From Technologies to IP Business Intelligence

Silicon Carbide From materials to devices, modules & circuits

Patent Landscape Analysis

December 2024



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ONE-HOUR PRESENTATION

The author of the report is available to address any questions you may have.

A **one-hour online presentation** of the report is included with your purchase. This session offers the opportunity for a direct interaction with the author, including a presentation of the results and a dedicated Q&A session.

Feel free to contact the author to schedule a meeting.





INTRODUCTION Context of the report

In the <u>Silicon Carbide (SiC) patent landscape 2022</u>, KnowMade found out that the **intellectual property (IP) activities were ramping up for SiC devices**. Many historical players aimed to increase the perimeter of protection for their SiC inventions at this time. Electric vehicles (EV) had been driving the emergence of the power SiC market prompting SiC companies to file **more patents in strategic regions for this industry**, such as **Europe** and **China**. In parallel, early leaders in the young SiC market have maintained or even accelerated their IP activities to prepare for a **stronger competition in the next few years**, since the EV boom led many new players to speed up the development of SiC technology. In this context, patents may be leveraged by leading SiC companies to **protect their market share** and thereby **secure the large investments** that have been required to enter the SiC industry. **The growing competition in the market is already conspicuous in the IP landscape**.

Furthermore, Chinese research organizations and companies have progressively ramped up their inventive activity since 2015. In 2023, Chinese entities have produced more than 70% of all power SiC patent publications. 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 2022, **KnowMade** released an <u>analysis</u> of the emerging Chinese SiC ecosystem based on the patenting activities of Chinese players across the SiC supply chain. An impressive number of newcomers were identified in the Chinese SiC patent landscape lately, of which many companies involved in the SiC wafer industry. With such a high number of companies involved in SiC wafer developments, China has already succeeded in stopping the shortage situation but opened a period of economic instability for many suppliers due to a fierce price competition. **This new context may favor patent litigations between SiC wafer suppliers**.

In 2021, two of the main early players in the power SiC market (ST, Wolfspeed) were sued by a US academic player (Purdue University), 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 enforceable patents. The acceleration of IP activities is even more sensitive for **trench MOSFET technology**. It highlights the fact that most companies in the SiC device patent landscape have integrated trench MOSFET in their technological roadmap, leading to an acceleration in patent filings in this area. As a result, trench MOSFET has become an increasingly competitive IP space in recent years.

Eventually, most of the main companies pioneering the SiC market (incl. **Wolfspeed**, **STMicroelectronics**, **onsemi**, **Infineon**, **Rohm**) are developing themselves as integrated device manufacturers (IDM), making plans for a vertical integration of the SiC supply chain. Despite this general trend, the IP activities of these players are very contrasted across the SiC supply chain, highlighting quite differentiated IP strategies. While certain companies heavily rely on patents to assert their position in the market, other companies have not significantly developed their patent portfolio across the SiC supply chain. Although leading SiC companies may rapidly adjust their IP strategy to adapt to the fast evolution of the SiC industry, additional moves such as IP/manufacturing partnerships or M&A are expected to significantly reshape the SiC patent landscape. ,



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The report aims to provide a comprehensive view of the **power SiC patent landscape** along the whole supply chain / value chain, which has been split in the following 5 main categories and 10 main sub-categories:



More in details, the patent landscape analysis provides an overview of **power SiC patent landscape**:

- To describe global patenting trends (time evolution of patent filings, geographical evolution of patent filings);
- To identify the main IP players and the newcomers in the different segments of the supply chain;
- To determine the status of their **patenting activity** (active / inactive) and their **dynamics** (ramping up, slowing down, steady);
- To identify the IP collaborations (patent co-filings) and IP transfers (changes of patent ownership) in the power SiC patent landscape;
- To provide a detailed picture of the Chinese SiC ecosystem focusing on the patenting activity of Chinese entities.

In addition, the report includes **IP profiles**, which provide a comparison and an overview of the patent portfolios and the recent patenting activity of **Wolfspeed**, **STMicroelectronics**, **onsemi**, **Infineon**, **Rohm**, **SK**, **Coherent**, **General Electric** and **San'an**.

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The patent selection is performed by KnowMade's analysts. 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:





- 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**.



