From Technologies to IP Business Intelligence

Silicon Carbide

From materials to devices, modules & circuits

Patent Landscape Analysis

May 2022

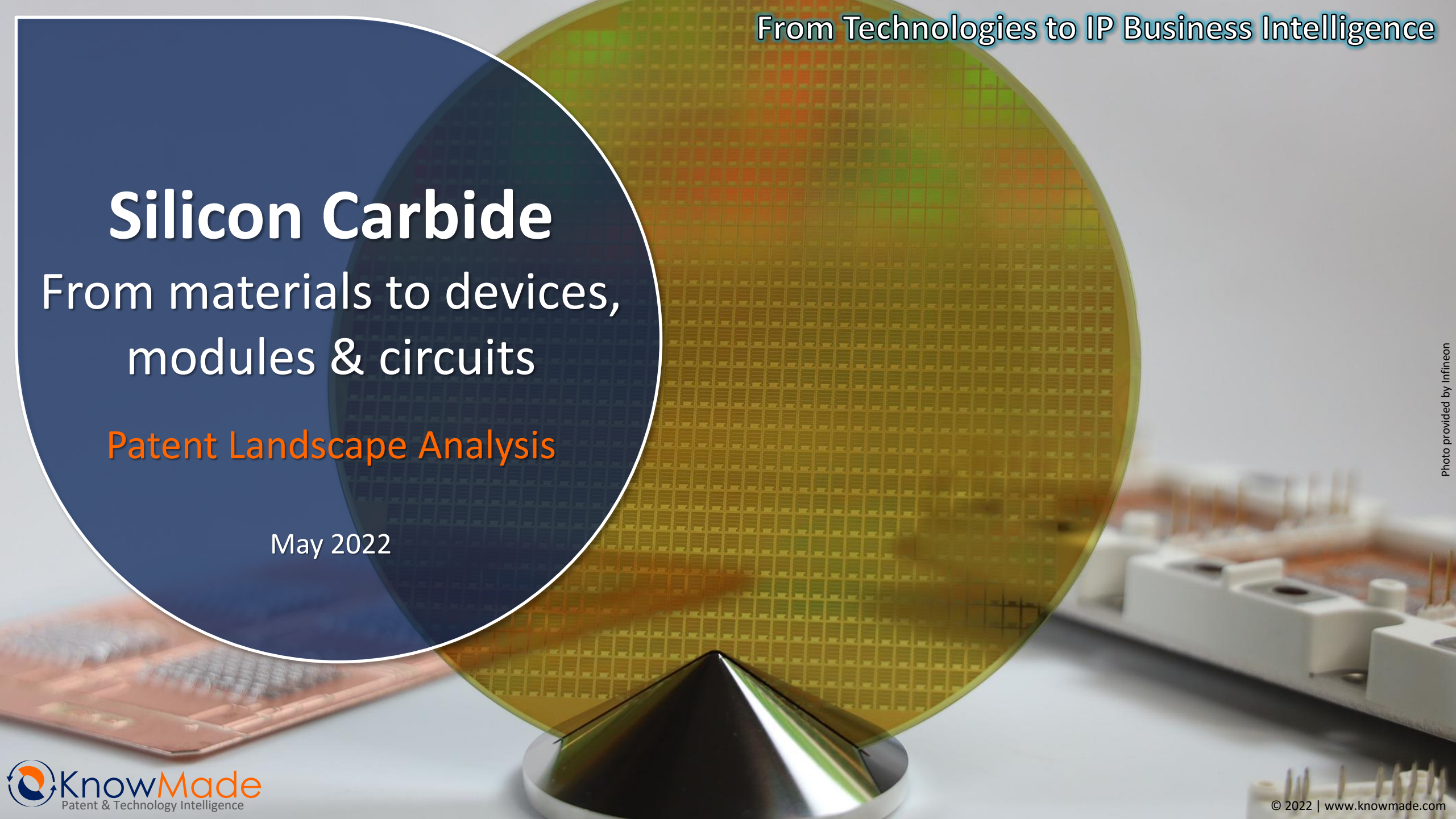

Photo provided by Infineon

KnowMade
Patent & Technology Intelligence

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KnowMade

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INTRODUCTION

Context of the report

THE SIC MARKET IS BOOMING, DRIVEN BY THE ADOPTION OF SILICON CARBIDE (SIC) POWER DEVICES IN ELECTRIC VEHICLES (EV)

In recent years, more and more automotive players have investigated the use of SiC power devices, especially in the EV main inverter controlling the motor. In 2018, with the release of the Model 3, **Tesla** was the first company to adopt power SiC technology in its in-house EV inverter, just before historical automakers such as **Hyundai**, **General Motors** and **BYD** also announced their intention to adopt power SiC in EV systems. **Tesla**'s SiC power device supplier is **STMicroelectronics (ST)**, which holds a 40% share of the SiC power device market as of 2021. In Europe, the main competitor to **STMicroelectronics** is **Infineon**, the second-placed SiC power device manufacturer in terms of revenue in 2021, which exhibited a +126% rise in revenue in 2020/2021 by entering the main inverter business with the base of industrial applications [1]. What's more, **Infineon** will supply **Hyundai** with SiC power modules for the production of its 800-V battery platforms. The competition will also come from **Danfoss** and **Semikron**, which joined forces in the power module business in 2022, and are currently the main European challengers in the SiC power device market. In North America, the main market player is **Wolfspeed**, which is also the world leading supplier of SiC wafers, and has multiple long-term supply agreements (LTSA) with several top-6 power device makers (**ST**, **Infineon**). **Wolfspeed** also signed an LTSA with **onsemi**, which is the main challenger in North America (far ahead of **GeneSiC**, **UnitedSiC** and **Microchip** in terms of revenue) and exhibited rapid growth in 2020/2021, similar to that of other leading power device makers (**ST**, **Wolfspeed**). Finally, in Asia, the competition mainly comes from **Rohm Semiconductor** in Japan, which has doubled its revenue since 2017 and ranked fourth in the SiC power device market in 2021. Furthermore, major Japanese corporations are preparing for power SiC ramp-up as well, and have already demonstrated significant market revenue, including **Mitsubishi Electric**, **Fuji Electric** and **Toshiba**.

