GaN Devices for Power Electronics
Patent Investigation
A New Type of Report Providing a Clear Link Between IP Situation and Market Evolutions

A Patent Investigation allows understanding the technology & market from a patent perspective.
- More than describing the status of the IP situation, a Patent Investigation provides a missing link between patented technological solutions and market, technological and business trends.
- In-depth technological analysis of patents leads to understanding of strategic decisions and positioning of key players within the value chain.
- By combining their technical knowledge, business understanding and patent search, Yole Développement and Knowmade are able to provide unique analysis and added value in this report.

Yole & Knowmade’s New Reports
- Essential patent data
- Patent analysis
- Technological segmentations
- Technology analysis
- Key players & key patents
- Market trends
- Market implication of IP landscape
- Full searchable patent database
SCOPE OF THE REPORT

• This report provides a detailed picture of the patent landscape for Power Electronics based on III-nitride materials. All patents related to GaN for power applications were considered: substrates, epi-wafers, semiconductor devices, transistors, diodes, discrete components, power module, packaging, circuits and systems.

• This report covers patents published worldwide up to April 2015. We have selected and analyzed more than 4,900 patents split in more than 1,960 patent families relevant to the scope of this report.

• The patents have been manually categorized by
  ▪ Technological segment: substrates & epi-wafers, semiconductor devices, discrete components, power modules, packaging, circuits and power systems.
  ▪ Substrate for GaN: bulk, SiC, Si, Sapphire.

• Market data from Yole Développement are also provided to add some context regarding business trends and metrics.

• This report provides a clear link between the IP situation and the market evolutions.

• Note that essential patent data on GaN-on-Silicon technology have been analyzed last year in our report “GaN-on-Silicon Substrate Patent Investigation” published in April 2014 (more details).
The **1,962 patents** were **manually categorized** using keyword analysis of patent title, abstract and claims, in conjunction with expert review of the object of inventions.

In this report we use the following patent segmentation:

- **Power GaN**
  - **Wafers**
    - Substrates & Epi-wafers for power electronics, and Epitaxy, Doping, Material issues ...
  - **Semiconductor Devices**
    - Transistors (HEMT, HFET, MOSFET, JFET ...) and Diodes at the semiconductor level
  - **Components**
    - Discrete components, Power modules and Packaging
  - **Circuits & Systems**
    - Drive circuit, switching circuit, control circuit, PFC circuit ... Inverters, Converters ...
  - **Substrate for GaN**
    - GaN-on-SiC
    - GaN-on-Si
    - GaN-on-Sapphire
    - GaN bulk
  - **Technology Challenges**
    - Vertical Device (CAVET)
    - E-mode (N-off)
    - E/D-mode Monolithic
    - Cascode (N-off)
    - Dynamic R-on
    - Breakdown Voltage
    - Gate Charge (Miller effect)
    - Current Collapse
    - Stray Inductance
    - Chip-Scale Package
    - Thermal Issues

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**PATENT SEGMENTATION (1/3)**

**SAMPLE REPORT**
INTRODUCTION

GaN Devices in Power Application

GaN device market size split by applicative markets (M$)

Yole Développement, 2015

<table>
<thead>
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<td>Chargers, Motors, windmills, &amp; C&amp;I</td>
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<td>Integrated Devices (IGBT)</td>
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IP OVERVIEW
Time Evolution of Patent Publications

Power GaN IP Dynamics
1,960+ patent families
Comprising 4,900+ patent documents
including 1,700+ granted patents

The second wave is an indication of a future ramp-up of the market

Patent Publications expected in 2015

First wave of patent publications

Innovation trigger

A patent family is set of patents filed in multiple countries by a common inventor(s) to protect a single invention.

A patent document is a patent filed in one country (1st application or extensions)

Note that the patent search was done in March 2015, thus the data corresponding to the year 2015 are not complete.

Studies into the suitability of the GaN material for power applications began in 2006, and coincide with the first wave of patent filings. The number of patent publications has sharply increased since 2010 with the commercialization of first Power GaN devices. Currently, the second peak of patent filings combined to the increase of granted patents is a positive indication that GaN Power market is ramping up. So far, there are only a few players selling Power GaN products (Infineon/IR, EPC, GaN Systems and Transphorm) and the GaN device market is still small, estimated at $10M in 2015. But the ramp-up will be quite impressive starting in 2016. The market will multiply by 30 from now and reach more than $300M in 2020 (Yole Développement, GaN and SiC for power electronics applications, Jul 2015).
**IP OVERVIEW**

**Power GaN Patent Assignees**

**Ranking of Patent Assignees**

(according to their patent portfolio size)

* A patent family is a set of patents filed in multiple countries by a common inventor(s) to protect a single invention.

