

POWER SiC

MOSFETs – SBDs – Modules

Patent Landscape Analysis

January 2019

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Recent developments from major IP players to address reliability issues due to gate oxide in SiC trench MOSFET.

SiC SCHOTTKY BARRIER DIODE 91

- Time evolution of patent applicants
- IP leadership of patent assignees
- Key patent families
- Historical patent applicants and their recent patents
- New entrants and their patents
- Conclusion

SiC POWER MODULE 114

- Time evolution of patent publications
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- Conclusion

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SCOPE OF THE REPORT

- This report provides a detailed picture of the patent landscape for **SiC-based power electronics, covering MOSFETs, Schottky barrier diodes (SBD) and power modules.**
- This report covers **patents published worldwide up to October 2018.**
- We have selected and analyzed more than **1,600 patent families** (inventions) relevant to the scope of this report.

| | Selected | Excluded |
|--|----------|----------|
| Patents related to SiC-based power semiconductor devices (MOSFETs, SBDs) or modules | X | |
| Patents claiming devices (MOSFETs, SBDs) or modules that specifically use SiC | X | |
| Patents describing SiC as the preferred solution | X | |
| Patents describing devices (MOSFETs, SBDs) or modules that can use WBG selected from SiC, GaN, or Diamond, including an embodiment focused on SiC | X | |
| Patents describing devices (MOSFETs, SBDs) or modules that can use WBG selected from SiC, GaN, or Diamond, without any embodiment or preferred solution on SiC | | X |
| Patent claiming systems using SiC but without inventive aspect related to SiC. | | X |

KEY FEATURES OF THE REPORT (1/2)

- The report provides **essential patent data** for **Power SiC MOSFETs, SBDs and modules**.
- It provides **in-depth patent analyses** of **key technologies** and **key players** including:
 - Time evolution of patent publications and countries of patent filings.
 - Current legal status of patents.
 - Ranking of main patent applicants.
 - Joint developments and IP collaboration network of main patent applicants.
 - Key patents.
 - Granted patents near expiration.
 - Relative strength of main companies IP portfolio.
 - Key patents on technology issues.



KEY FEATURES OF THE REPORT (2/2)

- The report also provides an extensive **Excel database** with all patents analyzed in the report. This **patent database** allows multi-criteria searches, including:
 - Patent publication number
 - Hyperlinks to the original documents
 - Priority date
 - Title
 - Abstract
 - Patent assignees
 - Technical segmentation
 - Legal status for each member of the patent family



Disclaimer: This report **does not provide** any insight **analyses or counsel regarding legal aspects** or the validity of any individual patent. Knowmade is a research firm that provides technical analysis and technical opinions. Knowmade is not a law firm. The research, technical analysis and/or work proposed or provided by Knowmade and contained herein is not a legal opinion and should not be construed as such.

OBJECTIVES OF THE REPORT

Understanding the **competitive landscape** and **technology developments** from a **patent perspective**

- Know the **key IP players**, their **key patents**, their IP/technology **strategy** and their **future intents**
- Identify **new entrants**, their **technology** and **market areas** of interest
- Follow the **technology trends** and identify **emerging technologies**
- **Benchmark** patent portfolios and know competitors' **strengths** and **weaknesses**
- Identify the **key patents** (seminal, blocking, valuable) and the **key technical solutions** that address hot technical issues
- Identify **free technologies** which can be used safely and mitigate the **risks of patent infringement**
- Identify **technologies to acquire** and potential **R&D partners**

Very complementary to market research

- Key market players
- Supply chain
- Technology Readiness Levels (TRL)
- Market product
- Emerging technologies/applications
- Forecast

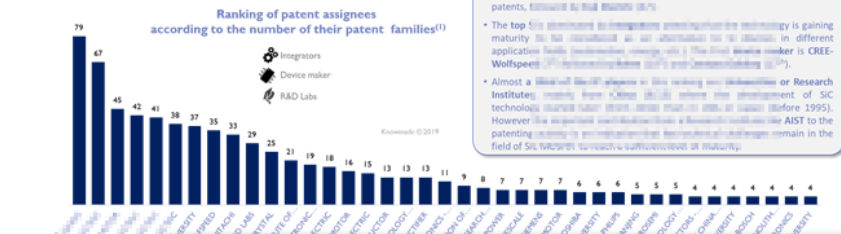
SiC MOSFETs

Patent assignees, IP dynamics, patent legal status, patent geographical coverage

SAMPLE

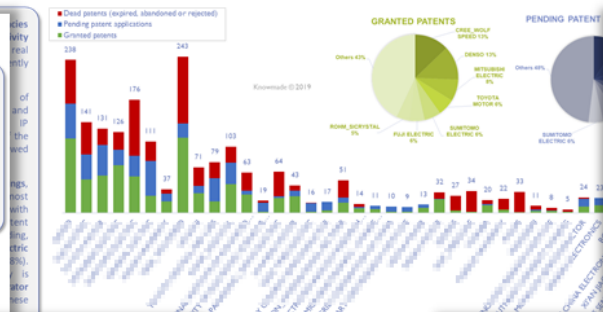
SiC MOSFET: PATENT LANDSCAPE OVERVIEW

Leading patent applicants



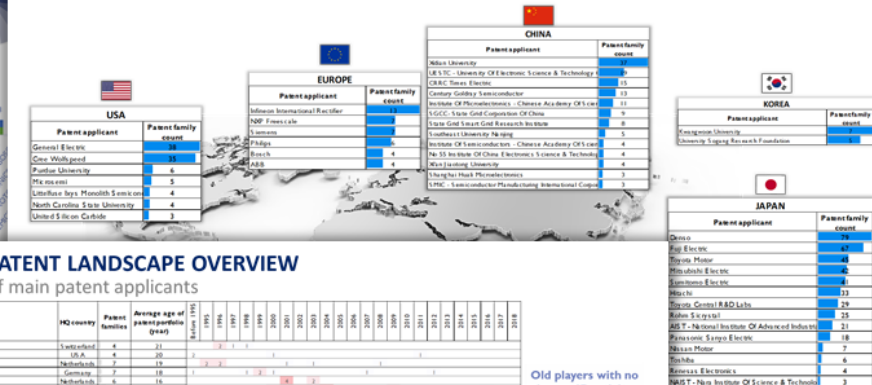
SiC MOSFET: PATENT LANDSCAPE OVERVIEW

Main IP players: Number of patents and current legal status



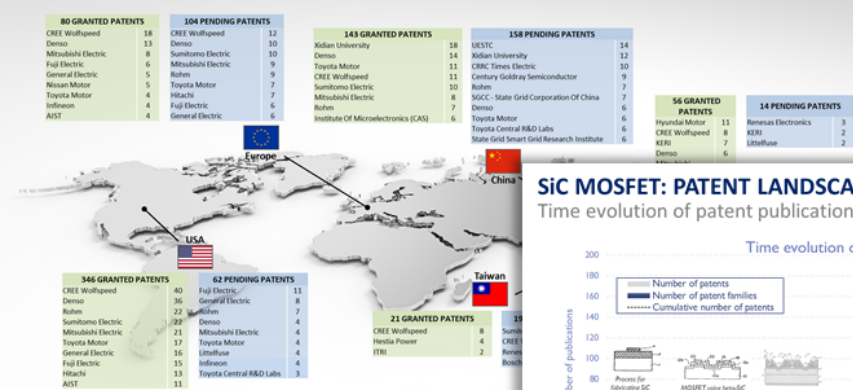
SiC MOSFET: PATENT LANDSCAPE OVERVIEW

Main patent applicants by country of head office



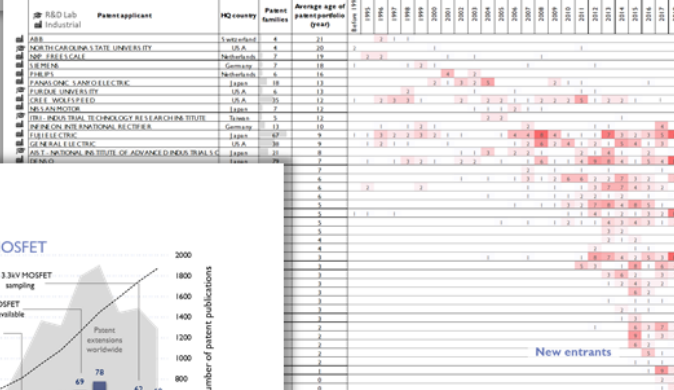
SiC MOSFET: PATENT LANDSCAPE OVERVIEW

Geographic coverage of patent filings and corresponding current legal status of patents