Rank	Area	Company	2020	2021
1	Europe	STMicroelectronics	$290M	$450M
2	Europe	Infineon Technologies	$110M	$248M
3	North America	Wolfspeed	$108M	$165M
4	Asia	ROHM	$103M	$108M
5	North America	onsemi	$55M	$78M
6	Asia	Mitsubishi Electric	$26M	$28M

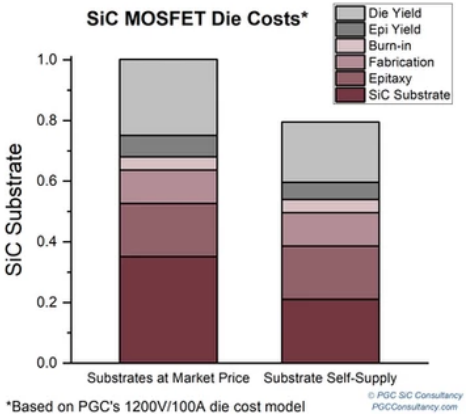
2020-2021 revenue – Top 6 SiC power device makers [1]

THE SIC INDUSTRY IS ADAPTING TO LIMIT THE RISKS RELATED TO WAFER SUPPLY AND COST COMPETITIVENESS

Growing SiC crystals is a long and difficult process, and making high-quality and large-area SiC wafers is still expensive, so the number of companies capable of supplying such wafers is very limited. In order to alleviate both problems, major SiC power device players have signed LTSAs with multiple SiC wafer suppliers (e.g., **Infineon** with **Wolfspeed** and **Showa Denko**, **ST** with **Wolfspeed** and **SiCrystal**), and/or adopted a vertical integration model by acquiring SiC material suppliers for substrate self-supply (e.g., **ST** acquired **Norstel**, **Rohm** acquired **SiCrystal**, **onsemi** acquired **GTAT**), reshaping the SiC ecosystem [2]. Furthermore, more and more SiC wafer suppliers are developing the technology for 200mm SiC wafers, which are expected to be cheaper eventually than their 150mm counterparts and thereby represent a mid-term or long-term solution [2]. Several manufacturers are sampling 200mm SiC wafers (**Wolfspeed**, **II-VI**, **SiCrystal**, **ST**, **GTAT**, **SK Siltron CSS**). In the meantime, several companies are developing disruptive technologies to address the cost and supply issues and have now entered the SiC ecosystem (e.g., **Siltectra**, **Disco** providing laser slicing/thinning; and more recently **Soitec** and **Sumitomo Metal Mining** providing SiC engineered substrates).

CHINA AIMS TO BUILD A DOMESTIC SUPPLY CHAIN FOR POWER SIC TECHNOLOGY

It seems that China has been a little bit late to develop its SiC industry, but is now willing to catch up at all levels of the value chain, funding numerous SiC industrial and R&D projects in recent years. As an example of Chinese ambitions to serve its own market, in 2021, **San'an Optoelectronics**, a new entrant in the power SiC landscape, announced the establishment of China's first vertically-integrated SiC line, representing a $2.5B investment. However, for a new player in SiC to meet the material quality required by SiC power devices would normally not only require strong expertise and big investment, but also many years of development in crystal & epitaxial growth, slicing, polishing, etc., not to mention the difficulty of SiC device manufacturing and testing, and tough requirements from automotive applications (the main market for power SiC). Accordingly, the current development of power SiC technology in China raises many questions in the SiC industry.



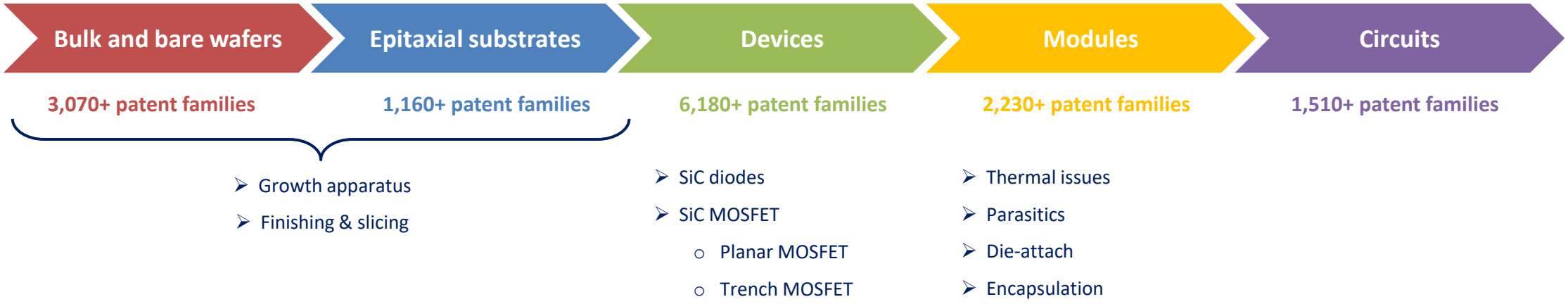
The cost breakdown of a SiC MOSFET die, based on a best-in-class 2021 1200V/100A device on a 150mm substrate [2]

[1] *Power SiC 2022 report, Yole Développement, 2022*
[2] *Taking Stock of SiC, Part 1: a review of SiC cost competitiveness and a roadmap to lower costs, PGC Consultancy, 2021*

INTRODUCTION

Description of the report

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 patent landscape analysis includes **IP profiles**, which provide an overview of the patent portfolios and the recent patenting activity of the **top 10 IP players** and **top 6 power device market players**.