**Number of Patent Families**

- **Industrials**
- **Non-profit organizations**


**Other non-profit organizations:** University Tohoku, CEA, CNRS, US Navy, ETRI, Massachusetts Institute Of Technology (MIT), AIST, Fudan University, ITRI, Kyungpook National University, Nanjing University Of Aeronautics & Astronautics (Nua), National Chiao Tung University, Suzhou Inst. of Nano Tech. & Nano Bionics, Univ. of California, Agency for Sci. Tech. & Res. (ASTAR), California Inst. of Tech. (CalTech), Hong Kong Univ. of Sci. & Tech., Insti. of Semiconductors (Chinese Aca. Of Sci.), Inst. of Microelectronics (Chinese Aca. Of Sci.), CNES, Central Research Institute of Electric Power Industry (CRIEPI), Nagoya University ...

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IP OVERVIEW

IP Collaboration Network

- Number in black on each link between patent assignees is the **number of co-assigned patent families** in the data set of the study.
- Number up right to each bubble is the number of patent families for this applicant in the data set of the study. Bubble size is proportional to the number of patent families selected for the study.
### IP OVERVIEW

**Power GaN Patent Assignee – Origin of GaN Involvement**

<table>
<thead>
<tr>
<th>Si power pure-players</th>
<th>Si power players already involved in III-V &amp; Compounds</th>
<th>Semicon global players with GaN LED activity</th>
<th>New GaN pure-player entrants</th>
<th>LED pure-players</th>
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<td>Sanken</td>
<td>Infineon <strong>SiC power</strong></td>
<td>LG Electronics <strong>GaN LED</strong></td>
<td>transphorm</td>
<td>Seoul</td>
</tr>
<tr>
<td>FURUKAWA ELECTRIC</td>
<td>Fujitsu <strong>SiC power</strong></td>
<td>Samsung <strong>ELECTRONICS</strong> <strong>GaN LED</strong></td>
<td>GaN Systems</td>
<td></td>
</tr>
<tr>
<td>RENESAS</td>
<td>Sumitomo <strong>SiC power</strong></td>
<td>Hitachi <strong>Inspire the Mind</strong></td>
<td>AVogy</td>
<td></td>
</tr>
<tr>
<td>TOYOTA</td>
<td>Toshiba <strong>SiC power</strong></td>
<td>Mitsubishi <strong>SiC power</strong></td>
<td>Micro GaN</td>
<td></td>
</tr>
<tr>
<td>ROHM</td>
<td>Mitsubishi <strong>SiC power</strong></td>
<td>TDK <strong>SiC power</strong></td>
<td>EPC</td>
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<tr>
<td>NXP</td>
<td>ROHM <strong>SiC power</strong></td>
<td>Nichia <strong>SiC power</strong></td>
<td>EPC</td>
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<td>INFINEON</td>
<td>Infineon <strong>SiC power</strong></td>
<td>NTT <strong>SiC power</strong></td>
<td>EPC</td>
<td></td>
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<tr>
<td>NXP</td>
<td>Infineon <strong>SiC power</strong></td>
<td>Samsung <strong>GaN RF</strong></td>
<td>EPC</td>
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<tr>
<td>ROHM</td>
<td>Infineon <strong>SiC power</strong></td>
<td>Infineon <strong>SiC power</strong></td>
<td>EPC</td>
<td></td>
</tr>
<tr>
<td>SHINDENGEN</td>
<td>Infineon <strong>SiC power</strong></td>
<td>Infineon <strong>SiC power</strong></td>
<td>EPC</td>
<td></td>
</tr>
<tr>
<td>From Si to GaN</td>
<td>From compound semi to power GaN</td>
<td>From LED &amp; Power to GaN</td>
<td>GaN from scratch</td>
<td>From LED to Power ?</td>
</tr>
</tbody>
</table>

- **Infineon** acquired **International Rectifier** (Aug. 2014).
- **Panasonic** licenses their N-off GaN transistor out to **Infineon** in 2015.
- **Transphorm** obtained in 2013 a non-exclusive worldwide patent license agreement to **Cree** (GaN HEMT & Schottky diode). In 2014 it obtained exclusive licensing rights to **Furukawa Electric’s GaN patent portfolio**.
- **Fujitsu Semiconductor** and **Transphorm** collaborate (business integration of their GaN power device solutions in Nov 2013. Start of mass production of **Transphorm**’s GaN power devices in Jan 2015).
- **NXP** and **Freescale** merged in March 2015.
- **Velox Semiconductor** acquired by **Power Integrations** in 2010.

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IP OVERVIEW
Time Evolution of Patent Publications

Dates are defined from the earliest publication date for each patent family. Bubble size is proportional to the number of published patent families.

