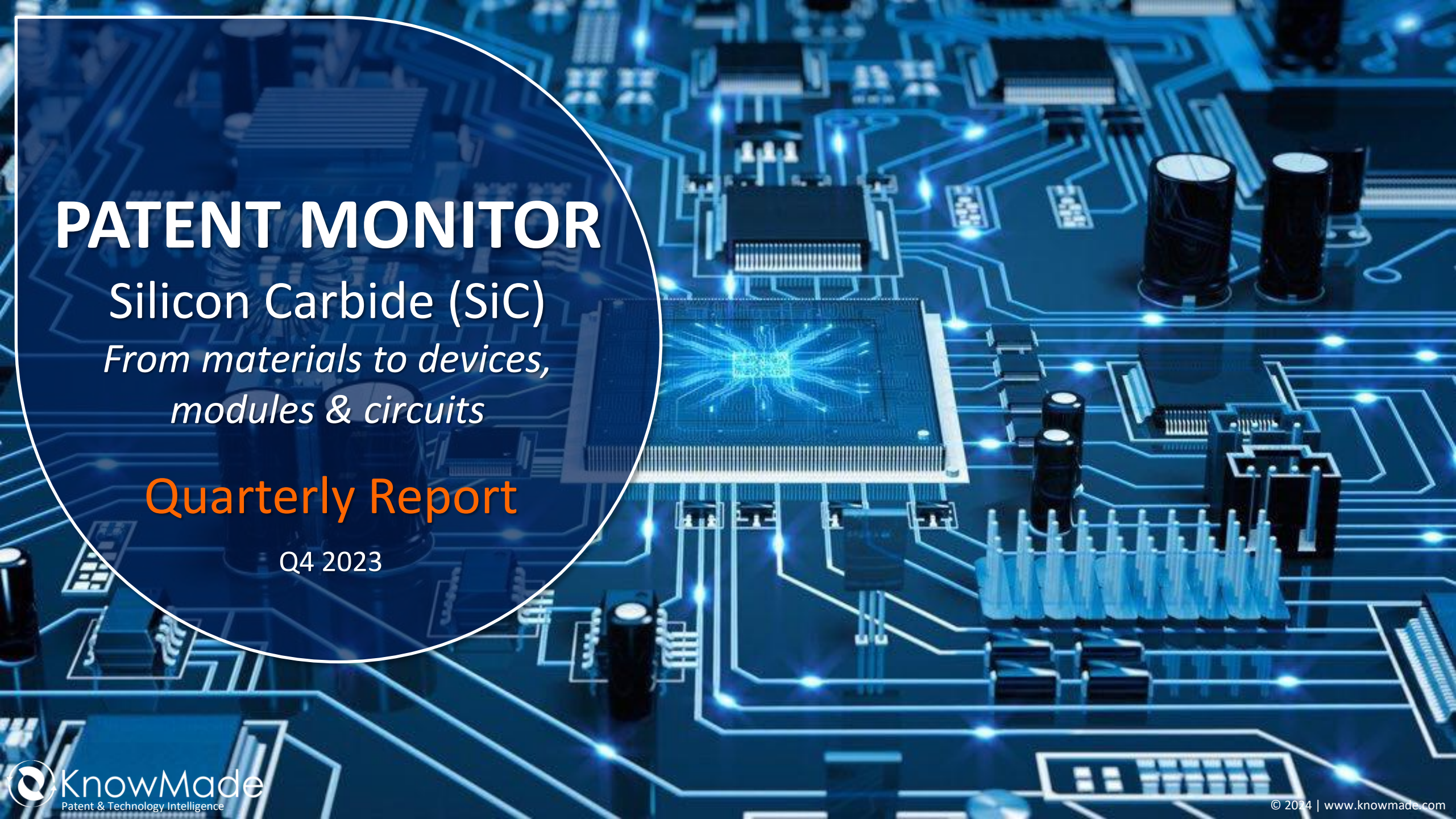

PATENT MONITOR

Silicon Carbide (SiC)

From materials to devices, modules & circuits

Quarterly Report

Q4 2023

KnowMade
Patent & Technology Intelligence

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IP activity of the quarter and description of key patents.

- ROHM
- Infineon
- Sumitomo Electric
- Mitsubishi Electric

INTRODUCTION

INTRODUCTION

Context

In the Silicon Carbide (SiC) IP landscape 2022, KnowMade pointed out that the global intellectual property (IP) competition for SiC power devices was on the rise. On the one hand, many well-established IP players and IP leaders, that used to focus on certain regions to protect their inventions, were now patenting their inventions in additional geographical areas, especially in Europe and China. As electric vehicles (EV) were driving the emerging power SiC market, companies had been adapting their IP strategies accordingly. On the other hand, notable market players that hadn't been significantly involved in the patenting activity, started protecting new inventions related to SiC power devices. Considering the level of investments that have been required to establish a robust SiC supply chain, patents may be an important tool for early SiC companies to secure their market share as new competitors enter the market.

Furthermore, Chinese research organizations and companies have progressively ramped up their inventive activity since 2015. In 2023, Chinese players have produced more than 70% of all power SiC patent publications. In 2022, KnowMade released an analysis of the emerging Chinese SiC ecosystem based on the patenting activities of Chinese players across the SiC supply chain. Even though the quality of such patents may be questioned, this situation brings about new challenges for global competitors in the semiconductor market looking to develop their manufacturing and business activities in China.

In 2021, two of the main early players in the power SiC market were sued by a US academic player, leveraging two fundamental patents related to **planar MOSFET technology**, to seek damages and get potential royalties from its IP. In the next few years, more litigations cases are expected between SiC players, as most of the main players in the SiC power device landscape have significantly improved their IP position since 2022, in terms of granted patents. The acceleration of IP activities is even more sensitive for **trench MOSFET technology**, which may become one of the main directions for power SiC market. Yet it has become a very busy IP space, making difficult for challengers to protect new gate trench designs.

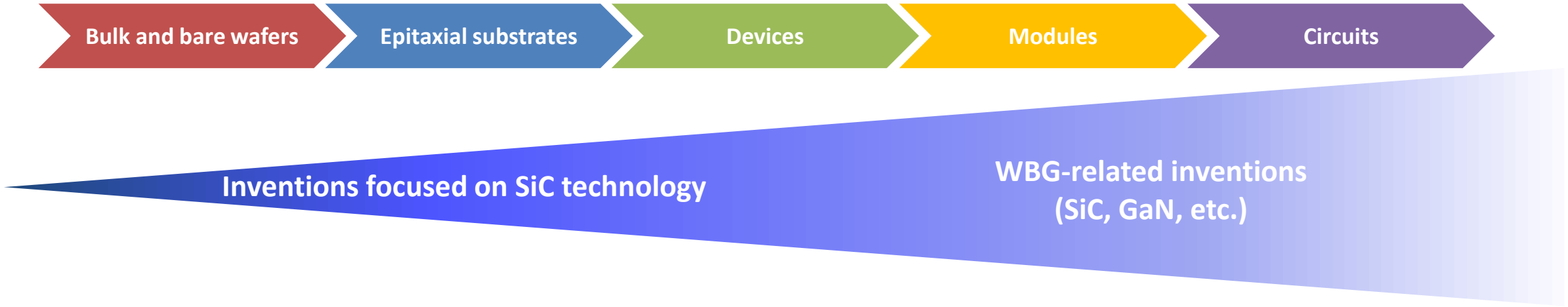
Importantly, several players apparently lack an IP strategy consistent with their ambitions in the power SiC market. This situation suggests that important moves (IP/manufacturing partnerships, M&A, …) are yet to come, further reshaping the SiC patent landscape.

In this context, it is crucial to monitor patent activity and IP strategies of key players. Such knowledge can assist in understanding your competitors' R&D roadmap and strategies, evaluate the risks, and detect business opportunities. The **SiC patent monitoring service** allows you to take advantage of a **quarterly-updated Excel database** and benefit from both **quarterly analysis reports** and **direct interaction with our analysts**.

METHODOLOGY

Research strategy and scope of the patent monitor

Due to different strategies of patent filings across the supply chain, the scope of the patent selection must be tuned according to the position in the supply chain, as illustrated below:



Included

- SiC substrate patents describing growth apparatus for **crystal growth (bulk)** and **epitaxial growth (thin films)**.
- SiC substrate patents related to **wafering (slicing, finishing)**.
- SiC substrate patents describing **SiC-on-SiC epitaxial structures**.
- SiC device patents describing **electronic devices** (MOSFET, IGBT, JFET, diodes, etc.).
- Power module patents describing **based on WBG devices**.
- WBG circuit patents describing **circuits and operating methods specific to SiC devices**.
- WBG circuit patents describing **driver and protection circuits for Wide bandgap (WBG) devices**.

Excluded

- Substrate patents claiming different materials in addition to SiC (i.e., generic patents)
- SiC substrate patents describing **heterostructures (SiC-on-X, X is not SiC)**
- SiC device patents describing **other devices (optoelectronic devices, sensors, MEMS, etc.)**
- WBG power module patents including specifically **GaN devices.**
- WBG circuit patent describing **circuits and operating methods not specific to SiC devices**.
- WBG circuit patent describing **driver and protection circuits for GaN specifically.**

METHODOLOGY

Segment definition

Patents were categorized according to their current legal status, and their technologies/applications

SEGMENTATION BY LEGAL STATUS & EVENT

NEW PATENT FAMILIES: Patent families published for the first time during the quarter (extensions from older patent families are excluded).

PATENT FAMILIES NEWLY GRANTED: Patent families granted for the first time during the quarter (granted patents from older patent families containing already granted patents are excluded).

PATENTS NEWLY EXPIRED/ABANDONED: Granted patents expired or abandoned during the quarter.

IP COLLABORATIONS: Patent co-filed by different entities.
PATENT TRANSFER: Re-assignments (change in patent ownership) during the quarter.
LITIGATION/OPPOSITION: Patent litigation in US and oppositions in Europe.

TECHNICAL SEGMENTATION

Value chain segmentation*:*

- **Bulk SiC**
- **SiC epitaxial substrates**
- **Devices**
- **Modules & Packaging**
- **Circuits & applications**

Technical segmentation*:*

- **SiC substrate:** Growth apparatus, finishing and slicing
- **SiC devices:** SiC diodes, SiC MOSFET (planar, trench)
- **SiC packaging and modules:** Thermal issues, parasitics, die-attach, encapsulation

PATENT MONITOR

Take advantage of quarterly updates on IP activities

CONTENTS

Quarterly IP database (Excel file)

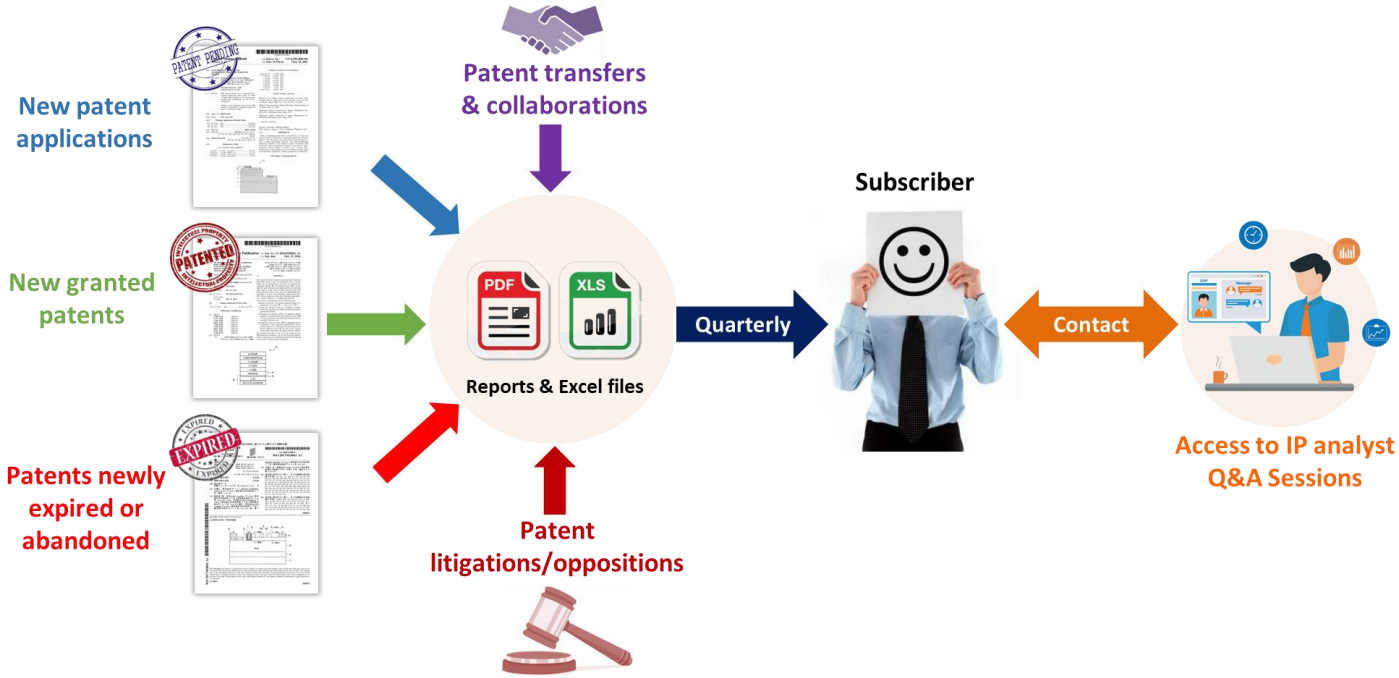
- New patent families
- Patent families granted for the first time
- Patents newly expired or abandoned
- Transfer of IP rights (re-assignment, licensing)
- Patent litigation and opposition
- Patents categorized by technology, supply chain segment, application, etc.

Quarterly IP report (PDF slide deck)

- Key fact & figures of the quarter
- Graphs and comments covering the patent landscape evolutions
- A close look at the key IP players, newcomers, and key patented technologies

Access to IP analyst (100h per year)

- Q&A session and discussion with our IP analysts regarding the quarterly report results, trends, analyses, specific patented technologies or companies' patent portfolios in the field of the patent monitor.