INTRODUCTION

Scope of the report

- This report provides a detailed picture of the patent landscape related to **Silicon Carbide (SiC)**:
  - **Bulk SiC** (growth methods, growth apparatus)
  - **Epitaxial SiC wafers** (homo-epitaxial growth methods, growth apparatus for SiC epitaxy)
  - **SiC devices** (MOSFET, JFET, MESFET, bipolar devices)
  - **SiC modules and circuits**
- This report covers patents published worldwide up to **August 2021**.
- We have selected and analyzed more than **13,700 patent families** (inventions) relevant to the scope of this report.

Included

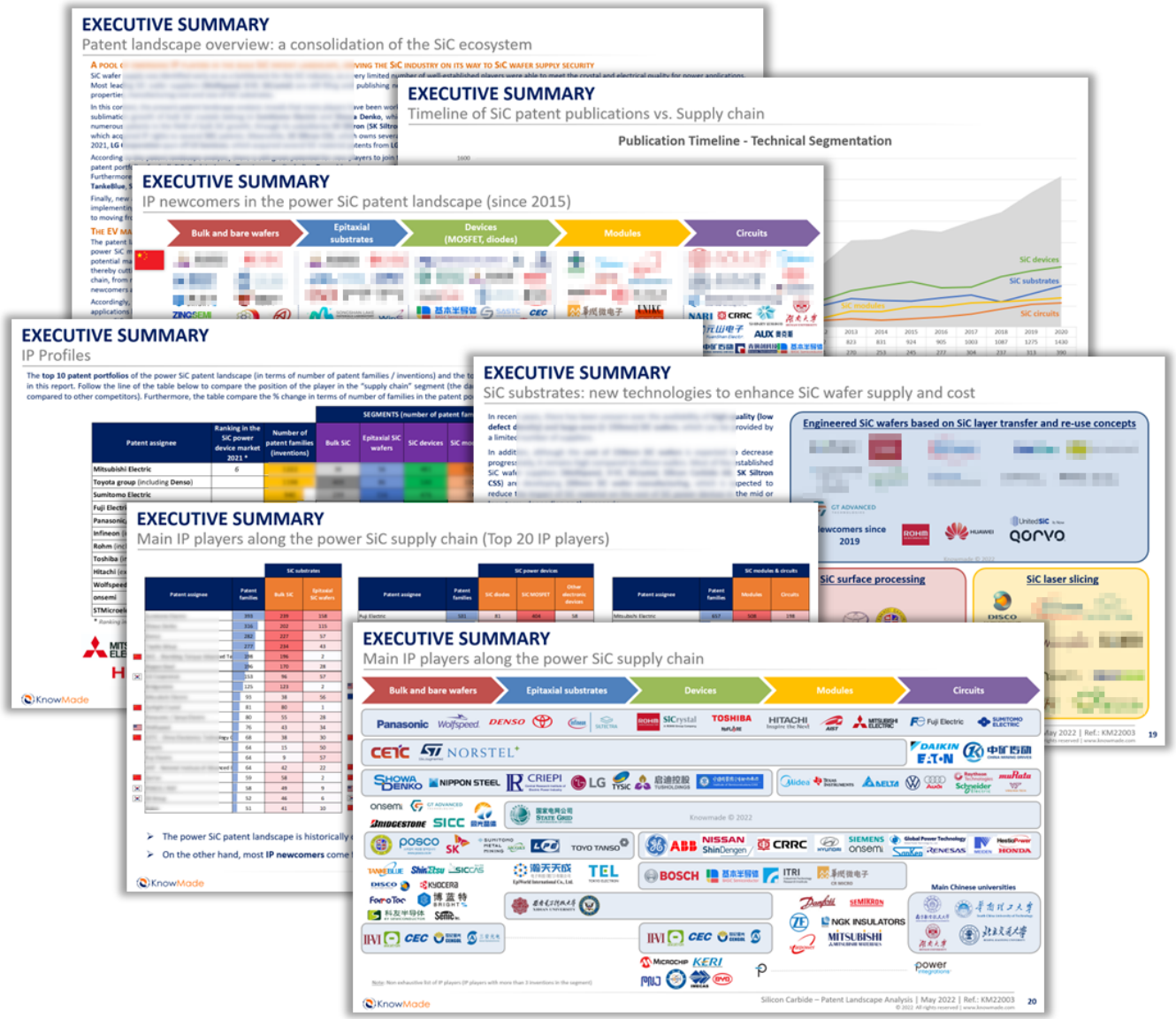
- SiC substrate patents describing growth apparatus for **crystal growth (bulk)** and **epitaxial growth (thin films)**.
- SiC substrate patents related to **wafering (slicing, finishing)**.
- SiC substrate patents describing **SiC-on-SiC epitaxial structures**.
- SiC device patents describing **electronic 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