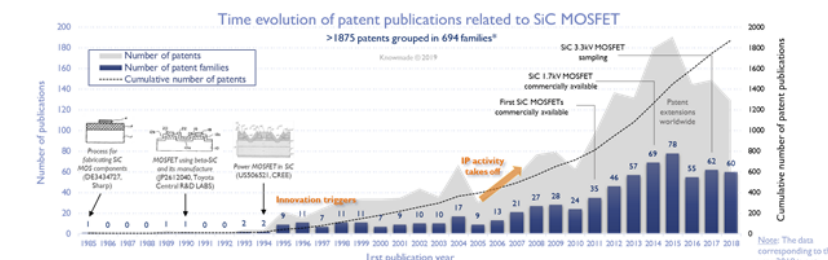
SiC MOSFET: PATENT LANDSCAPE OVERVIEW

Time evolution of main patent applicants



SiC MOSFET: PATENT LANDSCAPE OVERVIEW

Time evolution of patent publications



- The first patents relevant to the field of SiC MOSFET were filed in Germany and Japan in the mid-1980's.
- The level of patenting activity took off in 2005 for SiC MOSFET with a remarkable acceleration in patent filing between 2011 and 2015, concomitant with the commercialization of the first SiC MOSFET products.
- SiC MOSFET technology has become more and more mature but some reliability and packaging issues are still investigated to fully benefit from Silicon Carbide's advantages. Therefore a steady patenting activity is expected in the coming years.

⁽¹⁾A patent family is a set of patents filed in multiple countries to protect a single invention by a common inventor(s). A first application is made in one country – the priority country – and is then extended to other countries.

SiC MOSFETs


Focus on key players and new entrants

SAMPLE


SiC MOSFET: PATENT LANDSCAPE OVERVIEW

New entrants


Relevant New entrants selected from SiC MOSFET IP landscape have at least 7 patents (UESTC) with an average of patent portfolio less than 3 years. It includes a Chinese company (Century Goldray) and a Taiwanese company (Hestia Power).




Century Goldray semiconductor is a new entrant in SiC MOSFET IP landscape. It has filed different SiC MOSFET architectures (DMOS, VMOS, VMOS and other conventional MOSFET-integrated Schottky diodes).



CRRC Times Electric filed its first patent family in 2015 and has filed 15 patent families since then. So far, the patenting activity of CRRC has concerned the optimization of the structure and manufacturing method of self-aligned planar SiC MOSFETs, with 4 patent applications shared with the Institute of Microelectronics (Chinese Academy of Sciences). Several patents focused on improving gate oxide layer quality. Dynes semiconductor which was acquired by CRRC in 2008 is collaborating on the trench SiC MOSFET device with a pending patent common to both companies filed in 2016.



UESTC has filed 18 patent application between 2005 and 2018 concerning equally planar university's inventions address self-aligned processes, the integration of SBD in the optimizations to reduce static and dynamic losses and to enhance gate reliability.



SGCC - State Grid Corporation of China (3 patent families) in collaboration with its research Institute has started filing patent applications about SiC MOSFET for power application. 2015. Planar-type and trench-type devices are addressed as well as a super-junction MOSFET in the MOSFET structures and methods to improve the quality of gate oxide and its reliability of these inventions.

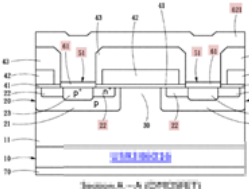
| | Planar SiC MOSFET | Trench SiC MOSFET | SiC SBD | SiC Power Module |
|---|---|---------------------------------|---------------------------------|---------------------------------|
| Key IP players still active | General Electric | General Electric | General Electric | General Electric |
| Key IP players less or no longer active | CREE/Wolfspeed Fuji Electric | CREE/Wolfspeed Fuji Electric | CREE/Wolfspeed Fuji Electric | CREE/Wolfspeed Fuji Electric |
| IP Challengers | | | | |
| IP new entrants | Hestia Power Century Goldray CRRC Times Electric UESTC | | | |

SiC MOSFET: PATENT LANDSCAPE OVERVIEW

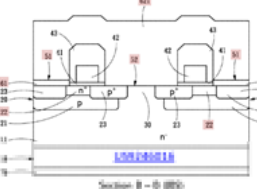
Focus on Hestia Power

Hestia Power entered SiC MOSFET IP landscape in 2006 and has filed 7 patent families since then. Hestia's IP portfolio contains 8 granted patents and 5 pending patents, distributed over Taiwan (1), USA (1) and China (1). The segmentation of Hestia's portfolio reveals that 6 patent families concerns SiC planar MOSFET and 1 patent family is related to SiC trench MOSFET.

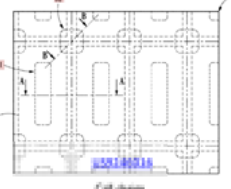
The first inventions (US20040616, CN18330670) concern a monolithic BE integrated SiC MOSFET (IMOS). An anti-parallel BE-diode is integrated to the planar MOSFET structure in order to suppress the saturation of its PN body diode. The inventors provide self-designed limiting area penalty and a method of fabrication using exactly the same processes as for a conventional DMOS, that is, producing the same manufacturing costs.



Section A-A (DMOSFET)



Section B-B (BE)




Cell design

In the manufacturing process, the source openings 56 are first manufactured and the first metal layer 61 is formed to obtain a good ohmic contact with the source region 22. Then, gate openings 53 and the junction openings 52 are manufactured, followed by forming the second metal layer 62, thereby forming a good Schottky contact by the second metal layer at the junction openings with SiC.

WOLFSPEED BUSINESS OVERVIEW

Wolfspeed – has slowed down its patent filing activity since 2015.

There have been a lot of changes in the last 3 years. due to excess capacity decided to restructure. It planned to invest \$850 million.



Revenue (Millions)

FF 2017 - \$1,470 (million) Actual


FF 2018 - \$1,340 (million) Target

Source: CREE

As shown on the graph LED & Lighting were by far the biggest segments of CREE compared with Wolfspeed business. Yet the latter was already much more profitable with respect to LED and lighting products.

However when CREE had to terminate Wolfspeed acquisition by Infineon due to national security concerns from the Committee on Foreign Investment in the United States in 2017, it decided that it will refocus on its Wolfspeed business, and announced it will expand scale of Wolfspeed investing heavily but equally. Furthermore, CREE's CEO Gregg Lorenz, appointed in 2017, announced in 2018 that he expects Wolfspeed largest segment of the company, as illustrated on the graph.

slowdown in CREE's patenting activity concerning SiC MOSFET may be technology. Indeed the company may consider that its SiC MOSFET technology, and that critical challenges for market acceptance is no longer at chip integration into power systems, which tends to be confirmed by its move to APEI, which was a global leader for power module and power electronics.

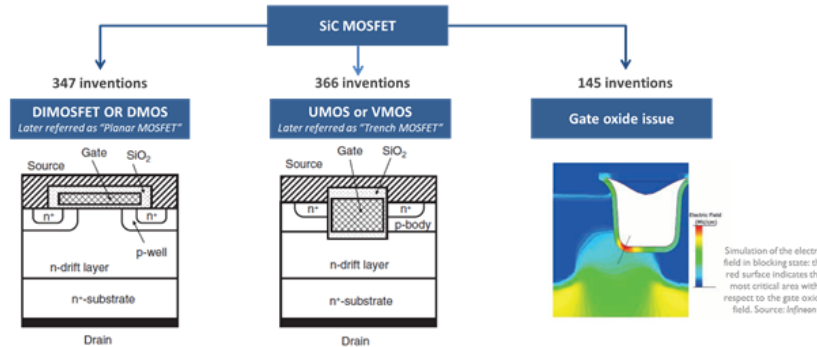


Patent segmentation: planar MOSFETs, trench MOSFETs, and gate oxide issues

SAMPLE

Planar MOSFET, Trench MOSFET, Gate oxide issue

The **SIC MOSFET** related patents have been categorized in the three following segments. In the next pages we analyze each segment and detail the patenting activity, the key patent assignees and the key patents.



Planar SiC MOSFET vs Trench SiC MOSFET

[illegible]

Note: A patent family can belong to multiple segments.

