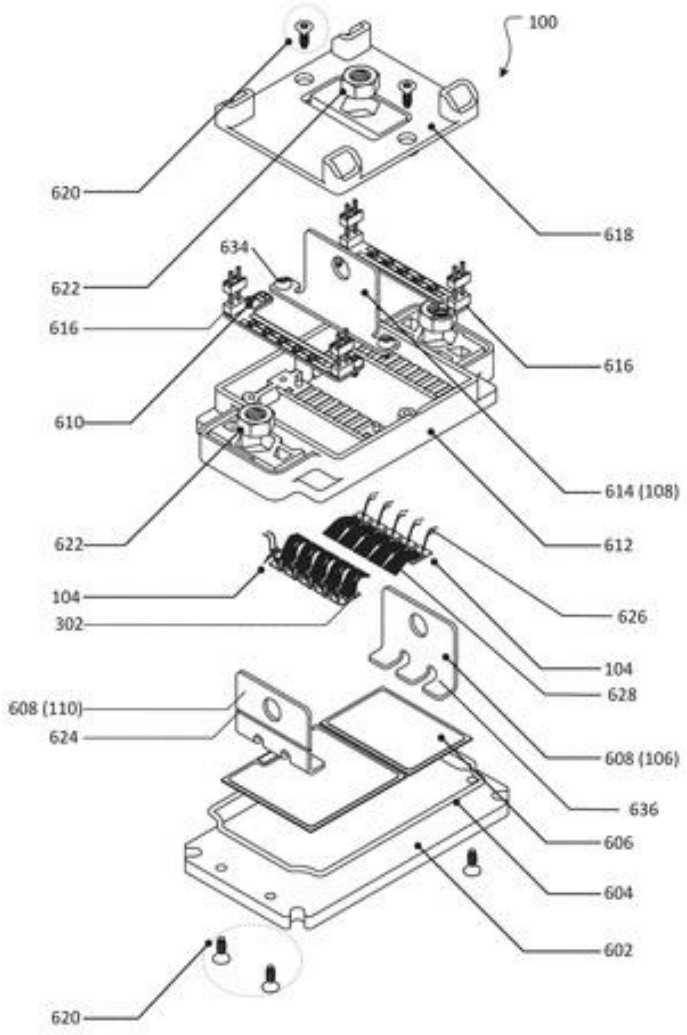


WBG Power Modules

Pure WBG player: Cree/Wolfspeed's patents

Wolfspeed | A CREE COMPANY

High-power Low-inductance Fast-switching power module



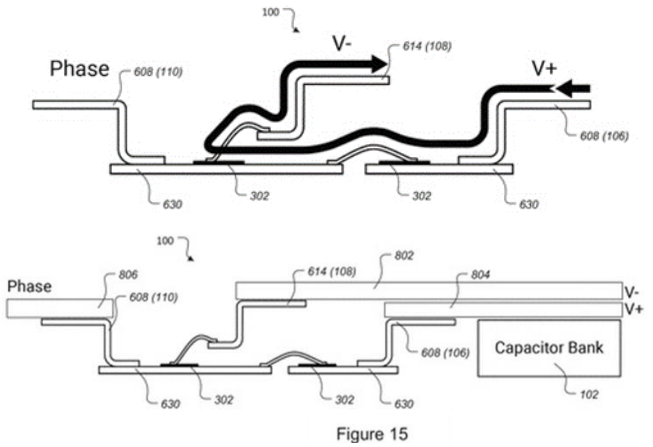


Figure 15

Reduction of parasitic inductance
(multilevel current path, laminated buss bars)