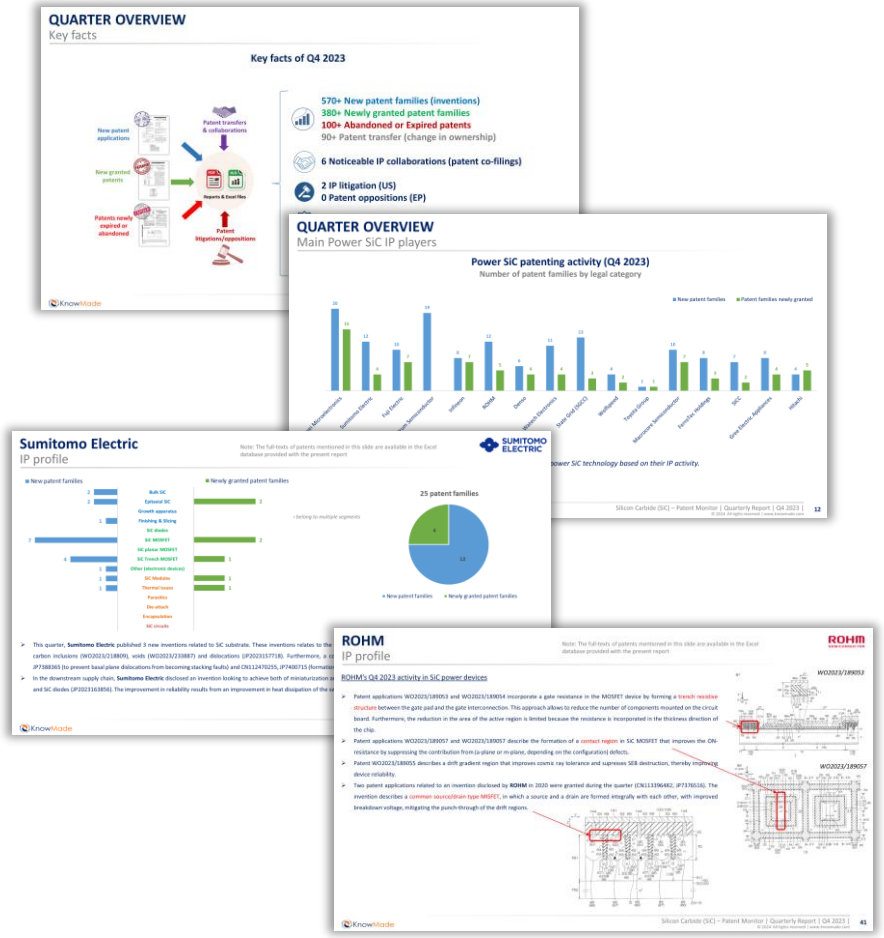
WHY YOU SHOULD SUBSCRIBE

- ✓ Track your **competitors**, partners or clients
- ✓ Identify **newcomers** to your technology field
- ✓ Early detect **opportunities** and risks for your business strategy
- ✓ Be ahead of **technology trends**
- ✓ Identify emerging research areas and **cutting-edge technology** developments
- ✓ Mitigate patent **infringement risks**
- ✓ Take advantage of **free technologies**

PATENT MONITOR
Quarterly report

On a quarterly basis, this report will provide the IP trends over the last three months, with a close look to key IP players and key patented technologies.

- Main patent applicants, their notable patent filings and technologies.
- New entrants and their patents.
- Technology trends and notable patented technical solutions.
- Key patents newly granted, their owners and claimed inventions.
- Main IP right transfers (reassignments, licensing agreements).
- Key patents newly expired or abandoned, their owners and their potential market impact.
- Noteworthy news on patent litigation and opposition, plaintiffs and defendants, patents and products involved.

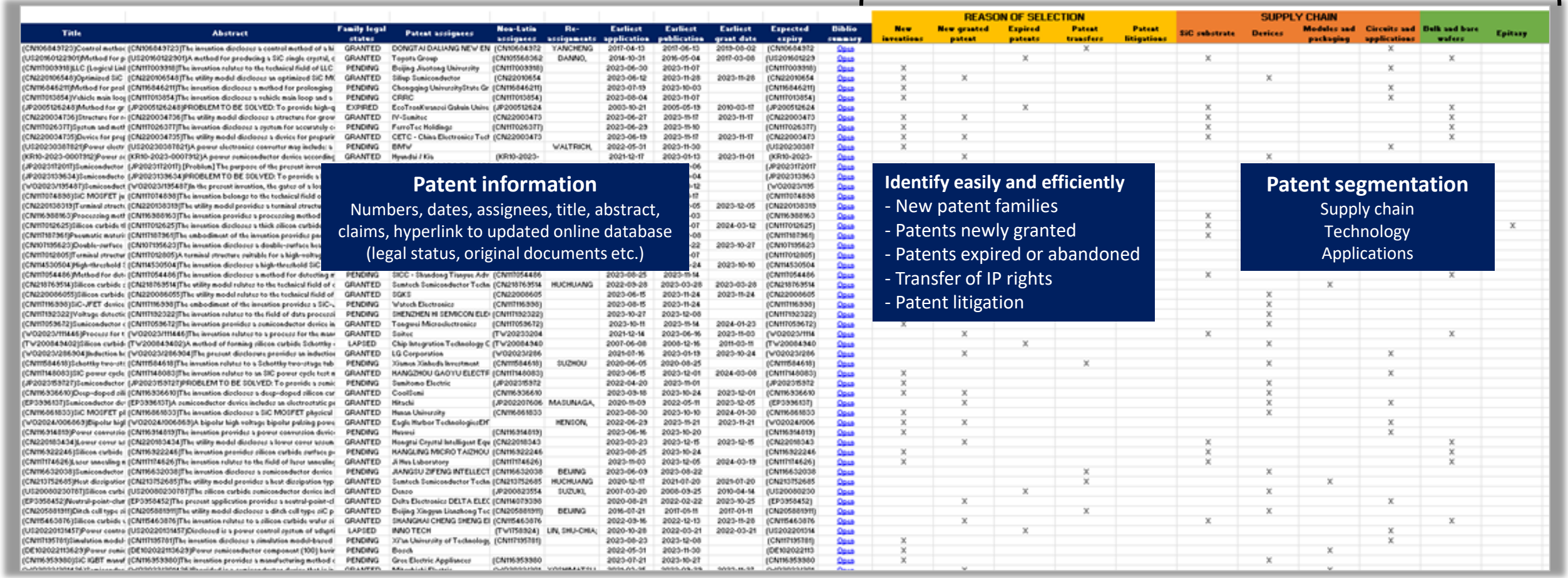


PATENT MONITOR

Quarterly IP database

Segments

(a X indicate a patent belonging to the segment)



Title	Abstract	Family legal status	Patent assignees	Non-Latin assignees	Re-assignments	Earliest application	Earliest publication	Earliest grant date	Expected expiry	Biblio summary	REASON OF SELECTION: New inventions	New granted patent	Expired patents	Patent transfers	Patent litigations	SUPPLY CHAIN: SiC substrate	Devices	Modules and packaging	Circuits and applications	Bulk and bare wafers	Epitaxy
(CN106843723)Control method	(CN106843723)The invention discloses a control method of a hi	GRANTED	DONGTAI DALIANG NEW EN	(CN106843723)	YANCHENG	2017-04-13	2017-06-13	2019-08-02	(CN106843723)	Opus				X					X		
(US20160122901)Method for p	(US20160122901)A method for producing a SiC single crystal, c	GRANTED	Toyota Group	(CN105568362)	DAINO,	2014-10-31	2016-05-04	2017-03-08	(US20160122	Opus			X			X				X	
(CN111003918)LLC (Logical Lin	(CN111003918)The invention relates to the technical field of LLC	PENDING	Beijing Jiaotong University	(CN111003918)		2023-06-30	2023-11-07		(CN111003918)	Opus	X								X		
(CN220106548)Optimized SiC	(CN220106548)The utility model discloses an optimized SiC MC	GRANTED	Silmp Semiconductor	(CN220106548		2023-06-12	2023-11-28	2023-11-28	(CN220106548	Opus	X	X					X				
(CN116846211)Method for prol	(CN116846211)The invention discloses a method for prolonging	PENDING	Chongqing UniversityState Gr	(CN116846211)		2023-07-19	2023-10-03		(CN116846211)	Opus	X								X		
(CN111013854)Vehicle main loop	(CN111013854)The invention discloses a vehicle main loop and s	PENDING	CRRC	(CN111013854)		2023-08-04	2023-11-07		(CN111013854)	Opus	X								X		
(JP2005126248)Method for gr	(JP2005126248)PROBLEM TO BE SOLVED: To provide high-q	EXPIRED	EcoTronKyosaci Gakuin Univ	(JP2005126248		2003-10-21	2005-05-19	2010-03-17	(JP2005126248	Opus			X			X				X	
(CN220034736)Structure for n	(CN220034736)The utility model discloses a structure for grow	GRANTED	IV-Sumitec	(CN220034736		2023-06-27	2023-11-17	2023-11-17	(CN220034736	Opus	X	X				X				X	
(CN111026377)System and meth	(CN111026377)The invention discloses a system for accurately c	PENDING	FerroTec Holdings	(CN111026377)		2023-06-29	2023-11-10		(CN111026377)	Opus	X					X				X	
(CN220034735)Device for prep	(CN220034735)The utility model discloses a device for preparir	GRANTED	CETC - China Electronics Tech	(CN220034735		2023-06-13	2023-11-17	2023-11-17	(CN220034735	Opus	X	X				X				X	
(US20230367021)Power electr	(US20230367021)A power electronics converter may include: a	PENDING	BMW		WALTRICH,	2022-05-31	2023-11-30		(US20230367	Opus	X								X		
(KR10-2023-0007312)Power c	(KR10-2023-0007312)A power semiconductor device according	GRANTED	Hyundai / Kia	(KR10-2023-		2021-12-17	2023-01-13	2023-11-01	(KR10-2023-	Opus		X					X				
(JP2023172017)Semiconductor	(JP2023172017) [Problem] The purpose of the present inve						-06		(JP2023172017	Opus											
(JP2023133634)Semiconducto	(JP2023133634)PROBLEM TO BE SOLVED: To provide a						-04		(JP2023133634	Opus											
(WO2023/195487)Semiconduct	(WO2023/195487)In the present invention, the gates of a lo						-12		(WO2023/195	Opus											
(CN111046886)SiC MOSFET ja	(CN111046886)The invention belongs to the technical field o						-17		(CN111046886	Opus											
(CN220136319)Terminal structu	(CN220136319)The utility model provides a terminal structu						-05	2023-12-05	(CN220136319	Opus											
(CN116388163)Processing meth	(CN116388163)The invention provides a processing method						-03		(CN116388163	Opus						X					
(CN111012625)Silicon carbide st	(CN111012625)The invention discloses a thick silicon carbide						-07	2024-03-12	(CN111012625)	Opus						X					X
(CN111187361)Pneumatic mutu	(CN111187361)The embodiment of the invention provides pa						-08		(CN111187361)	Opus						X					
(CN107195623)Double-surface	(CN107195623)The invention discloses a double-surface bre						-22	2023-10-27	(CN107195623	Opus											
(CN111012605)Terminal structur	(CN111012605)A terminal structure suitable for a high-voltag						-07		(CN111012605	Opus											
(CN114530504)High-threshold	(CN114530504)The invention discloses a high-threshold SiC						-24	2023-10-10	(CN114530504	Opus											
(CN111054486)Method for det	(CN111054486)The invention discloses a method for detecting	PENDING	SICC - Shandong Tianyue Adv	(CN111054486		2023-08-25	2023-11-14		(CN111054486	Opus						X				X	
(CN218763514)Silicon carbide s	(CN218763514)The utility model relates to the technical field of	GRANTED	Sumtech Semiconductor Techn	(CN218763514	HUCHUANG	2022-09-28	2023-03-28	2023-03-28	(CN218763514	Opus								X			
(CN220086055)Silicon carbide	(CN220086055)The utility model relates to the technical field of	GRANTED	SGKE	(CN220086055		2023-06-15	2023-11-24	2023-11-24	(CN220086055	Opus							X				
(CN111116356)SiC-JFET device	(CN111116356)The embodiment of the invention provides a SiC-J	PENDING	Wutech Electronics	(CN111116356)		2023-08-15	2023-11-24		(CN111116356)	Opus							X				
(CN111192322)Voltage detectic	(CN111192322)The invention relates to the field of data processi	PENDING	SHENZHEN HI SEMICON ELEC	(CN111192322)		2023-10-27	2023-12-08		(CN111192322)	Opus							X				
(CN111053672)Semiconductor c	(CN111053672)The invention provides a semiconductor device in	GRANTED	Tongwei Microelectronics	(CN111053672)		2023-10-11	2023-11-14	2024-01-23	(CN111053672)	Opus	X						X				
(WO2023/111446)Process for t	(WO2023/111446)The invention relates to a process for the man	GRANTED	Soitec	(TW202323204		2021-12-14	2023-06-16	2023-11-03	(WO2023/1114	Opus		X				X				X	
(TW200843402)Silicon carbide	(TW200843402)A method of forming silicon carbide Schottky	LAPSED	Chip Integration Technology C	(TW200843402		2007-06-08	2008-12-16	2011-03-11	(TW200843402	Opus			X				X				
(WO2023/286904)Induction he	(WO2023/286904)The present disclosure provides an induction	GRANTED	LG Corporation	(WO2023/286		2021-07-16	2023-01-19	2023-10-24	(WO2023/286	Opus		X							X		
(CN111584618)Schottky two-ste	(CN111584618)The invention relates to a Schottky two-stage tub	PENDING	Xiamen Xiaohua Investment	(CN111584618)	SUZHOU	2020-06-05	2020-08-25		(CN111584618)	Opus				X			X				
(CN111148083)SiC power cycle	(CN111148083)The invention relates to an SiC power cycle test m	GRANTED	HANGZHOU GAOYU ELECTR	(CN111148083)		2023-06-15	2023-12-01	2024-03-08	(CN111148083)	Opus	X								X		
(JP2023153727)Semiconductor	(JP2023153727)PROBLEM TO BE SOLVED: To provide a semic	PENDING	Sumitomo Electric	(JP2023153727		2022-04-20	2023-11-01		(JP2023153727	Opus	X						X				
(CN116936610)Deep-doped sili	(CN116936610)The invention discloses a deep-doped silicon cur	GRANTED	CoolSemi	(CN116936610		2023-08-18	2023-10-24	2023-12-01	(CN116936610	Opus	X	X					X				
(EP3396137)Semiconductor dir	(EP3396137)A semiconductor device includes an electrostatic pr	GRANTED	Hitachi	(JP2022076066	MASUNAGA,	2020-11-09	2022-05-11	2023-12-05	(EP3396137)	Opus		X					X		X		
(CN116861833)SiC MOSFET pl	(CN116861833)The invention discloses a SiC MOSFET physical	GRANTED	Hunan University	(CN116861833		2023-08-30	2023-10-10	2024-01-30	(CN116861833	Opus	X						X				
(WO2024/006663)Bipolar high	(WO2024/006663)A bipolar high voltage bipolar pulsing powe	GRANTED	Eagle Harbor TechnologiesINT		HENSON,	2022-06-29	2023-11-21	2023-11-21	(WO2024/006	Opus	X	X							X		
(CN116316819)Power conversio	(CN116316819)The invention provides a power conversion devic	PENDING	Huawei	(CN116316819)		2023-06-16	2023-10-20		(CN116316819)	Opus	X								X		
(CN220108434)Lower cover su	(CN220108434)The utility model discloses a lower cover vacuum	GRANTED	Hangzhou Crystal Intelligent Equ	(CN220108434		2023-03-23	2023-12-15	2023-12-15	(CN220108434	Opus		X				X				X	
(CN116322246)Silicon carbide	(CN116322246)The invention provides silicon carbide surface p	PENDING	HANGLING MICRO TAIZHOU	(CN116322246		2023-08-25	2023-10-24		(CN116322246	Opus	X					X				X	
(CN111174626)Liner annealing m	(CN111174626)The invention relates to the field of liner annealing	GRANTED	Ji Hua Laboratory	(CN111174626)		2023-11-03	2023-12-05	2024-03-19	(CN111174626)	Opus	X					X				X	
(CN116632038)Semiconductor	(CN116632038)The invention discloses a semiconductor device	PENDING	JIANGSU ZIFENG INTELLECT	(CN116632038	BEIJING	2023-06-09	2023-08-22		(CN116632038	Opus				X			X				
(CN213752685)Heat dissipation	(CN213752685)The utility model provides a heat dissipation typ	GRANTED	Sumtech Semiconductor Techn	(CN213752685	HUCHUANG	2020-12-17	2021-07-20	2021-07-20	(CN213752685	Opus				X				X			
(US20060230787)Silicon carbi	(US20060230787)The silicon carbide semiconductor device incl	GRANTED	Denso	(JP2006023554	SUZUKI,	2007-03-20	2006-03-25	2010-04-14	(US20060230	Opus			X				X				
(EP3958452)Neutral-point-clar	(EP3958452)The present application provides a neutral-point-cl	GRANTED	Delta Electronics DELTA ELEC	(CN114079398		2020-08-21	2022-02-22	2023-10-25	(EP3958452)	Opus		X					X				
(CN205881911)Ditch cell type si	(CN205881911)The utility model discloses a ditch cell type silC p	GRANTED	Beijing Xinguan Lianzhong Tec	(CN205881911)	BEIJING	2016-07-21	2017-05-11	2017-01-11	(CN205881911)	Opus				X			X				
(CN115463876)Silicon carbide s	(CN115463876)The invention relates to a silicon carbide wafer si	GRANTED	SHANGHAI CHENG SHENG EI	(CN115463876		2022-03-16	2022-12-13	2023-11-28	(CN115463876	Opus		X				X				X	
(US20220131457)Power contro	(US20220131457)Disclosed is a power control system of adapti	LAPSED	INNO TECH	(TW1758324)	LIN, SHU-CHIA;	2020-10-28	2022-03-21	2022-03-21	(US20220131	Opus			X						X		
(CN111195701)Simulation modul	(CN111195701)The invention discloses a simulation model-based	PENDING	Xi'an University of Technology	(CN111195701)		2023-08-23	2023-12-08		(CN111195701)	Opus	X								X		
(DE102022113623)Power semic	(DE102022113623)Power semiconductor component (100) havir	PENDING	Bosch			2022-05-31	2023-11-30		(DE102022113	Opus	X							X			
(CN116953980)SiC IGBT manuf	(CN116953980)The invention provides a manufacturing method	PENDING	Gree Electric Appliances	(CN116953980		2023-07-21	2023-10-27		(CN116953980	Opus	X						X				