- For instance, **automotive** companies are adopting **trench MOSFET** technology as efficiency essential for its application

- On the contrary, other companies in the energy sector interested in power electronics have put the technology

- Also, a company that aims at increasing the reliability of SiC devices in the short term, some how more reliable solution

IP trends for main patent applicants

[illegible]

Other integrator companies including **Fuji Electric** and **Semikrome Electric** with an important portfolio for **planar MOSFET** have intensified **R&D on trench MOSFET** in the last 4 years, targeting different applications. French MOSFET are expected to offer better performance with respect to planar MOSFET in the lower voltage market (e.g. HEV/EC LPS, power supplies, industrial motors).

Car manufacturers such as Toyota Motor and Hyundai are willing to develop their own proprietary technology and focus on trench SiC MOSFET.

The same trend is observed for the automotive component maker Denso and for the device manufacturer Ixiam, which is already well positioned on the HEV/EV market.

Integrator companies, such as Mitsubishi and General Electric are not developing their IP on 30-nm MOSFET, suggesting that this technology does not offer a significant advantage compared to cheaper and more reliable planar MOSFET. This is the case for applications requiring higher voltages (e.g. rail traction, wind turbines, smart power grids).

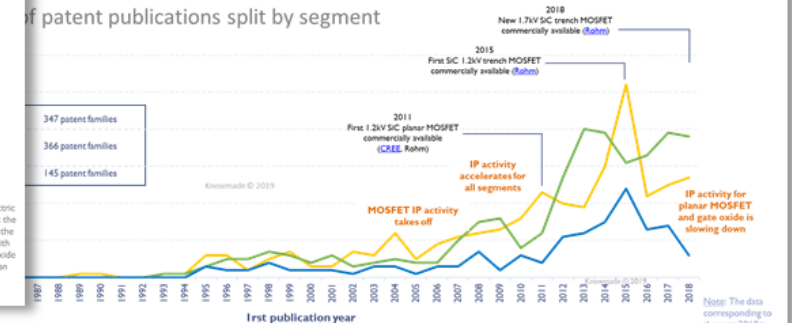
Planar SiC MOSFET vs Trench SiC MOSFET

Note: A patent family can belong to multiple segments

| Planar | | Trench | | Gate Oxide | |
|---------------------------------------|-----------------|--------------------------------------|-----------------|---------------------------------------|-----------------|
| 347 patent families | | 366 patent families | | 145 patent families | |
| Patent applicant | Patent families | Patent applicant | Patent families | Patent applicant | Patent families |
| Mitsubishi Electric | 29 | Denset | 73 | Denset | 15 |
| General Electric | 26 | Fuji Electric | 53 | Fuji Electric | 14 |
| Xerox University | 26 | Toshiba Motor | 43 | Samsung Electronics | 8 |
| CRIL R. Waikanae | 24 | Toshiba General R&D Labs | 28 | General Electric | 7 |
| Samsung Electronics | 19 | ULI Inc. | 25 | ULI Inc. | 7 |
| Fuji Electric | 19 | Hitachi | 22 | CRILC Toshiba Electric | 6 |
| Asi TV | 17 | Robert L. Cooper I | 22 | Mitsubishi Electric | 6 |
| CRILC Toshiba Electric | 13 | Hyundai Motor | 13 | Toshiba Motor | 5 |
| ULI TV | 12 | Mitsubishi Electric | 13 | Toshiba General R&D Labs | 5 |
| Patent & Service Electric | 12 | Xerox University | 11 | Hitachi | 5 |
| Hitachi | 11 | CRIL R. Waikanae | 11 | Xerox University | 5 |
| Intel West, Of Microelectronics (CAS) | 10 | General Electric | 9 | CRIL R. Waikanae | 5 |
| Digital | 8 | ULI TV | 8 | Mitsubishi | 5 |
| Concord Systems Semiconductor | 8 | Century Electronics Ltd Inductor | 7 | Asi TV | 4 |
| KEBI | 8 | Indepco, Inductance Inductor | 7 | Xerox University | 4 |
| Robert L. Cooper I | 7 | Panasonic, Toshiba Electric | 6 | Intel West, Of Microelectronics (CAS) | 4 |
| Samsung | 7 | KEBI | 5 | Kwangju, University | 4 |
| Indepco, Inductance Inductor | 6 | S. Eric, Gold S. Eric, Gold R. China | 5 | Southeastern University, Nanjing | 4 |
| Hitachi | 6 | S. Eric, Gold S. Eric, Gold R. China | 5 | | |
| NDP, Panasonic | 6 | | | | |

A patent family is a set of patents filed in multiple countries to protect a single invention by a common inventor(s). A first application is made in one country – the priority country – and is then extended to other countries.

of patent publications split by segment



- The level of IP activity related to **Gate oxide** has been significant between 2012 and 2017.
- The IP activity related to **Trench MOSFET** reached a maximum level in 2013 and is similar in 2018, which can be explained by the fact that certain players were on **Planar MOSFET** and chose to switch to **Trench MOSFET** (e.g. Rohm).

Note: The data corresponding to the year 2018 is not complete since the last search was done in October 2018.

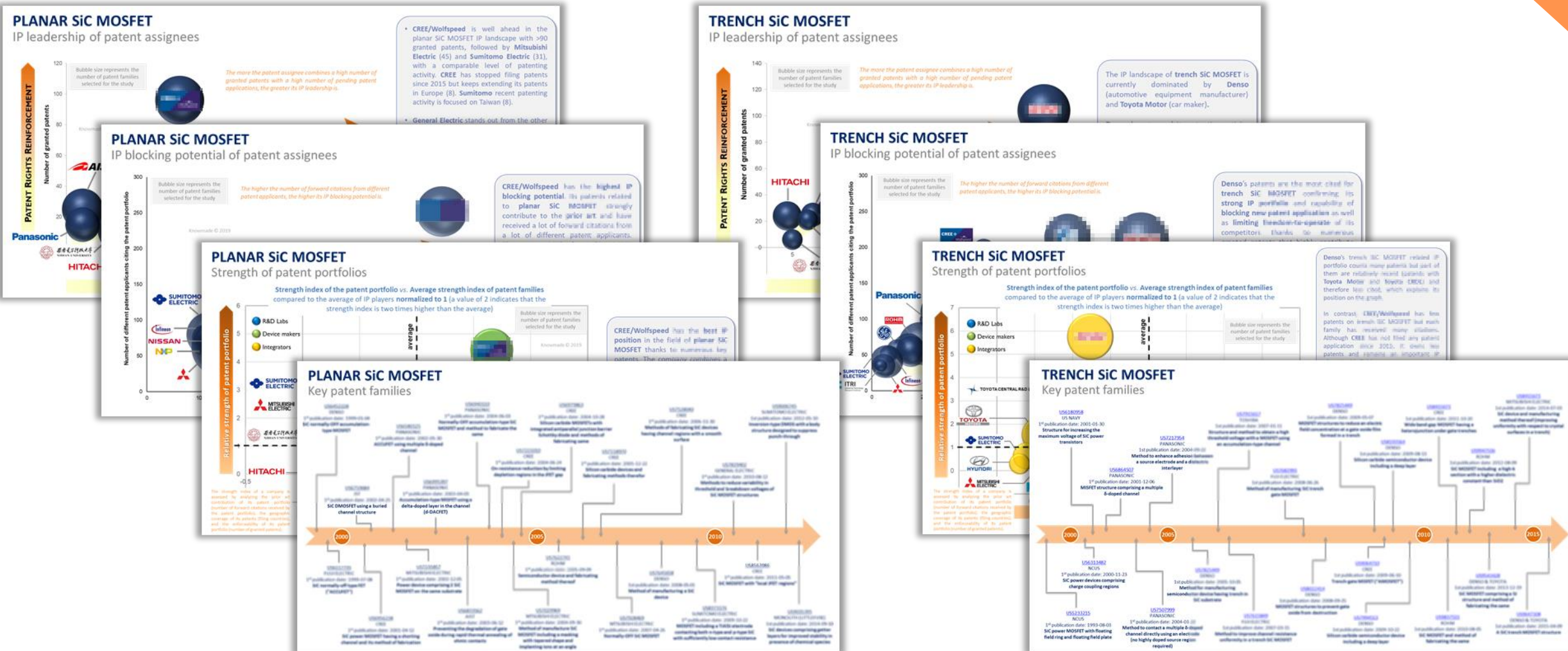
SiC MOSFETs

Patent Portfolios Benchmarking: who has the best patent portfolio?