Note: The data corresponding to the year 2015 may not be complete since the patent search was done early March 2015.

- Infineon acquired IR in 2014.
- Licensing agreements: Infineon/Panasonic, Transphorm/Furukawa
- Collaborations: Transphorm/Fujitsu, Silicon Valley Bank
- Co-assignee of Avogy’s patents

The first wave of patent publications between 2005 and 2009 is mainly due to American companies (International Rectifier, Power Integrations) and Japanese companies (Panasonic, Rohm, Kyushu, Toshiba, Toyota).

Mitsubishi and Fujitsu have shown an interest in Power GaN technology since 2010 with a significant increase of their patenting activity in this domain.

The patents published in the second period (2010-2014) mainly originate from American companies (International Rectifier, Fujitsu, Transphorm, USA, Avogy, USA, Infineon (DE) and Samsung (KR)).
### ANNOUNCED GAN TRANSISTOR PRODUCTS

**Studies into the suitability of the GaN material for power applications began in 2006.**

<table>
<thead>
<tr>
<th>Year</th>
<th>Product/Device</th>
<th>Manufacturer/Inventor</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>800 V / Si GaN FET</td>
<td>SanKen</td>
<td>Nov. 2008</td>
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<tr>
<td>2009</td>
<td>1260 V / Si GaN Noff FET</td>
<td>Renesas</td>
<td>Dec. 2009</td>
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<td>2009</td>
<td>600 V / Si GaN HFET</td>
<td>EPC</td>
<td>May 2010</td>
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<td>2009</td>
<td>30 V / Si Point-of-Load</td>
<td>Microsemi</td>
<td>2010</td>
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<td>2010</td>
<td>200 V / Si E-mode GaN FET</td>
<td>IOR</td>
<td>Mar. 2010</td>
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<td>2010</td>
<td>600V / SiC E Z-GaN Transistor</td>
<td>transphorm</td>
<td>2011 (EZ-GaN™ platform)</td>
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<tr>
<td>2011</td>
<td>600 V / Si GaN FET</td>
<td>Fujitsu</td>
<td>2012</td>
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<tr>
<td>2011</td>
<td>900 V / SiC GaN E-MOSHEMT</td>
<td>VisIC Technologies</td>
<td>2012</td>
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<td>2012</td>
<td>600 V / Si GaN FET</td>
<td>Fujitsu</td>
<td>Jul 2013</td>
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<tr>
<td>2012</td>
<td>650 V / SiC GaN HEMT</td>
<td>Transphorm</td>
<td>2012</td>
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<tr>
<td>2012</td>
<td>900 V / SiC GaN E-MOSHEMT</td>
<td>VisIC Technologies</td>
<td>2012</td>
</tr>
<tr>
<td>2013</td>
<td>100 V &amp; 650 V / Si GaN Noff HEMT</td>
<td>Transphorm</td>
<td>May 2014 (GaNPX™ package)</td>
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<tr>
<td>2013</td>
<td>600 V / Si GaN Transistor</td>
<td>VisIC Technologies</td>
<td>May 2015</td>
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<tr>
<td>2014</td>
<td>600 V / Si GaN FET</td>
<td>VisIC Technologies</td>
<td>Cascode configuration 2013 (GaNPwIR™ Gen 2.1)</td>
</tr>
<tr>
<td>2015</td>
<td>600 V / Si GaN Transistor in a TO-247 Package</td>
<td>Transphorm</td>
<td>Mar. 2015</td>
</tr>
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</table>

**First Appearance of Key Players in the Power GaN IP arena**

- **2009:** First commercial GaN-based integrated power stage devices (iP2010 and iP2011 family of devices).
- **2010:** Mass production in 2014
- **2012:** Commercially available

*IR’s GaN devices are only for specific clients.*
IP OVERVIEW
Mapping of Patenting Activity

For each country or geographical zone:
• Number of different patent assignees.
• Number of patent families including at least one patent filed in the country.
• Number of patent families including at least one patent in a legal status category in corresponding country.
• Time evolution of patent publications.

Note: A patent family can include patents in different legal status and thus may appear in more than one category within the same country. For the legal status definition please refer to the Annex at the end of the report.
A lead period in patenting activity and patent grants heralds a future market domination.

The market domination of USA until 2013 is consistent with its lead in terms of granted patents from 2005 to 2010. Japan, witness of an increase of its enforceable patents since 2010, is ramping up and enlarges its market share.
TECHNOLOGY SEGMENTATION
Patent Family Split by Technology Segment

1960+ patent families on GaN power electronics

A patent family is a set of patents filed in multiple countries by a common inventor(s) to protect a single invention.