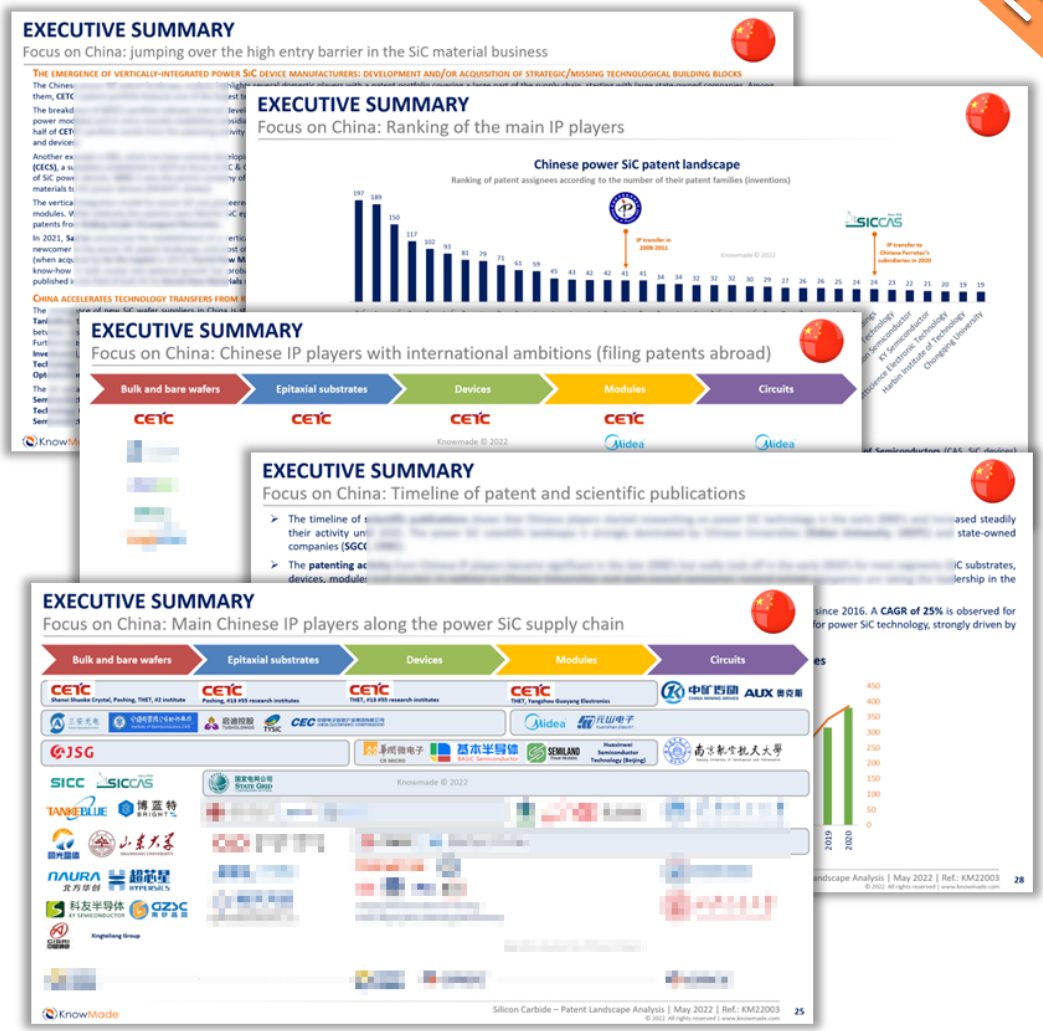
- SiC substrate patents claiming materials different from SiC (generic patents)
- SiC substrate patents describing **heterostructures (SiC-on-X, X is not SiC)**
- SiC device patents describing **other devices (optoelectronic devices, sensors, MEMS, etc.)**
- WBG power module patents including specifically **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.**