Patent information

Numbers, dates, assignees, title, abstract, claims, hyperlink to updated online database (legal status, original documents etc.)

Identify easily and efficiently

- New patent families
- Patents newly granted
- Patents expired or abandoned
- Transfer of IP rights
- Patent litigation

Patent segmentation

Supply chain
Technology
Applications

PATENT MONITOR

Access to an IP analyst for 100h per year

Take advantage of direct interaction with our analysts by phone call and/or email

On-demand Q&A sessions and discussions with our IP analysts regarding quarterly report results, trends, analyses, specific patented technologies, or companies' IP portfolios in the field of the Patent Monitor.

Contact: contact@knowmade.fr

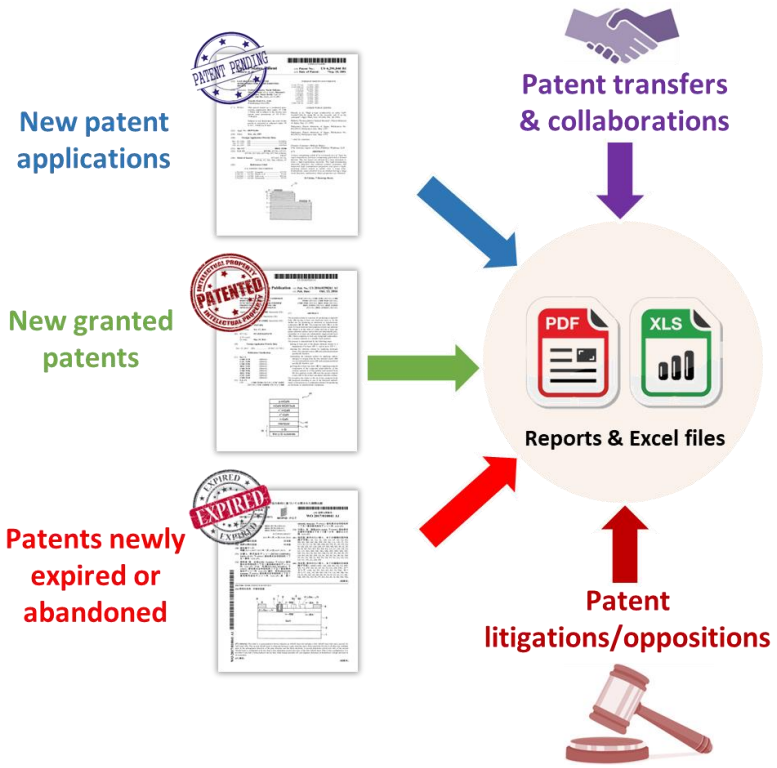
Examples of questions:

- Could you tell me more about the patent portfolio of this company?
- What is exactly the invention claimed in these patents?
- Can you give me the patents filed by this company on these specific technologies?
- Can you shortly analyze the patents of this new entrant?
- What are the patents issued in Japan and Korea for this application?
- Please give me more details about this patent litigation.
- We want to file a new patent. Can you help us to assess the prior-art in this field?
- I would like to invalidate these patents. Could you do a prior-art search?
- Can you help me to identify in patents the technical solutions to solve this issue?
- I would like to assess my freedom of operating in USA. Can you provide me with the granted US patents covering this technology?
- I am looking for free technologies I could use safely without infringing valid IP rights. Can you provide me with newly expired patents related to this technology?

QUARTER OVERVIEW

QUARTER OVERVIEW

Key facts of the quarter



570+ New patent families (inventions)
380+ Newly granted patent families
100+ Abandoned or Expired patents
90+ Patent transfer (change in ownership)

6 Noticeable IP collaborations (patent co-filings)

2 IP litigation (US)
0 Patent oppositions (EP)

>40 Newcomers identified

4 Key IP players selected and analyzed

Clickable logo to IP profiles

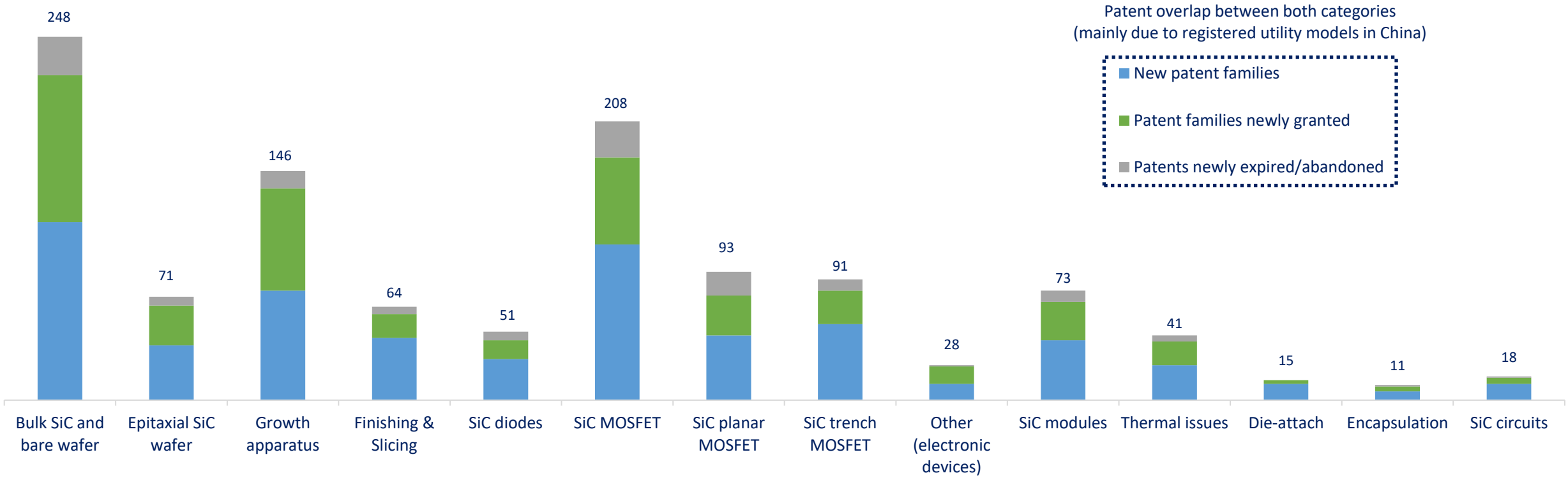
ROHM SEMICONDUCTOR | Infineon | SUMITOMO ELECTRIC | MITSUBISHI ELECTRIC

QUARTER OVERVIEW

Where are the patenting activities currently focused?

Power SiC patenting activity (Q4 2023)

Number of patent families by legal category

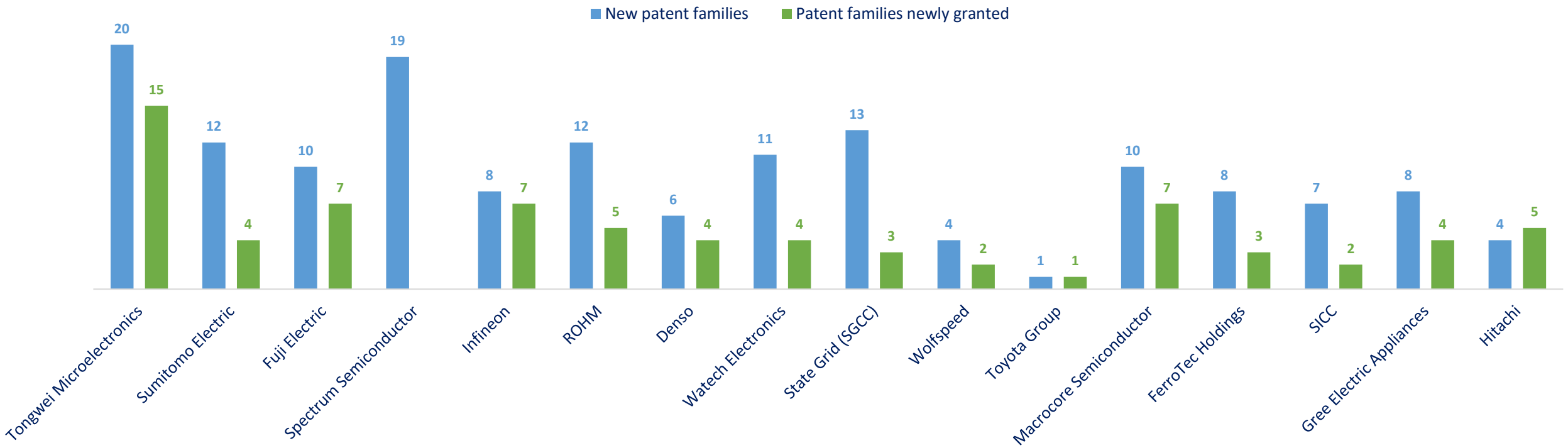


QUARTER OVERVIEW

Main Power SiC IP players

Power SiC patenting activity (Q4 2023)

Number of patent families by legal category



This ranking identifies players focused on power SiC technology based on their IP activity.

New patent families

QUARTER OVERVIEW

Main players driving the power SiC patenting activity across the supply chain

Main IP players driving the IP activity in each segment of the supply chain have been identified according the number of their new patent families (inventions) published during the quarter

QUARTER OVERVIEW

Notable new inventions (1/2)

Note: The full-texts of patents mentioned in this slide are available in the Excel database provided with the present report

Bulk and bare wafers

DENSO — US20230352574

A polishing method that utilizes anodic oxidation and is capable of efficiently creating a difficult-to-process material such as single crystal SiC into a target shape having a high-quality surface that is scratch-free and damage-free

Hermes Epitek — US20240068124

An apparatus for producing SiC crystal having a composite seed crystal, formed by multiple graphite layers and SiC seeds. A density or a thickness of each of graphite layer is gradually adjusted to reduce the difference between the thermal expansion coefficient and Young's modulus between graphite SiC.

BOYA ADVANCED MATERIALS 博雅新材 — WO2023/217196

Crystal growth device (PVT method), comprising: a crucible, the crucible comprising a raw material cavity used for placing raw materials, and a growth cavity used for crystal growth; and a thermal insulation apparatus arranged on at least one side surface outside the crucible.

SICOXS — WO2024/048239

A technique for bonding a c-SiC layer on poly-SiC substrate w/o the occurrence of interface resistance in a junction interface

Epitaxial substrates

SUMITOMO ELECTRIC — WO2023/218809

The SiC substrate contains a plurality of C inclusions. The main surface has a plurality of pits formed therein. The plurality of C inclusions each have a maximum length of 2-50 µm along a direction perpendicular to the main surface, and the plurality of pits each have an area of 3,000 µm^2 or larger. The ratio of the area density of the plurality of pits to the area density of the plurality of C inclusions is 0.008 or less.

SUMITOMO ELECTRIC — WO2023/233887

A SiC substrate according to the present invention has a 1st main surface and a 2nd main surface that is on the reverse side of the 1st main surface. First voids are present in the 1st main surface. The surface density of the 1st voids is less than 0.9 void per cm^2. When viewed in a direction that is perpendicular to the 1st main surface, the widths of the 1st voids are 10 µm to 100 µm. When viewed in a direction that is parallel to the 1st main surface, the widths of the 1st voids become wider from the 1st main surface toward the 2nd main surface. When viewed in a direction that is parallel to the 1st main surface, the depths of the 1st voids are smaller than the thickness of the SiC substrate. The 1st main surface is a carbon surface or a surface that is inclined to the carbon surface at an off angle of 8° or less.

Devices

Infineon — US20230317666

Laser thermal annealing process to an Ohmic contact between SiC and a metal, while reducing a surface roughness of the resulting metal silicide layer

Diodes

nexperia — US20230402550

To provide MPS diodes with improved available Schottky area, whilst balancing current leakage.

onsemi — US20230395730

Diodes that include multiple Schottky contacts with different respective barrier heights, to improve both forward and reverse operating characteristics.

Infineon — US20230326974

SiC diode having a low forward voltage in combination with surge current resistance and avalanche robustness

LEAP SEMICONDUCTOR — US20230317861

MPS diodes having reduced current leakage with improved Schottky contact area and forward voltage VF characteristics

Modules

BOSCH — US20240021610

Cascade arrangement incl. a substrate, a JFET, a MOSFET, and at least one sensor system, and semiconductor module

BorgWarner — US20230327597

A power module for an inverter, incl. a Si switch; a SiC switch; an Si gate driver; and a SiC gate driver.

Thermal management

SanRex — US20230360991

Power module having a small ON-resistance and capable of operating at a high frequency

Hitachi Energy — WO2023/222195

A power module that enables faster and/or more reliable detection of mal functions , like overheating.