SAMPLE

Planar SiC MOSFETs

Trench SiC MOSFETs

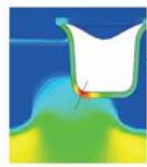


GATE OXIDE

Introduction

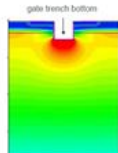
This section will go through recent developments from major IP players to address reliability issues due to gate oxide in SiC trench MOSFET.

In trench SiC MOSFET, the gate structure usually has a U-shape. When the MOSFET is turned off, a high reverse bias (up to 1.7kV) is established between the gate electrode and the drain electrode. The resulting electric field concentrates at the corners of the bottom trench and may damage the gate oxide and lead to V_{th} instability (PBT/NBTI) or oxide breakdown (TDOB). Therefore there is a need to establish a structure for mitigating the electric field generated in the trench gate portion in order to guarantee long-term reliability.



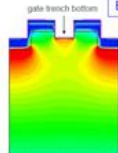
Simulation of the electric field in blocking state: the red surface indicates the most critical area with respect to the gate oxide field. Source: Infineon

Standard trench MOSFET



Suppression of the electric field concentration at the bottom of the gate trench is achieved by the double trench structure of SiC MOSFET. Source: Rohm

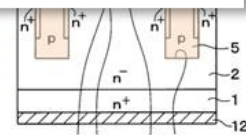
ROHM 3G SiC MOSFET



Eox: 35% lower

The double trench SiC MOSFET (source trench and gate trench) described next in patent publication [US20180114856](#) and above illustrates an approach allowing to mitigate the electric field near the gate oxide.

Limiting layer (7) are formed simultaneously, using the plane direction dependence of the epitaxial growth of a p-type SiC layer and an n-type SiC layer. The n-type limiting layer allows to avoid an increase of JFET resistance due to depletion regions that would extend from the deep p-type layers towards the trench gate.



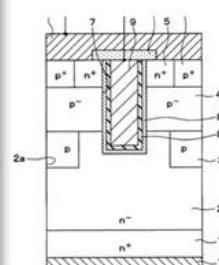
The shape of the trench is controlled using a combination of heat treatment under (H_2 , SiH_4) atmosphere and sacrificial oxidation of the trench where the oxidation rate is determined by the impurity concentration profile.

gate oxide. The 2nd insulating layer extends from the bottom of the trench up to the boundary between the channel and the drift layer. The 2nd insulating layer is obtained by thermal oxidation of a silicon layer and has a high dielectric breakdown resistance. The 2nd insulating layer may or may not overlap channel region. Overlapping the channel region allows to eliminate the leakage current appearing in the vicinity of the boundary in short-circuit configuration.

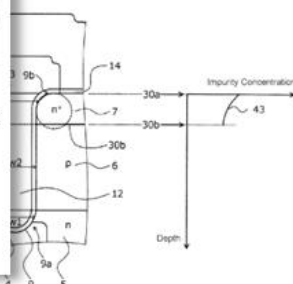
A complementary approach implemented by Wolfspeed in this patent consists of incorporating deep recessed P⁺ junctions into the transistor structure in order to reduce the electrical field at the gate oxide by shielding the gate oxide. In general, it has been noted that the deeper the recessed P⁺ junction, the lower the electrical field underneath the gate oxide, which improves the reliability of the device.

The trench shape may be obtained using a combination of sacrificial thermal oxidation and H_2 annealing. In addition, oxide thickness along the trench is modulated using a CVD method to reset t_{ox} , H_2 annealing overall gate capacitance and preventing the bottom portion from having a dielectric breakdown when the gate is turned off. In addition, the authors provide a method to easily form an electric field relaxation region (structure for alleviating the electric field of the gate finger portion) which is deeper than the bottom portion of the gate finger trench, and to increase the density of such regions in the gate finger portion therefore reducing occurrence of avalanche breakdown at the gate finger portion.

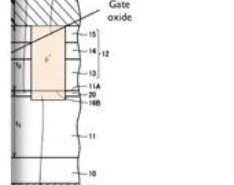
DENSO



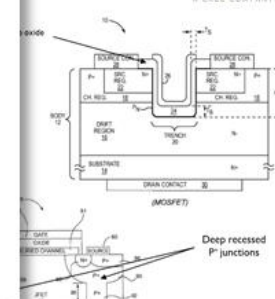
FE



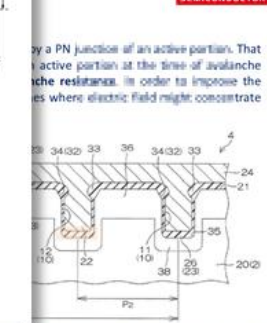
SUMITOMO ELECTRIC



Wolfspeed
A CREE COMPANY



ROHM SEMICONDUCTOR



SiC Schottky Barrier Diodes (SBDs)

Key IP players, their key patents and their recent patent applications

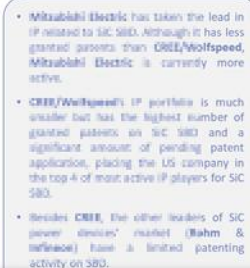
SAMPLE

Time evolution of patent applicants

Old players with no
longer IP activity

Historical players still active.

IP leadership of patent assignees



Key patent families



2017 U520170345891

An alternative method to fabricate power SiC JBS diodes that have a superjunction-

type drift region is presented. The authors resort to the ion crystal to increase implantation depth and enhance ion implantation depth. As a result, the method may also decrease fabrication cost of such device structures.

Panasonic

2018 15271820328901

2016 1159491399

The present invention provides more effective passivation techniques in order to improve device

Fuji Electric

2018 11月17日 星期四

A structure is proposed that reduces current concentration at the p-type guard ring region 5 of a 1700V or higher SiC MIP and prevents destruction at the p-type guard ring region 5. Under a contact gap toward the foundation (Al electrode) of the Al wire, the current density increases and by resistance change consequent to temperature rise, the current distribution moves toward the outer periphery. Accordingly, when the density of the electric electrolysis is increased from near the Al wire toward the outer periphery, surge current may be caused to flow uniformly in a plane.

2017 1630160358914

The present invention provides a method to improve the ohmic contact on a p-type SiC region of a HRS structure, in order to enhance forward surge capability. A Ti-Al alloy layer 8a is provided on the surface of the ohmic electrode. A Ni silicide layer 8b is provided in the ohmic electrode 8. Ti 8a is locally present inside the Ni silicide layer 8b. The Ni silicide layer 8a includes NiTi as a main constituent.

2017 [US0123019](#)

The present invention provides a 600V SiC MOSFET having an **edge termination** structure that can reduce or suppress the **electric field** affecting the edge termination area. Moreover, taking advantage of photolithography and ion implantation techniques, it is possible to reduce the number of **manufacturing steps**. Also, as the reduction of impurity concentration moving away from the active region does not rely on implantation dosage or activation rate in this approach, **process-related variations** of device characteristics are eliminated.