Patent landscape overview

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

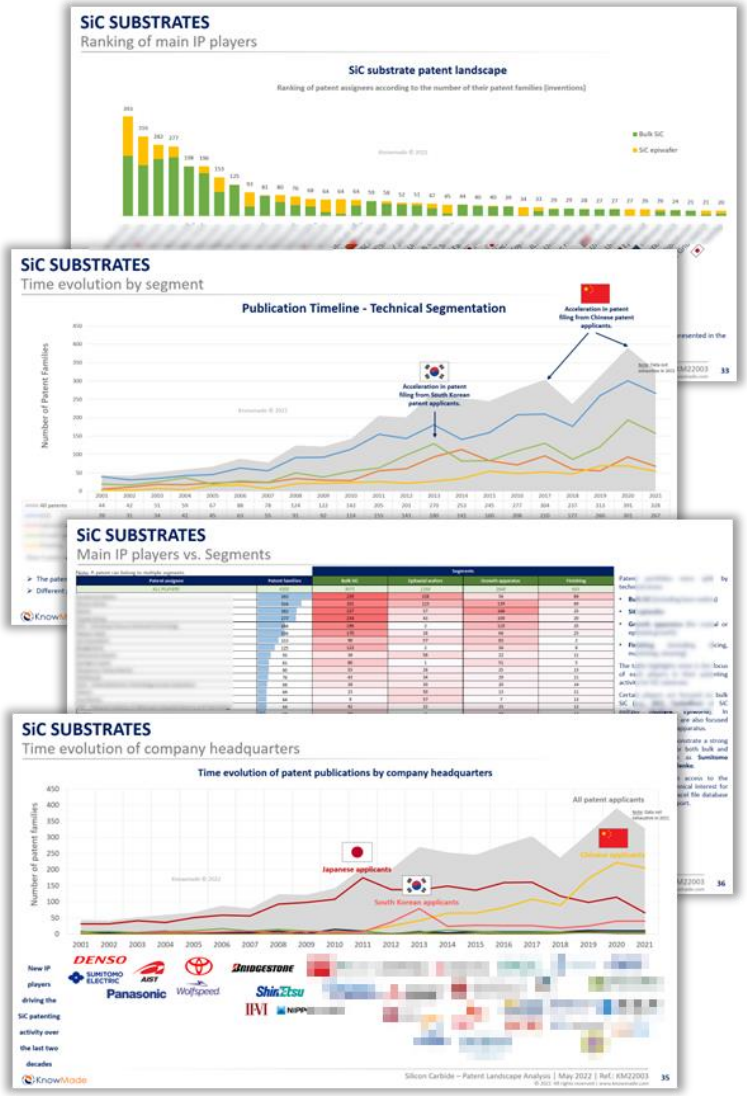


Focus on Chinese ecosystem

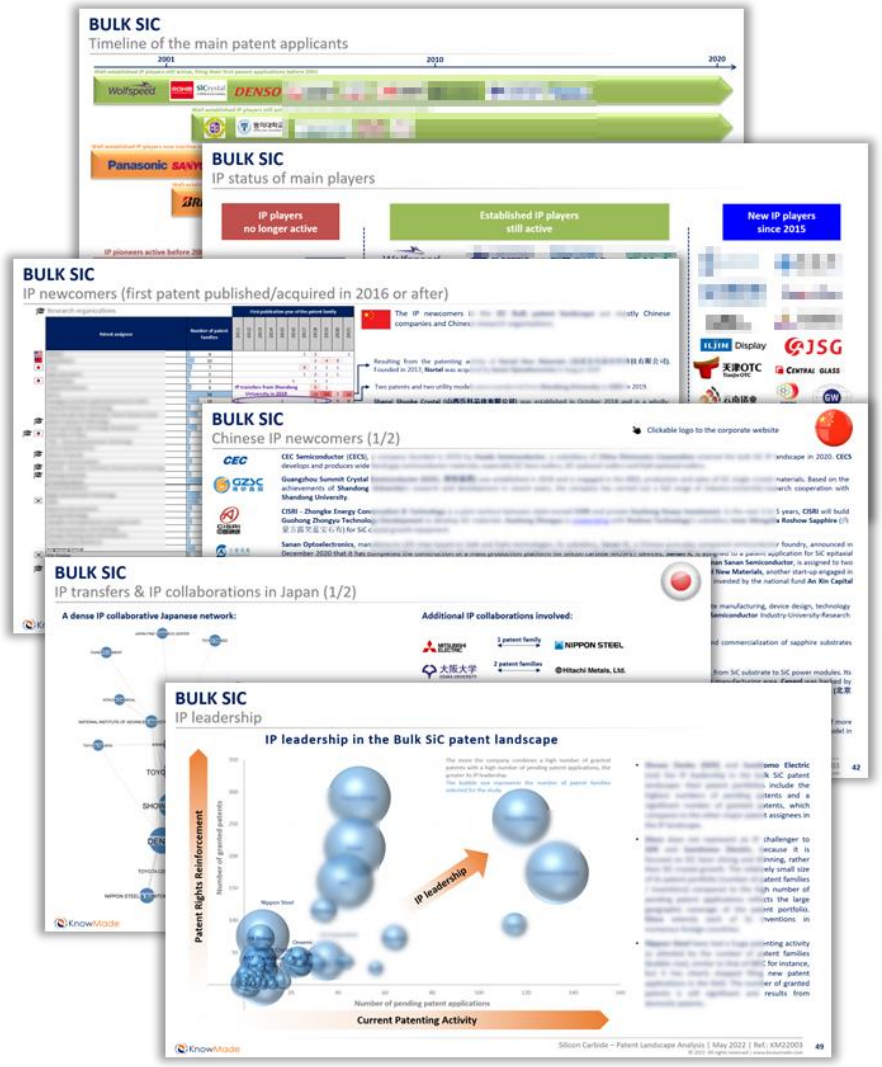


SiC substrates

General trends, Key patent assignees, Newcomers, IP collaborations, Patent legal status