Circuits (drive circuit, switching circuit, control circuit, PFC circuit …) and Electronic Systems (inverters, converters …)

Components 14%

Discrete components, Power modules and Packaging

Wafers 5%

Substrates & Epi-wafers for power electronics, and Epitaxy, Doping, Material issues …

Circuits & Systems 21%

Semiconductor Devices 60%

Transistors (HEMT, HFET, MOSFET, JFET …) and Diodes at the semiconductor level

Processed wafer

GaN-on-XX

Chips
TECHNOLOGY SEGMENTATION
Time Evolution of Patent Publications Split by Technology Segment

Power GaN IP Dynamics by Technology Segment
1,960+ patent families

- GaN Power (all patents)
- Wafers
- Semiconductor Devices
- Components
- Circuits & Systems

* A patent family is a set of patents filed in multiple countries by a common inventor(s) to protect a single invention

Notes: 1) A patent can be found in several categories. 2) The patent search was done in March 2015, thus the data corresponding to the year 2015 are not complete.

- The number of patent applications related to GaN Power Components (discrete, module & package) and Circuits & Systems increased in a second time over the 2010-2015 period while the first Power GaN devices were commercialized. “Power Components” patents were mainly filed by [insert names], while “Circuits & Systems” patents were mainly filed by [insert names].
- Patents claiming GaN substrates and GaN templates especially developed for power applications appeared in mid-2000s, and a steady increase of patent publications was observed over the 2010-2015 period. Main patent applicants are epi-makers both with merchant business and no merchant business.
## TECHNOLOGY SEGMENTATION

Main Patent Assignees by Technology Segment

<table>
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<tr>
<th>SEGMENT</th>
<th>Patent Families</th>
<th>Assignees</th>
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</thead>
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<td><strong>Wafers</strong></td>
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<tr>
<td><strong>Semiconductor Devices</strong></td>
<td>1200+</td>
<td>220+</td>
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<td><strong>Components</strong></td>
<td>280+</td>
<td>70+</td>
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<tr>
<td><strong>Circuits &amp; Systems</strong></td>
<td>430+</td>
<td>120+</td>
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![GaN-on-XX](image.png)

CREDITS

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## TECHNOLOGY SEGMENTATION

Matrix Key IP Players / Technology Segments

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<th>Patent Assignees</th>
<th>Number of Patent Families</th>
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<th>Semiconductor Device</th>
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<th>Circuit &amp; System</th>
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<th>GaN-on-SiC</th>
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TECHNICAL CHALLENGES
Patent Family Split by Technology Challenges

1960+ patent families on GaN power electronics

A patent family is a set of patents filed in multiple countries by a common inventor(s) to protect a single invention. Note that a patent family can be found in several categories.
## TECHNICAL CHALLENGES
GaN Power Transistor - Patent Differentiation of Key IP Players

<table>
<thead>
<tr>
<th>DEVICE</th>
<th>OPERATING</th>
<th>PACKAGING</th>
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</table>
| D-mode (Normally-on) | casc
dode (N-off circuit-based approach) | Vertical Device (CAVET) | Dynamic R-on | Low Stray Inductance Package | Thermal Management (package, module) | Chip-Scale Package |
| GaN-on- SiC        | transpher |                         | transpher     |                       |                                      |                     |
| GaN-on- Si          | MITSUBISHI ELECTRIC | power integrations | IGR | FURUKAWA ELECTRIC | Panasonic | IGR | IGR | IGR | EPC |                     |
| GaN-on- Sapphire    | BOHM      |                           |              |                        |                                      |                     |
| Bulk GaN           | Knowmade  © 2015 |                           |              |                        |                                      |                     |

Knowmade © 2015
# TECHNICAL CHALLENGES

Matrix Key IP Players / Technology Challenges

<table>
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<tr>
<th>Patent Assignees</th>
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The colored cells highlight the main features of the patent portfolio. Note that a patent can be found in several categories.
SEMICONDUCTOR DEVICES
Degree of Specialization

Degree of IP specialization in GaN Power semiconductor devices

Size of the whole patent portfolio (normalized)

Big companies such as Furukawa, Panasonic, Infineon, Fujitsu, Mitsubishi ... cover a wide range of technologies with their patent portfolios, thus they have a very low specialization degree in GaN power semiconductor devices. International Rectifier (IR) and Power Integrations (POWI), originally Si Power pure players, show a high specialization degree. GaN Systems, EPC, and Transphorm stand out with a very high specialization degree, their patent portfolios are mainly dedicated to GaN power semiconductor devices. POWI and Infineon gained IP focused on GaN power semiconductor devices thanks to...
SEMICONDUCTOR DEVICES
Mapping of Main Current Patent Holders

1220+ patent families on Semiconductor Devices
640+ patent families including at least one granted patent

Number of patent families* containing granted patents in the corresponding country.