Encapsulation

Wolfspeed — US20230378010

Power devices w/ moisture barriers

Infineon — US20230369177

Molded semiconductor package having an embedded inlay

ST — US20230361010

To improve thermal dissipation performance in packages for small IC (miniaturization)

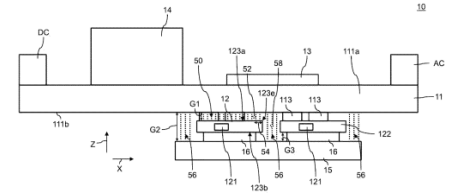
Circuits

FANUC — US20240021610

A motor drive device drives a motor by using a plurality of power, adjusts so as to unbalance the loss in the power elements, and reduces the impact of a temperature gradient in the power elements.

ROLLS ROYCE — US20230387821

Power electronics converter with stacked carrier substrates



Audi — US20230387099

Power electronics arrangement with parallel connected semiconductor switches

Audi — US20230378865

Dynamic switching time variation in pulse inverters

QUARTER OVERVIEW

Notable new inventions (2/2)

Note: The full-texts of patents mentioned in this slide are available in the Excel database provided with the present report

Bulk and bare wafers

Pallidus — US20240071743

Methods and systems for the electrochemical finishing of SiC wafers, using an applied electrical bias, an electrolytic oxidant removal solution and light to remove raised surface features and imperfections of a SiC wafer.

soitec — WO2023/186498, WO2023/194682

Composite c-SiC on poly-SiC substrates for power electronics applications

ZADIENT — WO2023/222790

Improved furnace apparatus for crystal production with seed holder repositioning unit

TANKEBLUE — CN117187948

SiC crystal growth device with enhanced heat dissipation, maintaining uniformity of radial temperature gradient, accurate temperature control and uniform cooling.

ZADIENT — WO2023/222787

A method for producing at least one crack-free SiC piece

SICC — CN117051478

High-uniformity conductive SiC substrate: the doping concentration change rate is less than 10% or the carrier concentration change rate is less than 5%.

ZADIENT — WO2023/222785

A SiC growth substrate for growing SiC in a CVD reactor

Epitaxial substrates

ITES — JP7368041

The present invention relates to a defect inspection method, a defect inspection device, and a method for manufacturing a SiC chip for detecting ground surface dislocations (BPD) converted to through-blade-shaped dislocations (TED) at the interface between a substrate layer and a buffer layer in a silicon carbide substrate having a substrate layer, a buffer layer, and a drift layer.

ARCHE — KR10-2023-0146238

Preparing method of SiC thin film with reduced defects

ARCHE — KR10-2023-0146239

Preparing method of a SiC thin film using a substrate having improved surface roughness

Devices

Wolfspeed — US20230361212

Dynamic performance of on-chip current sensors

Planar MOSFET

ST — US20240006527

SiC MOSFET with reduced switching oscillations

fss fast SiC semiconductor — US20230361209

Depletion mode N-channel SiC power MOSFET

三安光电 Sanan Optoelectronics — US20230387290

SiC MOSFET device integrated w/ a Schottky diode having a reduced forward bias voltage, a reduced gate electrode capacitance, a reduced diode current leakage, a larger breakdown voltage and an improved current density.

Trench MOSFET

LEAP SEMICONDUCTOR — US20230326972

To reduce C_{GD} capacitance of V-groove SiC N-MOSFETs

Infineon — US20230352520

Trench gate structure w/ a shielding region to further shrink cell layout dimensions and reduce the $R_{ON}xA$

fss fast SiC semiconductor — US20230387215

To increase channel width density of trench SiC MOSFET

Modules

Die attach

McMaster University — US20230352372

Silver sintered molybdenum (SSM) packaging for power semiconductor devices

Wolfspeed — US20230317670

Packaged electronic devices having transient liquid phase solder joints

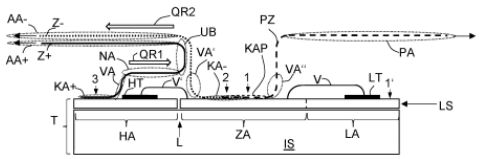
Parasitics

MEKTEC NIPPON MEKTRON, LTD. — DE102023202848

SiC power module comprising a flexible printed wiring board

vitesco TECHNOLOGIES — WO2023/232565

Half-bridge module with parallel supply leads connected to insulated pads between two strip sections and to one of the strip sections of a conductor layer



Infineon — US20230335530

Multi-chip device w/ gate redistribution structure

HUAWEI — WO2023/222220

Power converter package with shielding against common mode conducted emissions

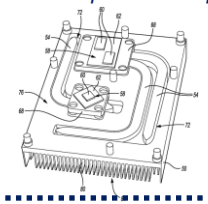
Circuits

dSPACE — WO2023/208554

Device and method for symmetrical current distribution in three-point NPC inverter phases connected in parallel

Ford — US20230371204

Thermal energy management system for an electrified vehicle component comprising a SiC



QUARTER OVERVIEW

Main IP players and IP newcomers worldwide

Clickable logo to corporate websites

Patent assignee	Number of new patent families (inventions)	SEGMENTS (number of new patent families)				
		Bulk SiC	Epitaxial SiC wafers	SiC devices	SiC modules	Circuits
All Players	**583**	**143**	**44**	**206**	**61**	**132**
Sumitomo Electric	12	2	2	8	1	
ROHM	12			8	3	1
Mitsubishi Electric	10			2	3	5
Fuji Electric	10			7		3
FerroTec Holdings	8	7	1			
Infineon	8			6	2	
Denso	6	2		4		
Bosch	6		1		2	3
AIST	5	1		3		1
Arche	5	1	4			
Vitesco	4				3	1
Hitachi	4				2	2
Wolfspeed	4			2	2	
EYEQ Lab	4			4		
STMicroelectronics	4			2	2	
Volkswagen Group	3				1	2
Zadient Technologies	3	3				
Disco	3	2	1			
Sumitomo Metal Mining	3	3				

Main IP players

Wolfspeed

SUMITOMO ELECTRIC · ROHM SEMICONDUCTOR · MITSUBISHI ELECTRIC · Fe

Infineon · BOSCH · vitesco TECHNOLOGIES · ST

ARCHE · EYEQ Lab

New IP players

dSPACE · KCTECH · TERADYNE · MEKTEC NIPPON MEKTRON, LTD.

Scientific Visual · 漢民 · Hermes Epitek · EPI 嘉晶電子

BorgWarner · ThermoFisher SCIENTIFIC · FEI

and SCDevice, TU Delft, University of Nebraska…

QUARTER OVERVIEW

Main IP players and IP newcomers in China

Clickable logo to corporate websites

Patent assignee	Number of new patent families (inventions)	SEGMENTS (number of new patent families)				
		Bulk SiC	Epitaxial SiC wafers	SiC devices	SiC modules	Circuits
All Players	583	143	44	206	61	132
Tongwei Microelectronics	20	19		1		
Spectrum Semiconductor	19			19		
State Grid (SGCC)	13			7	2	4
Watech Electronics	11			10	1	
Macrocore Semiconductor	10			7	2	1
Gree Electric Appliances	8	1		6	1	
Hunan University	7			1	2	4
BASiC Semiconductor	7		1	6	1	
SICC	7	7				
IV-Semitec	6	6				
Beijing Smart Energy Research Institute	6		1	5		
CRRC	5				1	4
Chongqing University	5			2		3
Sirius Semiconductor	5			5		
SICO Semiconductor	5	3	2			
CETC	5	3		1	1	
Best Compound Semiconductor	5	1	4			
Xidian University	4			4		
San'an	4	1		2		1
Hefei Anxin Ruichuang Semiconductor	4			4		
UESTC	4			2		2
Hoshine	4	4				
Nantong Gangfeng Technology	4	4				
Jiangsu Jixin Advanced Materials	4	3		1		
Zhejiang Xinke	4		4			

Main IP players

New IP players

and FAW Group, Siliup Semiconductor, Prisemi, Great Wall Technology, GAC group…

QUARTER OVERVIEW

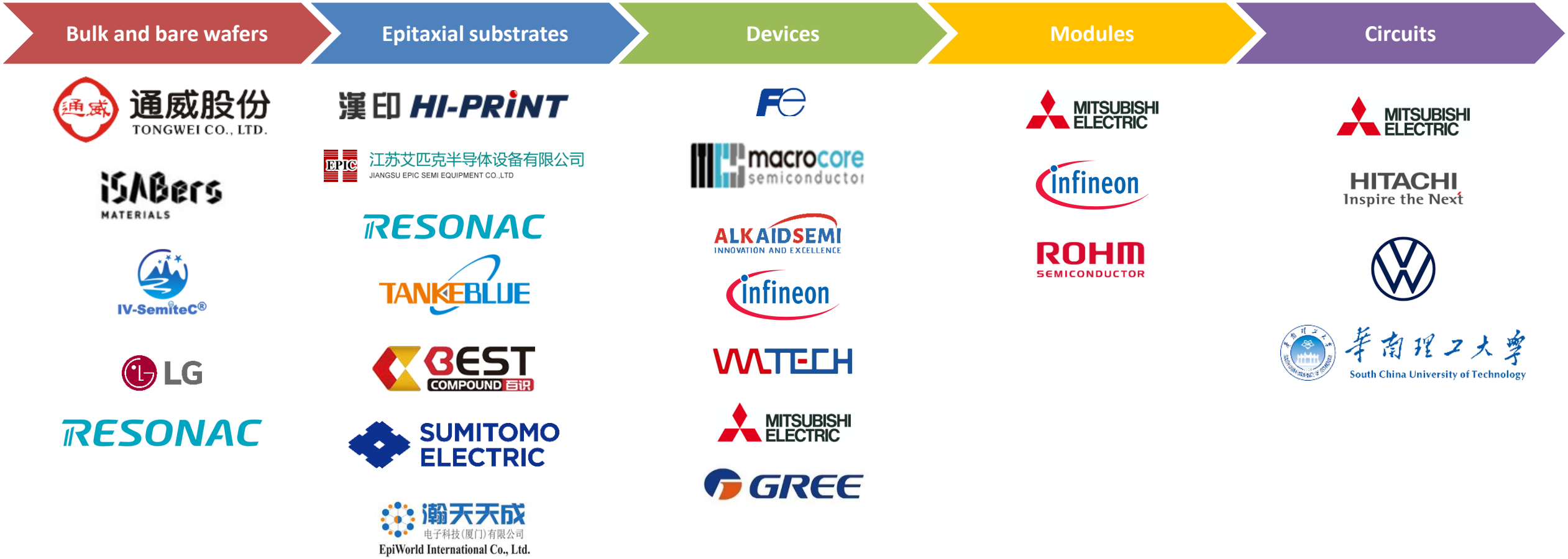
New patent families (inventions): Focus on SiC power devices

Patent assignee	Number of new patent families (inventions)	SEGMENTS (number of new patent families)					
		SiC diodes	SiC MOSFET	Planar MOSFET	Trench MOSFET	Undefined MOSFET	Other SiC devices
All Players	**206**	**33**	**125**	**52**	**61**	**13**	**48**
Spectrum Semiconductor	19	1	18	17	1		
Watech Electronics	10		4	1	1	3	6
ROHM	8		7		6	1	1
Sumitomo Electric	8		7		4	3	1
State Grid (SGCC)	7		4	2	2		3
Fuji Electric	7		7		7		
Macrocore Semiconductor	7						7
Infineon	6	1	3		3		2
BASiC Semiconductor	6		3	1	1	1	3
Gree Electric Appliances	6	2	1	1			3
Beijing Smart Energy Research Institute	5		2	2			3
Sirius Semiconductor	5		4		4		1
Denso	4		4		4		
Xidian University	4	3	1	1			
Hefei Anxin Ruichuang Semiconductor	4	1	1	1			2
EYEQ Lab	4	4					
AIST - National Institute of Advanced Industrial Science and Technology	3		3		3		
Hubei Jiufengshan Laboratory (JFS)	3	1	2		2		
Fudan University	3		2	1	1		1

Newly granted patent families

QUARTER OVERVIEW

Main players reinforcing their IP position across the supply chain



Main players reinforcing their IP position in each segment of the supply chain have been identified according the number of their patent families (inventions) firstly granted during the quarter

QUARTER OVERVIEW

Notable new granted patents (1/2)

Note: The full-texts of patents mentioned in this slide are available in the Excel database provided with the present report

Bulk and bare wafers

US11827997

A simple and low-cost stripping method for SiC single crystal wafers, avoiding damage layer or stress residue on surfaces or sub-surfaces, w/ simple operation and low cost.

US11827997

A SiC ingot growing system and a method of measuring graphite articles to secure growth reproducibility of the ingot.

CN114351253

To obtain a SiC single crystal decreased in defects such as threading dislocations.

JP7372312

SiC composite substrate less likely to cause delamination, breaking and cracking.

JP7400451

Method capable of reducing an internal stress caused in a cooling process of a SiC ingot by reducing a radiation heat produced from a remaining SiC raw material in an inner bottom part of a crucible after a growth of the SiC ingot.

CN114808128

SiC wafer w/ XRD FWHMs less than 16 arcsec and the difference of FWHM at different positions of the 1st surface and the 2nd surface is less than 5 arcsec

Epitaxial substrates

EP4056739

To grow an epitaxial layer on a substrate of monocrystalline SiC which is essentially nearly free from carbon inclusion and basal plane dislocation

CN114959898

SiC epitaxial wafer for high-voltage and ultrahigh-voltage device

JP7400715

To suppress formation of macro-defects over a wide range on a large diameter SiC epitaxial substrate (150mm or more)

TWI824118

To reduce the number of parameters to be controlled for the epitaxial growth of SiC

JP7388365

To provide a SiC epitaxial substrate and a SiC semiconductor device to suppress basal plane dislocations from becoming stacking faults

JP7392417

To provide an apparatus for producing a SiC epitaxial wafer for simultaneously depositing a SiC epitaxial film on a plurality of SiC substrates, capable of increasing the uniformity of carrier concentration in a SiC epitaxial film deposited on each SiC substrate.

Devices

US11817478

Termination structures that can reduce dynamic output capacitance switching losses

US11824094

SiC planar gate JFETs w/ improved R_{ON}

JP7371257

A method for forming an electrical contact using laser annealing

Diodes

JP7400128

MPS diode device

US11830920

SBD w/ a low forward voltage and a low reverse current

Planar MOSFET

US11776994

SiC MOSFET with reduced channel length and high V_{TH}

US11843061

SiC power devices with improved short circuit capabilities

US11798981

4H—SiC electronic device with improved short-circuit performances

US11824083

To suppress a decrease in gate oxide reliability

US11830914

To increase channel density

Modules

JP7368450

The lead member is bonded to the metal plate by laser welding to provide improved reliability

US11804424

To place the bond wire onto the die and to allow a large clip to be placed over the die. The large clip can be either over-molded or exposed to allow efficient dual side cooling.

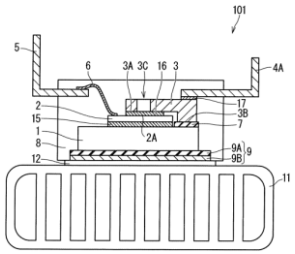
Thermal management

US11916029

To improve heat radiation from an Al electrode while suppressing diffusion of Cu from a Cu film into a passivation film

JP7387059

To achieve both high heat dissipation and low production cost from front surface side of the semiconductor element



US11916029

WBG semiconductor package connected to a fluid heat sink

Circuits

US11843240

Device and process for fault detection of a power device (especially w/ shorter fault withstand time, e.g., SiC MOSFET)

US11798786

Power converters and power supply systems for generating high frequency power supplied to a plasma process

EP3584915

An input circuit for a power supply, w/ high efficiency and high dielectric strength in the event of overvoltages

US11848604

Single-stage AC-DC converter circuit with power factor correction function

US11894783

A semiconductor device in which power transistors are driven in parallel and having different saturated currents. The drive circuit is common to the power transistors.