Focus on bulk SiC



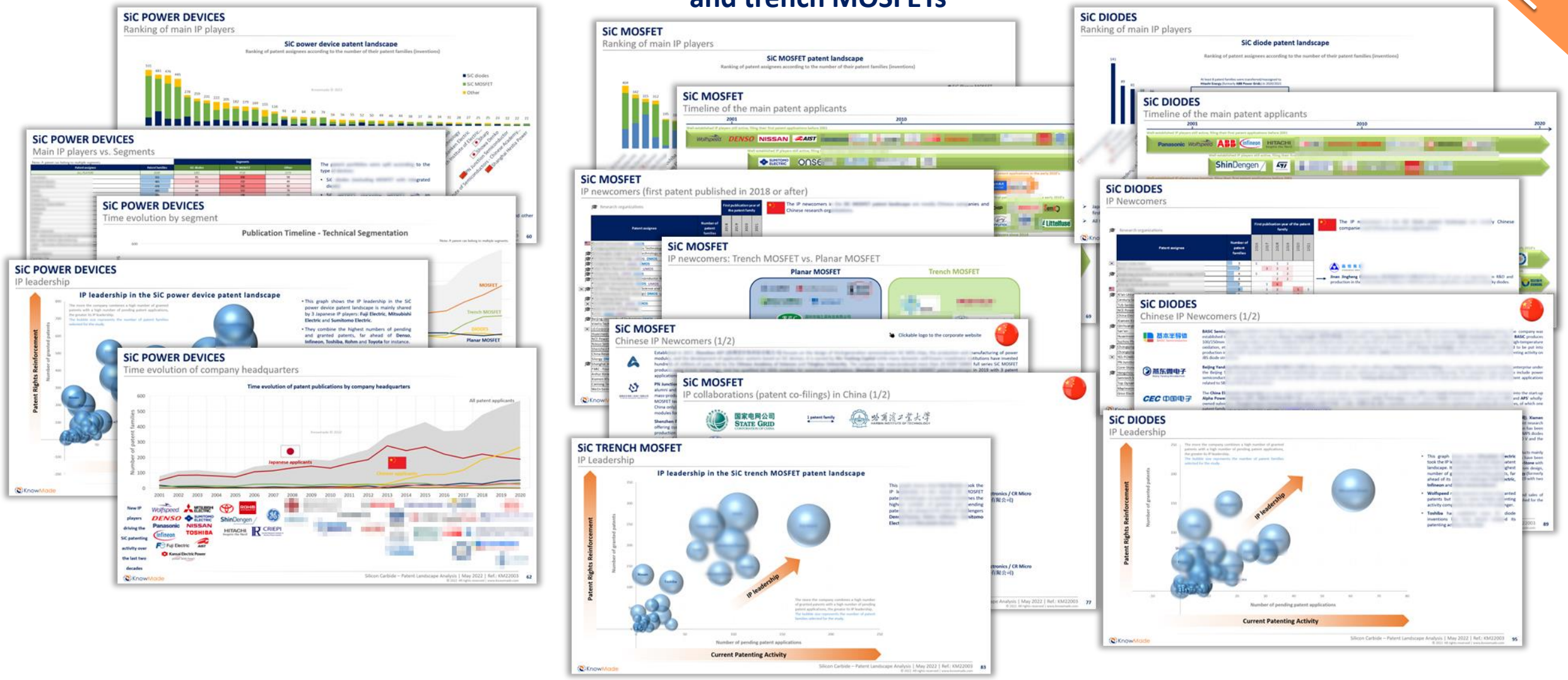
Focus on epitaxial SiC substrates

SiC power devices

General trends, Key patent assignees, Newcomers, IP collaborations, Patent legal status

Focus on SiC planar MOSFETs and trench MOSFETs

Focus on SiC diodes

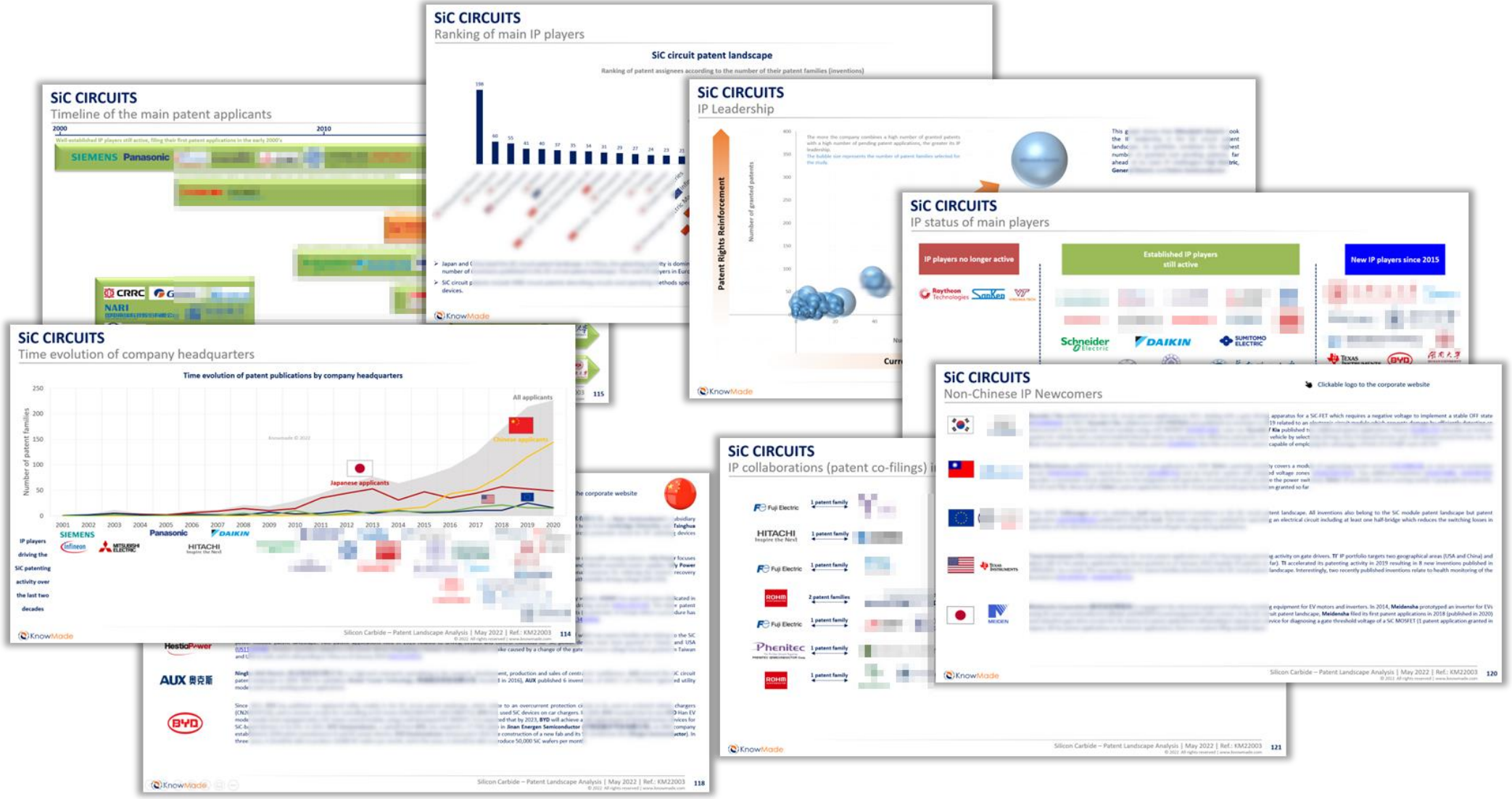


SiC power modules

General trends, Key patent assignees, Newcomers, IP collaborations, Patent legal status