* A patent family is a set of patents filed in multiple countries by a common inventor(s) to protect a single invention.

USA
762 patent families (429 granted)

International Rectifier
47

29

28

26

Transphorm
Avogy

Velox Semiconductor
2

Power Integrations

China
385 patent families (88 granted)

Fairchild

Taiwan
139 patent families (45 granted)

Furukawa
Sumitomo Electric
International Rectifier

Japan
766 patent families (296 granted)

Japan

Europe

Korea

424 patent families (42 granted)

191 patent families (83 granted)
SEMICONDUCTOR DEVICES
Power GaN IP Players

• 3220+ patents split in 1220+ patents families.
• 1540+ pending patents split in 770+ patent families, and 1210+ granted patents split in 640+ patent families.
• Few academics are active on GaN power semiconductor devices, with only 180+ patents split in 60+ patent families.

International Rectifier (IR) has currently the most important 2340+ granted patents from 889 patent families. It is the main current IP holder in Japan (867 granted patents) as well. Infineon/IR are leading the patenting activity in Europe where together they have 290 pending patents. Infineon shows a significant interest for GaN with 22 pending patents.

• Fujitsu owns currently 1340+ granted patents on GaN power semiconductor devices, mainly in Korea and Japan, and it has a strong IP position in Europe. Fujitsu has strongly increased its patenting activity on GaN semiconductor devices as revealed by the number of pending patents the company has in the different offices, making Fujitsu the main patent applicant in the domain across the world with 2200+ pending patent applications. This demonstrates a growing interest of Fujitsu in GaN power semiconductor devices, and it should become a leading player in all those countries in the near future.

• Transphorm has currently a granted patent portfolio (88) with a significant presence in Japan, Europe, and USA. With 140+ patents currently in the pipeline, Transphorm is currently the main patent applicant. It is strengthening its IP position in Japan and China (31), USA and Europe as well.

• Furukawa holds 350+ granted patents on GaN power semiconductor devices and is currently the main patent owners in Japan.

• Power Integrations holds 200+ enforceable patents on GaN power semiconductor devices (63 in USA, 19 in Japan, 12 in Europe) as well.

• Asian companies have a strong IP position in USA (78 in USA, 59 in Japan, 52 in Europe), for patents related to GaN power semiconductor devices, but they are practically non-existent in Europe.

• Korean companies (Samsung, LG) hold most of granted patents in Korea, but Korean companies (Samsung, Seoul Semiconductor, LG) have increased their patenting activity and are currently the main patent applicants on Korean territory.
SEMICONDUCTOR DEVICES

IP Collaboration Network

- Number in black on each link between patent assignees is the number of co-assigned patent families in the data set of the study. The minimum link size is 3 co-assigned patent families.
- Number up right to each bubble is the number of patent families for this applicant in the data set of the study. Bubble size is proportional to the number of patent families selected for the study.

8 Co-filings and 5 patent rights acquisitions from Advanced Power Device Research Association

FURUKAWA ELECTRIC

6 co-assigned patent families, acquired patent rights (IP security agreement)

ADVANCED POWER DEVICE RES. ASS.

Patent rights acquired by Furukawa

SUMITOMO ELECTRIC INDUSTRIES

3 co-assigned patent families
Sumitomo Electric acquired Eudyna in 2009 (formed by Fujitsu in 2004), and changed its trade name to Sumitomo Electric Device Innovations (SEDI)

3 co-assigned patent families

POW1 acquired Velox in 2010
(8 re-assigned patent families)

VELOX SEMICONDUCTOR

POWER INTEGRATIONS

FUJITSU

24 co-assigned patent families.
In 2013, Transphorm acquires
Fujitsu’s GaN on SiC power electronics

24 co-assigned patent families.

US patents acquired by Widebandgap in 2005
(U57205629, US7105575, US7019344, US7026669)

RENESAS

3 patent families re-assigned to Renesas Electronics.

GENESIS SEMICONDUCTOR

TOYOTA MOTOR

TOYOTA CENTRAL R. AND D.

AVOGY

RENESAS

 TRANSPHORM

F20751706-1 2015 Knowmade
# SEMICONDUCTOR DEVICES

## Summary of Main Assignees’ Patent Portfolio

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<th>Patent Assignees</th>
<th>No. of patent families*</th>
<th>Oldest priority year of the patent portfolio</th>
<th>No. of patent families filed / year (average)</th>
<th>No. of alive patents (granted or pending)</th>
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</table>

* A patent family is a set of patents filed in multiple countries by a common inventor(s) to protect a single invention.
SEMICONDUCTOR DEVICES
Leadership of Patent Assignees

- **International Rectifier** (acquired by Berkshire Hathaway in 2014) has a significant patent portfolio on GaN devices. It is not only large but also enforceable, with active patenting and IP challenges (100+ patents).