CN113708639

Method and system for constructing driver circuit of wireless charging system using SiC MOSFET devices

US11837599

Device incl. an electrostatic protection circuit and a SiC MOSFET

QUARTER OVERVIEW

Notable new granted patents (2/2)

Note: The full-texts of patents mentioned in this slide are available in the Excel database provided with the present report

Bulk and bare wafers | **Epitaxial substrates** | **Devices** | **Modules** | **Circuits**

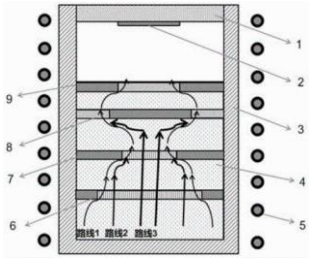
Bulk and bare wafers

RESONAC — JP7400450

To provide a manufacturing apparatus capable of growing the SiC single crystal at a uniform speed in a radial direction.

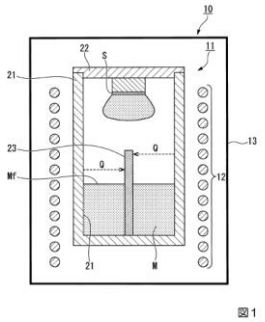
TANKEBLUE — CN114990696

SiC single crystals with low inclusion inclusions: plurality of blocking discs positioned on the surface and inside a SiC raw material are arranged in the device, through holes are formed in the central areas of part of the blocking discs, through holes are formed in the edge areas of part of the blocking discs, and through holes are formed in the edge areas of the blocking discs



RESONAC — JP7358944

To provide a heat transfer member for SiC single crystal growth capable of preventing the deposit of SiC in the central part of a crucible from occurring even when having a large size allowing the manufacturing of a SiC single crystal grown into a large diameter and a long size to effectively use a SiC raw material; a crucible for SiC single crystal growth; and a method for manufacturing the SiC single crystal.



SICC — CN113957533

SiC substrate with low dislocation density: The dislocation density of the annular region on the edge of the SiC substrate is low, and the dislocation density of the central region is low; and no small-angle grain boundary is generated in the annular region at the edge, and the crystallization quality is high.

Devices

Trench MOSFET

KERI — JP7389239

Trench-gate SiC MOSFET device having a high-quality, stable gate oxide film

APPLIED MATERIALS — US11804537

Methods for fabricating SiC MOSFETs using channeled ion implants

Infineon — US11791383

SiC device having a ferroelectric gate stack and improved short-circuit/overcurrent protection

Hitachi Energy — EP4128362

To improve current density in an on-state.

Infineon — US11799026

SiC device w/ a dual mode sense terminal, electronic systems for current and temperature sensing

APPLIED MATERIALS — US11798982

Self-aligned trench SiC MOSFETs

Undefined MOSFET

HUAWEI — JP7402929

Method for thinning SiC device wafer

mi2-factory — JP7405453

Ion implantation method for forming a drift regions and thereby to industrially produce a high quality, high output SiC MOSFET with less effort at lower cost.

HITACHI — JP7402929

SiC MOSFET w/ an electrostatic protection circuit

Modules

Die attach

MITSUBISHI ELECTRIC — JP7392632

To suppress void in a solder between a semiconductor chip (SiC, GaN) and a die pad

DENSO — JP7367631

To solder SiC chips to form a double-sided heat dissipation structure

Parasitics

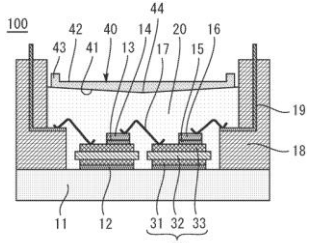
ROHM SEMICONDUCTOR — DE112021001168

To reduce the surge voltage applied to the switching elements

Encapsulation

MITSUBISHI ELECTRIC — US11837514

The barrier layer prevents moisture and gas such as sulfur gas from entering the inside of the power semiconductor module. The barrier layer with such a structure has difficulties in standing still in a horizontal state and may not be stacked stably. The present disclosure provides a semiconductor device and a power converter in which barrier layers can be stacked stably.



Circuits

US11831250

Power electronics building blocks (PEBBS) with enhanced power density, reduced size, isolated power ports (e.g., using "low-voltage" 1.7 kV SiC MOSFETS)

ThermoFisher SCIENTIFIC FEI — US11846664

A method comprising, generating and applying an electrostatic discharge (ESD) test pulse to a device under test (DUT) by discharging an ESD test capacitor through a back-to-back-connected pair of SiC FETs in response to gate pulses applied to gates of the back-to-back connected pair of SiC FETs.

Audi — US11831248

An inverter for an electric machine incl. a DC/AC converter based on SiC MOSFET

PRE heliox — US11791734

A bidirectional power converter, comprising a number of flyback converter units connected in parallel and based on SiC semiconductor switches.

QUARTER OVERVIEW

Main players (outside China) reinforcing their IP position across the supply chain

Patent assignee	Number of patent families (inventions) newly granted	SEGMENTS (number of new patent families)				
		Bulk SiC	Epitaxial SiC wafers	SiC devices	SiC modules	Circuits
All Players	380	118	32	115	37	82
Mitsubishi Electric	12			3	4	5
Infineon	7			4	3	1
Fuji Electric	7		1	6		
LG Corporation	6	4	1			1
Resonac	6	4	2			
Hitachi	5			2	1	3
ROHM	5			2	2	1
Volkswagen Group	4				1	3
Soitec	4	4	1			
Denso	4	2		1	1	
Sumitomo Electric	4		2	2	1	
FerroTec Holdings	3	3				
Toyo Tanso	2	2				
DRY CHEMICALS	2	2				
Sumitomo Metal Mining / SICOXS	2	2				
Hyundai / Kia	2			2		
Wolfspeed	2			1		1
Applied Materials	2			2		
General Motors	2					2
Toshiba	2			2		
CRIEPI	2	2				
Bosch	2			2		

Main IP players

MITSUBISHI ELECTRIC

Infineon

FE

LG

RESONAC

HITACHI
Inspire the Next

ROHM
SEMICONDUCTOR

QUARTER OVERVIEW

Chinese players reinforcing their IP position across the supply chain

Patent assignee	Number of patent families (inventions) newly granted	SEGMENTS (number of new patent families)				
		Bulk SiC	Epitaxial SiC wafers	SiC devices	SiC modules	Circuits
All Players	380	118	32	115	37	82
Tongwei Microelectronics	15	15				
iSabers Materials	8	8				
Macrocore Semiconductor	7			6	1	
HI-PRINT	6		6			
TankeBlue	5	3	2			
IV-Semitec	5	5				
Jiangsu Jixin Advanced Materials	5	4		1		
National Third Generation Semiconductor Tech	5			5		
Zhejiang University	5	4				1
AlkaidSemi	5			5		
Best Compound Semiconductor	4	1	2		1	
Hoshine	4	4				
Gree Electric Appliances	4			3		1
Watech Electronics	4			4		
UKing Photoelectric Technology	4	4				
LINTON Group	3	3				
CETC	3	2			1	
State Grid (SGCC)	3			2		1
Jiangsu Epic Semi Equipment	3		3			
Hunan University	3			2		1
SCUT - South China University of Technology	3					3
UESTC - University of Electronic Science & Tech	3			3		

Main IP players

通威股份 TONGWEI CO., LTD.

iSABers MATERIALS

macrocore semiconductor

漢印 HI-PRINT

TANKEBLUE

IV-SemiteC®

ALKAIDSEMI INNOVATION AND EXCELLENCE

QUARTER OVERVIEW

Newly granted patent families: Focus on SiC power devices

Patent assignee	Number of newly granted families	SEGMENTS (number of new patent families)					
		SiC diodes	SiC MOSFET	Planar MOSFET	Trench MOSFET	Undefined MOSFET	Other SiC devices
All Players	**115**	**15**	**70**	**32**	**27**	**11**	**31**
Macrocore Semiconductor	6						6
Fuji Electric	6	2	5		3	2	
National Third Generation Semiconductor Technology Innovation Center (Nanjing)	5		5	3	2		
AlkaidSemi	5		5	5			
Infineon	4		3		3		1
Watech Electronics	4		3	3			1
Mitsubishi Electric	3		3	2	1		
Gree Electric Appliances	3	1	1	1			1
UESTC - University of Electronic Science & Technology of China	3						3
Hitachi	2		2		1	1	
ROHM	2		2		2		
Sumitomo Electric	2		2		1	1	
State Grid (SGCC)	2		1	1			1
Hunan University	2		1			1	1
Chongqing Wattscience Electronic Technology	2		1	1			1
Tengrui Microelectronics Technology	2	1					1
Siliup Semiconductor	2		2		2		
Beijing Smart Energy Research Institute	2		1	1			1
Sanders Microelectronic Devices	2	2					
Hyundai / Kia	2		2	2	1		
Applied Materials	2		2		2		
Wuxi Chaao Microelectronics Technology	2	2					
Toshiba	2	1	1	1			
Sunnychip Semiconductor	2		2	1	1		
Beijing University of Technology	2		1			1	1
Bosch	2		1	1			1
Xinhe Semiconductor	2		1	1			1

Patents newly expired or abandoned

QUARTER OVERVIEW

Dead patents: new IP in the public domain?

		SEGMENTS													
Patent assignee	Number of dead patents	Bulk SiC and bare wafer	Epitaxial SiC wafer	Growth apparatus	Finishing & Slicing	SiC diodes	SiC MOSFET	SiC planar MOSFET	SiC trench MOSFET	Other (electronic devices)	SiC modules	Thermal issues	Die-attach	Encapsulation	SiC circuits and applications
All Players	**107**	**31**	**7**	**14**	**6**	**7**	**29**	**19**	**9**	**9**	**9**	**5**	**1**	**1**	**7**
Wolfspeed	17	2	2	2	1	1	9	9		4					
Toyota Group	12	9					1		1						
Sumitomo Electric	10	3	1	1	1		2	1	1	2					
Mitsubishi Electric	9	1				1	1		1		3	2	1	1	3
Panasonic / Sanyo Electric	6						4	3	1		1				
AIST - National Institute of Advanced Indus	6					1	3	2							
Infineon	5					1				2					1
Denso	5	1					2	1	1						
Fuji Electric	4					1	1		1		1				1
Kwansei Gakuin University	3														
EcoTron	3	3													
Mitsubishi Materials	3										3	3			
TankeBlue	3	3		3											
HITACHI METALS	3	3			3										
SICC - Shandong Tianyue Advanced Techno	2	2			1										
Synlight Crystal	2	2		2											
EpiWorld	2		2	2											
Hitachi	2					1	1		1						
Power Integrations	2									1					1
Kyoto University	2														

If a patent is dead (expired or abandoned), is it possible to make the formerly patented product?

An expired patent cannot be asserted against competitors. However, other live patents may still cover different parts, features or combinations described in the expired patent. Moreover, in some countries, a lapsed patent can be reinstated/restored by paying an additional fee plus the maintenance fee, and reasoning that delay or nonpayment of the maintenance fee within the prescribed period was unintentional.

QUARTER OVERVIEW

Notable dead patents

Note: The full-texts of patents mentioned in this slide are available in the Excel database provided with the present report

SiC substrates (bulk, bare and epitaxial wafers)

TANKEBLUE **CN1247831**

To provide a novel SiC crystal growth device based on the principle of the Modified Lely crystal growth method, and the device can be used for growing large-size or even ultra-large-size SiC crystals without large equipment modification

Wolfspeed **US7695565**

Sublimation chamber for phase-controlled sublimation

PROTERIAL **US8530353**

A method of manufacturing a SiC substrate, incl. the step of removing, by a vapor phase etching process, at least a portion of a work-affected layer which is formed by mechanical flattening or cutting on the surface of the SiC substrate.

SUMITOMO ELECTRIC **US8013343**

P-type SiC substrate having high resistivity

SICC **CN1282770**

Apparatus and method of growing great diameter 6H-SiC monocrystal

TANKEBLUE **CN1261622**

Method and apparatus for growing SiC single crystal by PVT, which can keep the temperature difference between a charge level and a crystal growth level constant or stable as much as possible in the growth process

Wolfspeed **US6974720**

Methods of forming high voltage SiC power devices utilize high purity SiC drift layers that are derived from high purity SiC wafer material, instead of prohibitively costly epitaxially grown SiC layers

Wolfspeed **US7018554, US7279115**

Method to reduce stacking fault nucleation sites and reduce forward voltage drift in bipolar devices

Devices

Wolfspeed **US8124480**

Methods of fabricating SiC devices incorporating multiple floating guard ring edge terminations

SUMITOMO ELECTRIC **US9153661**

SiC IGBT

Diodes

Infineon **US6861723**

Schottky diode having overcurrent protection and low reverse current

HITACHI **US9159562**

Trench type Schottky junction semiconductor device

Planar MOSFET

AIST **US8952391, US9490338**

A SiC vertical MOSFET having low ON-resistance and high blocking voltage

Wolfspeed **US8492827**

SiC MOSFETs which may reduce on-state resistance

ROHM SEMICONDUCTOR **US8030162**

To prevent dielectric breakdown of a gate oxide film

PURDUE UNIVERSITY **US8035112**

SiC power DMOSFET with self-aligned source contact

SUMITOMO ELECTRIC **US8030162**

To improve gate oxide reliability

Modules

Infineon **US6900537**

High power SiC and silicon semiconductor device package

Panasonic **US7230273**

To produce semiconductor module w/ a high yield in spite of using a WBG semiconductor having many defects.