Patent assignees, IP dynamics, key players, key patents

SAMPLE

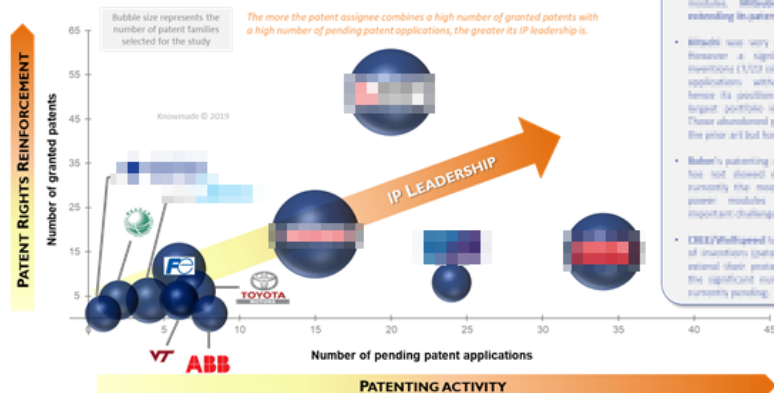
Segmentation

| Patent assignee | Number of patent families on SiC Power Modules | SEGMENTS | | | | | |
|--|--|-----------------|-----------------|------------------------------------|---------------|--------------------|--------------------|
| | | Full SiC Diodes | Full SiC MOSFET | Full SiC modules (Diodes & MOSFET) | Other modules | Thermal management | Voltage derivation |
| Infineon | 30 | 14 | 1 | 19 | 196 | 104 | 30 |
| ROHM ELECTRIC | 29 | 1 | 6 | 7 | 22 | 20 | 1 |
| ROHM ELECTRIC | 25 | 3 | 8 | 14 | 24 | 20 | 5 |
| Infineon Technologies AG | 11 | | | 4 | 4 | 6 | 4 |
| DAEWOO ELECTRIC, HYUNDAI REFRIGERATION EQUIPMENT | 8 | | | | | | |
| Infineon | 7 | | | | 8 | 5 | 2 |
| Infineon Technologies AG | 6 | 4 | | | 1 | 1 | 1 |
| BAIC, CHINA TRUCK GRID CORPORATION OF CHINA | 6 | | | | 3 | 3 | 3 |
| SHENYI MICROELECTRONICS | 6 | 1 | 2 | 3 | 4 | 4 | 2 |
| Infineon Technologies AG | 5 | 4 | | | | | 1 |
| Infineon | 5 | | | | 5 | 3 | |
| Infineon Technologies AG | 5 | | | | 5 | 3 | |
| POWER MOS TRANSISTORS | 5 | | | | 5 | 2 | 4 |
| Infineon | 4 | | | | 4 | 1 | 1 |
| Infineon Technologies AG | 4 | 4 | | | | | |
| Infineon Technologies AG | 4 | | | | 2 | 4 | |
| Infineon Technologies AG | 4 | | | | 4 | 4 | |
| Infineon Technologies AG | 4 | 1 | 1 | 1 | 4 | 4 | 4 |
| Infineon Technologies AG | 4 | 1 | 1 | 1 | | | |
| Infineon Technologies AG | 3 | | | | 2 | 2 | |
| SOUTH CHINA UNIVERSITY OF TECHNOLOGY | 3 | | | | 3 | | |
| CHINA TIMES ELECTRIC | 3 | | | 2 | 1 | 1 | |
| Infineon Technologies AG | 3 | | | | | | |

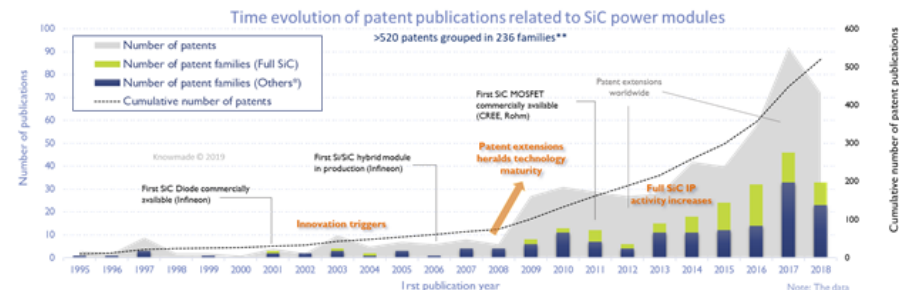
The numbers represent the number of inventions by a common inventor.

Note: A patent family can belong to more than one technology class.

IP leadership of patent assignees



Time evolution of patent publications



- The first Si/SiC hybrid module was released in 2006 by **Infineon** while IP activity in the field of **SiE power modules** (full SiC & hybrids) really took off in 2008.
- Once SiC MOSFET were in production in 2011, several companies started releasing **full SiE modules**, which translated to a steady increase of the patenting activity on **full SiC modules** from 2012 to 2016.

^aOthers refers to: hybrid power modules (Si devices + SiC devices), modules with SiC devices not specified (MOSFET or diodes), modules with power semiconductor not specified (Si, SiC, GaN...).

²² A patent family is a set of patents filed in multiple countries to protect a single invention by a common inventor. A 1st application is made in one country – the priority country – and is then extended to other countries.

Electric (69%) confirming that it has been the most important issue for the development of SiC power modules.

• Historical players with recent IP activity in SiC power modules are integrator companies (Hitachi, Mitsubishi Electric and Fuji Electric) except for Rohm.

Key patent families

As shown on this timeline, most key patents are held by **Mitsubishi Electric** and address challenges related to **hybrid modules** (miniaturization, thermal management, parasitic signals, etc.). Since 2012, key patents are increasingly focused on **full SiC modules** and new key players have come up on the timeline.



Old players
with no
longer IP
activity

- Established IP players

New entrants

SiC Power Modules

Review of patent portfolio of main IP leaders and new entrants

SAMPLE

SiC POWER MODULE

Focus on a new entrant: Danfoss Silicon Power

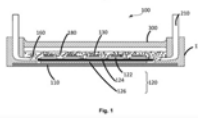
Danfoss Silicon Power GmbH, based in Germany, is a leader in customised power modules for automotive, solar, wind and industrial applications. It operates as a subsidiary of Danfoss Drives A/S, which is one of the four segments of Danfoss A/S operations, based in Denmark.

Danfoss Silicon Power has established in 2018 a new facility in Ulster, NY (USA) for the production of SiC power modules. The company is part of a transatlantic collaboration with General Electric and the Polytechnic Institute through the New York Power Electronics Manufacturing Consortium (NY-PEMC), interested in bandgap semiconductor materials and processes.

and 4 patent families related to full SiC MOSFET modules in 2018. Most inventions focus on the enhancement of the the interconnects inside the power module:

using SiC MOSFETs and lateral Point Clamped (NPC) IGBT topologies for high efficiency

2020 (US20200114000) - A power module may use parallel switches to increase the overall current (e.g. lateral asymmetry) may lead to current distribution asymmetry. In more current than the others. Therefore, manufacturers have to reduce the maximum current. The inventors present a method and device to obtain a well balanced current SiC MOSFET in a three-level inverter, allowing for higher current capabilities, improved efficiency and no extra cost.

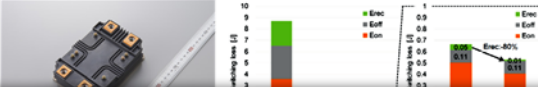


SiC POWER MODULE

Mitsubishi Electric

Mitsubishi Electric has been implementing SiC power modules in a wide range of products since 2010. For instance, the company commercialized its first 1.7 kV Si/SiC modules for rail traction systems in 2013. Later on, it has developed 3.3 kV full SiC solutions, on the market since 2015.

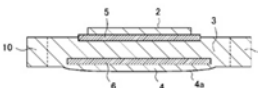
More recently, in January 2018, it claimed to offer the world's highest power density among power semiconductor modules rated from 1.7 kV to 6.5 kV with a 6.5 kV full silicon carbide (SiC) power semiconductor module. The technology is based on an original structure with integrated MOSFET and diode on a single chip and its newly developed package. A new insulating substrate capable of high thermal conductivity and high heat tolerance has been developed in collaboration with ROHM Electronics Materials Co. Ltd., Mitsubishi Materials Corp., Denso Co. Ltd., and Japan Fine Ceramics Co. Ltd. and combined with Mitsubishi Electric's new reliable die bonding technology. Mitsubishi Electric's development of a 6.5 kV full SiC power module has been supported by a project that is subsidized by the Japanese New Energy and Industrial Technology Development Organization (NEDO).



SiC POWER MODULE

Mitsubishi Electric

A common feature to Mitsubishi Electric's full SiC modules is their integrated substrate. With respect to a conventional structure, it is possible to improve thermal management (thermal resistance/ conductivity) and to make power modules more compact (size/weight) with increased power density. Mitsubishi Electric is still improving its integrated substrate solutions, addressing more specifically the problems of warpage when bonding ceramic material to metal due to different thermal expansion coefficients, which significantly degrades the heat dissipation characteristics of substrates.

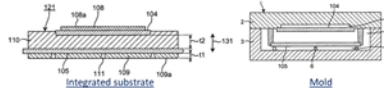


SiC POWER MODULE

Mitsubishi Electric

Metal-ceramic bonding substrate, and a manufacturing method thereof (US2018131583, 2018-07-19 MITSUBISHI ELECTRIC)

The inventors take advantage of the spherical convex shape of the heat dissipating surface to apply high pressure when bonding the heat radiating fins, which improves the heat dissipation. Also, the invention provides a way to eliminate warp deformations when solidifying the metal due to difference in thermal coefficient expansion between metal and ceramics.