- 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.**

INTRODUCTION

Reading guide: find the right information in the report

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Report sections	Your concern	TECHNOLOGY For R&D teams, engineers, scientists	IP For IP teams, patent attorneys	MARKET For executives, business developers	PLAYER Zoom in a competitor / partner
PATENT LANDS • Ranking of playe geo/tech coverage, • Patent filings dyn • IP collaborations • Patent litigation,	SCAPE OVERVIEW ers (enforceability, current activity, prior-art contribution, etc.) namics per player s (co-filings, IPR transfers) /oppositions	Innovators	Main patent owners IP risks/opportunities	Ecosystem (competitors, newcomers, partners, clients) Main trends IP vs Market	IP position vs Market position Player relationships (collaborations/ dependencies)
SEGMENTS AN • Patent filings dyn • IP leaders per se activity, blocking po • Key patents per se • Recent patenting	ALYSIS namics per segment gment (enforceability, current otential) segment g activity per segment	Technology trends Technology mapping	Blocking players IP risks/opportunities in each segment (FTO, litigation, licensing)	Benchmarking Markets of interest Future developments	IP position and level of investment in each segment Key IP developments
IP PROFILE OF • Patent portfolio activity evolution, p coverage, strengths, • Key patents • Recent patenting	KEY PLAYERS summary (portfolio size, IP patents legal status, geo/tech /weaknesses, etc.) g activity	Current R&D activities Technology roadmap	Blocking patents Geo/Tech coverage Link between patents and products	Future products Potential partners Potential targets	R&D investment level Key inventions Current IP activities Strengths / Weaknesses



INTRODUCTION Excel database

With this report, an Excel file is provided that includes all 19,000+ patent families (inventions) selected and analyzed in this study, along with the complete data assignee from the statistical analyses.

- In the first tab, you will find a useful patent database that allows for multi-criteria searching and includes patent publication numbers, hyperlinks to an updated online database (original documents, legal status, etc.), priority date, title, abstract, patent assignees, segments (SiC bulk & bare wafers, SiC epitaxial substrates, growth apparatus, finishing & slicing, SiC power devices, SiC diodes, SiC MOSFETs, planar SiC MOSFETs, trench SiC MOSFETs, packaging & module, thermal issues, parasitics, die-attach, encapsulation, circuits), and key patents.
- In the second tab, you will find a comprehensive statistical data table for all the patent assignees, including the number of patent families, timeline of patenting activity, number of granted patents and pending patent applications, and geographical coverage of patent portfolio.

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11162222	CH117418344	[CH11241B14]	[CH147448344]	PENDING	JSAP Trabalagies	[CH117418364]	2825-11-2	2824-81-15	ICH442	18344A		Infineon	444	369	1543	741	386	69	301	46	369	77	153	161	64	21	122	119	21	8	9	0	1	0
111155855	CH117418313	[CH49744B343]	[CHIEFFORMERS]	PENDING	Spratron Semianadaalar	[CH112418313]	2825-11-8	2824-81-15	ICH112	11313A Sara		Toshiba	443	339	1125	627	186	12	256	44	259	46	12	23	265	65	52	36	17	4	20	8	0	0
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Patent landscape overview

Executive summary





Patent landscape overview

General trends, key patent assignees and newcomers along the SiC supply chain



Focus on Chinese ecosystem

SANJOIN





SiC substrates (incl. bulk, epiwafers, growth apparatus, and finishing/slicing) General trends, Key patent assignees, Newcomers, Patent legal status, Geo coverage



(C)KnowMade

Focus on bulk SiC and SiC epiwafers



SiC power devices (incl. diodes, MOSFETs, other devices, and technological aspects) General trends, Key patent assignees, Newcomers, Patent legal status, Geo coverage



legal status, Geo coverage Focus on SiC diodes, planar SiC MOSFETs and trench SiC MOSFETS



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SiC power modules, packaging, and circuits

General trends, Key patent assignees, Newcomers, Patent legal status, Geo coverage





Benchmark of key players IP dynamics, IP position across the supply chain, IP leadership, Geographic coverage

A focus on main SiC device market players and/or companies investing significantly into building a vertically-integrated infrastructure for SiC is provided dedicated section. Such companies have adopted an IDM business model and look to integrate within the company every step of SiC manufacturing, material growth, to device manufacturing and packaging. Interestingly, the comparison of their IP activities highlights quite differentiated IP strategies.



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IP profile of key players IP portfolio summary, IP strategy, key patents and recent IP activity

A focus on main SiC device market players and/or companies investing significantly into building a vertically-integrated infrastructure for SiC is provided in dedicated section. For each player, the SiC patent portfolio is statistically analyzed to provide an overview of its strengths, its potential for reinforcement and level of IP activity. The recent patenting activity of the player is then reviewed. It allows to detect small signals, such as involvement in new technological areas or a strong IP activity in new regions, and it may provide insights into the company's strategic plans and recent evolutions of SiC technology.