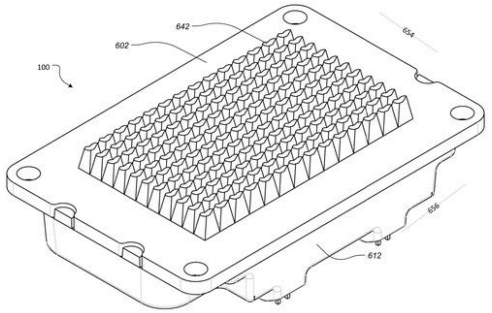
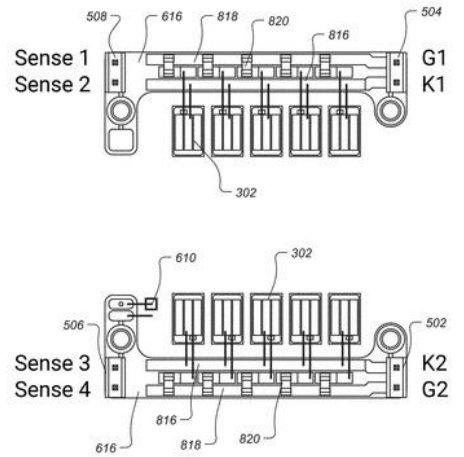
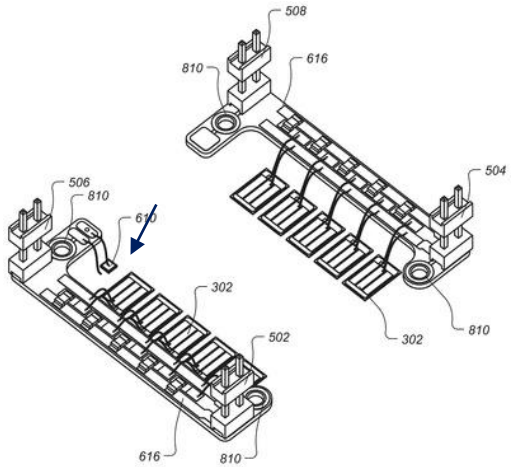


Figure 43

Heat dissipation
(pin-fin baseplate for direct cooling)



Parallelization of power devices
(uniform current sharing)



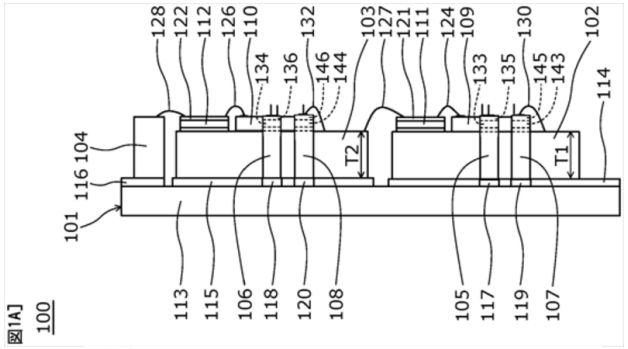
Sensors (temperature, diagnostic)

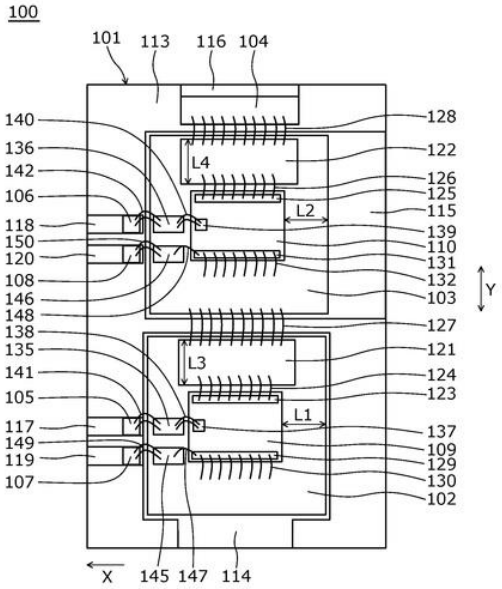
WBG Power Modules

Examples of recent GaN power module patents (2020)

Panasonic

- **Heat dissipation** at high-power/high-speed
- High-frequency characteristics (**stray inductance**)
- **Small-size** GaN power chips





GaN Systems

Low-profile, low-inductance power modules for **ultra-fast GaN-HEMTs**:

- Low-inductance terminals for gate and source-sense connections
- Low inductance gate drive loop
- Low inductance path for high-frequency current and balance inductances of the power commutation loops for each switch

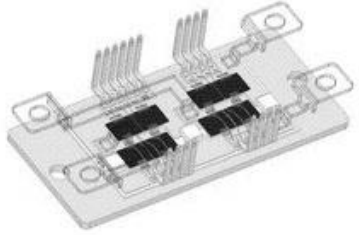


Fig. 21A
(Prior Art)

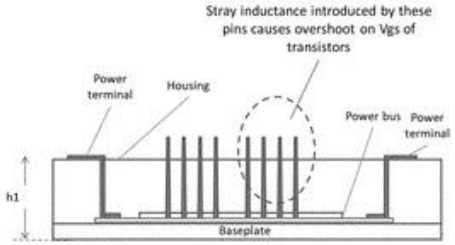


Fig. 21B
(Prior Art)