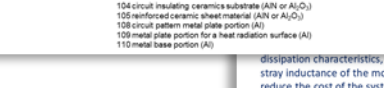


SiC POWER MODULE

Mitsubishi Electric

Metal-ceramic bonding substrate, and a manufacturing method thereof (US2018064124, 2018-10-15, MITSUBISHI ELECTRIC & DOWA)

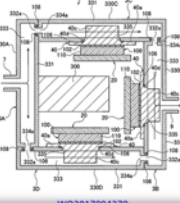
The invention provides a structure and a method to limit heat dissipation degradation when attaching a heat radiation fins to a warped substrate. Mismatch of the substrate occurs during solidification of the metal due to a different thermal expansion coefficient with respect to ceramic materials.



SiC POWER MODULE

Rohm

As mentioned before, miniaturization, cost and reliability of the assembly as well as yield have been central aspects in Rohm's portfolio dedicated to power modules, including SiC, GaN or Si power modules. In the last 3 years, Rohm's patenting activity has put the emphasis on thermal management and reliability due to high temperatures/high speed operation of power SiC modules. In a view to implement the modules in electric or hybrid cars as a result of the growing interest from the automotive industry, there are 11 recent inventions that are directed to the main function supplying the motor in electric or hybrid vehicles :



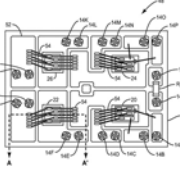
SiC POWER MODULE

Wolfspeed

strengthened its IP position on power modules by acquiring Arkansas Power Electronics International (APEI), a global leader in power applications, which is now CREE Raytheonville, Inc. The acquisition also provides to CREE Wolfspeed applications expertise at the systems level to accelerate delivery of a full spectrum of SiC power modules to meet customer requirements for performance and cost. Both oriented on multiple government contracts including for instance the development of a High-Performance SiC-based Plug-In Hybrid Electric

Next, latest inventions of CREE in the field on SiC power modules are briefly reviewed.

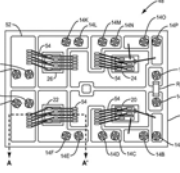
ever converter module including MOSFETs and diodes, employs an **Active Metal Brazed** layer which has a high thermal conductivity (≥ 30 W/m-K) to improve the thermal dissipation characteristics, while maintaining the structural integrity of the module. The invention aims at keeping the stray inductance of the module sufficiently low in target applications where a high switching frequency is required to reduce the cost of the system.



SiC POWER MODULE

Wolfspeed

Another invention (US201811480), promoted by the US Office of Naval Research, concerns a full SiC power modules for high switching frequency and high efficiency, including a number of sub-modules connected via **removable jumpers** allowing to repair or reconfigure the power module. Also, the power module may include a multilayer PCB to connect contacts from different dies, allowing to reduce stray inductance.



Useful patent database allows multi-criteria searches

SAMPLE

Patent information

Segments

Planar MOSFETs, Trench MOSFETs, Gate oxide, SBDs, Full SiC power modules, etc.

Patent applicants, current assignees, inventors

Current legal status of patents (granted, pending, expired, etc.)

ORDER FORM

Power SiC: MOSFETs, SBDs and Modules

Patent Landscape Analysis – January 2019

Ref.:KM19001

SHIP TO

Name (Mr/Ms/Dr/Pr):

Job Title:

Company:

Address:

City:

State:

Postcode/Zip:

Country:

VAT ID Number for EU members:

Tel:

Email:

Date:

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KnowMade S.A.R.L.
2405 route des Dolines
06902 Valbonne Sophia Antipolis
FRANCE

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To pay your invoice using a bank money wire transfer please contact your bank to complete this process. Here is the information that you will need to submit the payment:

Payee: KnowMade S.A.R.L.
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

Paypal

In order to pay your invoice via PAYPAL, you must first register at www.paypal.com. Then you can send money to the KnowMade S.A.R.L. by entering our E-mail address contact@knowmade.fr as the recipient and entering the invoice amount.

RETURN ORDER BY

E-mail: contact@knowmade.fr

Mail: KnowMade S.A.R.L., 2405 route des Dolines, 06902 Valbonne Sophia Antipolis, FRANCE

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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 use its best endeavours to inform the Buyer of an indicative release date and the evolution of the work in 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 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 Product’s electronic delivery format is defective, the Seller undertakes to replace it at no charge to the Buyer provided that it is informed of the defective formatting within 90 days from the date of the original 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 Products and their conformity to the order. Any claim for apparent defects or for non-conformity shall be

sent in writing to the Seller within 8 days of receipt of the Products. For this purpose, the Buyer agrees to produce sufficient evidence of such defects.

2.6 No return of Products shall be accepted without prior information to the Seller, even in case of delayed delivery. Any Product returned to the Seller without providing prior information to the Seller as required under article 2.5 shall remain at the Buyer’s risk.

3. PRICE, INVOICING AND PAYMENT

3.1 Prices are given in the orders corresponding to each Product sold on a unit basis or corresponding to annual subscriptions. They are expressed to be inclusive of all taxes. The prices may be reevaluated from time to time. The effective price is deemed to be the one applicable at the time of the order.

3.2 Payments due by the Buyer shall be sent by cheque payable to Knowmade, PayPal or by electronic transfer to the following account:

Banque Populaire Méditerranée, CAP 3000 Quartier du lac, 06700 St Laurent du Var, France

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.

3.3 Payment is due by the Buyer to the Seller within 30 days from invoice date, except in the case of a particular written agreement. If the Buyer fails to pay within this time and fails to contact the Seller, the latter shall be entitled to invoice interest in arrears based on the annual rate Refi of the «BCE» + 7 points, in accordance with article L. 441-6 of the French Commercial Code. Our publications (report, database, tool...) are delivered only after reception of the payment.

3.4 In the event of termination of the contract, or of misconduct, during the contract, the Seller will have the right to invoice at the stage in progress, and to take legal action for damages.

4. LIABILITIES

4.1 The Buyer or any other individual or legal person acting on its behalf, being a business user buying the Products for its business activities, shall be solely responsible for choosing the Products and for the use and interpretations he makes of the documents it purchases, of the results he obtains, and of the advice and acts it deduces thereof.

4.2 The Seller shall only be liable for (i) direct and (ii) foreseeable pecuniary loss, caused by the Products or arising from a material breach of this agreement

4.3 In no event shall the Seller be liable for:

a) damages of any kind, including without limitation, incidental or consequential damages (including, but 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 on the website, or in the Products;

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.

4.5 All the Products that the Seller sells may, upon prior notice to the Buyer from time to time be modified by or substituted with similar Products meeting the needs of the Buyer. This modification shall not lead to the liability of the Seller, provided that the Seller ensures the substituted Product is similar to the Product initially ordered.

4.6 In the case where, after inspection, it is acknowledged that the Products contain defects, the Seller undertakes to replace the defective products as far as the supplies allow and without indemnities or compensation of any kind for labor costs, delays, loss caused or any other reason. The replacement is guaranteed for a maximum of two months starting from the delivery date. Any replacement is excluded for any event as set out in article 5 below.

4.7 The deadlines that the Seller is asked to state for the mailing of the Products are given for information only and are not guaranteed. If such deadlines are not met, it shall not lead to any damages or cancellation of the orders, except for non-acceptable delays exceeding [4] months from the stated deadline, without information from the Seller. In such case only, the Buyer shall be entitled to ask for a reimbursement of its first down payment to the exclusion of any further damages.

4.8 The Seller does not make any warranties, express or implied, including, without limitation, those of

saleability and fitness for a particular purpose, with respect to the Products. Although the Seller shall take reasonable steps to screen Products for infection of viruses, worms, Trojan horses or other codes containing contaminating or destructive properties before making the Products available, the Seller cannot guarantee that any Product will be free from infection.

5. FORCE MAJEURE

The Seller shall not be liable for any delay in performance directly or indirectly caused by or resulting from acts of nature, fire, flood, accident, riot, war, government intervention, embargoes, strikes, labor 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 copyright law and conventions.

6.2 The Buyer agreed not to disclose, copy, reproduce, redistribute, resell or publish the Product, or any 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 the Product for purposes such as:

- Information storage and retrieval systems;

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

- use in any timesharing, service bureau, bulletin board or similar arrangement or public display;

- 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 consequences in their entirety.

6.4 The Buyer shall define within its company point of contact for the needs of the contract. This person will 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.

7. TERMINATION

7.1 If the Buyer cancels the order in whole or in part or postpones the date of mailing, the Buyer shall indemnify the Seller for the entire costs that have been incurred as at the date of notification by the Buyer of such delay or cancellation. This may also apply for any other direct or indirect consequential loss that may be borne by the Seller, following this decision.