Circuits

Patent transfers and collaborations

QUARTER OVERVIEW

Main IP transfers (patent reassignment) (1/2)

Note: The full-texts of patents mentioned in this slide are available in the Excel database provided with the present report

Bulk and bare wafers | Epitaxial substrates | Devices | Modules | Circuits

世纪金光 CENGOL → Beijing Xingyun Lianzhong Technology

4 patents in China
(CN103708463, CN104498901, CN106967386, CN113122914)

+ 14 utility models

LINTON → Lianke Semiconductor

1 patent in China
(CN114411257)

+3 utility models

世纪金光 CENGOL → Xinhe Semiconductor

10 patent and patent applications
+ 4 utility models

TOYOTA → DENSO

Methods and systems for predicting failure of a power control unit of a vehicle (US11704590)

Institute of Semiconductors CAS → HI-PRINT

Equipment and method for growing SiC film (CN103343329)

Dongguan University of Technology → 清芯半导体

SONGSHAN LAKE MATERIALS LABORATORY

7 patents and patent applications

深圳市电科智能科技有限公司
Shenzhen Electric Technology → Shenzhen Jingyu Science and Technology

2 utility models for SiC diode packaging

TOYO TANSO → TOYOTA

To provide a method for manufacturing a SiC wafer with a configuration in which an epitaxial layer having low BPD density is formed in a short time (EP3605585)

Zhejiang University → Hangzhou Xinzhu Semiconductor

- SiC trench MOSFET (CN113690321)
- SiC planar MOSFET (CN112599524)

QUARTER OVERVIEW

Main IP transfers (patent reassignment) (2/2)

Note: The full-texts of patents mentioned in this slide are available in the Excel database provided with the present report

Bulk and bare wafers | Epitaxial substrates | Devices | Modules | Circuits

世纪金光 CENGOL → **Jiangsu Zifeng Intellectual Property Service**

江苏紫峰知识产权服务有限公司

- **SiC JFET w/ integrated diode (CN106783851)**
- **SiC SBD w/ inverted T-shaped P+ region (CN211480044)**
- **Planar MOSFET (CN116632038)**

Suzhou Phoenixcore Electronic Technology → **Xinheda Investment**

4 patents and patent applications related to SiC diodes (SBD, JBS)

Huchuang Electronic Technology → 龍威亞太有限公司 DRAGON HUGE ASIA PACIFIC LIMITED

互创（东莞）电子科技有限公司

1 patent application and 2 utility models for SiC diode packaging

QUARTER OVERVIEW

Main IP collaborations (patent co-filings)

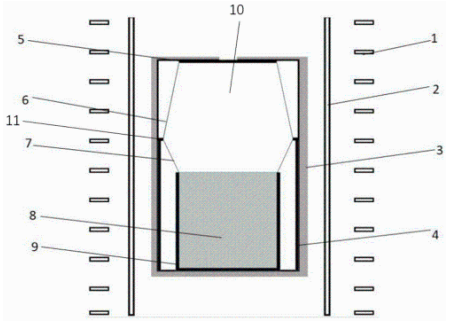
Note: The full-texts of patents mentioned in this slide are available in the Excel database provided with the present report

Bulk and bare wafers | **Epitaxial substrates** | **Devices** | **Modules** | **Circuits**

vcore 微核芯 ZHAO JING 兆晶科技 ZHAO JING SCIENCE AND TECHNOLOGY

CN117004907

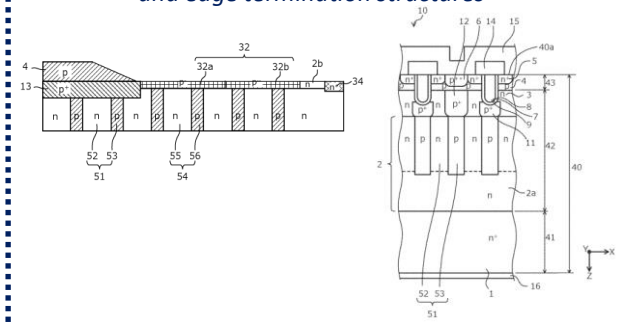
Method for preparing tantalum carbide film on surface of graphite piece by adopting PVT SiC crystal growth furnace



AIST Fuji Electric

US20230327017, US20230326961, US20230317842

SiC trench MOSFET w/ a superjunction structure and edge termination structures



DENSO MIRISE TECHNOLOGIES TOYOTA

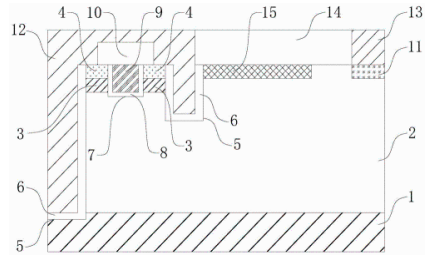
US20230369483

SiC trench MOSFET w/ a superjunction structure

国家电网公司 STATE GRID CORPORATION OF CHINA

US20230369483

Lateral SiC trench gate LDMOS with double-trench source structure



HANTINGCN 汉星能源 合肥工業大學 HEFEI UNIVERSITY OF TECHNOLOGY

CN117013807

Resonant gate drive circuit suitable for series connection of SiC MOSFET

国家电网公司 STATE GRID CORPORATION OF CHINA 重庆大学 CHONGQING UNIVERSITY

CN116973722

Method for monitoring junction temperature of SiC MOSFET device of bridge arm in bridge circuit

CN116859205

SiC MOSFET device grid degradation monitoring method and monitoring circuit

CN116846211

Method for prolonging operation life of SiC MOSFET in inverter

US litigations and EP oppositions

QUARTER OVERVIEW

Main US patent litigation filed or closed

Case 6:21-cv-00727: **Purdue University** vs. **STMicroelectronics**

Case 1:21-cv-00840: **Purdue University** vs. **Wolfspeed**

Summary

In July 2021, **Purdue University (Purdue)** filed a complaint in a West Texas court saying that **STMicroelectronics**' SiC transistors infringe two of **Purdue**'s patents (US8035112 and US7498633). In response to **Purdue**'s patent infringement lawsuit, **STMicroelectronics** filed a petition (inter partes reviews, IPR) at the US patent office (USPTO) to challenge the patentability of **Purdue**'s patents. Thereby, the company aimed to invalidate the patents and stop the litigation.

Later on, **Purdue** removed patent US8035112 from the case, after Patent Trial and Appeal Board (PTAB) instituted an IPR of the patent in 2022. On the other hand, **PTAB** denied **STMicroelectronics**' challenge to the patentability of a **Purdue**'s patent US7498633.

Note that **Purdue** also sued **Wolfspeed** in North Carolina federal court in 2021, accusing the company's semiconductor transistors of infringing the same patents. Likewise, **Purdue** later dropped one of the patents from the lawsuit (US8035112). Just like **STMicroelectronics**, **Wolfspeed** filed IPR to review the validity of **Purdue**'s patents, but all challenges were rejected by **PTAB**.

Therefore, the remaining patent-in-suit was patent US7498633 in both cases.

In December 2023, **STMicroelectronics** was held accountable for violating **Purdue**'s patent related to transistor technology. **Purdue** was awarded a $32.5 million damages and expects potential royalties exceeding $100 million before the patent's expiration in 2026. However, **STMicroelectronics** is expected to challenge the verdict by filing an appeal.

QUARTER OVERVIEW

Main US patent litigation filed or closed

Patent US7498633 (expected expiry date in 2026)

(first claim) A metal-oxide semiconductor field-effect transistor comprising:

a silicon-carbide substrate having a first concentration of first type impurities;

a drift semiconductor layer formed on a front side of the semiconductor substrate and having a second concentration of first type impurities less than the first concentration of first type impurities;

a current spreading semiconductor layer formed on a front side of the drift semiconductor layer;

a first source region;

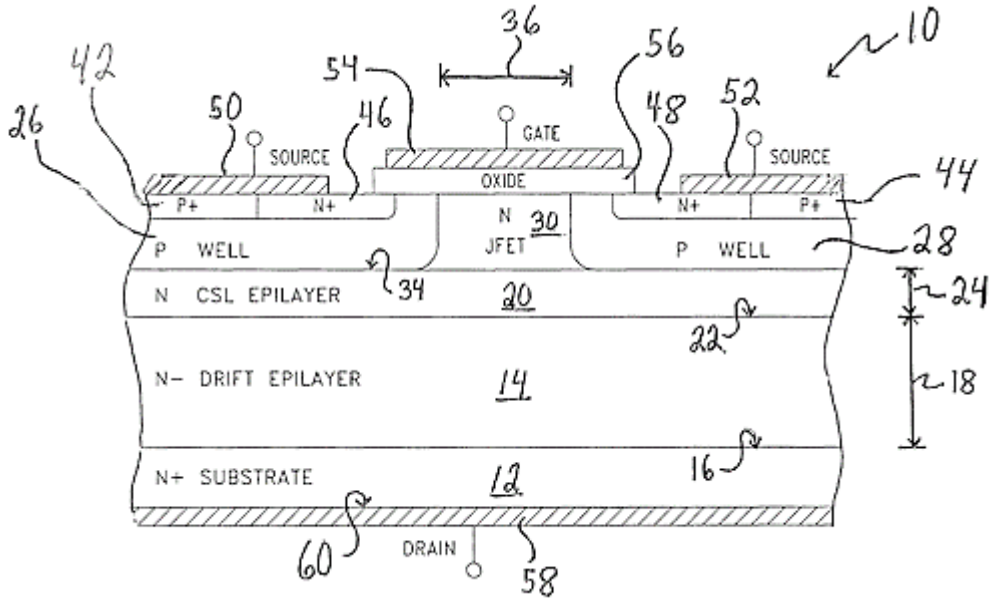
a second source region;

a JFET region formed on a front side of the current spreading semiconductor layer and defined between the first source region and the second source region, the JFET region having a third concentration of first type impurities that is greater than the second concentration of first type impurities;

a plurality of source regions; and

a plurality of base contact regions,

wherein the plurality of source regions and the plurality of base contact regions form alternating strips of N-type doped regions and P-type doped regions, the alternating strips being substantially orthogonal to respective source electrodes formed over the first and the second source regions.



QUARTER OVERVIEW

Main US patent litigation filed or closed

Patent US8035112 (expired in Q4 2023 for failure to pay maintenance fees)

(first claim) A silicon carbide power MOSFET, comprising:

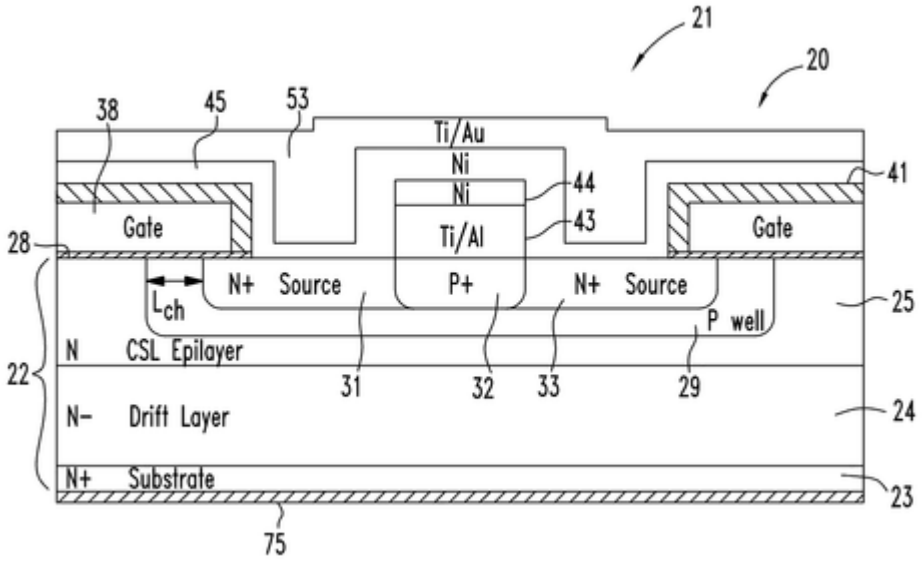
a silicon carbide wafer having a substrate and a drift layer on said substrate, said drift layer having a plurality of source regions formed adjacent an upper surface thereof;

a plurality of polysilicon gates above said drift layer, said plurality of polysilicon gates including a first gate adjacent a first of said source regions, said first gate having a top surface, a lower surface and a sidewall, said sidewall overlying said first source region;

a first oxide layer between said first gate lower surface and said upper surface of said drift layer;

a second, thicker oxide layer over said top surface and sidewall of said first gate; and

a conformal layer of metal extending laterally across said first gate top surface and sidewall and said adjacent first source region.



QUARTER OVERVIEW

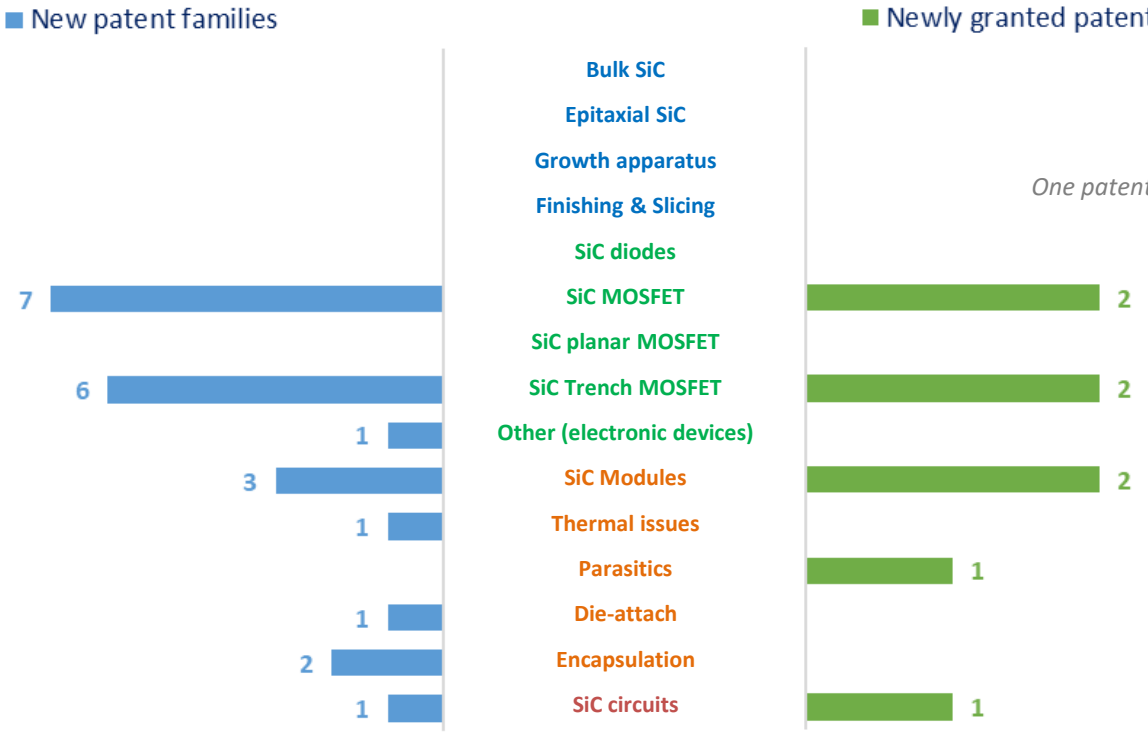
New EP oppositions filed

No EP opposition filed during this quarter

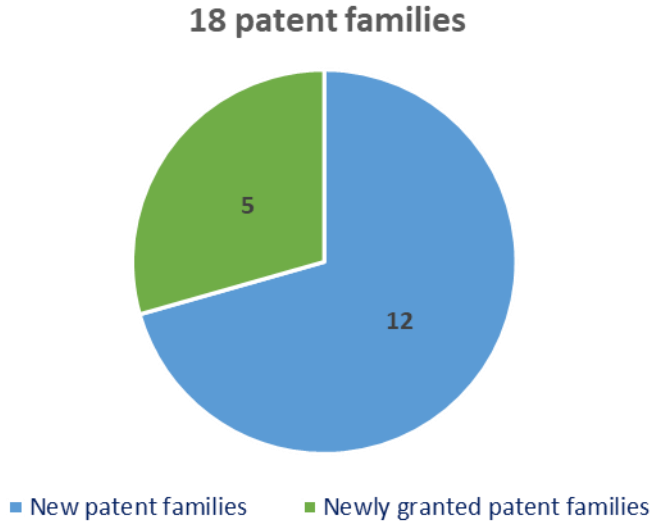
Focus on key players of the quarter

ROHM
IP activity of the quarter

Note: The full-texts of patents mentioned in this slide are available in the Excel database provided with the present report



One patent family may belong to multiple segments



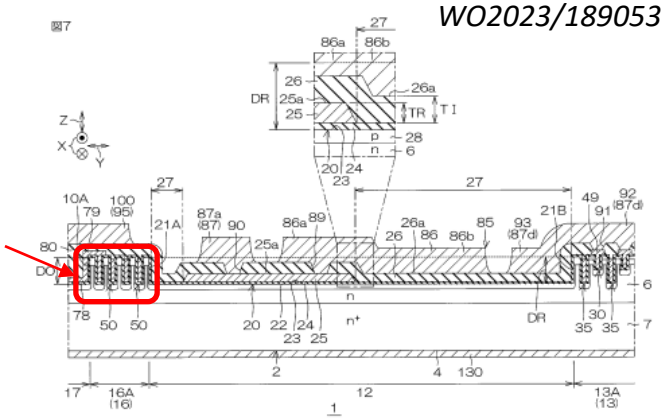
- This quarter, **ROHM**'s patenting activity has focused on SiC MOSFET, especially trench MOSFET (6 new PCT applications and 2 newly granted inventions).
- In the downstream supply chain, **ROHM** published a new patent application describing the formation of a **substrate-die-clip package**, improving the reliability of the passivation layer against thermal processes used to form the package (US20230378013). An additional publication describes a bootstrap circuit constituted to have a switch instead of a diode (WO2023/218988). Another publication describes a module using a Si IGBT in parallel with a SiC MOSFET to combine the distinct advantage of each device in different current regions (WO2023/189052). What's more, several inventions have been granted to **ROHM** in this part of the supply chain, such as patent JP7368450 (laser welding of an electrical connection member), patent JP7364487 (AC/DC power converter using a PFC circuit) and patent DE112021001168 (modules w/reduced inductance to limit surge voltage applied to switching elements).