ORDER FORM Silicon Carbide (SiC)

Patent Landscape Analysis – December 2024

Ref.:KM24005

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issued by the buyer at any time are hereby objected to by the seller, shall be wholly inapplicable to any sale acts it deduces thereof. made hereunder and shall not be binding in any way on the seller

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1.3 Orders are deemed to be accepted only upon written acceptance and confirmation by the Seller, within [7 days] from the date of order, to be sent either by email or to the Buyer's address. In the absence of any confirmation in writing, orders shall be deemed to have been accepted.

2. MAILING OF THE PRODUCTS

2.1 Products are sent by email to the Buyer:

- within [1] month from the order for Products already released: or

- within a reasonable time for Products ordered prior to their effective release. In this case, the Seller shall progress.

2.2 Some weeks prior to the release date the Seller can propose a pre-release discount to the Buyer. The Seller shall by no means be responsible for any delay in respect of article 2.2 above, and including in 4.6 In the case where, after inspection, it is acknowledged that the Products contain defects, the Seller by the other Party. cases where a new event or access to new contradictory information would require for the analyst extra time to compute or compare the data in order to enable the Seller to deliver a high quality Products.

2.3 The mailing of the Product will occur only upon payment by the Buyer, in accordance with the conditions contained in article 3.

2.4 The mailing is operated through electronic means either by email via the sales department. If the 4.7 The deadlines that the Seller is asked to state for the mailing of the Products are given for information 9. GOVERNING LAW AND JURISDICTION Product's electronic delivery format is defective, the Seller undertakes to replace it at no charge to the only and are not guaranteed. If such deadlines are not met, it shall not lead to any damages or cancellation 9.1 Any dispute arising out or linked to these Terms and Conditions or to any contract (orders) entered into download or receipt of the Product.

2.5 The person receiving the Products on behalf of the Buyer shall immediately verify the quality of the first down payment to the exclusion of any further damages. Products and their conformity to the order. Any claim for apparent defects or for non-conformity shall be 4.8 The Seller does not make any warranties, express or implied, including, without limitation, those of and Conditions. sent in writing to the Seller within 8 days of receipt of the Products. For this purpose, the Buyer agrees to saleability and fitness for a particular purpose, with respect to the Products. Although the Seller shall take

produce sufficient evidence of such defects

done by signing the purchase order which mentions "I hereby accept Knowmade's Terms and Conditions of delivery. Any Product returned to the Seller without providing prior information to the Seller as required guarantee that any Product will be free from infection. under article 2.5 shall remain at the Buyer's risk

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4.1 The Buyer or any other individual or legal person acting on its behalf, being a business user buying the consequences in their entirety. 1.1 The Contracting Parties undertake to observe the following general conditions when agreed by the Products for its business activities, shall be solely responsible for choosing the Products and for the use and 6.4 The Buyer shall define within its company point of contact for the needs of the contract. This person will

4.2 The Seller shall only be liable for (i) direct and (ii) foreseeable pecuniary loss, caused by the Products or

not limited to, damages for loss of profits, business interruption and loss of programs or information) arising out of the use of or inability to use the Seller's website or the Products, or any information provided may be borne by the Seller, following this decision. on the website. or in the Products:

thereof

4.4 All the information contained in the Products has been obtained from sources believed to be reliable The Seller does not warrant the accuracy, completeness adequacy or reliability of such information, which

cannot be guaranteed to be free from errors.

the liability of the Seller, provided that the Seller ensures the substituted Product is similar to the Product Buyer. initially ordered.

guaranteed for a maximum of two months starting from the delivery date. Any replacement is excluded for in due time. any event as set out in article 5 below.

information from the Seller. In such case only, the Buyer shall be entitled to ask for a reimbursement of its which shall have exclusive jurisdiction upon such issues.

reasonable steps to screen Products for infection of viruses, worms, Trojan horses or other codes "Acceptance": Action by which the Buver accepts the terms and conditions of sale in their entirety. It is 2.6 No return of Products shall be accepted without prior information to the Seller, even in case of delayed containing containing or destructive properties before making the Products available, the Seller cannot

5. FORCE MAIEURE

The Seller shall not be liable for any delay in performance directly or indirectly caused by or resulting from 3.1 Prices are given in the orders corresponding to each Product sold on a unit basis or corresponding to acts of nature, fire, flood, accident, riot, war, government intervention, embargoes, strikes, labor annual subscriptions. They are expressed to be inclusive of all taxes. The prices may be reevaluated from difficulties, equipment failure, late deliveries by suppliers or other difficulties which are beyond the control. and not the fault of the Seller.