- **New challengers** like **Infineon**, **Mitsubishi Electric**, **Toyota**, **Sanken Electric**, **Alpha & Omega**, **GaN Systems**, and **MicroGaIt** are becoming major forces in the IP landscape, expanding their patent portfolio with many new patent applications.

- **Sumitomo Electric**, mainly focused on vertical devices, has a noticeable patenting activity associated with already granted patents giving it a sizeable IP significance in GaN power semiconductor devices.

- **Panasonic** and **Furukawa** have a lesser current patenting activity but they are active in the IP arena with a significant number of patents on GaN devices.

Notes: Infineon acquired IR in 2014; Licensing agreements Infineon/Panasonic (2015), Transphorm/Furukawa (2014), Transphorm/Cree (2013); Collaborations Transphorm/Fujitsu (2013); POWI acquired Velox in 2010.
GaN Devices for Power Electronics - Patent Investigation | August 2015

**SEMICONDUCTOR DEVICES**

Strength Index of Patent Portfolios

**Portfolio Strength Index**

<table>
<thead>
<tr>
<th>Company</th>
<th>Strength Index</th>
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<tr>
<td>International Rectifier</td>
<td>210</td>
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<td>Alpha &amp; Omega</td>
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</table>

**Note:**
- Infineon acquired IR in 2014.
- Collaborations Transphorm/Fujitsu (2013)
- POWI acquired Velox in 2010

**International Rectifier and Furukawa**

**International Rectifier** and **Furukawa** hold several “seminal” patents with a significant blocking potential for Power GaN IP players. The patents of **International Rectifier** receive 3 times more citations than the average of key IP players of this report.

**International Rectifier** and **Furukawa** receive respectively in terms of portfolio size and in terms of their portfolio strength index. Their patents get almost 4 times more citations than the average of key IP players of this report. Note that the patents from **Panasonic** receive 5 times more citations. These citations come mainly from **Transphorm, Alpha & Omega, International Rectifier** and **Panasonic**.

**Sumitomo Electric** and **Fujitsu** have a large portfolio and thus show their large size of patent portfolio. **Sumitomo Electric** is more active on vertical devices, while **Fujitsu** started working on power semiconductor devices quite recently, much later than **Furukawa**.

In practice, only **IR, Transphorm, EPC** and **GaN Systems** have products on the market. **Transphorm** has an IP strength index of the GaN market is still at its early stages. The ranking of the companies is very volatile, as most of them just began working on GaN a few years ago.
SEMICONDUCTOR DEVICES
IP Blocking Potential of Main Patent Assignees

The more the number of forward citations from different patent applicants is high, the more the capacity to hamper the other firms’ attempts to patent a related invention is important. Note, however, that the identification of a “blocking patent” requires an in-depth specific analysis of each patent documents.

- **International Rectifier** (acquired by Infineon in 2014) has significant IP blocking potential. Their patents on GaN power semiconductor devices received

- **Toshiba and Panasonic** show

- **Fujitsu** have its patenting activity on GaN power semiconductor devices recently.
SEMICONDUCTOR DEVICES
Potential Future Plaintiffs

- To this date, GaN domain has
- Samsung Electronics has over 50 US patents, but has yet to file a patent suit in 2011
- International semiconductor companies have acquired many important patents
- Fujitsu combines its US patents with foreign filings
- Furukawa has invented several “seminal” patents
- Power GaN device is available for less than 20 years. The GaN power application is expected to increase dramatically in 2015
<table>
<thead>
<tr>
<th>Title</th>
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<th>Current Patent Assignee(s)</th>
<th>Expected Expiration Date *</th>
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<td>Compound semiconductor element resisitible to high voltage.</td>
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* Expected Expiration Date is dependent on the accuracy and timeliness of the information provided by the patent offices. This indicator may change at any time without notice based on new information received from the patent offices. No decision should be made based solely on this indicators.
FOCUS ON KEY POWER GAN PLAYERS
Mapping for Patents In-Force (granted)

The size of the logo is proportional to the number of granted patents.
FOCUS ON KEY PLAYERS
Patent Portfolio Quantity/Quality Score*

We use Knowmade’s proprietary KQ2* framework to identify strength of patent portfolio in Power GaN domain. Figures above depict the competitive positioning of key Power GaN players, in segments “Semiconductor Devices” and “Components”. The patent assignees are compared on the basis of Quantity Score and Quality Score. We use our proprietary algorithm based on bibliographical information of patents* to calculate and rank the patent portfolios.