Note: The full-texts of patents mentioned in this slide are available in the Excel database provided with the present report

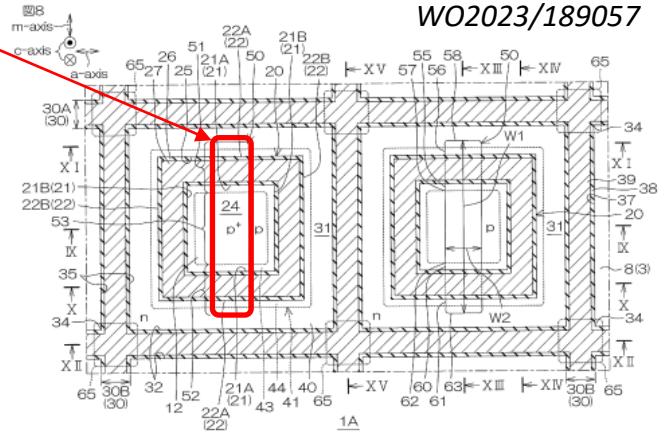
ROHM's Q4 2023 activity in SiC power devices

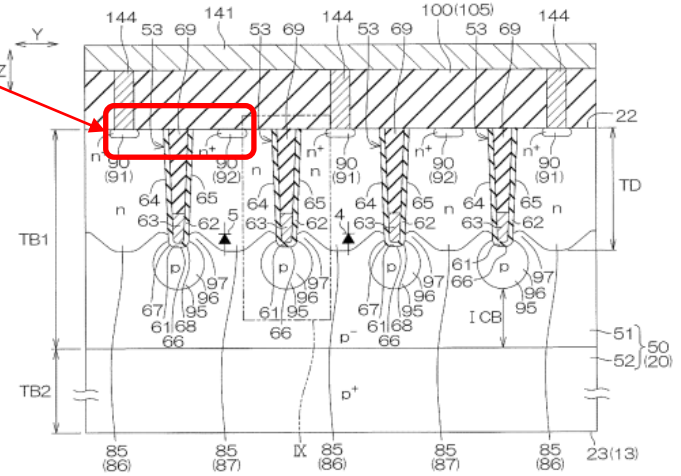
- Patent applications WO2023/189053 and WO2023/189054 incorporate a gate resistance in the MOSFET device by forming a trench resistive structure between the gate pad and the gate interconnection. This approach allows to reduce the number of components mounted on the circuit board. Furthermore, the reduction in the area of the active region is limited because the resistance is incorporated in the thickness direction of the chip.
- Patent applications WO2023/189057 and WO2023/189057 describe the formation of a contact region in SiC MOSFET that improves the ON-resistance by suppressing the contribution from (a-plane or m-plane, depending on the configuration) defects.
- Patent WO2023/189055 describes a drift gradient region that improves cosmic ray tolerance and supresses SEB destruction, thereby improving device reliability.
- Two patent applications related to an invention disclosed by **ROHM** in 2020 were granted during the quarter (CN113396482, JP7376516). The invention describes a common source/drain type MISFET, in which a source and a drain are formed integrally with each other, with improved breakdown voltage, mitigating the punch-through of the drift regions.

WO2023/189053



WO2023/189057





Infineon
IP activity of the quarter

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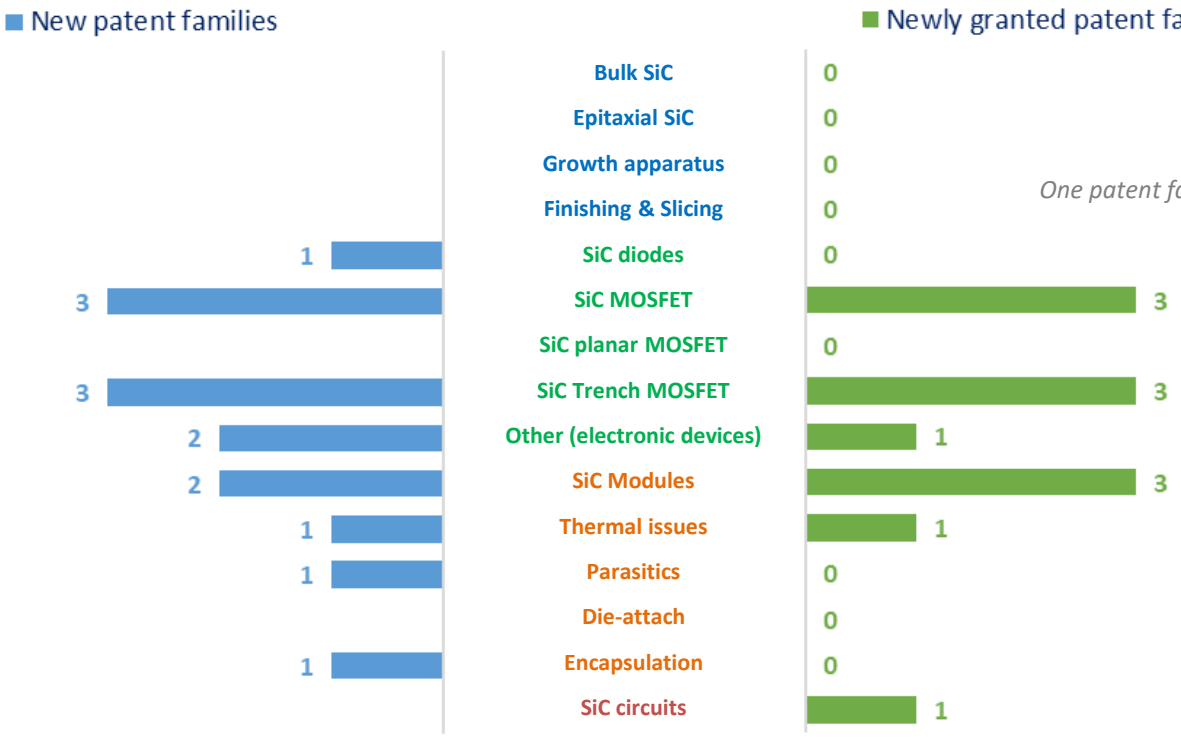
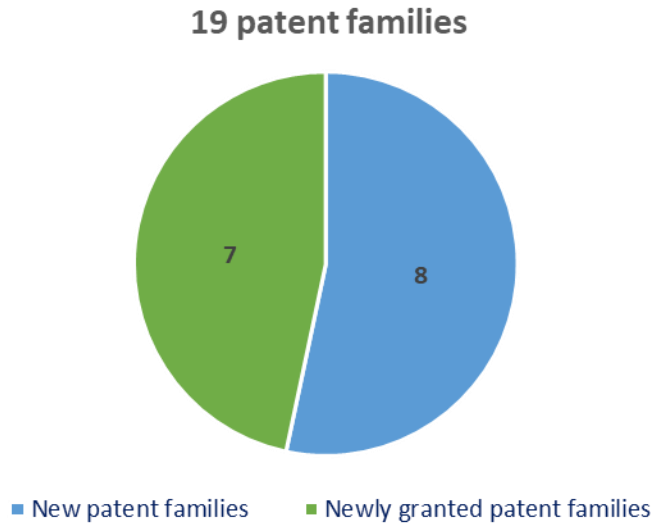


One patent family may belong to multiple segments



- This quarter, **Infineon**'s patenting activity has focused on SiC power devices (9 inventions) and SiC power modules (5 inventions). The quarter analysis of **Infineon**'s IP activities confirms its global IP strategy, with at least 8 triadic patent families identified (that have patent applications filed in US, Europe and China concomitantly).
- Furthermore, 5 patent families expired (a device package US6900537, an SBD w/ overcurrent protection US6861723, a SiC JFET/Si FET cascade circuit DE10350170) or were abandoned (a transistor w/ a shielding structure US8102012, a bipolar switching device/WBG normally-on transistor circuit US10475909) during the quarter.

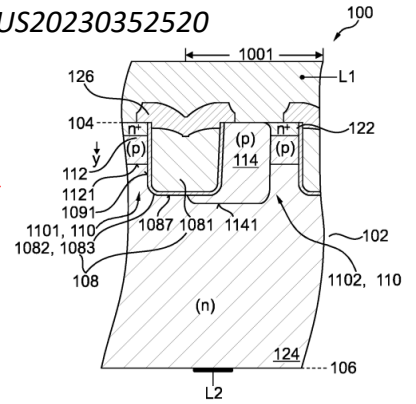
Infineon
IP activity of the quarter

Note: The full-texts of patents mentioned in this slide are available in the Excel database provided with the present report

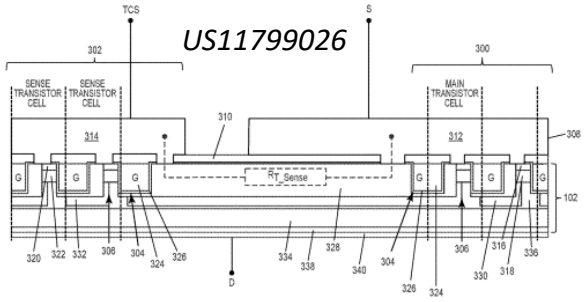
Infineon's Q4 2023 activity in SiC power devices

- Patent application US20230352520 relate to trench SiC MOSFET w/ a shielding region and the gate dielectric structure including the high-k dielectric layer. The structure allows for increasing the gate-to-source capacitance (CGS) without degrading reliability of the gate dielectric structure in the on-state, in a view to improve specific on-resistance and drain-induced barrier lowering.
- Patent US11791383 discloses a SiC MOSFET using a gate dielectric stack comprising a ferroelectric insulator, in order to enhance short-circuit/over current protection (US20230411460). Another approach to solve the problem is introduced in patent US11799026 and consists of co-integrating dual mode current and temperature sensing with SiC devices.
- Patent application US20230317666 describes a method to form an electrical contact with SiC using a metal silicide layer that is formed through laser annealing process with limited surface roughness.

US20230352520

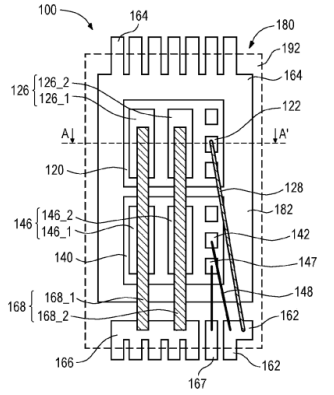


US11799026



Infineon's Q4 2023 activity in SiC power modules

- **Infineon**'s inventions in this part of the supply chain are not limited to SiC. Instead, the inventions are also applicable to other semiconductors such as GaN or Si IGBT.
- During the quarter, 3 patent applications were granted to **Infineon**, related to connection methods (US11848257, US11804424) and to a fluid heatsink (EP3852138).
- Furthermore, **Infineon** has disclosed a couple of new inventions covering a molded semiconductor package having an embedded inlay (US20230369177) and a multi-chip device with gate redistribution structure (US20230335530).