6 PROTECTION OF THE SELLER'S IPR

6.1 All the IPR attached to the Products are and remain the property of the Seller and are protected under French and international convright law and conventions

6.2 The Buyer agreed not to disclose convirgence under redistribute resell or publish the Product or any To ensure the payments, the Seller reserves the right to request down payments from the Buyer. In this part of it to any other party other than employees of its company. The Buyer shall have the right to use the Products solely for its own internal information purposes. In particular, the Buyer shall therefore not use

- Recordings and re-transmittals over any network (including any local area network):

- Posting any Product to any other online service (including bulletin boards or the Internet):

- Licensing, leasing, selling, offering for sale or assigning the Product.

6.3 The Buyer shall be solely responsible towards the Seller of all infringements of this obligation, whether this infringement comes from its employees or any person to whom the Buyer has sent the Products and shall personally take care of any related proceedings and the Buyer shall bear related financial

Buver and the Seller. Any additional, different, or conflicting terms and conditions in any other documents interpretations he makes of the documents it purchases, of the results he obtains, and of the advice and be the recipient of each new report in PDF format. This person shall also be responsible for respect of the copyrights and will guaranty that the Products are not disseminated out of the company.

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> 7.2 In the event of breach by one Party under these conditions or the order, the non-breaching Party may b) any claim attributable to errors, omissions or other inaccuracies in the Product or interpretations send a notification to the other by recorded delivery letter upon which, after a period of thirty (30) days without solving the problem, the non-breaching Party shall be entitled to terminate all the pending orders. without being liable for any compensation

8. MISCELLANEOUS

4.5 All the Products that the Seller sells may, upon prior notice to the Buyer from time to time be modified All the provisions of these Terms and Conditions are for the benefit of the Seller itself, but also for its use its best endeavours to inform the Buyer of an indicative release date and the evolution of the work in by or substituted with similar Products meeting the needs of the Buyer. This modification shall not lead to licensors, employees and agents. Each of them is entitled to assert and enforce those provisions against the

Any notices under these Terms and Conditions shall be given in writing. They shall be effective upon receipt

undertakes to replace the defective products as far as the supplies allow and without indemnities or The Seller may, from time to time, update these Terms and Conditions and the Buyer, is deemed to have compensation of any kind for labor costs, delays, loss caused or any other reason. The replacement is accepted the latest version of these terms and conditions, provided they have been communicated to him

Buver provided that it is informed of the defective formatting within 90 days from the date of the original of the orders. exceeding [4] months from the stated deadline, without in application of these Terms and Conditions shall be settled by the French Commercial Courts of Grasse,

9.2 French law shall govern the relation between the Buyer and the Seller, in accordance with these Terms



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- Power electronics
- RF & Wireless datacom
- > MEMS, Sensing & Imaging
- Photonics, Lighting & Display
- > Memory
- Packaging

ENERGY

- Batteries
- ➢ Fuel-cells
- Solar PV
- Power management



HEALTHCARE

- > New therapeutic tools
- Medical diagnostics
- Medical devices and imaging
- Drug discovery and delivery

AGRI-FOOD

- Food processing & formulation
- Vegan food
- Next-gen packaging
- Microbiology



SEMICONDUCTORS

Expertise



Power electronics

- Wide bandgap semiconductors
- Power devices and IC
- Power modules
- Power applications

RF & Wireless communications

- ➢ RF substrate & epiwafers
- > RF devices (SAW, BAW, PA/LNA, etc.), RFIC, MMIC
- RF front-end module, RF packaging
- > MIMO, beamforming, carrier aggregation
- 5G & 6G networks, Radar, mm-waves, microwaves, THz

MEMS, Sensing & Imaging

- MEMS sensors and actuators
- 3D imaging and sensing (ToF, CIS, thermal imaging, LiDAR, imaging Radar, event-based camera, etc.)
- > AI/ML, sensor data fusion



SEMICONDUCTORS

from materials and devices to circuits, packaging and modules/systems



Memory

- > SRAM, DRAM, flash
- 3D-stacked memories
- Emerging non-volatile memories (MRAM, PCM, RRAM, etc.)
- Embedded NVM

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- Optoelectronics & optical components (LED, OLED, laser, optical transceivers, waveguides, metasurfaces, etc.)
- Photonic crystal, photonic IC, silicon photonics
- > Optical communications, AR/VR, quantum

Advanced packaging

- Fan-Out WLP/PLP, 2.5D/3D IC
- ➢ SiP, SoC, Chiplets
- TSV, μbumps, interposer, interconnect bridge, hybrid bonding

Materials & Substrates

- Compound semiconductors
- Engineered substrates
- Epiwafers

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