- The green region comprises of the assignees with the best patent portfolios, which are exemplary in terms of quantity and quality of patents. **Knowmade** is the only assignee lying in the green domain. **Knowmade** is the best patent portfolio in area of Power GaN.
- **Panasonic** and **System** are the only assignees lying in the orange region for Semiconductor Devices and Components category respectively. Their patent portfolio lacks on quality because of **less citations**.
- Most of the key Power GaN players form a cluster in the red region with patent portfolio lacking on both patent quantity and quality. Their patent portfolios may rise in future after successful prosecution of their pending patents and/or more citations added.

*See evaluation metrics for portfolio KQ2 score in Annex at the end of the report.
TENTATIVE ESTIMATION OF MARKET SHARE OF GaN DEVICE MAKERS

- **IR/Infineon**, supplying to specific clients, has the best patent portfolio. *Internistic* is the strongest IP arm for GaN power market.
- **Transphorm**, a challenger, is ahead of other GaN Systems. Partnerships with PurePower, Fujitsu, and others put it in a strong position to take a leading role in the GaN device market.
- **EPC** has a strong focus on low voltage (<200 V) GaN while the others focus on 600V devices.
- **Panasonic** has devices in 2016.
INTERNATIONAL RECTIFIER (IR) / INFINEON
IR acquired by Infineon in 2014

IR & Infineon Power GaN IP Dynamics

- First patent applications: 2011
- Oldest priority year: 2011
- Patent average age: 6 years.
- IP collaboration: IP collaboration with Fuji on patents related to GaN devices (backside via for GaN Gen 1). Patent rights of Gen 1.1 acquired from Infineon in 2010.
- Main patent assignees cited by IR's patents: Panasonic, Toshiba, Cree.
- Main patent assignees citing IR's patents: Infineon, Fujitsu, Panasonic.

- IP collaboration: Acquisition of IR in 2014. Note that this acquisition does not yet appear in patent databases. The re-assignment of patents should be reveal in the next months.
- Main patent assignees cited by Infineon's patents: International Rectifier, Toshiba, Cree.
- Main patent assignees citing Infineon's patents: Toshiba, National Semiconductor.

Note: Patent search was done in March 2015, thus the data corresponding to the year 2015 are not complete.
INTERNATIONAL RECTIFIER (IR) / INFINEON
IR acquired by Infineon in 2014

Power GaN Patent Portfolio’s Features

- 3,500+ patents split in 1,600+ patent families
- 600+ granted patents
  Mainly in USA
- 2,500+ pending patents
  Mainly in USA
- 1,350+ backward citations / 790+ forward citations

High Strength Index

- IP blocking potential
- IP enforcement potential
  No propensity to litigate patents, as for now, but...

Technology Level
- Wafers
- Semicon Devices
- Components
- Circuits & Systems

Substrate for GaN
- GaN-on-SiC
- GaN-on-Si
- GaN-on-Sapphire
- GaN Bulk

Technology Issues
- E-mode (N-off)
- E/D-mode Monolithic
- Breakdown Voltage
- Current Collapse
- Dynamic R-on
- Gate Charge (Miller Effect)
- Stray Inductance Package

Semicon Devices

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Components

Note that the average of main patent assignee is set at 1 and the company values are normalized by the average main patent assignee.
Integrated half-bridge circuit with low side and high side composite switches


There are disclosed herein various implementations of an integrated half-bridge circuit with low side and high side composite switches. In one exemplary implementation, such an integrated half-bridge circuit includes a III-N body including first and second III-N field-effect transistors (FETs) monolithically integrated with and situated over a first group IV FET. The integrated half-bridge circuit also includes a second group IV FET stacked over the III-N body. The first group IV FET (340a, 340b) is cascaded with the first III-N FET (330a, 330b) to provide one of the low side (320b) and the high side (320a) composite switches, and the second group IV FET (340a, 340b) is cascaded with the second III-N FET (330a, 330b) to provide the other of the low side (320b) and the high side (320a) composite switches. The first and second III-N FETs are normally ON FETs, and the low side composite switch and the high side composite switch are normally OFF switches.
**GaN Devices for Power Electronics - Patent Investigation | August 2015**

### Key Patents

<table>
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<th>KEY PATENT FAMILY</th>
<th>KEY FEATURES</th>
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| III-nitride bidirectional switches | • Matrix converter technology is enabled by these bidirectional switch designs. Matrix conversion directly converts AC to AC, thus eliminating the need for a large DC filter capacitor. The matrix converter is composed of a set of bidirectional switches, thus permitting both generation and motoring using the same set of switches. Further, the matrix converter permits an optimized power factor and harmonic content of input currents and three-level voltage switching for reduced voltage stress.  
  • The switches have improved performance, e.g., lower loss, smaller size system, and fewer components over conventional devices and allow for very compact designs of high power circuits.  
  • Patents filed in USA, Europe and Japan via a PCT application.  
  • Patents granted in USA and Europe.  
  • 39 forward citations from Panasonic, Infineon, International Rectifier. |