SiC circuits

General trends, Key patent assignees, Newcomers, IP collaborations, Patent legal status



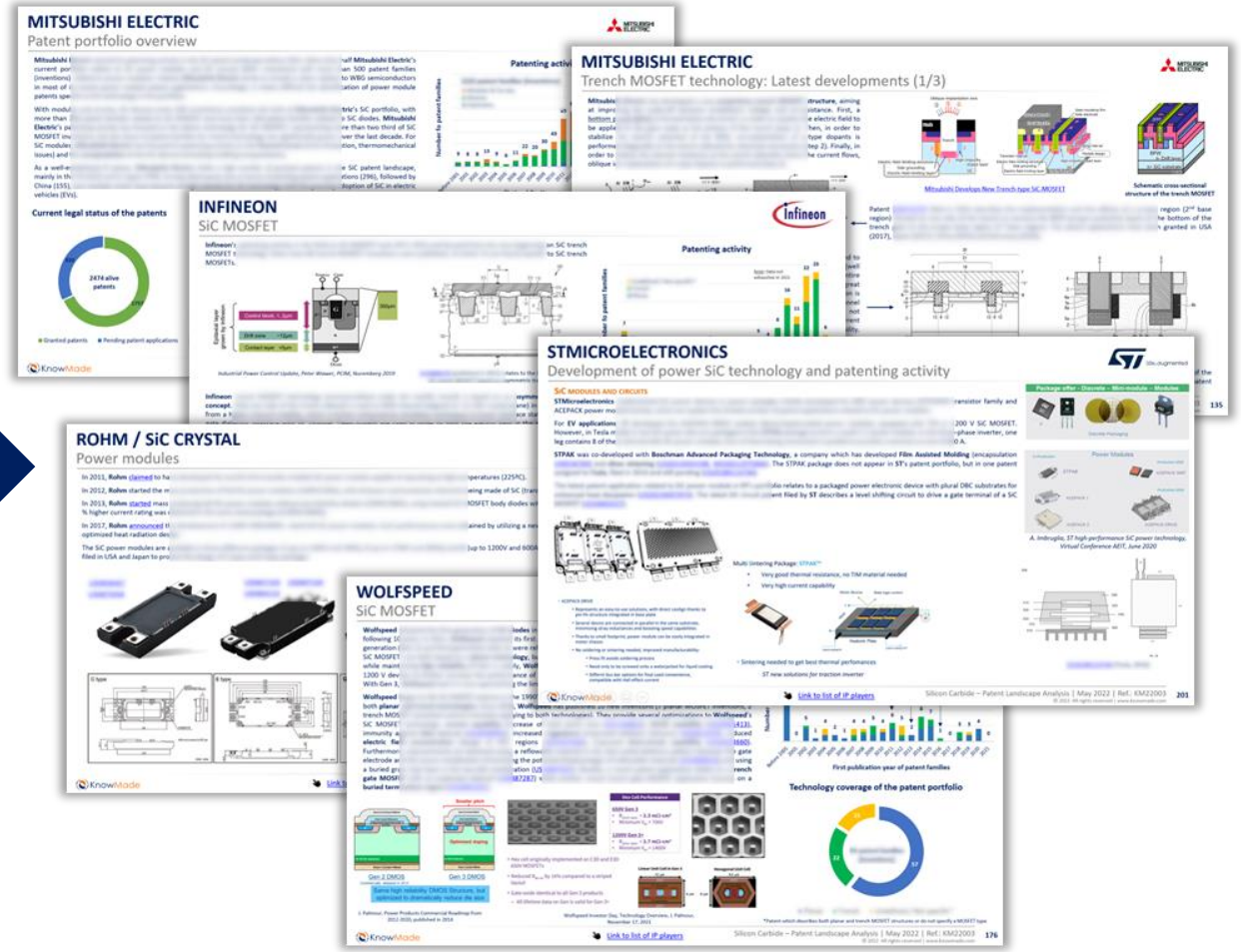
IP profile of key players

IP portfolio summary, IP strategy, key patents and recent IP activity

A focus on the top 10 IP players and **top 6 power device market players** is provided in a 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 in light of recent announcements related to SiC and related challenges.

MITSUBISHI ELECTRIC
Infineon
SUMITOMO ELECTRIC
ROHM SEMICONDUCTOR
TOYOTA
Wolfspeed
DENSO
TOSHIBA
HITACHI
life.augmented
onsemi
Panasonic