7.2 In the event of breach by one Party under these conditions or the order, the non-breaching Party may 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

All the provisions of these Terms and Conditions are for the benefit of the Seller itself, but also for its licensors, employees and agents. Each of them is entitled to assert and enforce those provisions against the Buyer.

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

The Seller may, from time to time, update these Terms and Conditions and the Buyer, is deemed to have accepted the latest version of these terms and conditions, provided they have been communicated to him in due time.

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.

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Patents
Technologies
Prior art
Scientific findings
Opportunities
Partners
Competitors
Newcomers
M&A targets

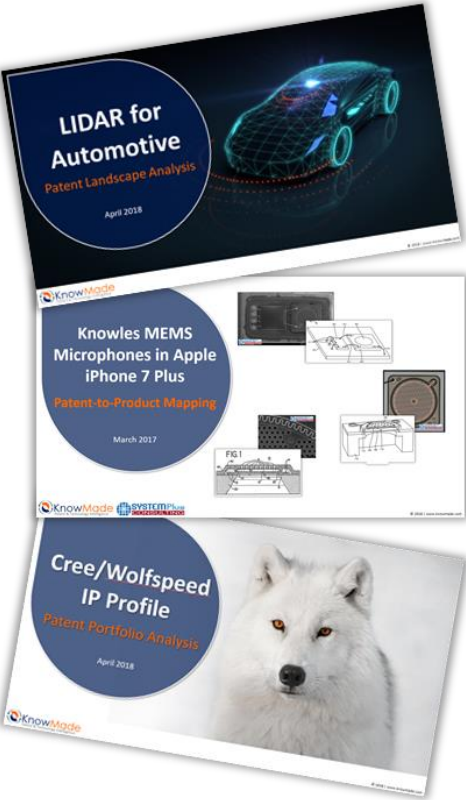


Patent landscape analysis
Scientific review
IP portfolio assessment
Patent valuation
Freedom-to-operate analysis
Litigation & licensing support
Patents linked to products
Technology scouting
Technology trends
Competitive IP landscape
Market trends
Reverse engineering

Make strategic decisions
Sustain competitive advantages
Speed R&D and enhance innovation process
Align R&D and IP with key business objectives
Strengthen IP portfolio and acquire technologies
Anticipate risks and defend core businesses
Explore new opportunities and monetize IP



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Patent Landscape Analysis
Patent-to-Product Mapping
Patent Portfolio Analysis
Patent Monitors



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Tailor-made analyses to meet your business needs and budgetary constraints



Off the shelf reports and analyses



Workshops and trainings

Tailor made to respond your requests
Direct interaction between your team and our experts at your site



WHAT IS OUR ADDED VALUE

Patent Search

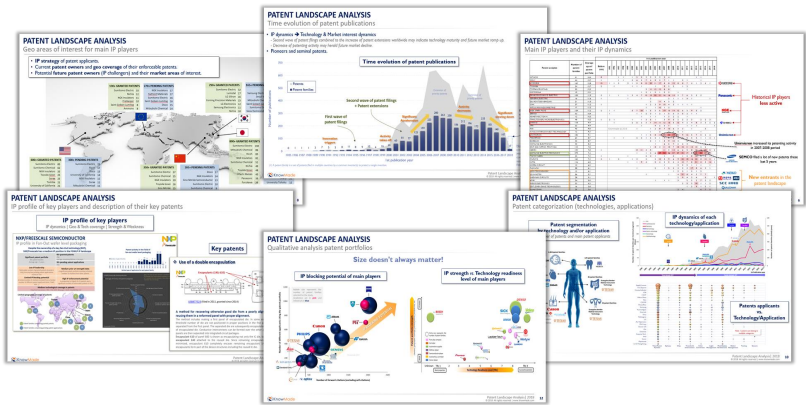
- ✓ **Strong technical expertise of our analysts with PhD degree**
 - Comprehensive search queries and keywords
 - Manual selection of relevant and related patents
 - Manual segmentation by technology & application

Analytics

- ✓ **State of the art statistical tools**
- ✓ **Innovative methodologies to deliver relevant IP analysis**
- ✓ **Business oriented data representation and graphics**

Results Analysis

- ✓ **Technical expertise**
 - Highly specialized analysts in your field
 - Benefit from knowledge capitalization
- ✓ **In-depth IP analysis combined with market data and reverse engineering ***
- ✓ **Customer support**



* Our partners



CUSTOM STUDY & CONSULTING

Tailor-made analysis to meet your needs and budgetary constraints

Prior art search

Evaluate the patentability of your invention in the course of a patent filing.
Invalidate competitor's patents in the course of patent litigation or in anticipation of one.
Make third-party observations concerning the patentability of competitor's inventions.

Patent landscape analysis

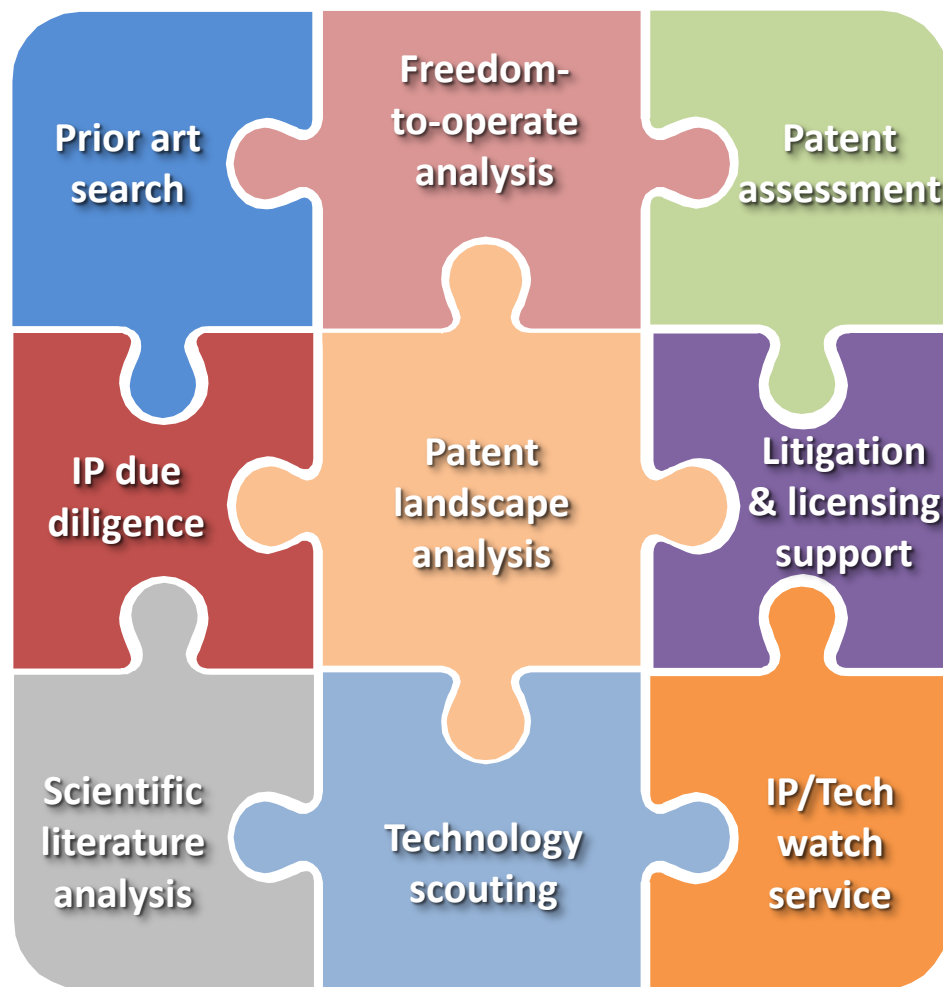
Understand the competitive environment and the technology trends from a patent perspective.
Identify key players, their IP strategy and their key patents.
Know IP collaborations, licensing agreements and litigation history.

Freedom-to-operate analysis

Assess the risks to infringe third-party patents.
Ensure that your products/processes can be safely manufactured, sold and used in specific countries without infringing patents held by others.

Litigation and licensing support

Evidence of infringement/non-infringement for offensive/defensive support.
Defend your position in licensing negotiation or patent litigation.



Patent assessment

Identify most valuable patents prior to patent acquisition/sales, licensing agreement, capital fundraising process, M&A or IP due diligence.
Estimate the financial value of your patent portfolio.