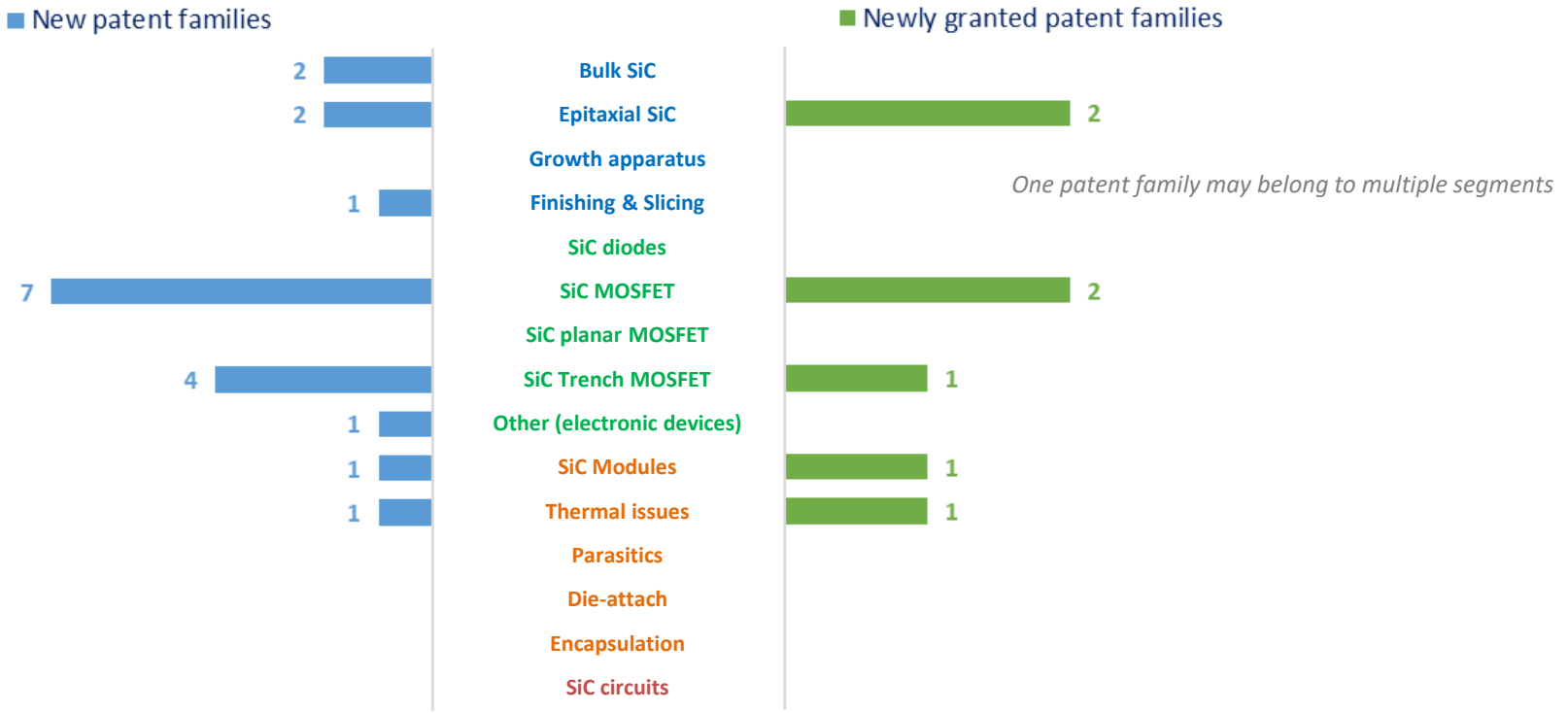


US20230352520

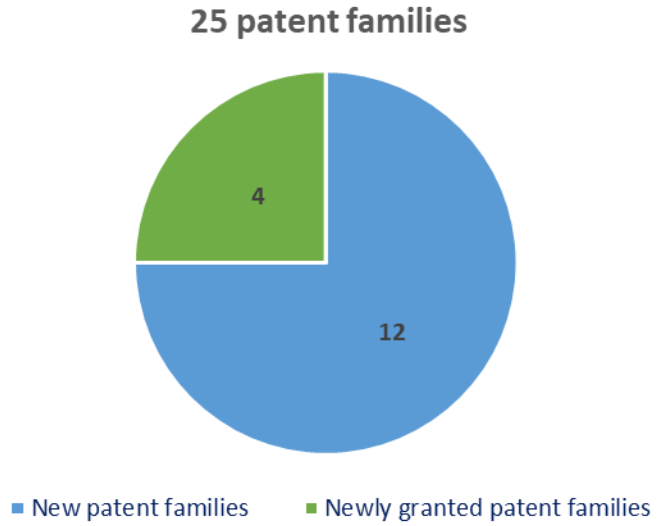
Sumitomo Electric

IP activity of the quarter

Note: The full-texts of patents mentioned in this slide are available in the Excel database provided with the present report



One patent family may belong to multiple segments



- This quarter, **Sumitomo Electric** published 3 new inventions related to SiC substrate. These inventions relates to the control of defect formation and distribution across SiC epitaxial wafers, such as carbon inclusions (WO2023/218809), voids (WO2023/233887) and dislocations (JP2023157718). Furthermore, a couple of new inventions disclosed previously have been granted this quarter: JP7388365 (to prevent basal plane dislocations from becoming stacking faults) and CN112470255, JP7400715 (formation of macro-defects on a large diameter SiC epitaxial substrate).
- In the downstream supply chain, **Sumitomo Electric** disclosed an invention looking to achieve both of miniaturization and improvement in reliability of a module comprising a plurality of SiC transistors and SiC diodes (JP2023163856). The improvement in reliability results from an improvement in heat dissipation of the switching elements.

Sumitomo Electric
IP activity of the quarter

Note: The full-texts of patents mentioned in this slide are available in the Excel database provided with the present report

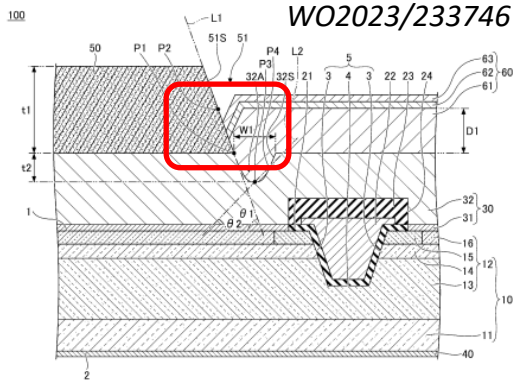
SUMITOMO ELECTRIC

Sumitomo Electric's Q4 2023 activity in SiC power devices

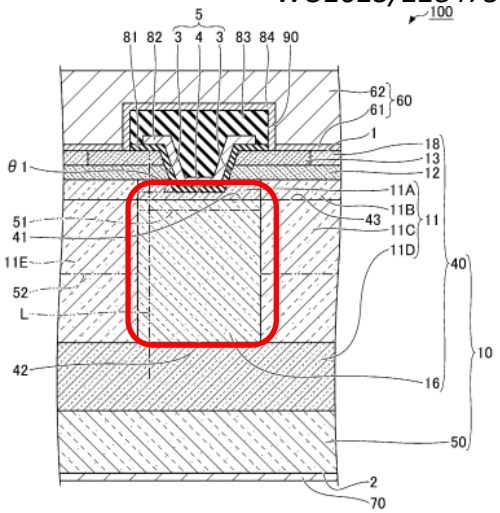
- In the SiC device IP space, **Sumitomo Electric** keeps focusing on trench MOSFET (4 new inventions and 2 newly granted patent families).
- Patent application **WO2023/233746** aims to suppress the occurrence of voids between a passivation layer 50 and a plating layer 60.
- Patent application **WO2023/228473** provides a SiC device with an electric field relaxation region, capable of both reducing on-resistance and improving breakdown voltage.
- Patent applications WO2023/223588, WO2023/223589 and WO2023/223590 aim to reduce the internal inductance of a SiC chip comprising a plurality of transistors cells.
- Patent application JP2023170355 provides a method to suppress the evaporation of Al during the formation of an ohmic contact electrode comprising Al, Ti and Si films.
- Patent application JP2023159727 aims to improve an adhesion between a Ni plating film and a passivation layer.

- What's more, a couple of inventions have been newly granted to **Sumitomo Electric**. Patent JP7388433 provides a semiconductor device to improve heat radiation from an aluminum electrode while suppressing diffusion of copper from a copper film into a passivation film.
- Patent JP7395972 provides a SiC trench MOSFET device, including an electric field relaxation region and a current diffusion region, capable of reducing both on-resistance and a short-circuit current.

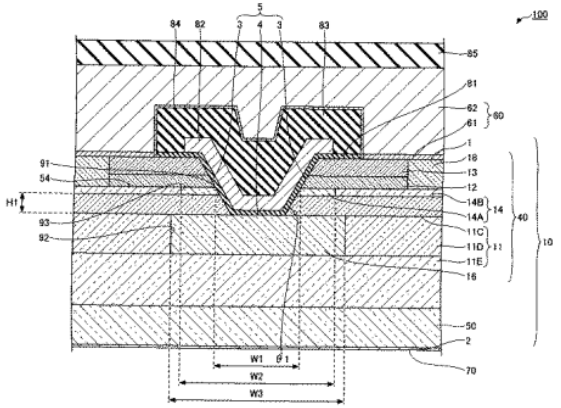
WO2023/233746



WO2023/228473



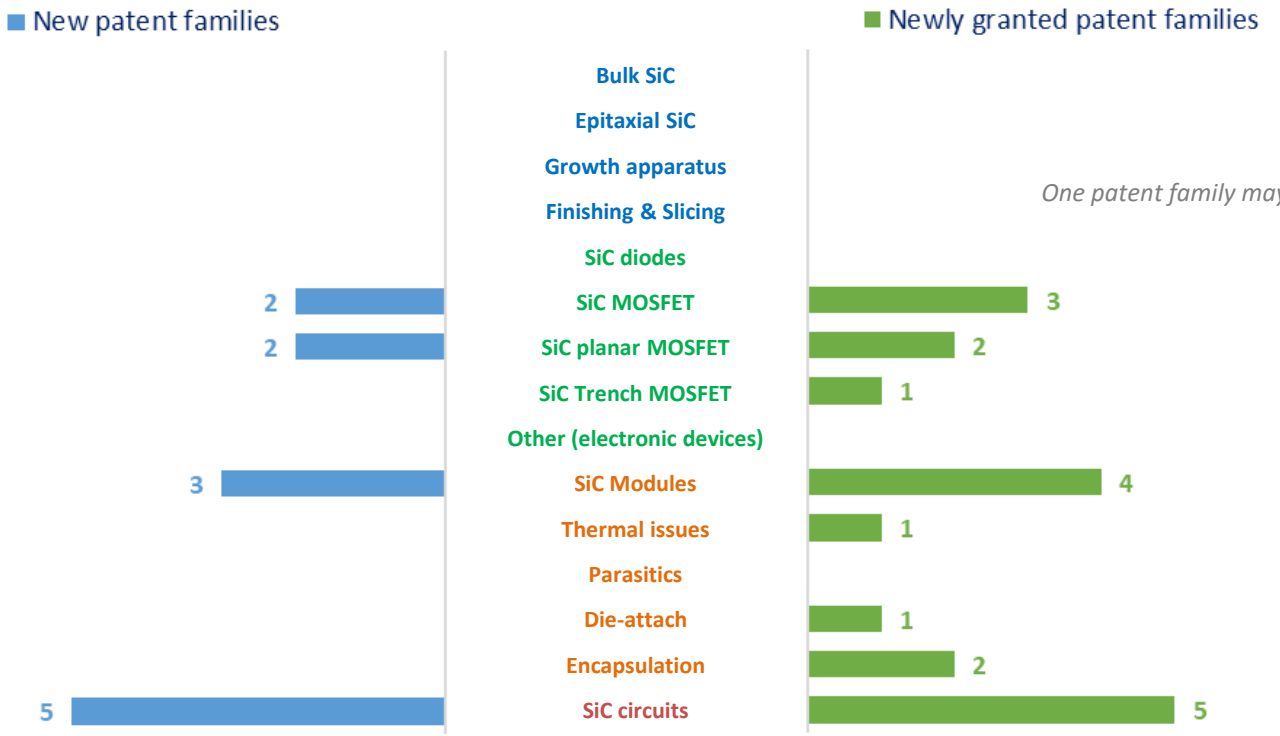
JP7395972



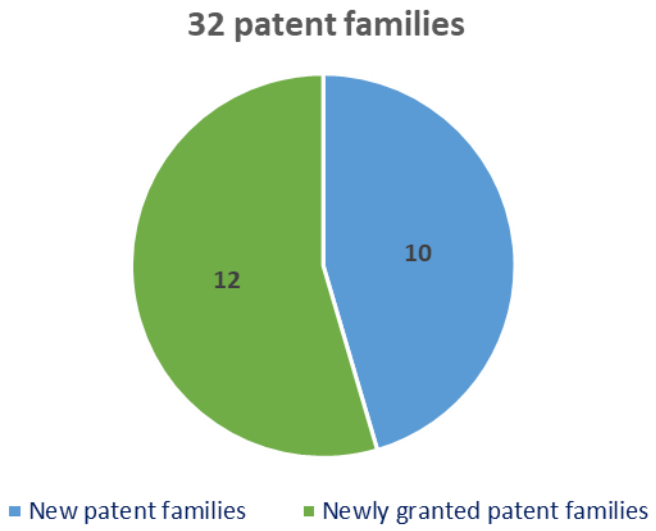
Mitsubishi Electric

IP activity of the quarter

Note: The full-texts of patents mentioned in this slide are available in the Excel database provided with the present report



One patent family may belong to multiple segments



- This quarter, 10 patent families (inventions) related to SiC lost a patent member, while more than 10 patent families were newly granted, and 10 new inventions were disclosed by **Mitsubishi Electric**.
- **Mitsubishi Electric**'s SiC IP activity put the emphasis on SiC circuits (although most inventions are not limited to SiC, but also apply to GaN for instance). Notable new inventions in this space include patent application WO2023/199472, addressing a scheme for a plurality of protection circuits without changing the layout of a switching element.
- What's more, patent US11894783 has been granted to **Mitsubishi Electric**, describing a common gate driver for an IGBT and a SiC MOSFET connected in parallel with each other.
- Most of the newly dead patents are abandoned patents but patent US7012332, related to a sealing structure for wide gap type semiconductor chip. In the field of SiC crystal growth, Mitsubishi Electric lost another patent, describing a method to grow a high-resistivity SiC single crystal containing boron and nitrogen impurities (US8013343). The technology was co-developed with **Sumitomo Electric** and **Kansai Electric** and patented in 2005.

Mitsubishi Electric
IP activity of the quarter

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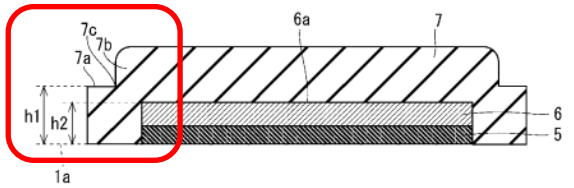
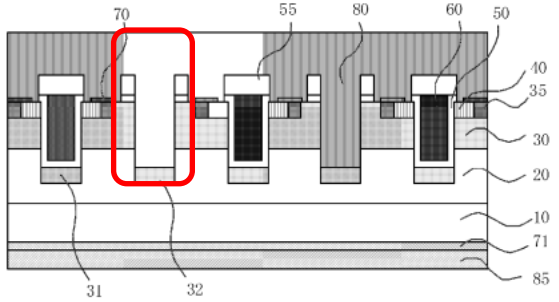
Mitsubishi Electric's Q4 2023 activity in SiC power devices

- A notable invention disclosed by **Mitsubishi Electric** this quarter is described in patent application WO2023/189164. The object of the invention is to improve the reliability of SiC devices by mitigating the damage caused to the gate electrode, when a thermal stress is applied during assembly or operation.
- A notable invention that has been newly granted during the quarter is described in patent JP7370476. The object of the invention is to provide a method of manufacturing a SiC trench MOSFET integrated with a built-in trench Schottky barrier diode (SBD). The invention aims to solve the problem that polycrystalline silicon material or metal silicide material may remain in unintended parts, causing contamination and reliability issues.

WO2023/189164



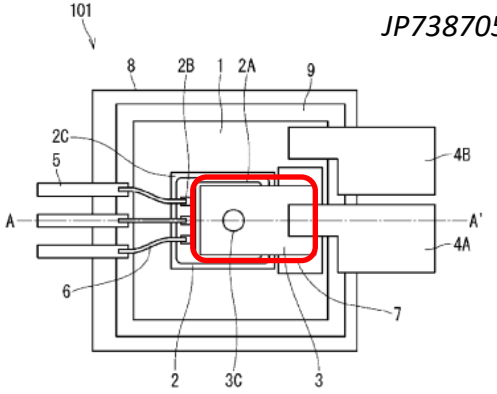
JP7370476



Mitsubishi Electric's Q4 2023 activity in SiC power modules

- Most of the inventions are not focused on SiC technology and may apply to other power semiconductors (e.g., GaN).
- Newly granted patent families include patent US11777419 which enables the suppression of cracking of a waterproof layer when the chip is mounted in a pressure bonding step and the suppression of reduction in breakdown voltage of the chip. Another family has been granted (JP7387059) which describes a method to improve heat dissipation, connecting a metal block to the upper surface of the chip.
- New inventions include patent application WO2023/209793. Patent application WO2023/203688.

JP7387059



KnowMade
Patent & Technology Intelligence

KnowMade SARL
2405 route des Dolines
06560 Valbonne Sophia Antipolis,
France

www.knowmade.com
contact@knowmade.fr