![Diagram of III-nitride bidirectional switches](image1)

| III-nitride bidirectional switches | Large source to drain barrier in the off state, low off state leakage, and low channel resistance in the access regions.  
  • Patents filed in USA, China and Taiwan via a PCT application.  
  • Patents granted in USA and Taiwan.  
  • More than 60 forward citations from Fujitsu, International Rectifier, Infineon, Samsung. |

![Diagram of III-nitride bidirectional switches](image2)

| III-nitride bidirectional switches | Planar Schottky diode currents.  
  • Patents filed in USA, China, Israel.  
  • 6 granted patents (US).  
  • More than 60 forward citations. |

![Diagram of III-nitride bidirectional switches](image3)
High density gallium nitride devices using island topology


A Gallium Nitride (GaN) series of devices—transistors and diodes are disclosed—that have greatly superior current handling ability per unit area than previously described GaN devices. The improvement is due to improved layout topology. The devices also include a simpler and superior flip chip connection scheme and a means to reduce the thermal resistance. A simplified fabrication process is disclosed and the layout scheme which uses island electrodes rather than finger electrodes is shown to increase the active area density by two to five times that of conventional interdigitated structures. Ultra low on resistance transistors and very low loss diodes can be built using the island topology. Specifically, the present disclosure provides a means to enhance cost/effective performance of all lateral GaN structures.
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30% of our business is in Asia

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  - Uncooled IR Imagers
  - IR Detectors
  - High End Gyro, Accelerometers and IMU
  - Non-Volatile Memory
  - MEMS for RF Filters and Antena Switches - BAW / SAW

- IMAGING & OPTOELECTRONICS
  - Camera Module Packaging (Vol 1 : Market & Technology Trends / Vol 2 Teardowns & Reverse Engineering)
  - Uncooled IR Imagers
  - Wafer Level Optics
  - Status of the CMOS Image Sensors
  - Machine Vision

- MEDTECH
  - Microfluidic for Sample Preparation
  - Microfluidic Applications
  - Sensors for Wearable Electronics And Mobile Healthcare

- COMPOUND SEMICONDUCTORS
  - High Purity Alumina (HPA)
  - Sapphire
  - Wide Bandgap Materials For Power Electronics: SiC, GaN (and also Ga2O3, AlN, Diamond, Graphene... as a trend)

- LED
  - LED Module
  - OLED for Lighting
  - UV LED
  - LED Phosphors Market

- POWER ELECTRONICS
  - Power Packaging
  - Thermal Management for LED and Power
  - Power Electronics for Renewable Energy
  - Energy Management For Smart Grid And Smart Cities
  - Status of Chinese Power Electronics Industry
  - New Technologies For Data Center
  - Inverter Market Trends For 2013 – 2020 And Major Technology Changes*
  - IGBT Markets And Application Trends
  - Power Electronics for HEV/EV*
  - Status of Power Electronics Industry

- ADVANCED PACKAGING
  - Advanced Packaging in Emerging Markets in China
  - Status of the Advanced Packaging Industry
  - Supply Chain Readiness for Panel Manufacturing in Packaging
    - WLCSP*
    - Flip Chip Business Update
    - 2.5D & 3DIC Business Update
    - Fan-Out and Embedded Business Update

- MANUFACTURING
  - Lithography for MEMS, Advanced Packaging and LED
  - Thinning & Dicing Equipment for Advanced Packaging, MEMS, Photovoltaics, LED, CMOS Image Sensors
  - Non-Volatile Memory

* Reports to be decided within 2015
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- Patent Infringement (crossed analysis based on Knowmade and System Plus Analysis expertise)
  - MEMS Microphone Applications (Q1)

- Patent Investigation (crossed analysis based on Knowmade & Yole Développement expertise)
  - Power GaN (Q2)
  - Phosphors for LED - Update (Q2)
  - MEMS Gyroscope - Update (Q2)
  - LED Packaging (Q4)
  - 6-axis & 9-axis IMUs (Q4)
  - Microbatteries (Q4)

- Patent Landscape
  - Capacitive Fingerprint Sensors (Q1)
  - Biomedical Photoacoustic Imaging (Q1)
  - ReRAM Non-Volatile Memories (Q2)

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  - SiC Modules, Devices and Substrates for Power Electronics Market
  - GaN-on-Si Substrate Technology and Market for LED and Power Electronics
  - Power GaN Market
  - Graphene Materials for Opto & Electronic Applications
  - Sapphire Applications and Market: from LED to Consumer Electronics

- LED
  - LED Packaging
  - LED Front-End Manufacturing Trends
  - LED Front-End Equipment Market

- POWER ELECTRONICS
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