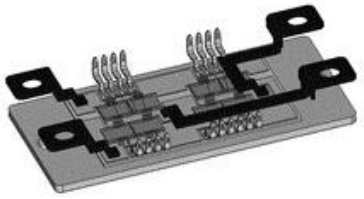


Fig. 21C

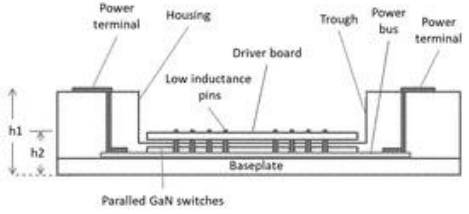
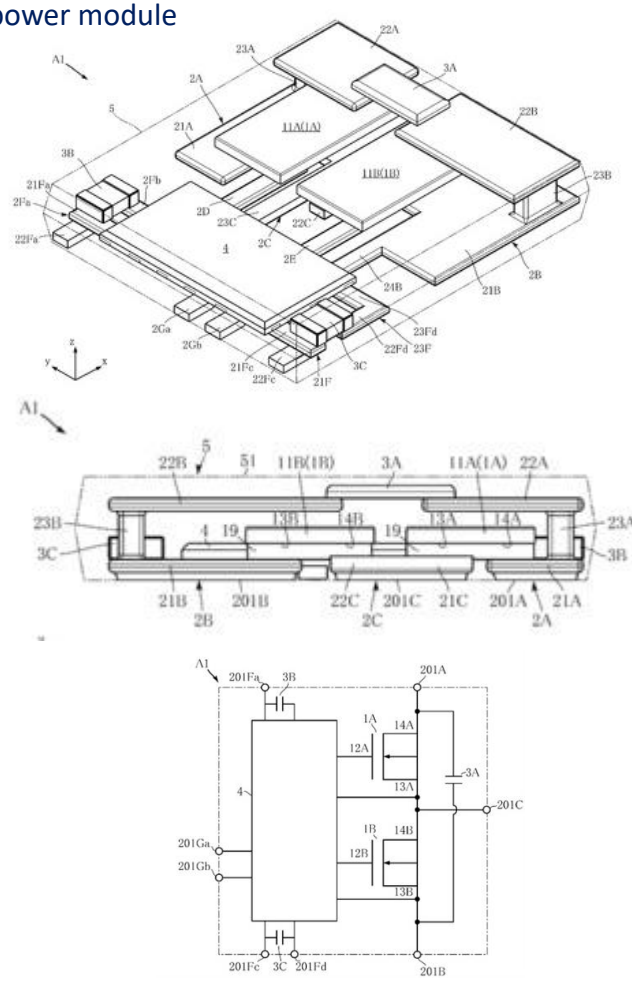


Fig. 21D

ROHM SEMICONDUCTOR

- Suppression of **surge voltage** in a half-bridge power module



Conclusion

Conclusions

Next-Generation Power Module Patent Landscape

Japanese IP players' domination

MITSUBISHI ELECTRIC · Midea · Fe · HITACHI · MITSUBISHI MATERIALS · Infineon · DENSO · TOYOTA

Chinese IP players lead the current IP activity

EV/HEV downstream supply chain members

vitesco TECHNOLOGIES · Calsonic Kansei · HYUNDAI · BOSCH · Ford · TOYOTA · NISSAN · DENSO · Audi · BYD · ZF · Valeo

Next-Generation Power Module Patent Landscape

Main patent applicants increase focus on Europe

Strong acceleration in WBG power modules

MITSUBISHI ELECTRIC · Infineon · Fe · HITACHI · ROHM SEMICONDUCTOR · TOYOTA · SUMITOMO ELECTRIC

SiC MOSFET IP players

ROHM SEMICONDUCTOR · Wolfspeed · GE · SUMITOMO ELECTRIC

THANK YOU!

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Patent Landscape Analysis

Power SiC (2019)
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GaN for Power & RF
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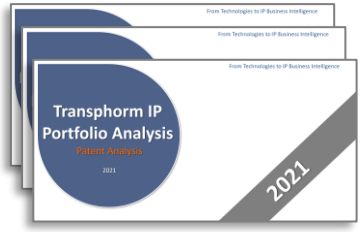
Transphorm IP Portfolio Analysis
Navitas IP Portfolio Analysis
…



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Competitive landscape | Technology trends | Opportunities / Risks | R&D and IP strategy

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Evaluate the risks to infringe patents

Prior art search, Freedom-to-operate analysis, Patent invalidation, Evidence of use, Patent valuation

Understand, anticipate and evaluate the competitive landscape and current technology developments

Patent landscape, Monitoring service, IP due diligence

Improve your R&D and IP strategy

Identify and get access to external innovation

Technology scouting, Scientific literature analysis

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