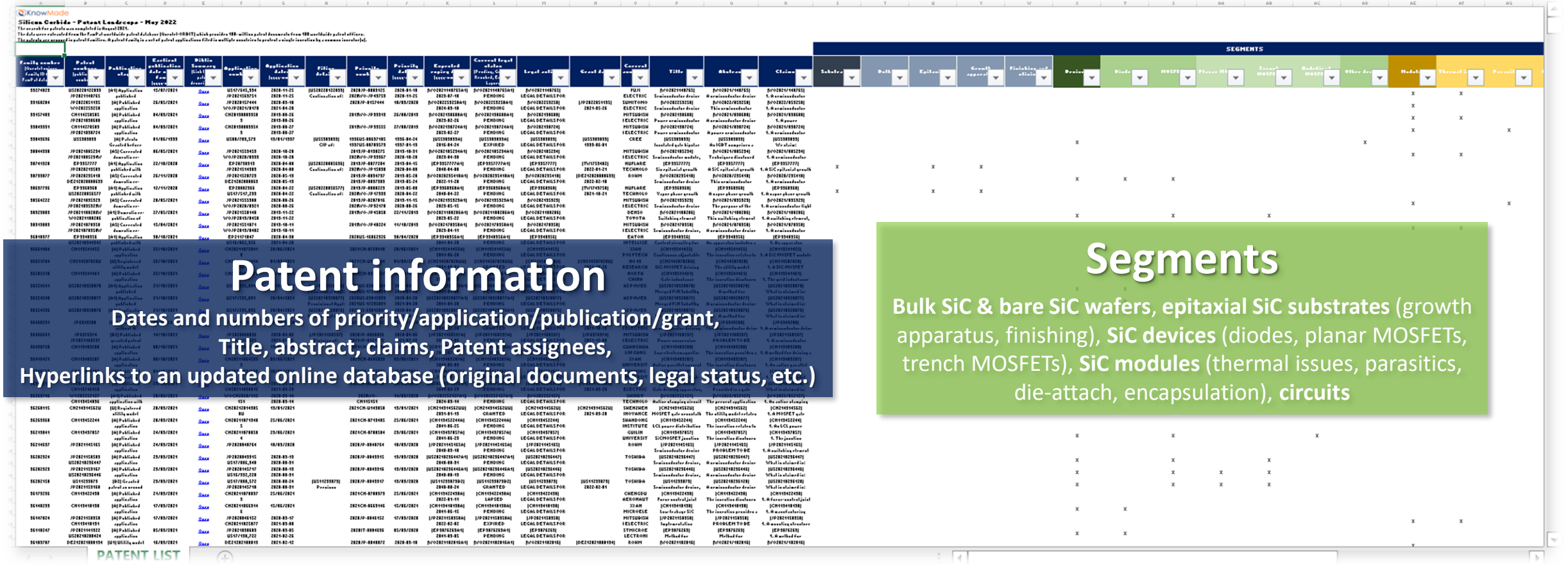
IP profile



Excel file with all patents analyzed in the report

Useful patent database allows multi-criteria searches

This report also includes an extensive **Excel database** with the **13,700+ patent families** (inventions) analyzed in this study. This useful patent database allows for **multi-criteria searches** and includes patent publication numbers, **hyperlinks to an updated online database** (original documents, legal status, etc.), priority date, title, abstract, patent assignees, patent's current legal status, and **segments** (bulk SiC, epitaxial SiC substrates, SiC diodes, planar SiC MOSFETs, trench SiC MOSFETs, SiC modules, circuits, etc.).



Patent information

Dates and numbers of priority/application/publication/grant,
Title, abstract, claims, Patent assignees,
Hyperlinks to an updated online database (original documents, legal status, etc.)

Segments

Bulk SiC & bare SiC wafers, **epitaxial SiC substrates** (growth apparatus, finishing), **SiC devices** (diodes, planar MOSFETs, trench MOSFETs), **SiC modules** (thermal issues, parasitics, die-attach, encapsulation), **circuits**

ORDER FORM

Silicon Carbide (SiC)

Patent Landscape Analysis – May 2022

Ref.:KM22003

SHIP TO
Name (Mr/Ms/Dr/Pr):
_____
Job Title:
_____
Company:
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Address:
_____
City:
_____
State:
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Postcode/Zip:
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Bank: Banque Populaire Méditerranée, CAP 3000 Quartier du lac, 06700 St Laurent du Var, France
IBAN: FR76 1460 7003 6360 6214 5695 139
BIC/SWIFT: CCBPFRPPMAR

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BIC or SWIFT code: CCBPFRPPMAR
IBAN: : FR76 1460 7003 6360 6214 5695 139

To ensure the payments, the Seller reserves the right to request down payments from the Buyer. In this case, the need of down payments will be mentioned on the order.

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b) any claim attributable to errors, omissions or other inaccuracies in the Product or interpretations 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.

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- Posting any Product to any other online service (including bulletin boards or the Internet);
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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 consequences in their entirety.

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9. GOVERNING LAW AND JURISDICTION

9.1 Any dispute arising out or linked to these Terms and Conditions or to any contract (orders) entered into in application of these Terms and Conditions shall be settled by the French Commercial Courts of Grasse, which shall have exclusive jurisdiction upon such issues.

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

KnowMade
Patent & Technology Intelligence

KNOWMADE PURPOSE

Turning **patents** and **scientific information** into **business-oriented report** for **decision makers** working in **R&D**, **Innovation Strategy**, **Intellectual Property**, and **Marketing**

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

KnowMade

Intellectual Property ⟷ **Innovation Strategy**

Patent your inventions

Assert your patents and defend your position in case of licensing/litigation

Evaluate the risks to infringe patents

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

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

Patent landscape, Monitoring service, IP due diligence

Improve your R&D and IP strategy

Identify and get access to external innovation

Technology scouting, Scientific literature analysis

MAIN FIELDS OF EXPERTISE

Wireless and Optical Communications

- RF components & modules
- Antenna & Networks
- Photonics (datacom/telecom)

Advanced Packaging
Innovative Materials
AI & Computing

Energy Mgt & Storage

- Power electronics
- Batteries & Fuel-cells
- PV

Sensors and Optoelectronics

- MEMS
- Sensors & Imaging
- Lighting & Display

Life Sciences and Healthcare

- MedTech
- Microfluidics
- Biotech & Pharmaceutics
- Agrifood

KNOWMADE OFFER

Patent Landscape Analysis
to give an overview on IP dynamics, IP trends and IP players

Tailor-made analyses

Meet customer's business needs and budgetary constraints

Off-the-shelf Reports

Monitors

Patent Monitoring Service
to track current R&D activity and early detect weak signals, opportunities and risks

Monthly IP database | Quarterly report
Access to IP analysts

KnowMade
Patent & Technology Intelligence

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