IP due diligence

Assess the patent portfolio of a company and reveal the SWOT matrix prior to patent acquisition/sale, licensing agreement or M&A.

Scientific literature analysis

Pinpoint key research findings and new emerging research fields, key laboratories and scientific experts, industrial/academic research collaborations, and identify prospective R&D partners.

Technology scouting

Identify, qualify and get access to external innovation.

IP & Technology watch service

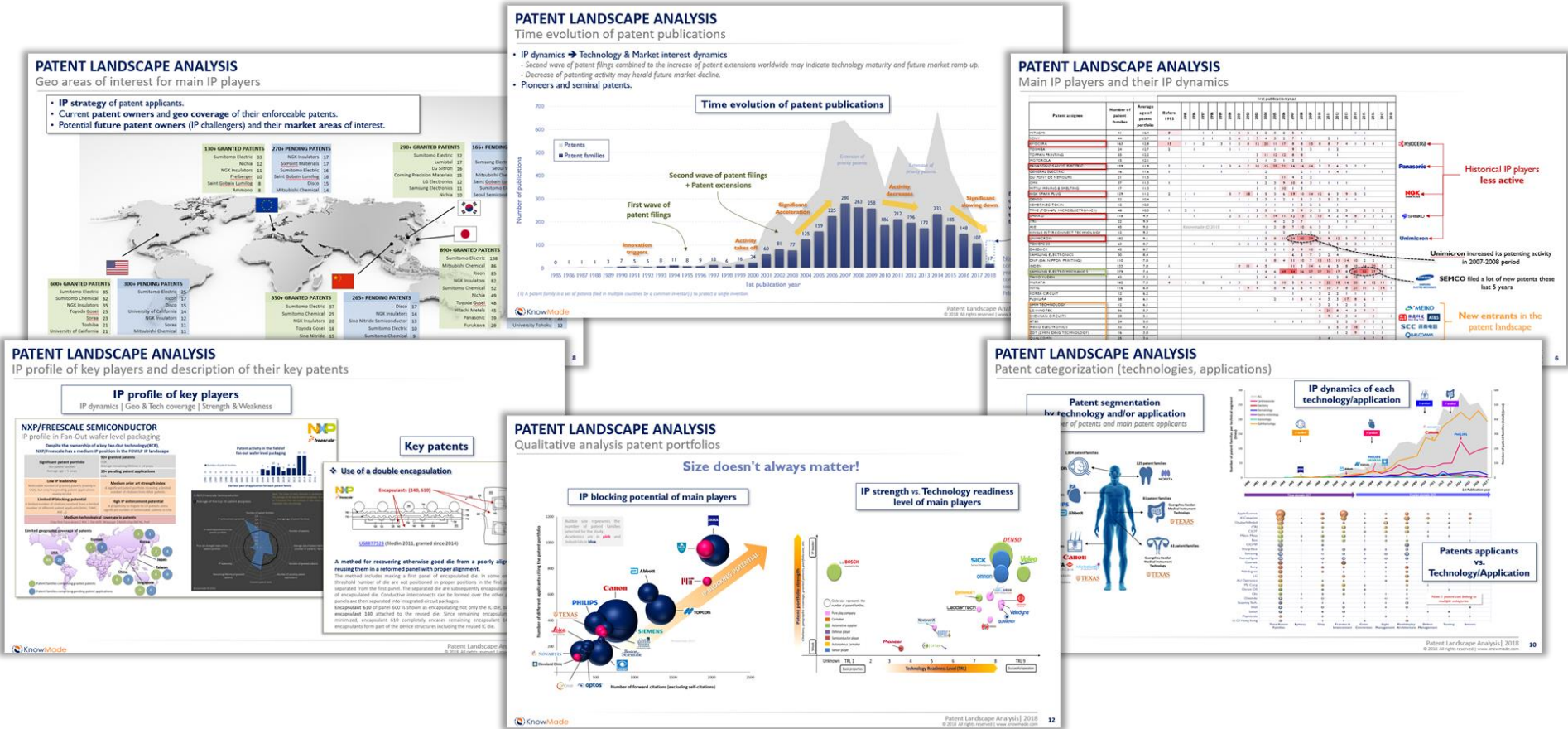
Follow IP/technology trends, keep a watch on your competitors and identify new entrants, anticipate the changes, early detect business opportunities and mitigate the risks.

OFF THE SHELF REPORTS

« Pre-packaged » analysis

Knowmade team of experts work all year long to collect patent and scientific information, identify and analyze the trends, the challenges, the emerging technologies, the competitive environments, and turn it into results to give you a complete picture of your industry landscape.

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OFF THE SHELF REPORTS

2019 reports collection

COMPOUND SEMICONDUCTORS

- **GaN-on-Silicon Substrate: Materials, Devices and Applications** – Patent Landscape 2019*
- **RF GaN: Materials, Devices and Applications** – Patent Landscape 2019*
- **Power SiC: MOSFETs, SBDs and Modules** – Patent Landscape 2019
- **Power GaN: Materials, Devices and Applications** – Patent Landscape 2019*
- **Patent Trolls in the Semiconductor Market** – Litigation Risk and Potential Targets 2017

POWER ELECTRONICS

- **Power SiC: MOSFETs, SBDs and Modules** – Patent Landscape 2019
- **Power GaN: Materials, Devices and Applications** – Patent Landscape 2019*
- **Fast Charging Technologies** – Patent Landscape 2019*
- **Wireless Power Charging** – Patent Landscape 2017

BATTERY AND ENERGY MANAGEMENT

- **Solid-State Batteries** – Patent Landscape 2019*
- **Battery Energy Density Increase** – Patent Landscape 2019*
- **Status of the Battery Patents** – Patent Landscape 2018
- **NMC Li-ion Batteries** – Patent Landscape 2017

RF DEVICES & TECHNOLOGIES

- **Antenna for 5G Wireless Communications** – Patent Landscape 2019*
- **RF Filter for 5G Wireless Communications** – Patent Landscape 2019*
- **RF GaN: Materials, Devices and Applications** – Patent Landscape 2019*
- **RF Front End Module for Cellphones** – Patent Landscape 2018
- **RF Acoustic Wave Filters: SAW, FBAR, SMR-BAW** – Patent Landscape 2017

PHOTONICS & OPTOELECTRONICS

- **Silicon Photonics for Data Centers: Optical Transceiver** – Patent Landscape 2019*
- **VCSEL** – Patent Landscape 2018
- **LiDAR for Automotive** – Patent Landscape 2018

DISPLAY

- **MicroLED Displays** – Patent Landscape 2018

IMAGING

- **Facial & Gesture Recognition Technologies in Mobile Devices** – Patent Landscape 2019*
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* Coming soon

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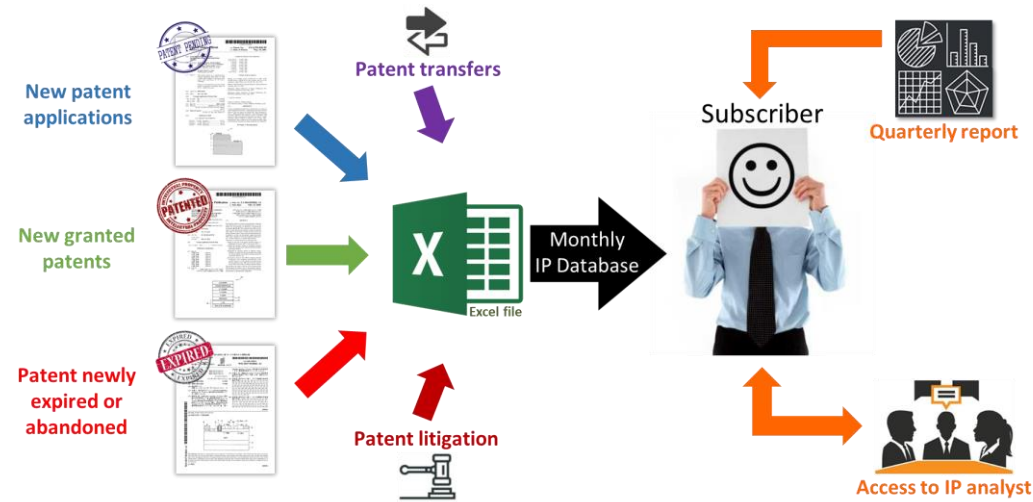
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